St. Mary River-Milk River Basins Study: Model Documentation Report Including Model Revisions That Followed Completion of the Study

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Introduction

The Milk-St. Mary River Basin Study Model was constructed with the CADSWES RiverWare software. It is a simulation model that uses utilities within the model and "rules" to simulate operations of the river systems on a daily time-step. The primary model inputs are historic hydrology and irrigation water-use data for the 1959-2009 period, and "future climate scenario" input data for a climate centered on 2030 or 2050, but based on weather patterns for the 1950-2001 period. The model links the Upper St. Mary River with the North Fork of the Milk River through the St. Mary Canal. It simulates the St. Mary River from its headwaters to where it crosses the International Boundary, and the Milk River from its headwaters to its confluence with the Missouri River. The sections below describe each major portion of the system, how the model simulates operations of each, and how the model simulates the system as a whole. This documentation describes the model for potential users, or for those who want to understand how the model simulates the systems and how the model input data were developed. The development of input data for the model, for historic and future climate conditions, also is described. A schematic of the model, as used in the St. Mary River Milk River Basin Study can be found in Appendix A. The model schematic also can be viewed, with the physical features displayed against a background map, in RiverWare under the geospatial view option.

The basic operations of the St. Mary and Milk Rivers system were modeled using guidelines set forth in the *Reservoir and River Operation Guidelines for the Milk River Project* (Reclamation, 2008). This guide identifies general reservoir target elevations, release rates, filling procedures, irrigation releases and deliveries, and river flows through the system. Information from Reclamation for the previous HYDROS Milk River Hydrology Model (Reclamation, 2004) also were used in developing the input data, rules and methods for simulating system operations.

While the model was being developed for the River Basin Study, technical support was provided by Hydros Consulting Inc., with memorandums in Appendixes B through D summarizing this work. Some significant revisions to the model where made following the publication of the St. Mary River and Milk River Basin Study. Descriptions of these revisions have been incorporated into this document and are further explained in a September 21, 2012 memorandum from Hydros Consulting in Appendix E.

Upper St. Mary River Basin

General Criteria

The natural flow of the St. Mary River is divided between the United States and Canada. The St. Mary Canal and Sherburne Reservoir are used to regulate and divert the U.S. share. The following are a list of general criteria that are used to operate the Upper St. Mary River system.

1. Early spring (mid-March through late-April, depending on conditions): Start up St. Mary Canal by ramping up no more than 150 cfs/day. Transfer U.S. natural flow share water and Sherburne Reservoir storage accumulated during the winter to Fresno Reservoir on the Milk River.

2. Late spring (May through early-July): Try to maintain 650 cfs St. Mary Canal flow at the St. Mary siphon with the U.S. share of natural flow, and releases from Sherburne Reservoir when necessary. Try to fill Sherburne Reservoir by early July.
3. Summer: Try to keep St. Mary Canal flow at about 650 cfs at the St. Mary siphon. Use United States share of St. Mary River natural flow first. Release stored water from Sherburne Reservoir when necessary to keep canal flow at near capacity.
4. End of irrigation season (usually late-September to mid-October): Continue St. Mary Canal diversions until Sherburne storage is depleted and/or U.S. share of natural flows drops below about 100 cfs. Canal diversions will be continued, even if not needed for Milk River irrigation demands, to bring Fresno Reservoir as close to the fall target (60,000 acre-feet) as possible.
5. Fall and winter: St. Mary Canal is shut off; Sherburne Reservoir outlet is closed (0 cfs outflow). Release excess stored water from Sherburne Reservoir during fall if anticipated March 1 storage would be above 40,000 acre-feet.

Sherburne Reservoir

Sherburne Reservoir is modeled as a RiverWare storage reservoir object. The streamflow inputs to the object are the total computed natural flows for Swiftcurrent Creek above Sherburne Dam. Outflows from the object go to the **Lower St. Mary Lake** confluence object, slot **Inflow 2**. Flow is stored and released from the reservoir object with the goal of providing water to keep the St. Mary Canal flowing near full during the irrigation season, especially when the U.S. share of the natural flow of the St. Mary River is insufficient to do so. Water generally is stored in the reservoir during the winter and released for diversion by the St. Mary Canal early in the spring, prior to snowmelt and when the natural inflows to Lower St. Mary Lake are still low. Flow is again stored in the object during the late May through early July runoff season, when the U.S. share typically exceeds the flow that can be diverted down the St. Mary Canal. This stored water is then released during the summer, after the U.S. share of St. Mary River natural flow drops below the canal capacity. Operational constraints and input data needed to simulate Sherburne Reservoir operations are contained within the **Sherburne Reservoir** object, or are contained in the associated RiverWare data object **SherburneData**. Some of the more important slots in the **Sherburne Reservoir** object are summarized in Table 1. Table 2 describes the slots in the **SherburneData** object.

Sherburne Reservoir operations are simulated using a combination of operational constraints and rules. A rule policy group in the RiverWare model called **Upper System Operations** contains the primary rules that are used to drive the operations of the Sherburne Reservoir object. These rules simulate operations of the reservoir based on the computed U.S. share of St. Mary River flow, and in conjunction with the St. Mary Canal diversion object, and the Lower St. Mary Lake Storage object…..when it is active.

Table 1. Some key slots in the Sherburne Reservoir Object

Slot	Description	Values
Inflow	Streamflow inputs to Sherburne reservoir	Historic inflow data, or projected future inflow in CFS
Elevation Volume Table	The volume of reservoir storage at various pool elevations	Reservoir Storage in acre-feet for pool elevations from 4729.3 to 4800
Max Release Table	Maximum reservoir outlet release at various pool elevations	Maximum Reservoir releases in CFS for pool elevations from 4725 to 4809
Unregulated Spill Table	Dam spillway capacities	Maximum spillway flows in CFS for pool elevations from 4791 to 4809

Table 2. Input data contained in the SherburneData object

Slot	Description	Value
SherburneMax	The storage volume at the spillway crest	66,147 acre-feet
SherburneMin	The minimum reservoir storage	3,100 acre-feet
SherburneRelease	Tracks releases from Reservoir	Daily flow in CFS
WinterOutflow	The winter release	Current operations are for zero. Can be set to other values.
Release Ratio Minimum Pool	This is used in rules to adjust inflows by a number slightly below 1 to bring the reservoir back up to minimum pool if it goes slightly below the minimum.	0.999
March 1 Target	The March 1 target storage	40,000 acre-feet
Minimum Irrigation Season Release	The minimum Sherburne Reservoir release during the irrigation season	Current operations are for 25 CFS.
Storage Release for Canal	Keeps track of releases of Sherburne stored water for the St. Mary Canal so canal flow can be increased to divert this water. Set in rule **Operate Sherburne to Release or Store Water based on Canal Requirements1**	Storage releases in CFS
Early Winter Max Volume	The maximum volume of storage permitted before December 15. This is to ensure that the March 1 target is not reached and outflows aren't increased during the mid-winter.	30,000 acre-feet
May 15 Target	The minimum storage target prior to spring runoff.	8,000 acre-feet

September 15 Target	The minimum target approaching the end of the irrigation season	8,000 acre-feet
Enable September 15 Target Switch	Allows enabling operations to achieve the September 15 minimum target.	0 = Off 1 = On

Lower St. Mary Lake

Lower St. Mary Lake is a natural lake with no controlled storage. There are two major inflows to Lower St. Mary Lake: the St. Mary River (the larger of the two) and Swift Current Creek. Because the lake has no active storage, for existing conditions it is simulated as the confluence object **LowerStMaryLake** in the model. The confluence object receives inflow from the following two slots: (1) **Inflow 1,** which is uncontrolled inflow to Lower St. Mary Lake (the compilation of St. Mary Rive inflows and uncontrolled inflows from the Swift Current Creek drainage including Boulder Creek) and, (2) **Inflow 2,** which is regulated outflow from Sherburne Reservoir. Regulated outflows from Sherburne Reservoir are generated by the **Sherburne Reservoir** storage object described above.

A storage reservoir object named **Lower St. Mary Lake Storage** has been added to the model just below the **LowerStMaryLake** confluence object. This storage object allows the simulation of a hypothetical control structure on Lower St. Mary Lake, which possibly could be used to store and release of water from the top of the lake. The **Lower St. Mary Lake Storage** object can be simulated to: (1) capture some of the U.S.-share flow from the upper St. Mary River during the winter, which currently flows to Canada, and later release this water for diversion down the St. Mary Canal early the following spring, and (2) again capture surplus U.S. share water during the spring-runoff season for release later during the summer. A data object **Lower St. Mary Lake Data** contains slots that define some of the operational parameters for this hypothetical reservoir (see Table 3). The RiverWare policy group **Upper System Operations** contains rules that control the Lower St. Mary Lake Storage object. Outflows from the **Lower StMary Lake Storage** object go to the inflow Slot for the **StMaryRiver** reach object.

Table 3. Lower St. Mary Lake Data Object Slots

Slot	Description	Value
Max Storage	This slot sets the maximum storage in lower St. Mary Lake. Set to 1 acre-foot above the minimum storage when simulated storage is not active.	Storage in acre-feet
Min Storage	This is the minimum storage in lower St. Mary Lake. It has been set at 5,000 acre-feet, although this is not the actual dead storage in the lake.	5,000 acre-feet
Minimum Flow	This slot can be used to set a minimum instream flow requirement below the lake, if it is operated as a reservoir.	Flow in cfs

Storage release for Canal	This is a series slot that tracks storage releases from the reservoir so that they can later be diverted down the St. Mary Canal.	Daily release in cfs
LSML Storage On Off Switch	This switch turns the hypothetical storage reservoir on or off.	1 = Storage Simulated 0 = No Storage Simulated

St. Mary River

Outflows from Lower St. Mary Lake are linked to the **SaintMaryRiver** reach object, which represents the St. Mary River to the diversion dam for the St. Mary Canal. The primary purpose of this object is to simulate where the St. Mary Canal diverts water from the St. Mary River. The reach object is linked to the **StMaryCanal** available flow based diversion object. The **SaintMaryRiver** reach object also contains a table slot **Minimum Bypass Values** that allows the user to set a minimum bypass flow through the St. Mary Diversion Dam, by month. The outflow from this reach is linked to the inflow slot for **StMary RiverIB** reach object.

St. Mary River IB

This reach object represents the St. Mary River at the International Boundary. This is the St. Mary River water that leaves the United States and flows into Canada. The object contains a **Local Inflow** slot which is input data for the natural tributary inflow to the St. Mary River between the St. Mary Canal Diversion Dam and the International Boundary. These inflows were derived from gaging station data. The object is useful for monitoring the flow of St. Mary River water to Canada to ensure that its share is delivered, while minimizing U.S. surplus deliveries.

St. Mary Canal

The St. Mary Canal diverts water from the St. Mary River at a diversion dam below Lower St. Mary Lake. The water initially is diverted into the canal on the west (left) bank of the river where it then flows north, paralleling the St. Mary River. About mid-way to the International Boundary, the canal crosses the St. Mary River through the St. Mary Siphon. It then flows east, towards the North Fork of the Milk River. Between the Diversion Dam and the St. Mary siphon, the canal losses substantial amounts of water and this water returns to the St. Mary River. These seepage losses between the Diversion Dam and St. Mary River siphon are not simulated; instead the canal diversions are modeled based on what the flow of the canal would be at the St. Mary siphon, after initial seepage losses.

The St. Mary Canal is modeled with three objects. The first is the **StMaryCanal** diversion object, which is linked to the **SaintMaryRiver** reach object, and simulates canal diversions from the St. Mary River based on the U.S. share and releases of stored water. The **Canal Route** aggregate distribution object was added to account for seepage from the Canal between the St. Mary Siphon and the North Fork of the Milk River. The seepage is simulated as 2 percent of the total Canal flow. The **Canal Drops Hydro** object simulates the hydropower that could potentially be produced where the Canal drops down to the North Fork of the Milk River—their currently is no hydropower facility on the canal. The outflow from the Canal is to the **Inflow2** slot of the **NorthMilkRiver** confluence object.

In the rules, the policy group **Determine Initial Canal Request** is used to initialize the St. Mary Canal request. The amount of water that is diverted down the canal is ultimately determined in the **Upper System Operations** policy group.

StMaryRiverComp Data Object

This data object contains a number of slots that are used for simulating the operations of the upper St. Mary River system, including the St. Mary Canal and Sherburne Reservoir. The object also contains slots that are used to define and track the apportionment of St. Mary River flow between the United States and Canada, and some of these slots are used by the rule policy group **Determine St Mary Nat Flow and US Canada Shares**. Table 4 summarizes the slots in the St. Mary River Comp data object.

Table 4. StMaryRiverComp Object Slots

Slot	Description	Value
StMaryNaturalFlow	A series slot which is set by the **St. Mary Natural Flow** rule. It logs total St. Mary River natural flows by day.	Flow in CFS
US share	A series slot which is set by the **U.S.Share** rule. It logs the daily U.S. share of St. Mary River natural flow.	Flow in CFS
Canada share	A series slot which is set by the **Canada Share** rule. It logs the daily Canada share of the St. Mary River natural.	Flow in CFS
Initial Canal Request	A series slot that is set by the **Determine Initial Canal Request** rule policy group. It logs the initial St. Mary Canal requests, for use in rules that simulate operations of the upper St. Mary system.	Canal Flow in CFS
St. Mary Canal Capacity	This slot is used to define the capacity of the St. Mary Canal at the St. Mary siphon. The maximum canal capacity also must be reset in the St. Mary Canal Diversion object. A new slot **St Mary Canal Monthly Max Capacities** is now used to set canal capacities by month.	Canal capacity in CFS, existing capacity is about 650 CFS
St. Mary Cutoff	This slot is used in the computation of flow shares for each country—flows above this rate during the irrigation season are split 50-50.	666 CFS
St. Mary Ratio	This ratio is used in the computation of flow shares below the cutoff rate; during the irrigation season the U.S gets 25% of the flow below the cutoff rate.	0.25
St. Mary Ratio 2	This ratio is used in the computation of 50/50 flow	0.5

	shares to each country above the cutoff during the irrigation season, and for all flows during the November through March period.	
Canal Min	This is the minimum flow that the model will run down the St. Mary Canal at the end of the irrigation season. It is called by the rule **Shut Off Canal in Fall When Less than 100 cfs**	Is set at 100 CFS
Canal Min2	If the Milk River system reservoirs are full and the river flow is high, this slot is used by the rule **Reduce Canal Diversions if Upper System is Full** to cut back St. Mary Canal Diversions.	Is set for now at 350 CFS
Canal Min3	Used by Rule **Reduce Canal Diversions for September 15 Target** to avoid drawing Sherburne Reservoir storage down too quickly.	Set to 550 CFS
Canal Max Week 1	Sets the initial maximum flow in the St. Mary Canal during spring start-up for week 1. Used by the rule **Ramp St Mary Canal Up in Spring**.	Currently 200 CFS
Canal Max Week 2	Sets the initial maximum flow in the St. Mary Canal during spring start-up for week 2. Used by the rule **Ramp St Mary Canal Up in Spring**.	Currently 300 CFS
Canal Max Week 3	Sets the initial maximum flow in the St. Mary Canal during spring start-up for week 3. Used by the rule **Ramp St Mary Canal Up in Spring**.	Currently 550 CFS
Canal Max Week 4	Sets the initial maximum flow in the St. Mary Canal during spring start-up for week 4. Used by the rule **Ramp St Mary Canal Up in Spring**.	Currently 600 CFS
Canal Max Daily Flux	Sets maximum daily fluctuation for the St. Mary Canal. Is called by the **Limit Daily St. Mary Canal Fluctuations** rule.	Currently 150 CFS
Fall Shutoff is Not Active	A fall shutoff switch discontinues diversions down the canal when **Canal Min** is reached. This slot toggles the switch off.	1.0
Full Shutoff is Active	This slot toggles the fall shutoff switch on. This keeps the canal from shutting down and starting up again multiple times during the fall.	2.0
Canal Shutoff	This is a series slot that records whether the canal shut off flag is on or off. The canal shutoff feature works in combination with rules in the **Determine Initial Canal Request** policy group.	1.0 or 2.0 based on whether canal is on
Balance Check Qnat	This is series slot with expression that serves as a balance check to make sure that all St. Mary River natural flow is accounted for and mass balance is achieved.	Flow in CFS

St. Mary River US Capture	This series slot with expression is another balance check to make sure that the US doesn't capture more than its share of St. Mary River flow.	Flow in CFS
Canal Start Dates	This slot contains historic St. Mary Canal start up dates for the 1959-2009 period. It is called by the **Irrigation Start Dates** function that is again referenced by the **Winter Season** and the **St Mary Canal Delivery Season** functions.	Table of fully specified start up dates for each year
StMary Canal Monthly Max Capacities	A table slot that allows maximum St. Mary capacities to be set by month. This table was added to simulate the current operations which recognize declines in effective capacity late in the irrigation season due to aquatic vegetation	Maximum Monthly Canal Flow in CFS

Rules used to simulate operations of the Upper St. Mary River System

The following three rule policy groups are used to simulate operations of the upper St. Mary River system:

1) **Determine St. Mary Nat Flow and US Canada Shares**
2) **Determine Initial Canal Requests**
3) **Upper System Operations.**

Determine St. Mary Nat Flow and US Canada Shares Policy Group

The natural flow of the St. Mary and Milk Rivers is divided between the United States and Canada by a 1921 Order of the International Joint Commission. The natural flow of the St. Mary River in the model is composed of three components: 1) inflow to Sherburne Reservoir, 2) all other inflow to Lower St. Mary Lake, and 3) tributary gains between the St. Mary Canal diversion dam and the International Boundary. The United States share of the natural flow of the St. Mary River during the irrigation season is 25% of the flow below 666 cfs, and 50% of the flow above 666 cfs. Outside of the irrigation season, it is 50% of the natural flow.

The **Determine St Mary Nat Flow and US Canada Shares** rule policy group defines the natural flow of the St. Mary River and the U.S. and Canadian shares of that flow. These defined shares are then written to the slots in the **StMaryRiverComp** data object for use by other rules. The rules in the **Determine St Mary Nat Flow and US Canada Shares** are summarized in Table 5. The three rules execute and compute the US and Canada Shares of the St Mary Natural Flow for all timesteps in the model while the model is on the first timestep. This is necessary because other rules need to have estimates of future natural flows (for example, in order to hit a target elevation on a specific date). The rules call functions in the **St Mary River Functions** and **General Functions** groups that do some of the computations. These functions are described following the Table 5 and the pseudo-code text that follows.

Table 5. Determine St. Mary Nat Flow and US Canada Shares Policy Group Rules.

Rule Name	Description
Canada Share	Computes the Canadian Share of St. Mary River natural Flow by calling the **Canadian Share** Function.
U.S.Share	Computes the U.S. Share of St. Mary River natural Flow by calling the **USShare** Function.
St. Mary River Natural Flow	Computes the natural flow of St. Mary River natural Flow by calling the **Natural Flow** Function. All natural flows are computed at the beginning timestep for use in subsequent computations

Function: **Natural Flow**

Computes the natural flow of the St. Mary River for each timestep.

St. Mary River Natural Flow = Sherburne Reservoir Inflow + Lower St. Mary Lake unregulated Inflow + Local Inflow from the St. Mary Canal Diversion Dam to the International Boundary

Function: **USShare**

Computes the United States share of St. Mary River natural flow for each timestep

```
IF
        Time-step is between November and March
                Natural Flow * 0.50
ELSE (for during the irrigation season)
        IF
                St. Mary River Natural Flow is <= 666 cfs
        THEN
                Natural Flow * .25
        ELSE
                666 cfs * .25 + (Natural Flow – 6666) * .5
        END IF
ENDIF
```

Function: **Canadian Share**

Computes the Canadian Share of St. Mary River natural flow

Canadian Share = Natural Flow – US Share

Determine Initial Canal Request Policy Group

The **Determine Initial Canal Request** policy group is used to set the initial target amount of water to divert down the St. Mary Canal. During the irrigation season, this generally is the canal capacity, although the rules reduce the initial request when circumstances dictate. During the winter, the St. Mary Canal is not operated and the canal request is zero. The initial canal request computed in this policy group is written to the **Initial Canal Request** slot in the

StMaryRiverComp data object. These initial canal requests are accessed by rules in the **Upper System Operations Group**, which refine the requests and determine canal diversions, and release or store water in the reservoirs. Table 6 summarizes the rules in this policy group. A more detailed pseudo-code type description of some of the more important or complex rules and functions follows the table.

Table 6. Determine Initial Canal Request Policy Group Rules.

Rule Name	Description
Deactivate Shutoff Flag Outside of Fall Season	Rule deactivates fall shut-off flag outside of the fall season so that it does not stop canal diversions the following spring.
Set Canal Request to Zero if Shutoff Flag is Active	This rule sets the St. Mary Canal request to zero when the fall shutoff flag is on.
Keep Fall Shutoff Flag Active for Subsequent Timesteps	This rule keeps the canal diversion request at zero during the fall once the shutoff flag has been activated; it keeps the canal from turning on and off multiple times during the fall.
Activate Fall Shutoff Flag When Canal First Goes to Zero	This rule activates the fall canal shut off flag.
Shut Off Canal in Fall When Less than 100 CFS	This rule shuts off the St. Mary Canal during the fall when the available flow to divert down it is less than a minimum threshold: 100 CFS is the minimum being used now.
Limit Daily St. Mary Canal Fluctuations	This rule limits St. Mary Canal daily fluctuations to avoid canal bank sloughing. The amount is currently set in the **StMaryRiverComp.CanalMaxDailyFlux** slot at 150 CFS.
Reduce Canal Diversions for September 15 Target	This rule measure releases from Sherburne Reservoir for the St. Mary Canal, if Sherburne Reservoir storage is being depleted too quickly in the late summer, so that the September 15 target is gradually met.
Reduce Canal Diversions for May 15 Target	This rule looks at the available storage in Sherburne Reservoir during the early spring and releases the stored water for the St. Mary Canal at a measured rate so that the May 15 target is reached.
Reduce Canal Diversions if Upper System is Full	This rule reduces St. Mary Canal Diversions if Fresno Reservoir is full, and if a substantial amount of water is flowing over the Dodson Diversion Dam on the Milk River.
Cut October canal diversions if Fresno is at target	This rule cuts back St. Mary Canal diversions during October if Fresno Reservoir storage is above the fall target and no water is needed for transfer to Nelson Reservoir.
Ramp St. Mary Canal Up in Spring	This rule is used to incrementally ramp up the flow of the St. Mary Canal during the spring. It limits the flow rates during the first 4 weeks of canal operation to rates defined in slots in the **StMaryRiverComp** data object.

Set Irrigation Requests to Canal Capacity	This rule initially sets the St. Mary Canal request during the irrigation season to the canal capacity, by month, as defined in the **StMaryRiverComp.St Mary Canal Monthly Max Capacities** slot: presently about 650 CFS, but gradually declining later during the summer as aquatic vegetation builds up.
Set Winter Season Canal Request to Zero	This rule sets the initial St. Mary Canal request to zero during the winter.

Rule: **Shut Off Canal in Fall When Less than 100 cfs**

IF
Fall Season (defined as September and October)
AND
7-day average US Share of St. Mary River flow < 100 cfs
AND
Sherburne Reservoir Storage is <= Minimum Storage
THEN
Initial Canal Request = 0 cfs
ENDIF

Note: other associated rules in the set keep the canal off once it is shut off for the first time (standard operating procedure is not to turn the canal on and off again during the fall), and allow the Canal to start up again during the spring. This rule was modified so that it uses a 7-day rolling average to compute when the available flow has dropped below 100 CFS, rather than the first day a flow below 100 CFS occurs.

Rule: **Reduce Canal Diversions for September 15 Target**

This rule begins executing on July 1 to determine whether or not to reduce the Initial Canal Request for the St. Mary Canal to avoid drawing down Sherburne Reservoir below the September 15 target prior to September 15. The rule determines the average daily canal diversion that will draw down the canal to the September 15 target by that date. If the current canal request is greater than this value, it is reduced to this value, but will not be reduced below Canalmin3 (550 cfs). The rule determines the estimated average canal diversion on July 1 and then updates its estimate on August 1.

IF
Sherburne Storage is greater than Sept 15 target AND Canal Request is greater than canal diversion that will hit the Sept 15 target)
THEN
Set Canal Request to MAX(canal diversion that will hit Sept 15 target; 550 cfs)
ELSE
IF
Sherburne Storage is less than Sept 15 target AND Canal Request is greater than 550 cfs)
THEN

```
        Set Canal Request to 550 cfs
    END IF
END IF
```

Rule: **Reduce Canal Diversions for May 15 Target**

This rule will reduce the canal diversions in the early season so that Sherburne Reservoir will not go below the May 15 target before that date. It determines this estimated canal diversion on the canal start date and updates the estimate on April 1, April 15, and May 1.

```
IF
    Sherburne Storage is greater than May 15 target AND Canal Request is greater than
    canal diversion that will hit the May 15 target
THEN
    Set Canal Request to MAX(canal diversion that will hit May 15 target; 350 cfs)
ELSE
    IF
        Sherburne Storage is less than May 15 target
    THEN
        Set Canal Request to MIN(Current Canal Request; 350 cfs)
    END IF
END IF
```

Rule: **Reduce Canal Diversions if Upper System is full**

During times when Fresno Reservoir is spilling and flows in the Milk River below Fresno Reservoir are high, this rule cuts back St. Mary Canal diversions, which can conserve stored water in Sherburne Reservoir.

```
IF
    Milk River system is full
    AND
    St. Mary Canal Diversions are greater than reduced rate
THEN
    Set Diversions to a reduced rate (currently 350 CFS before June 10 and 550 CFS after)
ENDIF
```

Function: **UpperSystemStateFull** (used by above rule)

The Upper System state is full when:

```
    Fresno Reservoir Storage >= Fresno full pool
    AND
    3-day average Milk River flow below Dodson Dam >= 400 CFS
```

Note: Dodson diversion dam typically captures all but minimum Milk River flows during the irrigation season and sends them to the Malta Irrigation District, Lake Bowdoin, or Nelson Reservoir. High flows below Dodson Dam during the irrigation season are generally considered wasted, so there is no need to divert additional St. Mary River water to the Milk River during these times.

Rule: **Cut October canal diversions if Fresno is at target**

This rule will shut off the canal during October if Fresno Reservoir is at the fall target and there is sufficient stored water in Nelson Reservoir. This leaves some more carry-over water in Sherburne Reservoir for the next season.

```
IF
        October
        AND
        Fresno Reservoir Storage is >= the October Target (minus a small amount for situations
        where it has been deliberately drawn slightly below target during the fall)
        AND
        Nelson Reservoir Storage is >= Nelson Midway October target
THEN
        Initial Canal Request = 0 cfs
END IF
```

Rule: **Ramp St. Mary Canal up in Spring**

This rule gradually ramps the flow of the St. Mary Canal up in the spring, such as is done in actual operations, rather than suddenly turning it on at capacity. The rule also looks up the historic canal start date in deciding when to set the first canal diversion request.

```
IF
        First 7 days after canal start date
THEN
        200 CFS (to break up snow and ice in the canal)
ELSE
        IF
                Next 7 days after canal start date
        THEN
                300 CFS
        ELSE
                IF
                        Next 7 days after canal start date
                THEN
                        550 CFS
                ELSE
                        IF
                                Fourth week after canal start date
                        THEN
                                600 CFS
                        ENDIF
                ENDIF
        ENDIF
ENDIF
```

Function: **Winter Season**

= November 1 to Canal Start Date

Function: **St. Mary Canal Delivery Season**

= Canal Start Date through October 31

Function: **Canal Div for Sept 15 Target**

This function takes a given date computes the daily average canal diversion that will hit the Sherburne Sept 15 Target.

=((Sherburne Storage at date – Sept 15 Target) + Projected US Share of St Mary River Flows between date and Sept 15) / Number of days between date and Sept 15

Function: **Canal Div for May 15 Target**

This function takes a given date computes the daily average canal diversion that will hit the Sherburne May 15 Target.

=((Sherburne Storage at date – May 15 Target) + Projected US Share of St Mary River Flows between date and May 15) / Number of days between date and May 15

The **Upper Systems Operations** policy group is used to set the final diversion request for the St. Mary Canal, and to operate Sherburne Reservoir, and Lower St. Mary Lake storage (when it is active) to supply stored water for the St. Mary Canal when it is needed.

Upper System Operations Policy Group

After the initial St. Mary Canal Diversion request is set and the U.S. and Canadian shares of the St. Mary River natural flow are defined, this group of rules determines the final canal request and operates the system to most efficiently divert and capture U.S. share water. If the U.S. share is insufficient to meet the diversion request, stored water is released from Sherburne Reservoir. If the U.S. share exceeds the diversion request, water is stored. Lower St. Mary Lake storage is an optional feature that can be used in simulating potential future operations of the Upper System; there is no controlled storage on Lower St. Mary Lake now. The rules in this group are summarized in Table 7. A more detailed pseudo-code type description of some of the more important or complex rules and functions follows the table.

Table 7. Upper System Operations Group Rules.

Rule Name	Description
LSML Pass inflow if below minimum	Rule does not allow releases greater than inflow when Lower St. Mary Lake minimum active storage is reached. Is only active when the Lower St. Mary Lake storage option is turned on.
LSML reset for inflow outflow	This rule was put in at high priority because some slots were being reset by lower priority rules that caused negative

	storages and other problems at Lower St. Mary Lake.
Set inflow to outflow if early winter target is reached	If Sherburne Reservoir storage rises above 30,000 acre-feet during the fall or early winter, the rule sets outflow to inflow to keep reservoir storage from increasing. This keeps storage from exceeding the 40,000 acre-foot winter maximum before spring.
Set Sherburne Outflow to inflow if winter and full	If Sherburne Reservoir reaches the March 1 target during the winter, the rule sets outflow to inflow. Note: this rarely occurs.
LSML store winter flows	When the Lower St. Mary Lake storage option is turned on, this rule stores available water above the U.S. share in Lower St. Mary Lake during the winter.
Set Sherburne Winter Outflow	Sets Sherburne outflows during the winter to the minimum specified in the **SherburneData** data object. Currently, there is no winter release.
Set Sherburne when below Minimum Storage	If Sherburne storage drops below minimum pool for any reason, this rule sets the outflow to slightly lower than the inflow in order to build storage back up to the minimum.
Set Sherburne to Winter Flow if Canal is off	When the St. Mary Canal is shut off, this rule makes sure that extra water is not released from Sherburne Reservoir.
Set Lower St. Mary Irrigation Season Minimum	This rule allows a minimum release from lower St. Mary Lake to be specified and enforced during the irrigation season, when lower St. Mary Lake storage is active.
Increase Canal Diversion with Lower St. Mary Lake Storage	This rule increases the St. Mary Canal diversion request when stored water from Lower St. Mary Lake is being released.
Increase Canal Diversion with Sherburne Available Storage	This rule increases the St. Mary Canal diversion request when stored water from Sherburne Reservoir is being released.
Operate Lower St. Mary Lake to Release or Store Water for Canal	When the Lower St. Mary Lake storage option is turned on, this rule stores and releases water from the Lake for the St. Mary Canal. When U.S. share of natural flow is insufficient to keep the Canal flow, water is released from Lower St. Mary Lake storage before it is released from Sherburne Reservoir.
Operate Sherburne to Release or Store Water based on Canal Requirements1	This rule sets the Sherburne Reservoir release for the purpose of storing and releasing water for the St. Mary Canal. It considers minimum outflows when setting the release.
Store Credit Water in Sherburne	This rule is only active when the annual balancing switch is on. It stores any extra “credit” water that is available in Sherburne Reservoir.
Pass Sherburne Inflow in	This low-priority rule initializes releases of water from

Irrigation Season	Sherburne Reservoir during the irrigation season as the minimum of the inflow, or the maximum release given inflow and reservoir storage.
LSML inflow equals outflow	This rule initializes the outflow from the Lower St. Mary Lake storage object as inflow. This setting is maintained unless the lake is operated as a storage reservoir.
Set St. Mary Canal to US Share plus Credit Water	This rule is only used when the annual balancing switch is turned; it resets the S. Mary Canal Diversion request to the U.S. share plus available credit water.
Set St. Mary Canal to US Share Only	This rule resets the St. Mary Canal request to the lesser of the Initial canal request or the U.S. share. Higher priority rules in this group will then reset the Canal request when stored water is released from Sherburne Reservoir or Lower St. Mary Lake. The rule is not active when the annual balancing option is turned on.

Rule: **Set St. Mary Canal to US Share Only**

This rule accesses the St. Mary Canal diversion request from the **StMaryRiverComp.Initial Canal Request** Slot and resets it to the US share, if the US share is less than the diversion request.

St. Mary Canal Diversion Request = Minimum of:

a) Initial Canal Request
b) US Share

Rule: **LSML store winter flows**

This rule stores water in Lower St. Mary Lake, and is only active during the winter season and when the Lower St. Mary Lake storage switch (in the **Lower StMary Lake Data** object) is on.

IF

Time step is between November 1 and the canal start date for the next calendar year
AND
Lower St. Mary Lake Storage < Lower St. Mary Lake maximum storage
AND
Inflow to Lower St. Mary Lake + Local Inflows between Lower St. Mary Lake and the International Boundary > Canadian Share
AND
Lower St. Mary Lake Inflow > Specified Minimum Flow for below the Lake

THEN

Release the Maximum of the following and store the remainder:

a. Canadian Share minus local inflow from Lower St. Mary Lake to the border
b. Lower St. Mary Lake inflow – amount of flow needed to fill to maximum pool

ENDIF

Rule: **Increase Canal Diversions with Lower St. Mary Lake Storage** (only active when switch for **Lower StMary Lake Data** object is on)

```
IF
    St. Mary Canal diversion request < Canal capacity
    AND
    Rule Operate Lower St. Mary Lake to Release or Store Water for Canal is releasing
    water for the St. Mary Canal
THEN
    Reset St. Mary Canal Diversion request to the U.S. share + the flow released from
    Lower St. Mary Lake for the canal
ENDIF
```

Rule: **Increase Canal Diversions with Sherburne Available Storage**

```
IF
    St. Mary Canal diversion request < Canal capacity
    AND
    Rule Operate Sherburne to Release or Store Water based on Canal Requirements1
    is releasing water for the St. Mary Canal
THEN
    Reset St. Mary Canal Diversion request to the U.S. share + the flow released from
    Sherburne Reservoir for the canal
ENDIF
```

Rule: **Operate Lower St. Mary Lake to release or store water for the canal**

Notes: This rule only is active when the switch in the Lower StMary Lake Data object is on. When it is active and stored water needs to be released for the St. Mary Canal, stored water will first be released from Lower St. Mary Lake first. Once all the Lower St. Mary Lake storage has been used, water will be released from Sherburne Reservoir.

```
IF
    Timestep is during St. Mary Canal delivery season
THEN
    IF
        St. Mary Canal diversion < St. Mary Canal request
        AND
        Lower St. Mary Lake Storage > Minimum storage
    THEN (Release stored water)
        Lower St. Mary Lake release = Inflow + Additional flow needed to fill St. Mary
        Canal
    ELSE
        IF
            Available Flow > St. Mary Canal request
            AND
            Lower St. Mary Lake storage < Maximum storage
            AND
            Flow at International Boundary > Canada share
        THEN (Store water)
            Release = St. Mary Canal diversion request + (Canada Share – Local
            inflow between Canal Diversion and International Boundary)
        ENDIF
    ENDIF
ENDIF
```

A second statement in this rule tracks releases of stored water and writes them to the **Lower StMary Lake Data.Storage Release for Canal** slot for later use by rule **Increase Canal Diversions with Lower St. Mary Lake Storage** as follows:

```
IF
        Timestep is during St. Mary Canal delivery season
        AND
        Initial St. Mary Canal Diversion < St. Mary Canal capacity (or lesser initial request)
        AND
        Lower St. Mary Lake available storage > 1 acre-foot
THEN
        Lower St. Mary Lake Storage Release for Canal = Flow needed to fill canal to capacity
        or lesser requested amount
ELSE
        0 cfs
ENDIF
```

Rule: **<u>Operate Sherburne to Release or Store Water based on Canal Requirements1</u>**

```
IF
        Timestep is during St. Mary Canal delivery season
        AND
        St. Mary Canal diversion < St. Mary Canal request
        AND
        Lower St. Mary Lake Storage <= Lower St. Mary Lake storage minimum
                                OR
                                Lower St. Mary Lake Storage switch is off
        AND
        St. Mary Canal Diversion < Initial Canal request
                                AND
                                Sherburne Reservoir Storage > Minimum
THEN    (Release stored water)
        Sherburne Reservoir Release = Inflow + Additional flow needed to fill St. Mary Canal
ELSE
        IF
                Available Flow > St. Mary Canal request
                AND
                Sherburne Reservoir storage < Maximum storage
                AND
                Flow at International Boundary > Canada share
        THEN    (Store water)
                Release = St. Mary Canal diversion request + (Canada Share – Local inflow
                between Canal Diversion and International Boundary)
        ENDIF
ENDIF
```

A second statement in this rule tracks releases of stored water by writing them to the **SherburneData.Storage Release for Canal** slot for later use by rule “Increase Canal Diversions with Sherburne Available Storage” as follows:

IF

```
        Timestep is during St. Mary Canal delivery season
        AND
        Lower St. Mary Lake storage <= Minimum
                OR
                Lower St. Mary Lake storage switch is off
        AND
        Initial St. Mary Canal Diversion < St. Mary Canal capacity (or lesser initial request)
        AND
        Sherburne Reservoir Storage > Minimum storage
THEN
        Sherburne Reservoir Storage Release for Canal = Flow needed to fill canal to capacity
        or lesser requested amount
ELSE
        0 cfs
ENDIF
```

There are a few rules in the **Upper System Operations** policy set that are used in conjunction with a third ruleset **Annual Accounting** for modeling a hypothetical change in how flow apportionments are managed. These rules will be discussed further in the next section.

Annual Accounting

Under the current international apportionment procedures for the St. Mary River, flows are balanced on a semi-monthly basis. That is, deficit deliveries to Canada during any given day can be offset by surpluses in other days, as long as the deliveries balance out during a 15 or 16-day division period. Rules were added to the model to simulate an annual balancing period. This would allow the United States to make daily deficit deliveries, as long as they are made up during another time of the year by surplus deliveries. Important to this system would be the accumulation of "credits", which are surplus deliveries to Canada. Deficit deliveries by the U.S. could not be made unless there was a credit to draw on. The annual balancing period would run from November 1 through October 31, so that winter surplus deliveries to Canada could be accumulated and then recaptured during the early spring. The other time that credits might be accumulated would be the spring-runoff period. These credits could then be drawn on during the summer. Montana and Alberta have been discussing an annual accounting arrangement, with stipulations for minimum instream flows at the International Boundary.

The **Annual Accounting** and **Upper System Operations** policy groups contain the rules that are used to simulate annual accounting. These rules fill and use data from slots in the **Annual Accounting** data object. Minimum flows at the International Boundary can be specified in annual accounting, and maximum credit caps can be simulated. A split credit accumulation period (winter and spring with maximum credit accumulation caps) also can be modeled. Under annual accounting operations, the model always will use the annual accounting credit water available to it before requesting releases from stored water in Sherburne Reservoir, or from Lower St. Mary Lake, if it is modeled as a storage reservoir. The slots in the **Annual Accounting** data object are described in Table 8. The data object also contains several statistical summary table slots which summarize model results as they apply to annual accounting, and these slots will not be further described here.

Table 8. Annual Accounting Data Object Slots.

Slot	Description	Value
Daily US Credit	This series slot logs the U.S. credits for each day, which are surplus deliveries to Canada. The credits are computed in the **Compute US Credit** rule.	Daily values in CFS
Total US Credit	This series slot accumulates the total U.S. credits during each year. It is computed in the **Compute US Credit Rule**.	Accumulated totals in acre-feet
Daily Draw on Credit	This series slot logs the daily draws on U.S. credits. It is computed in the **Set St. Mary Canal to US share plus Credit Water** rule.	Daily values in CFS
Total Draw on Credit	This series slot accumulates the total U.S. credit draws during each year. It is computed in the **Compute Total Draw on Credit** rule.	Accumulated totals in acre-feet. Set to zero at the beginning of each credit year.
Percent of Nat Flow for Min IB	This slot can be used to make sure that the flow at the International Boundary does not drop below a specified percentage of the total natural flow of the St. Mary River due to annual balancing.	Percentage
Min Flow at St Mary IB	This slot can be used to set a minimum flow at the International Boundary that flows can't be reduced below due to annual balancing. It can be used in combination with the Percent of Natural flow slot.	Flow in CFS
Annual Balancing Switch	This switch turns the annual balancing option on and off	1 = ON Any other number = OFF
Max Allowable Credit	This slot allows the option of putting a maximum cap on the credit that the U.S. can accumulate and draw on during annual balancing.	acre-feet

Table 9 lists and briefly describes the rules in the **Annual Accounting** policy group. Following the table are more detailed descriptions of the major rules in this set and some of the rules from the **Upper System Operations** policy set, which are used to simulate annual accounting. The first four rules in the table can be turned on and off, based on what type of annual accounting scenario is being run.

Table 9. Annual Accounting Group Rules (these rules only are active when the annual accounting balancing switch is on).

Rule Name	Description
Compute US Credit	Computes the daily credits accumulated by the United States, the cumulative total credit available to the U.S., and zeros the credit available at the start of each accounting year.
Compute US Credit Split Cap	A variation of the **Compute US Credit** rule which has been modified to examine options where there are two capped credit accumulation periods.
Compute US Credit LOI Cap	Another variation of the **Compute US Credit** rule that allows for the simulation of a credit system with a single 8,000 acre-foot cap, which is similar to the current "Letter of Intent (LOI)" arrangement with Canada.
Compute Total Draw on Credit	Accumulates the total draw on credit during an annual accounting year and writes it to the **Annual Accounting.Total Draw on Credit** slot.

Rule: **<u>Compute U.S. Credit</u>**

The first statement in this rule defines that daily U.S. credit as a volume as follows:

> = Flow to Volume: St. Mary River at International Boundary Flow - the Canadian share of that flow

The second statement accumulates the total U.S. credit.

```
IF
        Current timestep = start timestep
THEN
        0 acre-feet
ELSE
        IF
                Current timestep = November 1 (the start of the annual accounting year)

        THEN
                0 acre-feet
        ELSE
                Total U.S. accumulated credit at previous timestep + credit accumulated during
                current timestep
        ENDIF
ENDIF
```

Rule: **<u>Compute US Credit Split Credit Cap</u>**

The first statement in this rule defines the daily U.S. credit as a volume as follows:

> = Flow to Volume: St. Mary River at International Boundary Flow - the Canadian share of that flow

The second statement accumulates the total U.S. credit for time periods starting on November 1 and June 1, and zeroes the credits at the beginning of those periods. It also does not allow the credits to exceed the caps for the two periods.

```
IF
        Current timestep = start timestep
THEN
        0 acre-feet
ELSE
        IF
                Current timestep = November 1 (the start of the first credit period)
                OR
                Current timestep = June 1
        THEN
                0 acre-feet
        ELSE
                IF
                        Total accumulated credit during previous timestep <= Credit Cap
                        Total U.S. accumulated credit at previous timestep + credit accumulated
                        during current timestep
                ELSE
                        Maximum allowed credit (as defined in Annual Accounting: Max Allowable
                        Credit slot)
                ENDIF
        ENDIF
ENDIF
```

Rule: **Compute US Credit LOI cap**

This rule allows for a single credit that can be accumulated during the November through June period, that can't exceed 8,000 acre-feet. It is similar to the current "Letter of Intent" water sharing arrangement that is in place with Canada.

The first statement in this rule defines the daily U.S. credit as a volume as follows:

> = Flow to Volume: St. Mary River at International Boundary Flow - the Canadian share of that flow

The second statement accumulates the total U.S. credit for time periods November 1 to June 1, and zeroes the credits outside of those periods. It also does not allow the credits to exceed the cap.

```
IF
        Current timestep = start timestep
THEN
        0 acre-feet
ELSE
        IF
                Current timestep = is GT June 1 and LT November 1
        THEN
                0 acre-feet
        ELSE
```

IF
Total accumulated credit during previous timestep <= Credit Cap
THEN
Total U.S. accumulated credit at previous timestep + credit accumulated during current timestep
ELSE
Maximum allowed credit of 8,000 acre-feet
ENDIF
ENDIF

Rule: **Annual Accounting Total Draw on Credit**

This rule tracks the total draw on credit for use by the other annual accounting rules.

IF
Start Timestep
OR
November 1
THEN
Credit = 0
ELSE
Total draw on credit as computed during previous timestep - Draw on credit for current timestep
ENDIF

Annual Accounting Rules from Upper System Operations Group

Rule: **Store Credit Water in Sherburne**

This rule will store credit water in Sherburne Reservoir when it is available and not needed by the St. Mary Canal.

IF
St. Mary River Flow at St. Mary River Canal Diversion > Canal Request
AND
Sherburne Reservoir Storage < Maximum
AND
St. Mary River at International Boundary Flow > Specified minimum flow
AND
Credit water is available
THEN
Store credit water in Sherburne Reservoir, but maintain minimum flows at International Boundary (see **Min IB Flow** function)

Rule: **Set St. Mary Canal to US share plus Credit Water**

When the daily U.S. share of natural flow is not sufficient to meet the St. Mary Canal diversion request, this rule allows the Canal to divert available credit water. This credit water is drawn on before water from reservoir storage is released.

Saint Mary Canal Diversion Request = Minimum of:

a) The canal request
b) U.S. share of flow + Minimum of:
    i. Available credit water
    ii. The flow above the specified minimum flow at the International Boundary

Function: **Min IB Flow**

This function in the **St Mary River Functions** utility group defines a minimum flow at the International Boundary when the credit system is active.

Minimum flow at International Boundary = Maximum of:

a) Defined percent of total natural flow at that timestep (percentage defined in slot **Annual Accounting.Percent of Nat Flow for Min IB**)
b) A Specified absolute minimum flow (defined in slot: **Annual Accounting. Min Flow at St Mary IB**)

Milk River Basin Upstream of Fresno Reservoir

North Fork of Milk River

The North Fork of the Milk River originates in the U.S. in the Blackfeet Indian Reservation. The upper portions of the stream are simulated by the **Upper North Milk River** reach object. The inflows to this object are daily streamflow data from USGS gaging records, which have been naturalized to account for historic irrigation depletions. There is a water user object called **US Irrigation on North Milk** which simulates available-flow based irrigation diversions, consumption, and returns for 200 acres. During the most recent years, there hasn't been any active irrigation on this stream.

Outflows from the Upper North Milk River reach object goes to the **Inflow 1** slot of the **NorthMilkRiver** confluence object. This confluence object represents the junction of the St. Mary Canal with the North Fork of the Milk River. Simulated inflows from the St. Mary Canal go to the **Inflow 2** slot of the **NorthMilkRiver** confluence object.

Milk River at the Western Crossing of the International Boundary

The headwaters of the Milk River proper originate in the foothills area of the Blackfeet Indian Reservation. This stream is represented by the reach object **South Milk River** in the model, although the stream should technically be referred to as the Milk River—of which the South Fork is the largest tributary. The input inflow slot data for this reach are based on USGS gaging records for the Milk River at the Western Crossing of the International Boundary, which have been naturalized to account for historic irrigation depletions. There is a water user object called **US Irrigation on South Milk** which simulates 2,000 acres of available-flow based irrigation use in this watershed. Outflows from the South Milk River reach object go to the **MilkRiveratConfluence** confluence object.

Milk River at Confluence

The North Fork of the Milk River (including the St. Mary Canal water carried by it) joins the Milk River proper just west of the Town of Milk River, Alberta. This junction is represented in the model by the confluence object **MilkRiveratConfluence**. The slot **Inflow 1** to this object is the outflow from the **South Milk River** reach object. The slot **Inflow 2** is the outflow from the **NorthMilkRiver** confluence object.

Proposed Alberta Milk River Forks storage Reservoir

Alberta has proposed building a reservoir near the Milk River "Forks" (the confluence of the Milk River and the North Fork) to store and release for irrigation using the Canadian share of Milk River natural flow. The reservoir object **Proposed Alberta Forks Reservoir** represents this proposed reservoir. The rule policy group **Proposed Alberta Forks Reservoir** simulates how the proposed reservoir might be operated. There also is a rule in the **Milk River Shortage Sharing** policy group that allows Alberta Milk River irrigators to use only Canadian share Milk River water, including that stored and released by this reservoir. The data object **Alberta Storage**

Reservoir contains information that the rules use to simulate reservoir operations. The slots in this data object are summarized in the Table 10. Alberta irrigation is increased when this reservoir is simulated by increasing acres in the **Canadian Irrigation** object **Irrigated Area** slot. A maximum reservoir storage of 243,000 acre feet has been proposed, which might serve up to about 30,000 acres of irrigation in Alberta.

Table 10. Alberta Storage Reservoir Object Slots.

Slot	Description	Value
Alberta Reservoir On Off Switch	This slot specifies whether or not the reservoir simulation is active during a model run.	1 = Reservoir simulated 0 = No Reservoir Simulated
Alberta Reservoir Max Storage	This slot is for inputting the maximum storage for the proposed reservoir.	Storage in acre-feet
Minimum Release from Alberta Reservoir	This slot can be used to specify a minimum outflow from the reservoir.	Flow in CFS
Alberta Reservoir Minimum Pool	This slot allows input of a minimum storage for the reservoir.	Storage in acre-feet
Alberta Milk River Reservoir Target Release	This series slot with expression is for tracking targeted releases of stored water for Canadian Irrigation from the proposed reservoir.	Flow in CFS

The rules that are used to simulate the proposed Alberta Reservoir are contained in the **Proposed Alberta Forks Reservoir** policy group. These rules are summarized in Table 11. More details on some of the more important rules in this set follow the table. Details on some of the important functions used, which are in the **Milk Natural Flow Functions** utility group, also are provided.

Table 11. Proposed Alberta Forks Reservoir policy group rules.

Rule Name	Description
Minimum Release from Alberta Reservoir	Resets the release from the reservoir (when the reservoir is on) to a specified minimum flow if the release from lower priority rules is less.
Reduce Release for Alberta Minimum Pool	When the proposed reservoir reaches minimum pool, this rule sets the outflow to inflow. It also cuts back the downstream Canadian irrigation diversions correspondingly.
Alberta Release for Canadian Irrigation and US Share	This rule releases water from the reservoir for Canadian demands, while also releasing the U.S. St. Mary Canal water and Milk River natural flow that is needed so the share is met at the Eastern Crossing of the International Boundary.
Initialize Alberta Set Outflow to Inflow	This rule initializes the proposed reservoir by setting outflow to inflow.

Rule: **Minimum Release from Alberta Reservoir**

IF
    Proposed Alberta Reservoir Release < Minimum
Then
    Release = Minimum

Rule: **Reduce Releases for Alberta Minimum Pool**

This rule reduces the release from Alberta Forks Reservoir if the storage is less than the minimum pool elevation. It will reduce the release to a value that will keep Alberta Forks Reservoir right at the minimum pool. If the release is reduced, a Minimum Diversion Bypass is set for the Canadian Irrigation object so that the reduced release results in the same reduction in diversion.

IF
    Alberta Forks Reservoir Storage < Minimum Pool
THEN
    Set Alberta release to the value that will maintain the minimum pool
    Set the Minimum Diversion Bypass at Milk River Alberta Irrigation to the value currently bypassing this object (before reducing the Alberta release)
END IF

Rule: **Alberta Release for Canadian Irrigation and US Share**

This rule determines the release from Alberta Forks Reservoir that will meet the Canadian Irrigation demand and will meet the required flow rate at the eastern crossing.

Release from Alberta Forks Reservoir = Canadian Irrigation Demand + St Mary Canal + US Share of Milk River flow – US Irrigation Depletions on North/South Milk – Local Inflows occurring below Alberta Forks Reservoir

Function: **MilkNaturalFlow**

This function is used to compute the natural flow of the Milk River so that the U.S. and Canadian shares can be determined.

Milk River Natural Flow = Milk River at Western Crossing Flow (with 4-day time lag) + North Fork of Milk River above St. Mary Canal Flow (with 4-day time lag) + natural inflow between the Western and Eastern Crossings

Function: **Canada Share of Milk River Natural Flow**

The natural flow of the Milk River is divided in as similar manner as the flow of the St. Mary River, except that the United States gets the higher percentages of the first 666 cfs of Milk River natural flow. This function computes the Canadian share for each time-step as follows.

IF

```
        Time-step is between November and March
                Natural Flow * 0.50
ELSE (during the irrigation season)
        IF
                Milk River Natural Flow is <= 666 cfs
        THEN
                Natural Flow * .25
        ELSE
                666 cfs * .25 + (Natural Flow – 6666) * .5
        END IF
ENDIF
```

Function: **US Share of Milk River Natural Flow**

= Milk River Natural Flow – Canadian Share

Milk River in Alberta Local Inflow

The **Milk River in Alberta Local Inflow** reach object inputs tributary and mainstem gains between Western and Eastern Crossings of the International Boundary through the **Local Inflow** slot.

Evap of St Mary Canal Water

The **Evap of StMary Canal Water** reach accounts for evaporation of diverted St. Mary Canal water from the Milk River channel. The series slot **Variable GainLoss** accumulates the estimated daily evaporation losses for the imported St. Mary River water. These are computed by the **Evaporation on St. Mary Canal Flow in the Milk River** rule in the **Evaporation on St. Mary Canal Flow in the Milk River** policy group.

Rule: **Evaporation on St. Mary Canal Flow in the Milk River**

= 0.187 * St. Mary Canal Flow Imported to Milk River * Daily Channel Evaporation Rate

This simple linear regression equation was developed based on average pan evaporation by day for the 1990 through 2004 period for Ft. Assiniboine, Montana and the relationship for streamflow consumed per inch of pan evaporation from the report "Natural Flow and Water Consumption in the Milk River Basin, Montana and Alberta, Canada" (USGS, 1986).

Milk River in Alberta Irrigation

There are about 8,000 acres of sprinkler irrigation in Alberta that pump water from the Milk River. The **Milk River Alberta Irrigation** reach object and **Canadian Irrigation** water user object simulate this irrigation. The link to the irrigation is available flow based, although there is **Minimum Diversion Bypass** slot that is used with the rule **Alberta Irrigation Bypass of US Flow No Storage** rule in the policy group **Milk River in Alberta Accounting** which limits irrigation diversions to the Canada share of Milk River natural flow. The simulated Alberta irrigated acres can be increased through the object **Canadian Irrigation Data** to reset the irrigated area in Alberta when the proposed reservoir is modeled. The object contains the following two slots:

(1) **Override Canadian Irrigated Area On Off Switch**, which allows the irrigated are to be changed, and (2) **Canadian Irrigated Area when Overridden**, which allows the acreage to be reset. The following is an explanation of the rules in the Milk River in Alberta Accounting policy group.

Rule: **Alberta Irrigation Bypass of US Flow No Storage**

This rule bypasses U.S. share Milk River natural flow and U.S. St. Mary River water that is imported into the Milk River past the Canadian irrigation.

Bypass Flow = Minimum of:

a) Inflow to Milk River Alberta Irrigation object – Canada Share
b) 5.0 CFS

The Letter of Intent (LOI) arrangement with Canada allows Alberta to divert an additional 4,000 acre-feet of water from the Milk River channel during the irrigation season, in exchange for the United States being allowed to divert 8,000 acre-feet of extra St. Mary River water during the early spring. This option can be turned on or off. Rules in the **Milk River in Alberta Accounting** policy group account for this LOI water and allow Alberta to divert extra water from the Milk River until the 4,000 acre-feet of water is depleted.

Rule: **Compute Alberta Credit Balance**

This rule is active when the Milk River LOI on Off Switch in the **Milk River in Alberta Accounting** Object is on (Set to 1). It tracks the balance of LOI credit water available to Alberta as follows:

IF

April 1 = 4,000 AF (This sets the amount available at the beginning of the season)

ELSE

Milk River LOI Balance Previous Day – Daily LOI Credit Draw

ENDIF

Rule: **Compute Alberta Daily Credit Draw**

This rule computes the daily draw on credit by Alberta irrigation:

Max: Alberta Irrigation Diversion – Canada Share of Milk River; 0 CFS

Rule: **Compute Alberta Daily Credit Draw**

This rule allows Alberta to divert more than the Canada share of Milk River natural flow when the LOI option is active and there is a positive LOI balance.

Maximum

Canada Irrigation Diversions - Canada Share of Milk River Natural Flow

0 CFS

ENDIF

Rule: **Flow of Milk River at IB due US**

For double-checking purposes, this rule tracks the flow of the Milk River at the Eastern Crossing due to the US

Flow of the Milk River at the Eastern Crossing Due U.S. =

St. Mary Canal Flow Diverted to Milk River - Evaporation of St. Mary River Canal water from the Milk River Channel +
US Share of Milk River Natural Flow –
US Depletions from North Fork of the Milk River –
US Depletions from the Milk River Upstream of the Western Crossing –

The data object **MilkDataAndComputations** is used to make computations associated with the simulations of the Milk River in Canada. Table 12 below summarizes the slots in this object. Table 13 summarizes slots in the **Milk River in Alberta Accounting** Object.

Table 12. MilkDataAndComputations Object Slots.

Slot	Description	Value
Channel Evaporation	Table of average daily evaporation rates for use in computing Milk River channel evaporation	Daily evaporation rate in inches
Evap coeff	A coefficient used in computing Milk River evaporation per inch of pan evaporation based on the flow in the river. [Does not appear to be used anymore]	63.1 CFS
MilkRiverCutoff	This is the flow rate above which Milk River flow shares are split 50/50.	666 CFS
MilkRiverRatio1	The ratio of Milk River natural flow Canada is entitled to during the irrigation season for flows less than 666 CFS.	0.25
MilkRiverRatio2	The ratio of Milk River flow each country is entitled to during the non-irrigation season, and for flows about 666 cfs.	0.50
Milk River Irrigation Start Dates	These are the estimates of Milk River irrigation start dates by year. These dates were used for model calibration purposes.	Irrigation start day by year for 1950-2009.

Table 13. Milk River in Alberta Accounting Object Slots.

Slot	Description	Value
Milk River LOI Balance	Tracks the Canadian Milk River LOI balance by day	Maximum is 4,000 acre-feet
Milk River LOI On Off Switch	Turns the Milk River LOI	0 = Off

	option on or off	1 = On
Alberta daily credit draw	Tracks the Milk River LOI credit draws by Alberta by day	
Flow of Milk River at EC due US	Tracks the total flow of the Milk River at the Eastern Crossing that is due to the U.S. by day, including St. Mary Canal flow.	Flow in CFS
Canadian Share Natural Flow	Canada's daily share of Milk River natural flow	Flow in CFS
US Share Natural Flow	The U.S.'s daily share of Milk River natural flow	Flow in CFS
Milk River at EC Natural Flow	The natural flow of the Milk River at the Eastern Crossing	Flow in CFS

Milk River in Alberta Time Lag

The **Milk River in Alberta Tim Lag** reach object is used to simulate the time lag that it takes for St. Mary Canal water to flow from the North Fork of the Milk River to the Milk River at the Eastern Crossing of the International Boundary. The time lag used is 4 days; it is in the **LagTime** table slot for this object.

Milk River at Eastern Crossing

This location is represented by the **Milk River at Eastern Crossing** stream gage object that simply tracks the flow of the Milk River at the Eastern Crossing of the International Boundary. The inflows to the node are the outflows from the **Milk River Alberta Irrigation** reach node. The outflows are to the **Fresno Reservoir** storage object inflow slot.

Fresno Reservoir

General Criteria

The combined natural flow of the Milk River and diversions from the St. Mary Canal are stored and regulated in Fresno Reservoir near Havre. The following are a list of criteria that are used to model operations of Fresno reservoir, given the estimated 1999 storage of 92,880 acre-feet. For the St. Mary River and Milk River Basin Study, an estimated 2050 storage of 62,000 acre-feet was used and elevation-volume curves, targets and other operational parameters were adjusted to correspond to this level of storage.

1. End of irrigation season (usually late September to early October): Transfer stored water to Nelson Reservoir when Fresno Reservoir is above fall target (60,000 acre-feet) and Nelson Reservoir is below its fall target.
2. Fall and winter: Maintain a minimum release of 45 cfs to maintain flow for municipal water users.

3. Spring (March 15 to May 31): Transfer stored water to Nelson Reservoir if Fresno Reservoir is above target and Nelson Reservoir storage is below target.
4. Summer: Release flows from Fresno Reservoir to satisfy downstream irrigation demands without depleting storage too rapidly.
5. Late summer and early fall: Do not let storage to drop below 18,000 acre-feet so there is enough storage to support fall/winter minimum releases.

The rule policy group **Fresno Operations** is used to simulate the operations of the reservoir. Table 14 contains a summary of the active rules in this group. The Table does not describe several old rules that are still in the group, but no longer active.

Table 14. Fresno Operations Policy Group Active Rules.

Rule Name	Description
Set absolute minimum outflow	Allows Fresno releases to drop below the normal minimum to the lesser of 25 CFS or the inflow during infrequent times when there is not enough storage and inflow to maintain the normal minimum release of 45 cfs
Outflow=inflow for min pool	Sets outflow to the lesser of inflows or minimum releases when the reservoir pool reaches dead storage.
Reset Release to Normal Minimum if Too Low	Resets Fresno release to 45 cfs minimum when pool has risen above dead storage and the release is still below the minimum.
Set Fresno Release when Full	Avoids sharp release fluctuations when Fresno Reservoir is near full pool by keeping reservoir slightly above full pool and letting some water flow over the spillway.
Set Winter Minimum Release When Storage is High	This rule increases the winter releases when Fresno Reservoir is high to draw the Reservoir down to the Spring Target on March 1.
Set Winter Minimum Release	Sets winter release to the recommended minimum of 45 cfs.
Ramp Down after Spring Transfer	Gradually reduces Reservoir releases down to irrigation-demand driven rates after the Fresno-to-Nelson spring storage transfer period, when necessary.
Spring Storage Transfer to Nelson	Simulates transfers of stored water from Fresno Reservoir to Nelson Reservoir during the spring when Fresno Storage is above target maximum and Nelson is below target.
Draw Down in September if above target	This rule looks to see whether the reservoir is above target going into the fall. Starting in September and through October, the rule gradually brings the reservoir down to target (60,000 acre-feet) if necessary.
Reduce Release for Late Summer Fall if Flagged	Reduces late summer releases to inflow if reservoir drops below the fall target (15,000 acre-feet).
Late Summer Fall Release Reduction Flag	Turns on Late Summer-Fall Cut Back Flag if Fresno Reservoir Storage is below a set level (currently 15,000 acre-feet)
Fresno Irrigation Release	Sets releases from Fresno Reservoir during the irrigation

Demand Driven	season based on downstream demands and available storage in the reservoir.
Initialize Fresno Outflow for first Week	During the first week of the model run, initializes reservoir outflows by setting to inflow.

The following is a description of some of the more significant rules in the **Fresno Operations** group and associated functions in the **Fresno Functions** and **Lower Milk River Functions** utility groups.

Rule: **Set Winter Release When Storage is High**

This rule increases the winter releases in order to draw Fresno Reservoir down to the Spring Target on March 1 in cases were winter storage and inflow is high. This rule will not increase the release above 100 cfs, so the reservoir may not be drawn down to the Spring Target if inflows are too high.

IF

The current timestep is between December 1 and March 1, 2012

THEN

MIN (100 cfs; MAX (Fresno Inflow; 45 cfs; average daily release that would be required to hit spring target on March 1))

ELSE

IF

The current timestep is in November or between March 1 and the Irrigation Start Date

THEN

MIN (100 cfs; MAX (Fresno Inflow; 45 cfs))

END IF

END IF

Rule: **Spring Storage Transfer to Nelson**

If Fresno Reservoir is above target during the spring, this rule simulates a release from Fresno to fill Nelson. The rule primarily is intended to move water from Fresno to Nelson early during the spring before irrigation demands start or when irrigation demands are still very low.

IF

Fresno average weekly storage > Midway target (30,000 acre-feet in April and 25,000 acre-feet during May)

AND

Nelson Reservoir storage < 61,000 AF

THEN

Storage Release for Nelson = the Minimum of:

Fresno release at the previous timestep + 150 CFS

The maximum release given the reservoir elevation and inflow

325 CFS + Total Lower Milk River Irrigation Demands

ENDIF

Function: **Fresno Spring Transfer Period**

April 10 through May 31, 2011

Function: **Fresno Average Weekly Storage**

The average Fresno Storage for 7 days before the current timestep.

Function: **Fresno Release for Demands**

The average of the diversion requests for all irrigation objects on the Milk River below Fresno Dam for the timesteps 8 days following the current timestep multiplied by an adjustment factor based on the average weekly storage in Fresno Reservoir.

Rule: **Draw down in September if above target**

This rule executes in September and October to keep Fresno Reservoir below the October target value. It will release as much as possible to hit the October target without exceeding the Max October Drawdown Release.

IF

Current timestep is in September or October AND Fresno Storage is greater than October Target

THEN

MIN (Release that will draw down Fresno to October Target; max possible release; Max October Drawdown Release)

END IF

Rule: **Reduce Release for Late Summer Fall if Flagged**

This rule executes between August 1 and October 31. If the Late Summer Fall Cut Back Flag has been set, the release is cut back to the inflow, unless the release for demands is already less than the inflow. However, the release will not be cut back to less than 45 cfs. The Late Summer Fall Cut Back Flag is set to 1 by the previous rule if Fresno storage is less than 15,000 AF or if Fresno Storage has gone below 15,000 AF any time after August 1.

IF

Late Summer Fall Cut Back Flag = 1

THEN

MAX (45 cfs; MIN (Fresno inflow; Fresno Release for Demands))

END IF

Rule: **Fresno Irrigation Release Demand Driven**

During the irrigation season, simulated water releases from Fresno Reservoir are based on weekly-average downstream irrigation demands and reservoir storage. The downstream irrigation demands are the summation of the depletion requested slots for all irrigation objects in the **Lower Milk River** subbasin, which encompasses the entire river below Fresno Dam. These demand-based releases are adjusted up or down based on Fresno reservoir contents in relation to target contents. For instance, if it is August and irrigation demands are high but reservoir contents are below target, the release will be scaled back some so as to not empty the reservoir too quickly. Most of the logic in the rule is implemented by the **Fresno Release for Demands Function**, which works as follows:

```
IF
    Fresno Reservoir average weekly storage is >= Target
THEN
    Release = Total Lower Milk River irrigation demands * a release factor
ELSE
    IF
        Fresno Reservoir average weekly storage is slightly below Target
    THEN
        Release = Total Lower Milk River Irrigation demands * release reduction factor
    ELSE
        IF
            Fresno Reservoir average weekly storage is moderately below Target
        THEN
            Release = Total Lower Milk River Irrigation Demands * greater reduction
            factor
        ELSE
            IF
                Fresno Reservoir average weekly storage is substantially below
                Target
            THEN
                Release = Total Lower Milk River Irrigation demands * greatest
                reduction factor
            ENDIF
        ENDIF
    ENDIF
ENDIF
```

Operational criteria and input data need to simulate reservoir operations are contained within the Fresno Reservoir Object or the associated data object **FresnoData**. These inputs are summarized in Tables 15 and 16 below.

Table 15. Input slots for the Fresno Reservoir object.

Slot	Description	Value
Inflow	Inflows to Fresno Reservoir	Modeled inflows for 1959-2009 period; 1950 – 2001 for River Basin Study
Elevation Volume Table	The volume of reservoir storage at various pool elevations	Reservoir Storage in acre-feet for pool elevations from 2518 to 2590 feet
Max Release Table	Maximum reservoir outlet release at various pool elevations	Maximum Reservoir releases in cfs for pool elevations from 2518 to 2590 feet
Unregulated Spill Table	Dam spillway capacities	Maximum spillway flows in cfs for pool elevations from 2575 to 2593 feet
Elevation Area Table	The surface area of the reservoir for various pool elevations for use in evaporation calculations	Reservoir surfaces areas in acre-feet for pool elevations from 2518 to 2590 feet
Evaporation Rate	Used to compute reservoir evaporation	Daily net evaporation rates in inches

Table 16. Slots used in the Fresno Data object.

Slot	Description	Value
Fresno Max Pool	This is the maximum active storage of the reservoir.	Reservoir storage in acre-feet (varies by scenario from 62,000 to 90,000 acre-feet)
Fresno Minimum Pool	This is the absolute minimum reservoir storage (dead pool).	Reservoir storage in acre-feet (500 af)
Fresno Minimum Outflow2	This is the normal winter release rate, it is also used as a minimum outflow during other times of the year.	45 CFS
Fresno Minimum Outflow3	This is a lower minimum release for times when the 45 cfs release cannot be met without draining the reservoir.	25 CFS
Fresno Spring Target	This is the March 1 target for the reservoir; it leaves the upper portions of the pool available for flood control.	60,000 acre-feet
Absolute Minimum Outflow	There can be situations, dependent on scenario, when there is not enough water in the reservoir to maintain the 25 cfs minimum. This slot is used to set an absolute minimum during those times.	10 CFS
Fresno Min Target Pool	"Minimum" target volumes by month; used in conjunction with demands to set	Acre-feet

	the irrigation-season release.	
Fresno Target Pools	"Normal" target volumes by month; used in conjunction with demands to set the irrigation-season release.	Acre-feet
Fresno Midway Target Pool	Target volumes between the "Minimum" and "Normal" volumes by month; used in conjunction with demands to set the irrigation-season release.	Acre-feet
Release Increase Factor	Initial factor applied in the **Fresno Irrigation Release Demand Driven** rule when Fresno reservoirs are high (was over 1.0 when first used)	0.95
Release Reduction Factor	Release reduction factor applied when reservoir pools are moderately high in the **Fresno Irrigation Release Demand Driven** rule.	0.80
Release Reduction Medium	This is the medium release-reduction factor used in the **Fresno Irrigation Release Demand Driven** rule.	0.70
Release Reduction Factor Low	This is the release-reduction factor used in the **Fresno Irrigation Release Demand Driven** rule when Fresno Reservoir levels are low.	0.65
October Target	This is the fall target. Is used by the **Draw down in September if above target** rule.	42,000 acre-feet
October Transfer Flow	This is the flow rate at which fall transfers to Nelson Reservoir would be made.	450 CFS
Winter Low Pool	Is used to define the minimum pool going into the winter. Used by the **Late Summer Fall Release Reduction Flag** rule.	15,000 acre-feet
Fresno Fall Summer Minimum Pool [no longer used]	The minimum pool for the early fall and summer so that reservoir storage will not be depleted too quickly.	25,000 acre-feet
Spring Nelson Transfer Flow	Rate of Nelson transfer flow during spring; used in the **Spring Storage Transfer to Nelson** rule.	350 CFS
Fresno Max Flow Ramp Rate	During the Spring Transfer of storage to Nelson, this is the maximum daily increase in Fresno releases. Used in the	150 CFS

	Spring Storage Transfer to Nelson rule.	
Max October Drawdown Release	This is the maximum rate water is released from Fresno Reservoir during September and October if storage is above the fall target in the **Draw down in September if above target** rule.	500 CFS
Spring Transfer Ramp Down	The maximum daily reduction in Fresno releases following spring transfer to Nelson Reservoir. Used in the **Ramp Down After Spring Transfer** rule.	75 CFS
Late Summer Fall Cut Back Flag	Triggers reduced late summer releases from Fresno	Sets to 1 when flag is on
Fresno Release for Demands	Tracks the requested release from Fresno for irrigation demands	Flow in CFS

Fresno Accounting

The storage and delivery of water from Fresno Reservoir is tracked for two separate accounts: (1) the Milk River Project, and (2) the Fort Belknap Indian Reservation Irrigation Project. These accounts allocate 1/7 of the storage in Fresno Reservoir to the Ft. Belknap Indian Reservation, with the remainder going to the Milk River Project. The accounts are active during the irrigation season. Under the rules, the Fort Belknap Tribes are entitled to use the up to 125 cfs of direct Milk River natural flows for its irrigation demands. Flows above that, or a lesser amount of natural flow that the Tribes might be diverting at the time, can be stored in Fresno Reservoir, with 1/7 going into the Tribal account and the remaining going into the Milk River Project account. On November 1 of each year, the Tribal account is zeroed, but starts out again at 1/7 of what storage is in the reservoir on March 1 of the following year. The accounts are found in the **Fresno Reservoir** object: **FBIIP** (Fort Belknap Indian Irrigation Project) and **Reclamation** (Milk River Project). These accounts are active during the March 1 through October 31 irrigation season. The **Fresno Accounting** rule group contains all rules used to track accounting on Fresno Reservoir. Table 17 provides an overview of the rules in this new group.

Table 17. Fresno Accounting Rules.

Rule Name	Description
Set Reclamation Storage	The amount of water in the Fresno Reclamation storage account is computed as the total Fresno storage minus the FBIIP storage at each time step.
Limit FBIIP at 13,269	If FBIIP storage is greater than 13,269 AF at the end of any time step, excess water is transferred out of the account so that in never exceeds the 13,269 AF maximum.
Curtail FBIIP if Fresno Account less than Zero	If FBIIP account goes negative, curtail diversions by FBIIP diverters such that only Milk River natural inflows to Fresno Reservoir and tributary inflows below Fresno are taken. This rule uses the minimum bypass slot on the river reaches

	where FBIIP diverts.
Debit FBIIP for Diversions	If the natural flow in the Milk River is not sufficient to meet FBIIP demands on a given day, debit FBIIP's Fresno storage account
Set Fresno Gain Loss	1/7 of evaporative loss (or gain) on Fresno is charged against the FBIIP account. The remainder is assumed charged against Reclamation's account.
Allocate FBIIP inflows	Allocate 1/7 of the storable flows at Fresno to FBIIP. This calculation is a function of FBIIP diversions, tributary inflow, and flows at the Eastern Crossing
Set initial FBIIP Allocation	On March 1, transfer 1/7 of the current volume of Fresno Reservoir into the FBIIP account. This is FBIIP's initial allocation amount and will be added to or subtracted from based on the above rules.
Zero FBIIP Storage	On non-irrigation dates, set FBIIP storage to zero.

Rules **Curtail FBIIP if Fresno Account less than Zero**, **Debit FBIIP for Diversions** and **Allocate FBIIP inflows** contain the most significant logic of the rule group. The first curtails FBIIP diversion when the account goes to zero, and the second two are used to determine the debit from (outflow) and credit to (inflow) the FBIIP account on each time step. Rule **Curtail FBIIP if Fresno Account less than Zero** operates by setting minimum bypass flows at the FBIIP diversion locations, thereby limiting their diversions to only that water which is local inflow entering the river below Fresno. The logic of the two other rules is as follows:

Rule: **Debit FBIIP for Diversions**

```
IF
        Diversions > 247.9 AF
THEN
        IF
                Eastern Crossing Natural Flow +Tributary Flows < 247.9 AF
        THEN
                FBIIP Release From Storage = Diversions - (EC + Tributary Flows),
        ELSE
                FBIIP Release From Storage = Diversions - 247.9 AF
        ENDIF
ELSE
        IF
                        Diversions - (EC + Tributary Flows) < 0
        THEN
                        FBIIP Release From Storage = 0
        ELSE
                        FBIIP Release From Storage = Diversions - (EC + Tributary Flows )
        ENDIF
ENDIF
```

Rule: **Allocate FBIIP Inflows**

```
IF
        Diversions > 247.9 AF
                IF
                        Tributary Flows > 247.9 AF
                THEN
                         Total Storable Inflow to Fresno = Eastern Crossing Natural Flow
                ELSE
                        IF
                                (EC +Tributary Flows >= 247.9 AF)
                        THEN
                                Total Storable Inflow to Fresno = MIN (EC, EC + Tributary Flows -
                                Diversions)
                        ELSE
                                Total Storable Inflow to Fresno = 0
                        ENDIF
                ENDIF

ELSE
        IF
                Tributary Flows >= Diversions
        THEN
                Total Storable Inflow to Fresno = EC
        ELSE
                IF
                        EC +Tributary Flows < Diversions
                THEN
                        Total Storable Inflow to Fresno = 0,
                ELSE
                        Total Storable Inflow to Fresno = MIN(EC,  EC +Tributary Flows –
                        Diversions
                ENDIF
        ENDIF
ENDIF
```

Where:

Diversions = sum of FBIIP diversions
Tributary Flows = sum of local inflows below Fresno, but above FBIIP headgates
EC = Natural flow of the Milk river at the Eastern Crossing at t - 4 days
247.9 (AF) = 125 cfs (FBIIP has the right to divert the first 125 cfs of flow)

Total Storable Inflow to Fresno, as computed in rule **Allocate FBIIP Inflows**, must be divided by 7 to get the portion of storable inflow that is allocated to the FBIIP account. If the ending storage volume in the FBIIP account is greater than 13,269 AF, the excess water above that amount is transferred to the Reclamation account.

General in Functions used in Fresno Accounting Rules

Three functions support the Fresno accounting rules. These functions are found in the **Lower Milk River Functions** and **Milk Natural Flow Functions** groups, and a described below.

Function: **Milk Available Natural Flow at EC DATE**

Same as Milk Available Natural Flow at EC but allows modeler to specify a particular date instead of defaulting to current timestep

Functions: **Total Available Tributary Flow Belknap Tribes**

The sum of four local inflows representing tributaries to the Milk River below Fresno Dam and upstream of the FBIIP diversion points

Function: **FBIIP Diversion**

The sum of the two FBIIP diversions (Milk River Unit and White Bear Unit).

Milk River from Fresno Reservoir to Dodson Dam

Milk River at Havre

Outflows from the Fresno Reservoir object are inflows to the **Milk River at Havre** aggregate reach object. This object has a river travel time lag and local inflows associated with it, which are specified in the time lags and local inflow tables in this report (Tables 18 and 19). The **City of Havre** water user object simulates available-flow based municipal diversions from the Milk River by the city. The diversion rates used for this object are the same each year, but vary by time of year from 2 to 7 CFS (total to 2,600 acre-feet per year) and are summarized in the **Periodic Diversion Request** table for this object. Outside of the growing season, all of these diversions are assumed to immediately return to the Milk River. During the growing season, only a fraction of the water is modeled to return to the river. The return flows are a fraction of the water diverted, range from 1.0 outside of the growing season to .40 during late July and early August. The return flow fractions are specified in the **Periodic Fraction** slot for this object. There are no lag times for these returns. The monthly diversion rates and return flow percentages used were based on diversion and return records from the City of Havre for the 2008-2011. Return flows from the City of Havre water user object also are linked to the **Milk River at Havre** aggregate reach object.

Milk River Reaches and Irrigation Districts

The lower Milk River is simulated in the model using river reaches, and water user objects that represent Milk River Project Irrigation Districts, Milk River Project Contract Pumpers, the Fort Belknap Indian Reservation Irrigation Project, and non-district irrigators with private water rights. Most of the aggregate reach objects have time lags associated with them (Table 18). The time lags were added to the outflow from the node upstream of where the time lag is to take effect. For instance, the time lag of 2 days from Fresno Reservoir to the Ft. Belknap Canal was added to the outflow from the **Milk River at Havre** aggregate reach object, so it does not affect the diversions from the Havre reach object but does ensure that the flow is lagged 2-days before reaching the Fort Belknap Irrigation District Canal. The following table has the time lags used in each object. Because the time lag is applied to the outflow for the object, the lag is pertinent to the time that the stream flow reaches the next downstream diversion object.

Table 18. Time lags used for Milk River aggregate reach objects.

Aggregate Reach Object with Lag Time Slot	Time Lag (days)	Cumulative Time Lag from Fresno Reservoir
Milk River at Havre	2	2
Milk River to Ft. Belknap Canal	1	3
Milk River to Paradise Valley Diversion	none	3
Milk River to Harlem ID	1	4
Milk River to Ft. Belknap Reservation	3	7
Milk River to Dodson Dam	2	9

Milk River to Nelson Reservoir	3	12
Milk River to Vandalia Dam	2	14
Milk River to Mouth	2	16

Tributary Inflows

Milk River tributary inflows are added to the model at the aggregate reach objects, and at two confluence objects. The tributary inflows are added as daily input values ("I" flag) to the **Local Inflow** slots. More information on these inflows and how they were derived can be found in "Input Data" sections of the modeling documentation. Table 19 describes the tributary inflows added at each aggregate reach object in the model.

Table 19. Objects with Tributary Inflow Slots or Confluence Inflows

Object with Inflows	Streams that contribute to Inflows
Milk River at Havre	Big Sandy Creek and Beaver Creek
Milk River to Ft. Belknap Canal	Little Box Elder Creek
Milk River to Paradise Valley Diversion	Clear Creek
Milk River to Harlem ID	Lodge Creek and Battle Creek
Milk River to Ft. Belknap Reservation	None
Milk River to Dodson Dam	Peoples Creek
Milk River to Nelson Reservoir	None
Milk River at Frenchman Confluence	Frenchman River
Milk River at Beaver Creek Confluence	Beaver Creek
Milk River to Vandalia Dam	Whitewater River and Rock Creek
Milk River to Mouth	Buggy Creek, Willow Creek, Porcupine Cree

Channel Evaporation

Channel evaporation is modeled for each reach based on the average lengths and widths of the river, and historic pan evaporation data. The policy group **Milk River Evaporation** contains the rules that are used to compute evaporation for each reach. The logic used for each of the reaches is the same as follows.

> Channel Evaporation for Reach in AF = Net Evaporation Rate * (Channel Length * Average Channel Width).

The net evaporation rates used are daily values for the modeled period based on the Ft. Assiniboine pan evaporation data above Dodson Dam and Malta pan evaporation data for below Dodson Dam. River widths and lengths were estimated from aerial photographs.
The data object **Milk River Evaporation** contains the information that is used to model channel evaporation. The slots in this object are summarized in Table 20.

Table 20. Milk River Evaporation object slots that are used in channel evaporation computations.

Slot	Purpose	Value
Fresno Net Evap	Adjusted net pan evaporation for Fort	Daily evaporation in

	Assiniboine	inches
Nelson Net Evap	Adjusted net pan evaporation for Malta	Daily evaporation in inches
Fresno to Lohman Width	Average channel width for river reach	100 feet
Fresno to Lohman Length	Channel length for river reach	232,320 feet
Lohman to Paradise Width	Average channel width for river reach	90 feet
Lohman to Paradise Length	Channel length for river reach	95,040 feet
Paradise to Harlem Width	Average channel width for river reach	80 feet
Paradise to Harlem Length	Channel length for river reach	95,040 feet
Harlem to Ft Belknap Width	Average channel width for river reach	80 feet
Harlem to Ft Belknap Length	Channel length for river reach	126,720 feet
Ft Belknap to Dodson Width	Average channel width for river reach	50 feet
Ft Belknap to Dodson Length	Channel length for river reach	311,520 feet
Dodson to Nelson Width	Average channel width for river reach	50 feet
Dodson to Nelson Length	Channel length for river reach	517,440 feet
Nelson to Vandalia Width	Average channel width for river reach	100 feet
Nelson to Vandalia Length	Channel length for river reach	311,520 feet
Vandalia to Mouth Width	Average channel width for river reach	60 feet
Vandalia to Mouth Length	Channel length for river reach	617,760 feet

Milk River Irrigation Water Use

Milk River Irrigation diversions are simulated as water user objects that have available-flow based diversion links to aggregate reach and reach objects. Physically, these diversions are a series of diversion dams and pump stations. On the Milk River there are diversions dams on the Milk River for the Fort Belknap Canal Irrigation Districts, The Paradise Valley Irrigation District, and for the Fort Belknap Reservation Irrigation Project, the Malta Irrigation District, and the Glasgow Irrigation District. A pumping station provides water to the Harlem Irrigation District. Other contract water users and private water rights users generally pump there water from the Milk River at smaller pumping stations.

The Method used to compute the irrigation request for each object is to input irrigated acreages and evapotranspiration rates. Irrigation efficiencies also are input to compute the diversion amount. A certain amount of the diverted irrigation water is assumed to be irrecoverably lost (14-17%). Return flows from the irrigation also are modeled with a surface water-ground water return, and a lagged routing of groundwater returns over a 1-year period. Return flow is modeled with the *Variable Efficiency* method in RiverWare, which has the effect of increasing efficiencies somewhat when water is in short supply. Return flows are routed to the river reach or river reaches downstream from which the water was diverted. Incidental loss rates also are input for irrigation, and these losses are modeled as depletions that will not return to the system. Figure 1 is a schematic that explains how irrigation is modeled. Table 21 summarizes the irrigation objects for the Milk River from Fresno Dam to the mouth. The individual components of Aggregate irrigation diversion objects also are listed. The coefficients used to lag groundwater return flows are summarized in Table 22; surface returns are assumed to return to the river the same day as the irrigation.

Figure 1: Milk River irrigation modeling schematic.

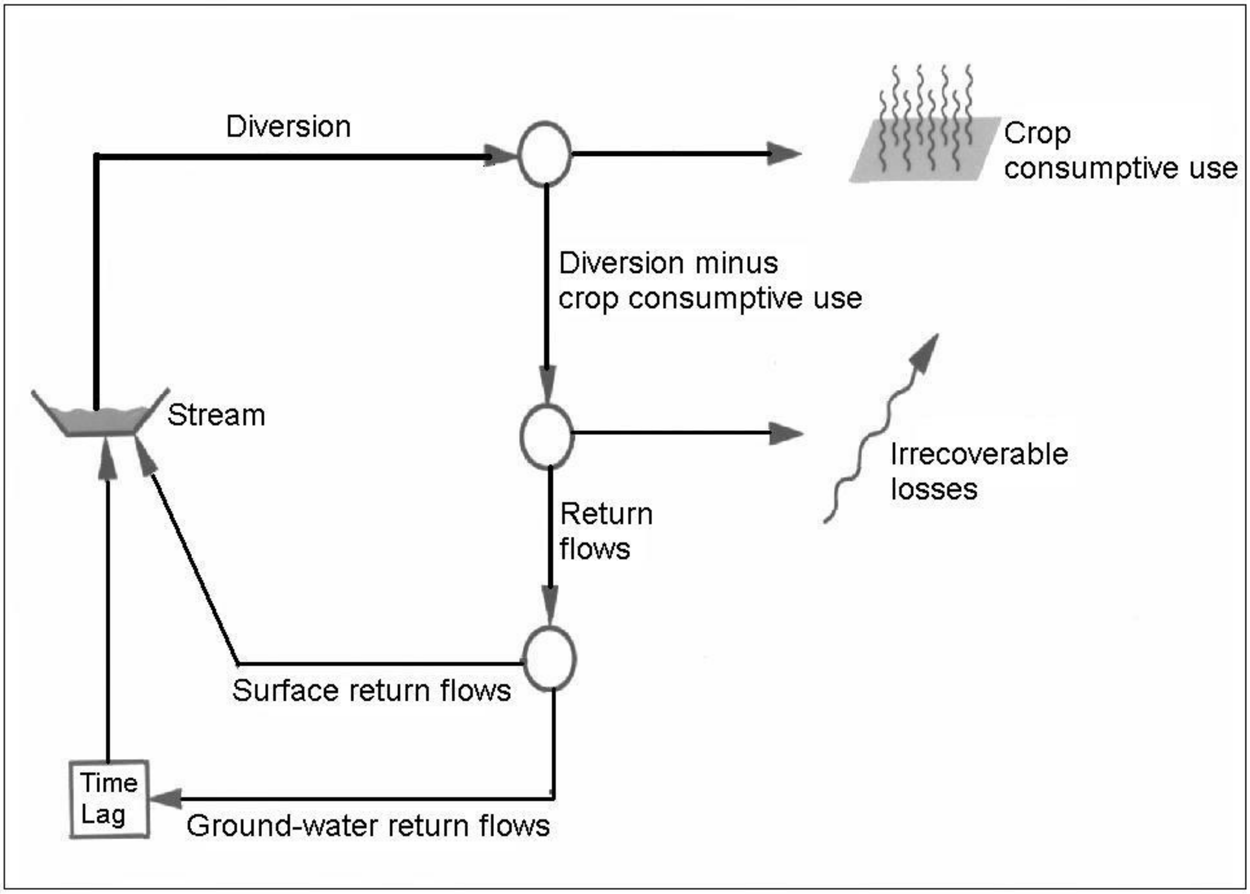


Table 21. Characteristics Used for Irrigation Objects.

Entity	Base Acres	Fallow Acreage Fraction	Max Flow (cfs)	% Efficiency	% Surface Water Return	% Ground-water Return	% Incidental Loss	Object that Return flows go to:
ND Irrigation Havre to FT Belknap	1,766	0	NA	45-50	0	36-41[a]	14	Milk River to Fort Belknap Canal
Private Irrigation Havre to FT Belknap	541	0	NA	45-50	0	36-41[a]	14	Milk River to Fort Belknap Canal
Fort Belknap ID	7,633	.23	160	26-34	15	34-42[a]	17	Milk River to Paradise Valley Diversion
Alfalfa Valley ID	3,709	.02	80	26-34	15	34-42[a]	17	Milk River to

								Paradise Valley Diversion
Zurich ID	8,801	.13	160	26-34	15	34-42 [a]	17	Milk River to Paradise Valley Diversion
Fort Belknap Canal Irrigation Districts Totals:	20,143		400					
ND Irrigation Paradise Valley Reach	1,082	0	NA	45-50	0	36-41 [a]	14	Milk River to Paradise Valley Diversion
Private Irrigation Paradise Valley Reach	155	0	NA	45-50	0	36-41 [a]	14	Milk River to Paradise Valley Diversion
Paradise Valley Irrigation District: West Portion	5,044	.09	123	26-33	15	35-42 [a]	17	Milk River to Harlem ID
Paradise Valley Irrigation District: East Portion	4,184	.09	102	26-33	15	35-42 [a]	17	Milk River to Ft. Belknap Reservation
Paradise Valley Irrigation Districts Totals:	9,228		225					
Harlem Irrigation District: East Portion	2,057	.04		26-33	15	35-42 [a]	17	
Harlem Irrigation District: West Portion	8,230	.04		26-33	15	35-42 [a]	17	
Harlem Irrigation District Totals:	10,287							
Fort Belknap Reservation Irrigation Project: Milk River Unit	4,276	0	122	20-26	17	40-46 [a]	17	Milk River to Dodson Dam
Fort Belknap Reservation Irrigation Project: White Bear Unit	1,975	0	48	20-26	17	40-46 [a]	17	Milk River to Dodson Dam
Fort Belknap Reservation Irrigation Project: Totals	6,251		170					
ND Irrigation FT Belknap to Dodson	3,615	0	NA	45-50	0	36-41 [a]	14	Milk River to Dodson Dam
Private Irrigation Harlem to Dodson	632	0	NA	45-50	0	36-41 [a]	14	Milk River to Dodson Dam

North Malta Irrigation District	10,496	.16	250	22-33	17	33-44	17	Milk River to Nelson Reservoir
Upper Malta Irrigation District: Upper	9,643	.14	270	19-30	17	36-47	17	Milk River to Nelson Reservoir
Upper Malta Irrigation District: Lower	1,043	.14	30	19-30	17	36-47	17	Milk River below Frenchman River
Upper Malta Irrigation District: Beaver Returns	5,272	.14	150	19-30	17	36-47	17	Beaver Creek
Upper Malta Irrigation District: Bowdoin Returns	2,136	.14	60	19-30	17	36-47	17	Lake Bowdoin
Dodson South Canal Irrigation: Totals	18,094		510					
Lower Malta Irrigation District: Milk Returns	2,817	.13	200	20-30	17	36-46	17	Milk River below Frenchman River
Lower Malta Irrigation District: Beaver Returns	14,954	.13	450	20-30	17	36-46	17	Beaver Creek
Lower Malta Irrigation: Total	17,771		650					
ND Irrigation Dodson to Nelson	1,806	0	NA	45-50	0	36-41	14	Milk River to Nelson Reservoir
Private Irrigation Dodson to Nelson	1,559	0	NA	45-50	0	36-41	14	Milk River to Nelson Reservoir
ND Irrigation above Beaver Creek	4,000	0	NA	45-50	0	36-41	14	Milk River below Frenchman River
ND Irrigation Nelson to Vandalia	4,252	0	NA	45-50	0	36-41	14	Milk River to Vandalia Dam
Private Irrigation Nelson to Vandalia	1,640	0	NA	45-50	0	36-41	14	Milk River to Vandalia Dam
Glasgow Irrigation District	19,249	.11	300	30-38	20	26-34	16	Milk River to Mouth
ND Irrigation Vandalia to Mouth	6989	0	NA	45-50	0	36-41	14	Milk River to Mouth
Irrigation above Frenchman Reservoir	531	0	NA	25-45	13-33	28	14	Frenchman River: IB to Reservoir
Irrigation below Frenchman	1,485	0	NA	25-35	32-42	16	17	Lower Frenchman

Reservoir: Upper								River
Irrigation below Frenchman Reservoir: Lower	2,000	0	NA	25-35	32-42	16	17	Milk River to Vandalia Dam
Frenchman River Irrigation: Total	**4,016**							

[a] Following model calibration, groundwater return flows for Milk River irrigation between Havre and Dodson Diversion Dams were reduced by 30%. That is, 30% of the groundwater return flow for irrigation objects in this section of the river were considered to be irrecoverably lost (depleted) from the system.

Table 22. Percentages of groundwater return flows that would return to source by month following irrigation.

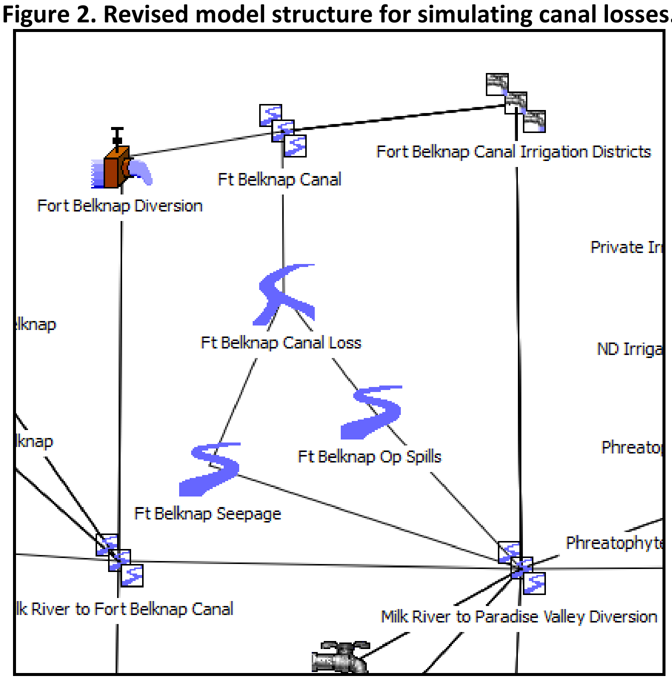
Month											
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
68%	7%	5%	4%	3%	3%	2%	2%	2%	2%	1%	1%

* Note: These "month" values are the summation of daily values. For instance, during each day of the first month, 2.2 percent of the return flow from irrigation during the previous day would return to the source and so forth.

Revisions to Irrigation Simulation Following the River Basin Study

Following the completion of the St. Mary River and Milk River Basin Study and Study recommendations, the model was enhanced so that canal and on-farm losses could be simulated separately for the Milk River irrigation districts. The screen capture from the enhanced model below (Figure 2) shows the new structure for a sample irrigation unit.

Figure 2. Revised model structure for simulating canal losses.



The previously used total efficiencies in the model were segregated into field and canal loss components. To account for canal seepage losses, seepage fractions were added to the new canal Reach Objects, which are used to represent the delivery canals. The canal losses were split into operational spills (direct flow back to surface water) and seepage to groundwater using a Bifurcation Object. The resulting losses are each routed through a Reach Object so that the operational spills to surface water and seepage to groundwater may use the appropriate routing coefficients. The routing coefficients used are very similar to those used for the total irrigation diversions in the previous versions of the model. Overall, the new method, which accounts for both canal and field efficiency components, results in efficiencies for each water user object (each irrigation district) that correspond to the total efficiencies used in the previous version of the model described in Table 21. More details on the revisions made can be found in Appendix E.

Several rules, functions, and expression slots needed to be enhanced to accommodate this change. These include the following:

- A data object called **Average Irrigation District Efficiencies** was added. This object contains expression slots to calculate the average efficiency on each timestep for each of the eight distribution canals and associated irrigation districts (combined canal and on-farm efficiency).
- **Vandalia Demand** function: Glasgow diversion requests were adjusted for canal losses.
- **Lower Malta Diversion Request Demand Based** rule: Lower Malta depletion volumes were adjusted for canal losses.
- **Malta South Diversion** rule: Lower Malta and Upper Malta diversions requested were adjusted for canal losses.
- **Diversion Request Routing** rule: added so that the diversions requested by groups of water users are routed to the diversion object connected to the Milk River after having been adjusted for the canal losses in the corresponding distribution canal, and checked to ensure that they don't exceed the canal capacity. This rule sets the diversion requests for the entire period of simulation at the first time-step, so that the Fresno Release for Irrigation Demand rule can use forecasted diversion requests.
- **Total Lower Milk Return Flows** function: altered so that it includes the return flows from canal losses.
- **Total Lower Milk Efficiency Adjusted Diversions** function: added to recreate the original effect of the **Total Lower Milk Irrigation Demands** function now that the **Depletion Requested** slots on some of the Lower Milk River Subbasin objects are no longer adjusted to account for canal capacities. This is now calculated directly in this function by multiplying the Diversion Requested by the "Average Irrigation District Efficiency" which includes both the canal and on-farm losses. Also, because the Diversion Requested and Depletion Requested slot values may be reduced from shortage sharing, this function refers to the original diversion/depletion requested values stored on the Original Irrigation Diversion Requests and Original Irrigation Depletion Requests data objects.
- **No Irrigation in January** initialization rule: added to set diversion requests for January to zero so that the water users near Ft Belknap dispatch in the correct chronological order.

- A function called **Average Irrigation District Efficiency** was added that looks up the value on the corresponding **Average Irrigation District Efficiencies** slot for a given day if the day is in the past, or otherwise returns the value from the day before the current time-step.

Milk River Water Distribution and Shortage Sharing

Because all water rights for the Milk River Project are of the same priority, Minimum Diversion Bypass slots are used in the aggregate reach objects to distribute Milk River Project water down the river, and also to distribute water within some of the irrigation district canals. This works by allowing a certain fraction of the total flow to pass by each diversion slot. When this fraction is less than the water users irrigation demand, there will be shortages and these shortages will be distributed downstream. Without the bypass flows, water shortages would be born disproportionately by the water users who are furthest downstream or at the end of the canal. The rules that control the by-pass flows are in the **Milk River Shortage Sharing** policy group. An example of how these rules work is as follows.

Irrigation Diversion Bypass = Minimum of:

a) Fresno Reservoir Release (adjusted for travel time) * by-pass flow fraction
b) The inflow to the slot

When there is ample flow in the river and/or irrigation demands are low, the bypass flow will have no effect because the irrigation diversion requested by the water user will be less than the total amount of water available to it, with or without the bypass flow. The bypass flows do not affect water diversions by the Fort Belknap Indian Reservation Irrigation Project, because these diversions are controlled by available Milk River natural flow and the stored water available to the Tribes per the **Fresno Accounting** rules. The bypass-flow fractions that must pass each diversion slot are listed in Table 23. These fractions were derived based on the acres irrigated by each user compared to the total acres irrigated, with further adjustment by trial and error. Note that the slots for private water-right irrigation have the same bypass flow as the Milk River project water user slots immediately in line above them. This allows these junior rights to only divert extra water in the river above the bypass flow rates. There are no minimum bypass flows for the Glasgow Irrigation District because it is the last Milk River Project user on the river and all flow would be available to it. A set minimum bypass flow also is used to distribute water for some elements of shared canal objects as listed in Table 24. The operations of these will be explained in more detail in the Dodson Dam and Malta Irrigation Districts sections.

Table 23. Bypass flow fractions used to distribute Fresno Reservoir releases during the irrigation season.

Rule\Aggregate Reach: Slot	Bypass Flow Fraction	Fraction of
Rule: Dodson Shortage Sharing		
Milk River to Dodson Dam: Malta IP North	.72	Flow at Dodson Diversion Dam
Milk River to Dodson Dam: ND Irrigation to Dodson	.83	Flow at Dodson Diversion Dam
Rule: Milk River to Belknap ID Shortage Sharing		

Milk River to Fort Belknap Canal: ND irrigation	.95	Fresno Reservoir Release
Milk River to Fort Belknap Canal: Fort Belknap Canal District	.82	Fresno Reservoir Release
Milk River to Fort Belknap Canal: Alfalfa Valley District	.75	Fresno Reservoir Release
Milk River to Fort Belknap Canal: Zurich District	.7	Fresno Reservoir Release
Milk River to Fort Belknap Canal: Private Irrigation	.7	Fresno Reservoir Release
Rule: Milk River to Paradise ID Shortage Sharing		
Milk River to Paradise Valley Diversion: Non District Irrigation	.75	Fresno Reservoir Release
Milk River to Paradise Valley Diversion: Paradise Valley Irrigation District A	.72	Fresno Reservoir Release
Milk River to Paradise Valley Diversion: Paradise Valley Irrigation District A	.6	Fresno Reservoir Release
Milk River to Paradise Valley Diversion: Private Irrigation	.6	Fresno Reservoir Release
Rule: Milk River to Harlem ID Shortage Sharing		
Milk River to Harlem ID: West Portion	.6	Fresno Reservoir Release
Milk River to Harlem ID: East Portion	.53	Fresno Reservoir Release
Milk River to Harlem ID: Non District Irrigation	.45	Fresno Reservoir Release
Milk River to Harlem ID: Private Irrigation	.45	Fresno Reservoir Release
Rule: Milk River to Vandalia Shortage Sharing		
Milk River to Vandalia Dam: ND irrigation	.8	Flow at Vandalia Diversion Dam

Table 24. Bypass flow fractions used to distribute releases within canal objects during the irrigation season.

Rule\Aggregate Reach: Slot	Bypass Flow as Fraction of Available Canal Flow
Rule: Dodson South Canal Shortage Sharing	
Dodson South Canal: Upper	.47
Dodson South Canal: Lower	.41
Dodson South Canal: Beaver Returns	.12
Dodson South Canal: Bowdoin Returns	End of Unit
Rule: Lower Malta Canal Shortage Sharing	
Lower Malta Canal: Milk Returns	.84
Lower Malta Canal: Beaver Returns	End of Unit

Within rules in the **Milk River Shortage Sharing** policy group rules, there also are assignments that set diversions to zero during the canal de-mossing period for the North Malta ID and Lower Malta ID water users. This is when these irrigation districts typically shut off their ditches to killoff the aquatic vegetation that grows in them. Ditches typically are shut off for about a two-week period. A simple assignment in the rules sets Lower Malta diversion requests during this period using the function that follows.

Function: **Canal DeMossing Season**

IF
Canal DeMossing Season
THEN
Diversion Request = 0 cfs

Shortage Sharing Revisions Following Completion of the River Basin Study

In order to better model the equitable distribution of available water, the previous shortage sharing rules were revised following the completion of the St. Mary and Milk River Basin Study. The new Fresno to Dodson Shortage Sharing and Nelson to Vandalia Shortage Sharing policy groups were created. The following summarizes the rules in these groups. More details on the shortage sharing revisions can be found in Appendix E.

Policy Group: ***Fresno to Dodson Shortage Sharing***

Rule: **Lower Malta Shortage Sharing**

This rule sets the Minimum Diversion Bypass slot on the Lower Nelson Canal object so that each of the Lower Malta sub-districts receive the same amount of water, *pro rata*, based on their irrigated acreage and the total Lower Malta diversion.

Lower Nelson Canal minimum bypass past Milk River returns irrigation unit =
Lower Nelson Canal outflow after seepage losses * (Beaver Creek returns irrigation unit diversion request/Total Lower Malta Irrigation District diversion request)

Rule: **Upper Malta Shortage Sharing**

This rule sets the Minimum Diversion Bypass slots on the Dodson South Canal object so that each of the Upper Malta subdistricts receive the same amount of water, *pro rata*, based on their irrigated acreage and the total Upper Malta diversion.

Dodson South Canal Upper Unit Minimum Diversion Bypass = Dodson South Canal after Losses Outflow
* (Upper Malta ID Lower Unit Diversion Requested + Upper Malta ID Beaver Creek Returns Unit Diversion Requested + Upper Malta ID Bowdoin Returns Unit Diversion Requested)
/ Upper Malta ID Total Diversion Requested

Dodson South Canal Lower Unit Minimum Diversion Bypass = Dodson South Canal after Losses Outflow
* (Upper Malta ID Beaver Creek Returns Unit Diversion Requested + Upper Malta ID Bowdoin Returns Unit Diversion Requested)
/ Upper Malta ID Total Diversion Requested

Dodson South Canal Beaver Creek Returns Unit Minimum Diversion Bypass = Dodson South Canal after Losses Outflow

* Upper Malta ID Bowdoin Returns Unit Diversion Requested
/ Upper Malta ID Total Diversion Requested

Rule: **Fresno to Dodson Subdistrict Shortage Sharing**

This rule sets the Minimum Diversion Bypass slot on each of the distribution canals (AggReach Objects in the model) such that each subdistrict receives the same amount of water, *pro rata*, based on their irrigated acreage and the total diversion at the river head-gate. This happens for the Fort Belknap, Paradise Valley, Harlem, and Fort Belknap Reservation Irrigation Projects.

Fort Belknap Canal Fort Belknap Irrigation District Minimum Diversion Bypass = Fort Belknap Canal after Canal Losses Outflow
* (Fort Belknap Canal Alfalfa Valley Irrigation District Diversion Requested + Fort Belknap Canal Zurich Irrigation District Diversion Requested)
/ Fort Belknap Canal Irrigation Districts Total Diversion Requested

Fort Belknap Canal Alfalfa Valley Irrigation District Minimum Diversion Bypass = Fort Belknap Canal after Canal Losses Outflow
* Fort Belknap Canal Zurich Irrigation District Diversion Requested
/ Fort Belknap Canal Irrigation Districts Total Diversion Requested

Paradise Valley Irrigation District West Unit Minimum Diversion Bypass = Paradise Valley Canal after Canal Losses Outflow
* Paradise Valley Irrigation District East Unit Diversion Requested
/ Paradise Valley Irrigation District Diversion Requested

Harlem Irrigation District West Unit Minimum Diversion Bypass = Harlem Irrigation District Canal after Canal Losses Outflow
* Harlem Irrigation District East Unit Diversion Requested
/ Harlem Irrigation District Total Diversion Requested

Fort Belknap Reservation IP Milk River Unit Minimum Diversion Bypass = Fort Belknap Reservation Canal after Canal Losses Outflow
* Fort Belknap Reservation IP White Bear Unit Diversion Requested
/ Fort Belknap Reservation Irrigation Project Total Diversion Requested

Rule: **Fresno to Dodson Subdistrict Shortage Sharing**

This rule performs the equitable distribution of available water, or shortage sharing, by reducing the **Diversion Requested** values for each of the private and project water users. For those irrigation projects that are served by a canal via a Diversion Object in the model, only the **Diversion Requested** slot needs to be reduced. For those users that are modeled as a Water User object connected directly to the river, both the **Diversion Requested** slot and possibly the **Depletion Requested** slot need to be reduced. The **Depletion Requested** value needs to be reduced such that the maximum efficiency is not exceeded. The private demands are reduced first until they are completely curtailed. Any remaining shortage is then applied to the project demands (irrigation districts and non-district contract holders). Both the private demands and project demands are reduced *pro rata* such that their percent reduction is the same. In other words, all private users are reduced by the same percentage and all project users are reduced by the same percentage, but the private users will always be fully curtailed before any project users are curtailed. Any water users that are not in the private or project subbasins (such as the Fort Belknap Indian Reservation) will not be curtailed; however, their demands may not be fully met if the release from Fresno is insufficient. This rule is very detailed and will not be outlined here.

Policy Group: ***Nelson to Vandalia Shortage Sharing***

Rule: **Nelson to Vandalia Shortage Sharing**

This rule controls the shortage sharing for water users between Nelson Reservoir releases to the Milk River and Vandalia Dam. Since these are all project users, they can all be shorted *pro rata*, based on the available water and the irrigated area of each project. For Water User objects that are connected directly to the river, the Depletion Requested slot may be reduced to ensure that the maximum efficiency is not exceeded. The rule works as follows:

```
Non District Irrigation Above Beaver Creek Diversion Requested =
        Non District Irrigation Above Beaver Creek Diversion Requested * Nelson to Vandalia
        Irrigation Reduction Multiplier

Non District Irrigation Nelson to Vandalia Diversion Requested =
        Non District Irrigation Nelson to Vandalia Diversion Requested * Nelson to Vandalia
        Irrigation Reduction Multiplier

IF
        Non District Irrigation Above Beaver Creek Diversion Requested * Nelson to Vandalia
        Irrigation Reduction Multiplier = 0 CFS
THEN
        Non District Irrigation Above Beaver Creek Depletion Requested = 0 CFS
        IF
                Non District Irrigation Above Beaver Creek Depletion Requested / (Non District
                Irrigation Above Beaver Creek Diversion Requested * Nelson to Vandalia
                Irrigation Reduction Multiplier) > ND Irrigation Above Beaver Creek Maximum
                Efficiency
        THEN
                Non District Irrigation Above Beaver Creek Depletion Requested = Non District
                Irrigation Above Beaver Creek Diversion Requested * Nelson to Vandalia
                Irrigation Reduction Multiplier * ND Irrigation Above Beaver Creek Maximum
                Efficiency
        END IF
        END IF
IF
        Non District Irrigation Nelson to Vandalia Diversion Requested * Nelson to Vandalia
        Irrigation Reduction Multiplier = 0 CFS
THEN
        Non District Irrigation Nelson to Vandalia Depletion Requested = 0 CFS
        IF
                Non District Irrigation Nelson to Vandalia Depletion Requested / (Non District
                Irrigation Nelson to Vandalia Diversion Requested * Nelson to Vandalia Irrigation
                Reduction Multiplier) > ND Irrigation Nelson to Vandalia Maximum Efficiency
        THEN
```

Non District Irrigation Nelson to Vandalia Depletion Requested = Non District Irrigation Nelson to Vandalia Diversion Requested * Nelson to Vandalia Irrigation Reduction Multiplier * ND Irrigation Nelson to Vandalia Maximum Efficiency
END IF
END IF

The following functions in the **Lower Milk River Functions** utility group are called in these rules:

Function: **Nelson to Vandalia Irrigation Reduction Multiplier**

IF
Nelson to Vandalia Irrigation Demand = 0
THEN
1
ELSE
1 – Nelson to Vandalia Irrigation Shortage / Nelson to Vandalia Irrigation Demand
ENDIF

Function: **Nelson to Vandalia Irrigation Shortage**

ND Irrigation above Beaver Creek Diversion Shortage
+ ND Irrigation Nelson to Vandalia Diversion Shortage
+ Glasgow Irrigation District Diversion Shortage

Function: **Nelson to Vandalia Irrigation Demand**

ND Irrigation above Beaver Creek Diversion Requested
+ ND Irrigation Nelson to Vandalia Diversion Requested
+ Glasgow Irrigation District Diversion Requested

Dodson Dam and the Malta Irrigation Districts

Physically, Dodson Dam is a diversion dam on the Milk River that diverts water in two directions: (1) to the north for the North Malta Irrigation District, and (2) to the South for the rest of the Malta Irrigation District, and to Nelson Reservoir and the Lake Bowdoin National Wildlife Refuge. In the model, Dodson Dam is represented by the **Milk River to Dodson Dam** aggregate reach object. Minimum diversion bypass slots in the **Malta IP South** and **Private Irrigation to Dodson** elements of this object assure a simulated minimum flow of 10 cfs below Dodson Dam. This is similar to current operations, which only let a small amount of flow to go flow below the dam during much of the irrigation season.

The diversion to the North Malta part of the Malta Irrigation District is modeled by a simple available flow/demand based diversion request by the **North Malt ID** water user object. Diversions to the southern portion of the Malta Irrigation District are more complex and are routed through the **Malta South Diversion** diversion object. Outflows from his object are linked to the **South Dodson Canal Aggregate Distribution Canal Object**, from where water is distributed to: (1) four irrigation elements on the Dodson South Canal, (2) Lake Bowdoin, and (3) Nelson Reservoir. Water also is supplied indirectly to the Lower Malta Irrigation District via Nelson Reservoir. The modeled capacity of the Malta South Canal is 550 cfs.

In simple terms, the criteria for operation of the Malta South Canal during the irrigation season (defined as March 15 to November 1) are as follows:

1. During the early part of the irrigation season, divert and store water in Nelson Reservoir up to operating targets. Sometimes this is done in conjunction with releases from Fresno Reservoir (see Fresno Operations section).
2. During the early spring, divert up to 3,500 acre-feet of water from the Nelson South Canal to Lake Bowdoin.
3. As the irrigation season progresses, divert as much water down the canal as possible, with priority to meeting irrigation demands for 18,094 acres in the Upper Malta Irrigation District. A set percentage of the water diverted and water above these demands is allowed to pass on to Nelson Reservoir.
4. During the fall, a transfer of storage might be made from Fresno Reservoir, with the canal diverting this transferred water to Nelson Reservoir.

The rule policy group **Dodson South Operations** is used to simulate operations of the Dodson South Canal system. Table 25 contains a summary of the active rules in this group. These rules use data contained in the **Dodson Nelson Data** data object, the slots for which are summarized in Table 26.

Table 25. Dodson South Operations Group Active Rules.

Rule Name	Description
Nelson Below Min Flag	Tracks whether Nelson Reservoir has been drawn down below the minimum level defined by the Nelson Rule Curves; includes a buffer to avoid oscillations.
Nelson Overfill Protection	Keeps Nelson Reservoir levels from going above the top of the conservation pool.
Fall Fresno Transfers to Nelson for November	Allows fall transfers of water to Nelson Reservoir as late as November.
Malta South Diversion	Diverts water through the Malta South Diversion to supply irrigated lands, Lake Bowdoin, and to fill Nelson storage.
Lower Malta Diversion Request Regression Based	Rule sets diversion requests from Nelson Reservoir for the Lower Malta Irrigation District. These are for two periods. The volumes are based on reservoir storages, and these volumes are distributed by day, based on average daily fractions of the total volume for the period of record.
Lower Malta Diversion Request Demand Based	Rule sets the diversion request from Nelson Reservoir based on Lower Malta Irrigation District total demands and a reduction factor that is based on the storage volume in Nelson Reservoir. The system can be operated with this or the previous rule by toggling the Demand Based Lower Malta switch to 1 in the Dodson Nelson Data Object.
Release from Nelson for Glasgow and Contractors	Releases stored water from Nelson Reservoir for the Glasgow Irrigation District and Reclamation contract pumpers when Milk River flow is insufficient to meet

	demands.
Set Nelson Outflow to Zero for Winter and Initialization	Sets Nelson outflows for zero during winter and at model initialization. There are still seepage losses from Nelson during the winter though. .
Bowdoin Cumulative Seasonal Diversions	Computes the cumulative seasonal diversions to Lake Bowdoin; sets to zero at the start of the season on March 15.
Deliver Water to Nelson Feeder Canal	When Nelson Reservoir storage is below target, this rule delivers a percentage of the water diverted down the Nelson South Canal to Nelson Reservoir based on how full the reservoir is.
Bowdoin Diversions	Sets Lake Bowdoin diversions to specified monthly inflow rates until annual contract volume is reached or lake is full.

Table 26. Dodson Nelson Data Object Slots

Slot	Description	Value
Nelson Rule Curves	Storage volumes used in the **Release from Nelson for Glasgow Contractors** rule in determining the amount of water to release for Glasgow ID demands.	Table of acre-feet values that vary by month.
Nelson Reduction Factors	Used to reduce releases for Glasgow and Contract water users based on available storage in Nelson Reservoir	Factors ranging from 0 to .9
Demand Based Lower Malta Switch	Allows user to select demand-based simulation of diversions from Nelson Reservoir to Lower Malta Irrigation District	Value of 1 selects demand-based simulation; 0 selects regression-based simulation
Bottom of Conservation Pool	The elevation at the bottom of the conservation pool for Nelson Reservoir	2,200 feet
Top of Conservation Pool	The reservoir elevation at the top of the Conservation Pool	2,221.60 feet
Volume at Top of Conservation Pool	The reservoir storage volume at the top of the conservation pool	79,220 acre-feet
Nelson Max Targets [not	The maximum desired reservoir	From 67,000 to 76,000

currently used]	storage volumes by month.	acre-feet
LowerRiverMin	[not active in current rules]	
Nelson Max Increase [not currently used]	Maximum incremental daily release increase.	.25
Nelson Max Decrease [not currently used]	Maximum incremental daily release decrease.	.25
Available Flow at Vandalia [not currently used]	A series slot with expression that is used to track the available flow at Vandalia Dam.	Daily flow in CFS
Demand at Vandalia [not currently used]	A series slot with expression that is used to track diversion at Vandalia.	Daily demand in CFS
Bottom Volume Conservation Pool	The bottom volume of the Nelson Reservoir conservation pool.	18,140 acre-feet
Nelson Max Outflow	Used to set the maximum outflow from Nelson Reservoir to the Milk River. Used by the **Release from Nelson for Glasgow and Contractors** rule.	250 CFS
Malta South Canal Max	Defines the maximum capacity for the Malta South Canal for use by the **Fresno Transfers to Nelson for November** and **Malta South Diversion** rules	550 CFS
Dodson Dam Min Overflow	Defines the minimum flow that should bypass the Malta South Diversion object and flow in the River below Dodson Dam.	10 CFS
Nelson Midway Oct Stor [not currently used]	For determining when to transfer fall flows from Fresno Reservoir.	42,000 acre-feet
Nelson Step Down	Used to gradually reduce releases from Nelson Reservoir when outflows are being shut off with the **Set Nelson Outflow** rule	50 CFS
Near Top of Conservation Pool	Used in determining when to cut back diversions to Nelson Reservoir in order keep reservoir slightly below full pool in the **Malta South Diversion** rule.	78,000 acre-feet
Lower Malta Start Dates	Is not used by currently active rules.	
Nelson Spring Transfer Target [not currently used]	The target contents to get Nelson Reservoir to during the spring transfer of water from Fresno Reservoir.	61,000 acre-feet

Nelson Feeder Canal Percentages	The percentage of the total flow of the Dodson South Canal that is specified to go to Nelson Reservoir in the **Deliver Water to Nelson Feeder Canal** rule.	Can be varied relative to targets, all are currently set at 0.30
Lower Malta Diversion Percentages	Daily fractions of the total volume of flow that are diverted from Nelson Reservoir by the Lower Malta Irrigation District for two specified irrigation periods. Used in the **Lower Malta Diversion Request Regression Based** rule.	Daily fractions of total volumes: decimal
Nelson Below Min Flag	Sets value to 1 when Nelson Storage drops below specified minimum. Used to avoid oscillations in Nelson releases when storage is near the minimum. Used in setting Nelson releases.	0 or 1
Nelson Oscillation Buffer Space	Used in the **Nelson Below Min Flag** rule to avoid oscillations of releases from Nelson when it approaches minimum storage.	Set at 1,000 acre-feet

Rule: **Malta South Diversion**

This is probably the most significant rule in this group; it sets the diversion request amount for the Malta South Canal during most of the irrigation season for the irrigation districts, Nelson Reservoir, and Lake Bowdoin up to the canal capacity. When Nelson Reservoir is full, the rule simulates diversions to meet demands only and not to store water.

IF

    Irrigation season
    AND
    Nelson Reservoir Storage is near the top of the conservation pool

THEN

        Request Diversion amount that is the minimum of the following:

a. The maximum canal capacity of 550 cfs
b. The summation of the diversion requests for the water users on the canal (taking into consideration canal capacities) + the amount of water needed to bring Nelson Reservoir storage to near the top of the conservation pool

ELSE

    IF

        If irrigation season
        AND
        Nelson Storage is approaching full pool

    THEN

Request Diversion amount that is the summation of irrigation demands given capacity limitation – the flow needed to bring Nelson storage back down the near top of conservation pool

ELSE

No Diversion (For during times outside of the normal irrigation season)

ENDIF

ENDIF

The near top of Conservation volume is a volume 1,220 acre-feet less than the actual top of the conservation pool for the reservoir. It was used instead to dampen erratic canal and reservoir operations that were occurring when the actual top of conservation pool was used.

Nelson Reservoir Operations

Nelson Reservoir serves three primary purposes: (1) to capture excess Malta South Canal diversions, (2) to supply water to the Lower Malta unit of the Malta Irrigation District, and (3) to release stored water back to the Milk River for use by the Glasgow Irrigation District downstream. In the model, water can flow to the reservoir through the **Nelson Deliveries** water user object, or through the **Dodson South Canal** aggregate reach object. During the irrigation season, a minimum set percentage of the total flow that is diverted from the Milk River through the South Dodson canal is modeled to flow to Nelson Reservoir through the **Nelson Deliveries** water user object, when the reservoir is not full. Other excess flows, when irrigation demands are low, are passed on to Nelson Reservoir as outflow from the **Dodson South Canal** aggregate reach object. The significant rules that simulate Nelson Reservoir are in the **Dodson South Operations** policy group and are summarized below.

Rule: **Release from Nelson for Glasgow and Contractors**

This rule releases water from reservoir storage for the Glasgow Irrigation District and Reclamation Contract holders when Milk River flows are insufficient to meet demands.

IF

Nelson Reservoir Storage is below "Minimum" target

THEN

Nelson Release = Downstream Demands at Vandalia – Available Milk River flows * "Below Minimum" reduction factor

ELSE

IF

Nelson Reservoir Storage is between the "Minimum" and "Midway" active storage level and the specified target storage for that month

THEN

Nelson Release = Downstream Demands at Vandalia – Available Milk River flows * "Below Midway" reduction factor

ELSE

IF

Nelson Reservoir Storage is between the "Midway" and "Target" storage level and the desired maximum storage for that month

THEN

Nelson Release = Downstream Demands at Vandalia – Available Milk River flows * "Below Target" reduction factor

ENDIF

ELSE
IF
Nelson Reservoir Storage is above the “Target” storage level
THEN
Nelson Release = Downstream Demands at Vandalia – Available Milk River flows * “Above Target” reduction factor
ENDIF

ENDIF
ENDIF

These statements have the effect of delivering water to the Glasgow Irrigation District when needed, while decreasing the rate of draw on Nelson Reservoir storage as the reservoir drops. All of the statements also have algorithms that prevent the computation of negative outflows, and keep Nelson Outflows from exceeding maximum outlet capacities. The statements only are effective during the irrigation season, per an execution constraint.

Functions that are used by this rule are in the **Lower Milk River Functions** utility group and include the following:

Function: **Vandalia Demand**

Glasgow Irrigation Diversion Requests three days in the future + Diversions for contract pumpers in the vicinity of Vandalia Dam three days in the future

Function: **Vandalia Available Flow**

The summation of all tributary inflows and irrigation return flows between Dodson and Vandalia Dams. Tributary inflows downstream of the Nelson Reservoir release point are lagged by three days to account for river travel times.

At times, Nelson Reservoir will be simulated to fill to above the top of the conservation pool. A rule was added to release water back to the Milk River during these times. The rule also step-down outflows at a controlled rate when the reservoir pool drops below the top of conservation, to avoid an abrupt shut-off.

Rule: **Set Nelson Outflow**

IF
Nelson Reservoir Storage > Top of Conservation Pool
THEN
Minimum of:
300 to 350 cfs (varies by month)
The maximum allowable release
ELSE
IF
Nelson Reservoir outflows the previous day were greater than monthly specified rates
THEN
Nelson Reservoir Release = Release the Previous Day – 50 cfs
ELSE
Nelson Reservoir Release = Zero
ENDIF

ENDIF

What this rule effectively does is to release as much water as the outlet allows when the reservoir storage is above the specified top of the conservation pool. The second IF statement steps the inflow down each day by 50 cfs once the pool drops below the Top of Conservation, rather than abruptly shutting the outlet off. Because this rule is at a lower priority, it doesn't affect outflow rates when releases are made from the reservoir for downstream irrigation demands.

Rule: **Deliver Water to Nelson Feeder Canal**

This rule sends a set percentage of the water that is diverted down the South Dodson Canal to Nelson Reservoir.

```
IF
        Nelson Reservoir Storage (at previous timestep) < Minimum storage
THEN
        Nelson Deliveries = Total flow diverted down Dodson South Canal * Nelson Feeder
        Canal Percentage for Minimum
  ELSE
  IF
          Nelson Reservoir Storage (at previous timestep) < Midway storage
  THEN
        Nelson Deliveries = Total flow diverted down Dodson South Canal * Nelson Feeder
        Canal Percentage for Midway storage
    ELSE
    IF
            Nelson Reservoir Storage (at previous timestep) < Target storage
    THEN
            Nelson Deliveries = Total flow diverted down Dodson South Canal * Nelson Feeder
        Canal Percentage for Target storage

      ELSE

              Nelson Deliveries = 0
ENDIF
```

Water is diverted from the **South Dodson Canal** aggregate distribution canal object to the reservoir through the **Nelson Deliveries** water user object by inputting the depletion request through the rule, with 100 % of the diverted water modeled as "depleted" to make sure that it gets to the reservoir. Note that other surplus flows also can flow to Nelson Reservoir through the Dodson South Canal aggregate reach object.

There are a few other factors that affect Nelson Reservoir storage. Evaporation rates are input to the evaporation slot and used with the elevation-area table to compute total acre-feet of evaporation. There is substantial seepage from Nelson Reservoir, and this is computed using the linear seepage method in RiverWare. The seepage coefficients used are based on historic observed elevation-based seepage patterns from the reservoir. Finally, water is removed directly from the reservoir by the Lower Malta Diversion object for the Lower Malta unit of the Malta Irrigation District.

The amount of water requested for diversion by the Lower Malta Irrigation District is set by either the rule **Lower Malta Diversion Request Regression Based or Lower Malta Diversion Request Demand Based**, dependent on which option is selected with the toggle switch in the **Demand Based Lower Malta Switch**, **Dodson Nelson Data Object**. Either approach will adjust the diversion request given the available storage in the system. A description of these two rules follows. The lower Malta Irrigation diversion is simulated by the rules to be off between June 21 and July 6, which corresponds to the first cutting of hay and the need to control the aquatic vegetation that has accumulated in the ditch.

Rule: **Lower Malta Diversion Request Regression Based**

IF
    Current timestep is between May 6 and June 21 (the first irrigation period)
THEN
    a) Call Function "Lower Malta Early Method 2" which computes the total volume which will be available to the district for this period
    b) Multiply total volume by the fraction of the volume for that day and return result
ELSE
    IF
        Current timestep is between July 6 and September 30 (the second irrigation period)
    THEN
        a. Call Function "Lower Malta Late Method 2" which computes the total volume which will be available to the district for this period
        b. Multiply total volume by the fraction of the volume for that day and return result
    ELSE
        Lower Malta Diversion Request = 0
    ENDIF
ENDIF

This rule calls the Functions**: Lower Malta Early Method 2** and **Lower Malta Late Method 2**. These functions are in the **Lower Milk River Functions** utility group and work as described below.

Function: **Lower Malta Early Method 2**

This function computes the volume available to the Lower Malta Irrigation Unit for the first irrigation period by using the April 30, Fresno and Nelson Reservoir storages.

Volume of Water Available to Lower Malta for May 6 to June 21 period =
(April 30 Fresno Reservoir Storage + April 30 Nelson Reservoir Storage) * .0737 + 2623 acre-feet.

Function: **Lower Malta Late Method 2**

This function computes the volume available to the Lower Malta Irrigation Unit for the second irrigation period by using the July 1 , Fresno and Nelson Reservoir Storages

Volume of Water Available to Lower Malta for July 6 to September 30 period =

(July 1 Fresno Reservoir Storage + July 1 Nelson Reservoir Storage) * .1449 - 208 acre-feet.

Rule: **Lower Malta Diversion Request Demand Based**

IF
Current timestep is between June 21 and July 6 (the traditional canal shut-down period)
THEN
Lower Malta Diversion Request = 0 CFS
ELSE
Lower Malta Diversion Request = Lower Malta Irrigation District Diversion Requested * Nelson Release Reduction Factor
ENDIF

Function: **Nelson Release Reduction Factor**

This function in the **Lower Milk River Functions** group adjusts the Lower Malta Diversion Request based on the available storage in Nelson Reservoir. As the available storage drops, diversions relative to the irrigation district demands are reduced.

Lake Bowdoin Operations

Lake Bowdoin is a closed lake located in a natural depression. Water flows into the lake from diversions from the Nelson South Canal, irrigation return flow, precipitation, and on rare occasions flood overflows from the Beaver Creek drainage. Water leaves the lake primarily through evaporation, although there also could be some seepage and occasional spill during flooding. Because most water leaves the lake through evaporation, the lake is saline. The normal volume of the lake might fluctuate from about 3,000 to 21,000 acre-feet. The lake is part of a National Wildlife Refuge complex that actually contains Lake Bowdoin and some smaller lakes, as well as surrounding prairie. Water deliveries also are made to two other smaller lakes on the refuge, but the RiverWare model simulate all water deliveries for the refuge as going to Lake Bowdoin, which receives 90 percent of the deliveries in actuality.

Lake Bowdoin is simulated as a RiverWare reservoir object. Water is diverted from the **South Dodson Canal** aggregate distribution canal object to the reservoir through the **Lake Bowdoin Diversions** water user object by inputting the depletion request—100 % of the diverted water is assumed to be depleted which has the effect of sending all of the water to the lake. The following two primary rules in the Dodson South Operations policy group are used to simulate and regulate deliveries of water from the Nelson South Canal to Lake Bowdoin.

Rule: **Bowdoin Cumulative Seasonal Diversions**

IF
Date = March 15 THEN
O CFS (resets seasonal diversion total)
ELSE
Lake Bowdoin Cumulative Diversions for Season + Lake Bowdoin Diversion for current time-step
ENDIF

Rule: **Bowdoin Diversions**

IF

Lake Bowdoin pool elevation > max elevation of 2212.7 feet

THEN

Discontinue Lake Bowdoin Diversion

ELSE

Divert Water to Lake Bowdoin at specified rates (these are only greater than zero for the month of April and May, when the rate is 80 cfs, and during September, when the rate is 20 cfs)

ENDIF

Water only is simulated to leave the lake through evaporation. Net evaporation data are input into the evaporation slot of the Lake Bowdoin reservoir object. An elevation-area table slot in the object also is used in the evaporation computations. Data that are used by the rules are contained in the RiverWare data object **Lake Bowdoin Data**. The slots in this object are summarized in Table 27.

Table 27. Summary of slots in the Lake Bowdoin Data object.

Slot	Description	Value
BowdoinMaxElevation	The maximum elevation of the lake for operational purposes	2,212.70 feet
Bowdoin Full Diversion	Sets the diversion rate to the lake as zero when the lake is full	0 CFS
Bowdoin Monthly Inflow Rates	Set rates that water can be diverted to lake Bowdoin at by month	80 CFS for March and April, 20 CFS for September, 0 CFS for all other months
Total Diversions to Bowdoin	A series slot that tracks annual diversions to the lake	Volume in acre-feet
Bowdoin Max Annual Diversion	The maximum annual volume that can be diverted to the lake	3,500 acre-feet

Frenchman River and Reservoir

The Frenchman River is the largest tributary to the Milk River with a drainage area of about 2,500 square miles, most of which is in Canada. There is irrigation and several smaller reservoirs in Canada, but this infrastructure is not included in the model. Recorded flows at the International Boundary for the 1959-2009 period are added through the **Inflow** slot of the **Frenchman River IB to Reservoir** reach object. The State of Montana owns a small reservoir on the main-stem of the Frenchman River, about mid-way between the International Boundary and the confluence with the Milk River. This reservoir originally stored about 7,500 acre feet, but over time the active storage has dropped to about 3,500 acre-feet due to sedimentation. There are about 531 acres of irrigation between the International Boundary and the Reservoir, and these are modeled as an available flow/demand based water use from the river. About 3,485 acres are irrigated below Frenchman Reservoir. These acres modeled through the **Irrigation below Frenchman Dam** aggregate diversion object which is linked to the Lower Frenchman River aggregate reach object. Some of the return flows from this object go back to the Frenchman River, with the rest going to the **Milk River to Vandalia Dam** aggregate reach object. Water for this irrigation is supplied from a combination of Frenchman River natural flow, and release from the Frenchman Reservoir object.

The Frenchman Reservoir policy group contains the rules that simulate Frenchman Reservoir operations. The rules allow the option of simulating a larger reservoir, which also can be used to deliver flow to Milk River irrigators during times of shortage. The major rules in this group are summarized below.

Rule: **Frenchman Spill Ops**

This rule forces a spill of any water stored above the Current Max Storage. The spill amount is recorded in a separate slot called Frenchman Spill for reference. There are no physical characteristics associated with the spillway in the model, so the rule will spill the full amount of water stored above the Current Max Storage. Therefore, the simulated storage will never go above this level.

IF

    Frenchman Storage > Current Max Storage

THEN

    Outflow = outflow required to bring the storage down to the Current Max Storage
    Frenchman Spill = increase in outflow due to this rule spilling the excess storage

END IF

Rule: **Release Additional Water for Milk River Irrigators**

This rule releases additional water from Frenchman Reservoir once the storage exceeds the user specified value on the Min Storage for Extra Milk Releases slot. Once the storage goes about this level, Frenchman Reservoir will release additional water (without going back below that level) to meet any irrigation shortages on the Milk River below the confluence with the Frenchman River.

IF

    Frenchman Storage > Min Storage for Extra Milk Releases

THEN

    MIN ((Outflow from previous rule + ND Irrigation Above Beaver Creek Diversion Shortage + ND irrigation Nelson to Vandalia Diversion Shortage + Private Irrigation Nelson to Vandalia Diversion Shortage + Glasgow ID Diversion Shortage); Outflow that will bring storage down to Min Storage for Extra Milk Releases)

END IF

Rule: **Release Water During Irrigation Season for Demands**

This rule releases from Frenchman Reservoir to meet the irrigation demands on the Frenchman River. If the Frenchman storage is less than the Current Min Storage, only the Minimum Release will be released.

IF
    Frenchman Storage > Current Min Storage
THEN
    MAX (Minimum Release; MIN (Frenchman Reservoir Irrigation Demands; Outflow that would bring the storage down to the Current Min Storage))
ELSE
    Minimum Release
END IF

Rule: **Frenchman Winter Ops**

IF
    Frenchman Reservoir Storage is < minimum storage
THEN
    Frenchman Reservoir Release = Minimum of:
    1. Specified Winter Release
    2. Reservoir Inflow
ELSE
    Specified Winter Release

There are two general functions used in the Frenchman Reservoir policy group. They are located in the **Lower Milk River Functions** a and **General Functions** utility groups

Function: **Frenchman Reservoir Irrigation Demands**

This function determined the demands on the Frenchman River below Frenchman Reservoir. It allows the Lower diversion site to make use of return flows from the upper diversions site.

    Irrigation below Frenchman Upper Diversion Requested + MAX (Irrigation below Frenchman Lower Diversion Requested – Three Day Average Return flow from Frenchman Upper; 0 cfs)

Function: **Irrigation Season**

    March 15 to November 1

The Frenchman Reservoir data object contains slots that are used in the operations of the Frenchman River. These slots are summarized in Table 28. Evaporation from the reservoir also is simulated using net evaporation input files, and a reservoir elevation-area table.

Table 28. Frenchman Reservoir Data Object Slot Summary.

Slot	Description	Value
Current Max Storage	Defines maximum reservoir storage.	3,500 acre-feet
Current Min Storage	Defines minimum reservoir storage.	1,500 acre-feet
Minimum Release	Defines minimum reservoir release during the irrigation season.	1.0 CFS
Winter Release	Defines minimum winter reservoir release.	2.0 CFS
Release Extra for Milk Diverters On Off Switch	Enables the option to release some stored water for downstream Milk River irrigators. This rule is only selected when an expanded reservoir option is modeled.	0 = Off 1 = On
Min Storage for Extra Milk Releases	Defines a minimum reservoir contents, below which supplemental releases will not be made for Milk River irrigators.	Set at 7,500 acre-feet

Beaver Creek

Beaver Creek is a relatively large southern tributary to the Milk River. It is modeled as a simple reach object called **Beaver Creek** and is connected to the Milk River through the **Milk River at Beaver Creek** confluence object. Inflows to the Beaver Creek reach object are based on gaged Beaver Creek flows for the 1959-2009 period. Some Irrigation return flows from the Lower Malta unit of the Malta Irrigation District are modeled to return to Beaver Creek. There are no water users linked to the object.

Phreatophytes

The earlier Reclamation HYDROSS model that was used for the North Central Montana Regional Feasibility Study modeled phreatophytes as a river demand based on acreages and a consumptive use rate (with no return flow). This model also includes similar phreatophyte demands on the river, which are modeled like irrigation water users with an acreage, evapotranspiration rate, efficiency (100%), and no return flow. Table 29 summarizes the phreatophyte water user objects and acres used. Monthly demands are set using the Blaney-Criddle/ Hargreaves-Samani ET methods described in the Milk River Irrigation Water Use section of this report.

Table 29. Phreatophyte water user objects in the model and acres used.

Object	Acres
Phreatophytes Havre to Fort Belknap	860
Phreatophytes FtBelknap to Paradise Valley	400
Phreatophytes PV to Harlem ID	400
Phreatophytes Harlem ID to FT Belknap Reservation	560
Phreatophytes Ft Belknap R to Dodson	1,440

Phreatophytes Dodson to Vandalia	3,120
Phreatophytes Vandalia to Mouth	1,840
Total Phreatophyte acres	**8,620**

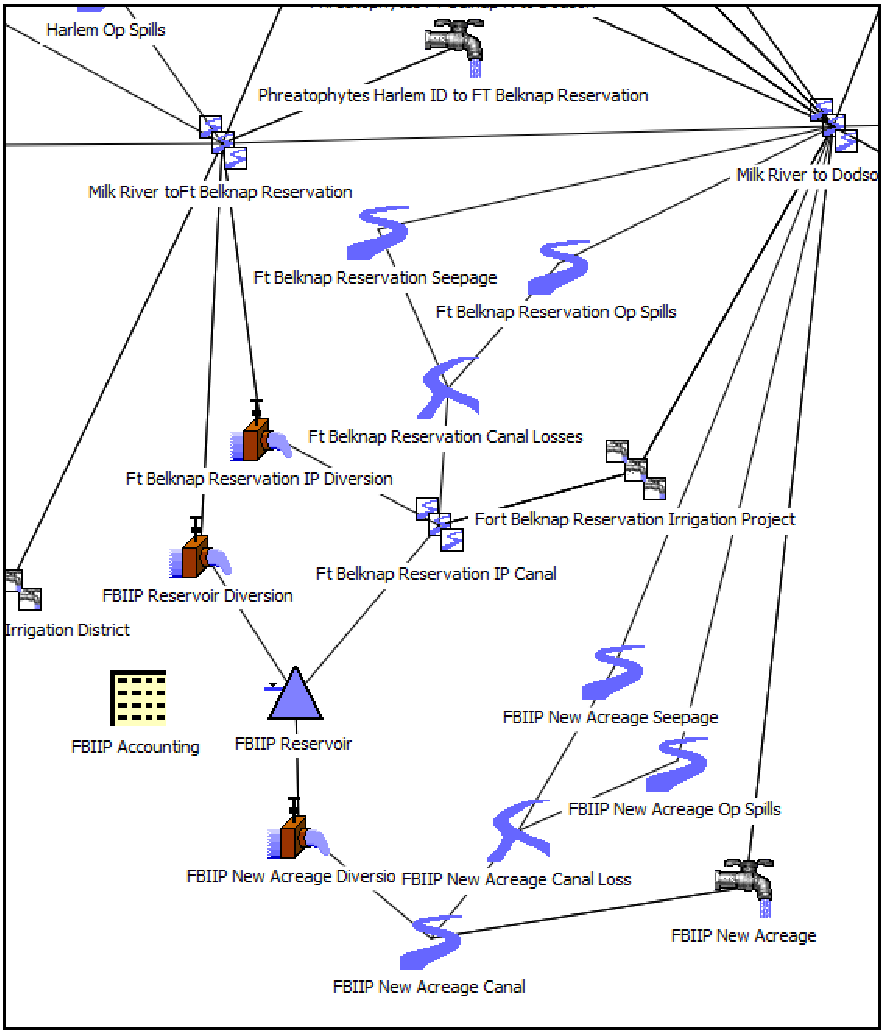
Potential Reservoir on Fort Belknap Indian Reservation

After the completion of the River Basin Study, the capability to model a potential off-stream storage reservoir on the Fort Belknap Indian Reservation was added. The reservoir was intended to be representative of water development associated with the Water Rights Compact between the State of Montana, the Fort Belknap Indian Community of the Fort Belknap Reservation, and the United States of America. Under the terms of the compact, the Tribes have the right to divert up to 645 CFS of the United States share of Milk River natural flow at the location of the Reservation. Up to 520 CFS of this water may be diverted to an off-stream reservoir to supply water for ups to 19,390 acres, including supplemental water that is already irrigated on the reservation. The reservoir was added to the model to simulate this type of potential future development.

The simulated diversion point for the off-stream storage reservoir is just downstream from the existing diversion for the **Ft. Belknap Reservation IP Diversion** object. In the model schematic, it appears that the FBIIP Reservoir diversion is upstream of the diversion for the existing acreage, but this was done to simplify the appearance of the schematic. If the **Milk River to Ft Belknap Reservation** object (AggReach Object) is opened, the model user will notice that the **FBIIP Reservoir** object diversion point is downstream from the from the diversion point for the existing acreage. This configuration allows the existing irrigated lands on the Fort Belknap Indian Reservation to have priority over the off-stream storage reservoir when diverting available Milk River natural flow. A schematic of the modifications to the model to include the reservoir and associated irrigation is shown in Figure 3 below. More details on the modeling of the potential Fort Belknap Indian Reservation Milk River storage reservoir can be found in Appendix E.

The **FBIIP Reservoir** can be simulated to store the portion of the Fort Belknap Reservation share of the Milk River natural flow that is not required by the existing FBIIP acreage. The maximum daily natural flow allocation to the Fort Belknap Reservation is set by the model user on the **FBIIP Accounting** object and is now at 60,000 acre-feet. The Reservoir may be enabled and disabled through the **FBIIP Reservoir On Off Switch** slot in the **FBIIP Accounting** object.

Figure 3. Schematic of Fort Belknap Reservation modeled irrigation after inclusion of potential off-stream storage reservoir.



In addition to the off-stream reservoir, a new water user object and the associated delivery canals were added to represent **New FBIIP Acreage** (currently set at 18,000 acres). Water stored in the **FBIIP Reservoir** will first be used to meet the requirements of the new acreage. Any remaining storage may be used to augment deliveries to the existing **Fort Belknap Reservation Irrigation Project** acreage (limited to the 170 cfs capacity of the existing canal). The delivery canal from the **FBIIP Reservoir** to the new acreage was configured to have a capacity of 1,000 cfs, such that canal capacity will not be a limitation. The distribution canal was implemented in the same manner as the existing distribution canals, such that losses occur due to operation spills and seepage to groundwater. A bifurcation object is used to split the canal losses into the surface and groundwater portions. These are then routed separately according to the surface water routing coefficients and groundwater routing coefficients. These are the same routing coefficients used to route the operational spills and groundwater seepage from the delivery canal to the existing **Fort Belknap Reservation Irrigation Project** acreage. All return flows are linked to the **Milk River to Dodson Dam** object and accrue just below the return flows from the existing FBIIP acreage.

Two rule policy groups were added for simulations of the Fort Belknap Reservation Reservoir: **FBIIP Reservoir Deliveries** and **FBIIP Reservoir Diversions**. The two rules in the **FBIIP Reservoir Diversion** policy group must execute before the shortage sharing rules and the Fresno accounting rules. This is required so that the shortage sharing rules provide the Milk River natural flow to the Fort Belknap Reservation for the existing irrigation, and the potential reservoir and associated irrigation. The rules are summarized below.

Policy Group: **FBIIP Reservoir Diversion**

Rule: **FBIIP Reservoir Diversion Request**

This rule sets the Diversion Request by the **FBIIP Reservoir** from the Milk River. This diversion is active from March 1 to October 31.

IF

  Date >= March 1 AND <= October 31

THEN

  MINIMUM OF:

- Total Natural Flow Available to Fort Belknap Tribe - Ft Belknap Reservation Existing Irrigation Demands
- Maximum daily natural flow allocated to the Fort Belknap Reservation as defined on the FBIIP Accounting data object - Ft Belknap Reservation Existing Irrigation Demands;
- Maximum diversion capacity of the supply canal for the FBIIP Reservoir
- The volume of empty space available in the FBIIP Reservoir

ELSE

  0 CFS

END IF

Rule: **FBIIP New Acreage Diversion Request**

This rule sets the diversion from the **FBIIP Reservoir** to the **FBIIP New Acreage** object.

IF

  FBIIP Accounting.FBIIP ON OFF Switch = 1.0

THEN

  MINIMUM OF:

- FBIIP New Acreage Diversion Request/ (1 – FBIIP New Acreage Canal Seepage Fraction);
- The maximum canal capacity
- The available storage in the FBIIP Reservoir

ELSE

  0 CFS

END IF

Policy Group: **FBIIP Reservoir Deliveries**

Rule: **FBIIP Delivery to Existing Acreage**

This rule augments the water supply to existing FBIIP acreage with reservoir storage, if the daily allocation of Milk River natural flow is insufficient to meet the diversion requirement. This only occurs after stored water is delivered to the new FBIIP acreage. The Outflow slot of the FBIIP Reservoir is linked to the Return Flow slot on the **Ft Belknap Reservation IP Canal:Canal Losses** object. This is the point in the delivery canal just below the location where canal losses are removed. Essentially this water goes directly to satisfy the existing FBIIP acreage on the **Fort Belknap Reservation Irrigation Project** object. The rule works as follows:

IF
    Fort Belknap Reservation Existing Irrigation Project shortage > 0 CFS
AND
    FBIIP Reservoir Storage > Minimum Storage
THEN
    MAXIMUM OF:
        MINIMUM OF:
            - Fort Belknap Reservation Irrigation Project total shortage (sum of shortages for Milk River and White Bear units)
            - Remaining storage in FBIIP Reservoir after deliveries to new acres have been removed
            - The remaining available capacity in the Fort Belknap Reservation Irrigation Project diversion canal (the current capacity is 170 CFS)
    0 CFS
END IF

The data object **FBIIP Accounting** was added for use in the simulation of the Fort Belknap Reservation potential off stream storage reservoir. The slots in this object are summarized in Table 30.

Table 30. FBIIP Accounting Data Object Slot Summary.

Slot	Description	Value
Max Daily Natural Flow Allocation	The maximum daily flow rate available to the Fort Belknap Indian Reservation	645 CFS
FBIIP Reservoir Min Storage	The minimum storage volume assigned to the FBIIP Reservoir	Currently set at 100 acre-feet
FBIIP Reservoir Max Storage	The maximum storage volume assigned to the FBIIP Reservoir	Currently set at 60,000 acre-feet
FBIIP Reservoir On Off Switch	Allows you to include or not include the FBIIP Reservoir in a simulation run	1 = On 0 = Off

Ruleset Summary and Initialization Rules

The main rule set (MilkSt Mary ruleset) that is used to run the model contains policy groups that are named Initialization Rules and Summary Rules. The rules in this set are described here. Please note that the rules in the Initialization Rules policy group are different than those in the Initialization Rules Set, which will be described later in this document.

Policy Group: **Initialization Rules**

Rule: **Record Original Diversion Depletion Requests**

This rule was added to the Initialization Rules Policy Group (within the MilkStMary ruleset, not the RiverWare i**nternal initialization rules).** This function records all of the Diversion Requested and Depletion Requested values to data objects called Original Irrigation Diversion Requests and Original **Irrigation Depletion Requests.** This was done because the shortage sharing rules may reduce the Diversion Requested and Depletion Requested values in order to ensu**re equitable shortage sharing.** It is useful for the model to keep track of the original value**s for computing shortage, etc.** The appropriate rules and expression slots were updated to refer to the Original Diversion/Depletion Requested values.

Rule: **Diversion Request Routing**

This rule was added so that the diversions requested by groups of water users are routed to the diversion object connected to the Milk River after having been adjusted for the canal losses in the corresponding distribution canal, and checked to ensure that they don't exceed the canal capacity. This rule sets the diversion requests for the entire period of simulation at the first timestep so that the Fresno Release for Irrigation Demand rule can use forecasted diversion requests.

Rule: **Milk River below Fresno Evaporation**

This rule computes and fills in the slots for Milk River channel evaporation for all reaches and all timesteps . This was done because other rules will need to know these losses for water distribution and shortage sharing. The channel evaporation slots for each object slot can be filled in prior to the model run because a constant river width and length is assumed, and because the daily evaporation data (inches) are input prior to the model run.

Policy Group: **Summary Rules**

These rules summarize and copy model results to data object slots. The data that are summarized are useful for checking that the model is performing properly, and for checking how changing parameters might change model results. The following is a brief description of what each of these rules does.

Rule: **Lower Milk River Demand Totalizer**

This rule computes 7-day running average total Milk River irrigation demands, from Fresno Reservoir to the mouth, and copies them to the Lower Milk Consumptive Use Demand slot in the Run Summary Accounting data object.

Rule: **Lower Milk River Return Flows**

This rule totalizes Milk River 5-day running average return flows, both surface and groundwater, from Fresno Reservoir to the mouth, and copies them to the Lower Milk River Total Return Flows slot in the Run Summary Accounting data object.

Rule: Lower Milk River Fresno Release Computer

This rule estimates the release needs from Fresno Reservoir by totaling 7-day running average irrigation demands and subtracting 6-day average downstream tributary inflows. Results are placed in the Estimated Fresno Release Needs slot in the Run Summary Accounting data object.

Rule: Tributary Inflow Fresno to Dodson

This rule estimates 7-day running average Milk River tributary inflows from Fresno Reservoir to Dodson Diversion Dam and copies them to the Fresno to Dodson Tributary Inflows slot in the Run Summary Accounting data object.

Rule: Compute Irrigation Diversion Shortage Percents

This rule estimates irrigation water shortages as a percentage of demand for each water user group and copies them to slots in the Irrigation Diversion Shortage Percent data object.

Other Data Objects

System State Accounting Data Object

Rules to simulate the operations of the St. Mary River system primarily are designed to simulate bringing as much St. Mary River water across to the Milk River for use by the United States. Sometimes though, there is no need for that water because there is ample stored water and natural flow in the Milk River basin to meet irrigation demands. Bringing more water across could also have detrimental effects during these times by increasing flooding. The **System State Accounting** object was set up to help determine those times when there probably is not a need to divert more St. Mary River water to the Milk River. Slots are referenced in the general function **Upper System State Full,** which is used by the **Reduce Canal Diversions if Upper System is Full** rule, with the "Canal" referred to being the St. Mary Canal. Some of the slots are simply used to check total storage volumes and accumulated natural inflows. Table 31 lists the slots in the System State Accounting data object.

Table 31. System State Accounting Data Object Slot Summary.

Slot	Description	Value
Total Reservoir Storage	Totalize combined Sherburne, Fresno, and Nelson Reservoir storage	Total storage in acre-feet for each timestep
System Inflows above Fresno	Totalizes all inflows for the St. Mary River and Milk River upstream of the International Boundary	Total inflows in cfs for each timestep
Accumulated Inflows	Accumulates "System Inflows" in the previous slot for each year. Set to zero on January 1.	Accumulated inflow in acre-feet at each timestep for the current year.

Storage plus inflow volume	Adds “Accumulated Inflows” and Total Reservoir storage	Acre-feet for each timestep.
System State Table	Table defines some system state cutoff volumes for various dates. Is not currently being used	Volumes in acre-feet

Run Summary Accounting Data Object

This data object is used to summarize results from a RiverWare run. It contains a number of series slots, series slots with expression, and statistical table slots. Because slots are regularly being added or removed from this objected, based on the types of results that are needed to analyze a particular run, most of these slots will not be described here. The slots used to characterize shortages will be described because these results were used in the St. Mary River-Milk River Basins Study Report. Shortages are computed and summarized for Milk River irrigation between Fresno Dam and the mouth of the river in the **Revised Total Milk ET Shortages Method 2** slot as follows:

Irrigation Depletion Shortage = (acres irrigated * evapotranspiration rate) – (Modeled Depletion * (1 – Incidental Loss Rate))

This is done for each water user and the shortages are summed in the slot to compute the total. These shortages are summarized by year in the **Revised Total Milk ET Shortage M2** table slot. Similar slots are used to track shortages in the Frenchman River basin.

The standard depletion shortage slots for the water user objects in RiverWare were not used for this application because these computations use a depletion request that is reduced if the diversion rate requested is greater than the maximum flow capacity for the water user object. In other words, shortages due to canal capacity limitations would not be accounted for as shortages. Also, incidental losses are considered part of the depletion request and not accounted for separately from water consumption due to crop ET.

Milk River at Mouth Accounting Data Object

This slot is used to estimate Milk River natural flows at the mouth, and flow depletions. It contains a couple of series with expression slots. The slots do not affect model operations and will not be discussed further here.

Historic Data Object

This slot contains historic data for streamflows, reservoir contents, and canal flows that correspond to various objects in the model. It is used for model calibration purposes and for comparing modeled scenarios to historic conditions. The slots all are series slots, and Table 32 lists that RiverWare model slot that produces output that corresponds to each historic data slot.

Table 32. Historic Data Object Slots and Corresponding RiverWare Object Slots.

Historic Data Slot	Corresponding RiverWare Object: Slot
St. Mary River at IB	StMaryRiverIB: Outflow
St. Mary Canal	StMaryCanal: Diversion
Sherburne Storage	SherburneReservoir: Storage
Sherburne Outflow	SherburneReservoir: Outflow
Milk River Eastern Crossing	Milk River at Eastern Crossing: Gage Outflow
Fresno Contents	Fresno Reservoir: Storage
Milk River Havre	Milk River at Havre: Outflow
Milk River at Harlem	Milk River at Fort Belknap Reservation: Outflow
Milk River at Dodson	Milk River at Dodson: Outflow
Milk River at Juneburg	Milk River below Frenchman River: Outflow
Milk River at Creek Crossing	Milk River to Nelson Reservoir: Inflow
Nelson Storage	Nelson Reservoir: Storage
Nelson Release	Nelson Reservoir: Release
Milk River at Tampico	Milk River to Vandalia Dam: Outflow
Milk River at Nashua	Milk River to Mouth: Outflow
Canal FBN ID	Run Summary Accounting: Fort Belknap ID total Diversions
Canal Paradise ID	Run Summary Accounting: Paradise ID total Diversions
Canal Harlem Pumps	Run Summary Accounting: Harlem ID total Diversions
Canal Reservation FB	Run Summary Accounting: Belknap Reservation total diversions
Canal Malta North	North Malta ID: Diversion
Canal Malta South	Malta South Diversion: Diversion
Canal Nelson Feeder	South Dodson Canal: Total Outflow
Canal Glasgow	Glasgow ID Diversion
Canal Lower Malta	Lower Malta Diversion: Diversion
Nelson Computed Net Inflow	Nelson Reservoir: Inflow
Frenchman Reservoir Storage	Frenchman Reservoir: Storage
Nelson Water Orders	Nelson Reservoir: Release
Bowdoin Total Diversions	Lake Bowdoin Diversions: Diversion
Fresno Outflow Reclamation	Fresno Reservoir: Outflow
Beaver Creek	Beaver Creek: Inflow
Clear Creek	Milk River to Paradise Valley Diversion: Tributary Inflow: Local Inflow
Frenchman River IB	Frenchman River IB to Reservoir: Inflow
Milk Western Crossing	South Milk River: Outflow
North Fork Milk Upper	Upper North Milk River: Outflow

Model Input Data

The main input data to the St. Mary River and Milk River Basins River System Model are streamflow, crop irrigation requirements, and evaporation rates. The model was initially developed and calibrated with streamflow input files based on historic gaging station records, crop irrigation requirements based on historic climate data, and evaporation rates based on historic pan evaporation data. The initial base time period that was modeled was 1959-2003. In early 2010, this period was extended to include 2004-2009 data. The 1959-2009 time period was chosen due to the availability of historic streamflow data. Although there probably was adequate streamflow data to go back further in time for the St. Mary River and Milk River to Fresno Reservoir, there wasn't a lot of earlier data available for Milk River tributaries downstream. As it is, a substantial amount of the model input data for lower Milk River tributaries are not actual gaged streamflow data, but are filled-in values based on correlations to other nearby streamflow gages.

For the St. Mary River-Milk River Basins Study, model input files for streamflow, crop irrigation requirements, and evaporation were developed for future climate scenarios centered on 2030 and 2050, as well as for a historic baseline condition. These input data were developed based on weather patterns for the 1950-2001 period, and future climate projections. This section will discuss how the input data sets were compiled for model development and calibration, and for running the model for future climate scenarios for the River Basin Study.

Input Data for Model Development and Calibration

Streamflow

St. Mary River and Tributaries to the International Boundary

Daily natural flow was computed for the period for the St. Mary River Basin for the following locations: (1) Swift Current Creek at Sherburne Dam, (2) Unregulated flow for the St. Mary River to the St. Mary Canal Diversion Dam, and (3) tributary inflow to the St. Mary River between the St. Mary Canal Diversion Dam and the International Boundary. All computations of natural flow for the St. Mary River drainage are in the Excel spreadsheet file: *UpperSt.MaryFlowData*.

Swift Current Creek Inflow to Sherburne Reservoir: The U.S. Geological Survey operates a gaging station on Swift Current Creek at Many Glacier (USGS gage #5014500), which is just upstream of Sherburne Reservoir. This gage accounts for most, but not all of the inflow to the Reservoir. Daily Sherburne reservoir outflow and reservoir contents data are available from Reclamation which could be used, to estimate the total inflow, through the reservoir water balance. However, using the reservoir water balance produced poor daily inflow estimates and many days with negative inflow. To account for the day-to-day changes in reservoir inflow while preserving mass balance, the USGS gage data and Reclamation storage and outflow data were used to conjunctively to estimate inflow. The basic math behind the procedure used was as follows:

> Total Sherburne Inflow = Daily Swift Current Creek at Many Glacier USGS gaged flow + ((reservoir outflow + change in reservoir storage) – Swift Current Creek USGS gaged flow) monthly flows disaggregated to daily

What this procedure did, in effect, was to add the ungaged portion of the reservoir inflow to the daily USGS gaged flow at Many Glacier. The computed ungaged inflow volumes were summed over a 30-day period and then distributed daily, based on the inflow patterns for the Swift Current Creek at Many Glacier gage, to mostly eliminate the occurrence of negative daily gains between the gaging station and the dam, while preserving mass balance.

Unregulated St. Mary River Flow to the St. Mary Canal Diversion Dam: For the purposes of the model, this included the St. Mary River and other inflow from the Swift Current Creek drainage downstream of Sherburne Dam. For most days, this flow was computed by simply subtracting the Reclamation recorded outflow from Sherburne Dam from the gaged flow for the St. Mary River at Babb USGS gage (USGS gage #5017500). At times though, this procedure would result in the computation of negative daily flows, usually when Sherburne Reservoir releases for the St. Mary Canal first began in the early spring. The reason for this seems to be that initial releases from Sherburne Dam temporarily go into storage in Lower St. Mary Lake (these flows mostly raise the lake level) and are not immediately realized as flow at the gage. The St. Mary River at Babb gage is located just below the Lake outlet. For periods when the computed flow was negative, daily outflows from Sherburne Reservoir were summed over a longer period, which included flows during and following the occurrence of the negative computed flows. These summed flows where then redistributed, daily, over the period and then subtracted from the St. Mary River at Babb gaged daily flows. This resulted in computed daily natural flows that were no longer negative for the days in question, but somewhat reduced for the other days in the period. This process preserved mass balance.

Tributary Inflow Between the St. Mary Canal Diversion Dam and International Boundary:

The total tributary inflow for this reach of the St. Mary River was computed as follows:

St. Mary River Tributary Inflow from Diversion Dam to International Boundary =
Flow of St. Mary River at the International Boundary (USGS gage #5020500)
+ Flow of the St. Mary Canal at the St. Mary siphon (USGS gage #5018500)
- Flow for the St. Mary River at Babb(USGS gage #5017500).

This procedure also resulted in the computation of some negative inflow between the Diversion Dam and International Boundary, although these instances were few. When negative gains were computed, the negative flow where summed with positive flows for days that followed, and the summed flow were then redistributed, daily, over the selected period to eliminate the negatives while preserving mass balance.

<u>Milk River and Tributaries Upstream of the Eastern Crossing of the International Boundary</u>

Natural Streamflow Input files were developed for the following three points in the Milk River watershed upstream of the Eastern Crossing: (1) the North Fork of the Milk River where it crosses the International Boundary, (2) the Milk River at its Western Crossing of the International Boundary (sometimes called the South Fork of the Milk River), and (3) additional Milk River gains between the Western and Eastern Crossings of the International Boundary. All computations of natural flows for the Milk River upstream of the Eastern Crossing are in the Excel spreadsheet file: *Milkdata*.

North Fork of Milk River at International Boundary: The U.S. Geological Survey operates a gaging station (#6133500) on the North Fork of the Milk River near the International Boundary and upstream of where the St. Mary Canal discharges into the river. The gage was in operation throughout the 1959-2009 period, but it is generally only operated during March through October. Currently, no one is irrigating with North Fork water upstream of the gaging station, but there has been irrigation in the past. Daily average flows from the gaging station data were used as the basis for determining the natural flows for this station. The average amount of land irrigated was estimated to be 339 acres, with an average depletion of 0.8 acre-feet per acre. To account for the effects of this irrigation, gaged data from all but the most recent years where adjusted throughout by adding the following amounts to the daily flows during the irrigation season: May = 1.4 cfs, June = 1.7 cfs, July = 0.7 cfs, August = 0.5 cfs, and September = 0.2 cfs. Because the gaging station was not operational during the winter, all winter input data were set to zero. In actuality, the North Fork does produce water during the winter. Combined winter inflows for the North Fork and Milk River proper are included in the input data for the Milk River at the Western Crossing station

Milk River at the Western Crossing of the International Boundary: The U.S. Geological Survey and Water Survey of Canada cooperatively operate a gaging station on the Milk River at its Western Crossing of the International Boundary (USGS station #6133000). Daily discharge records generally are complete for this station, but it is a seasonal gage that usually is only operated from March through October. Daily discharge data where adjusted to account for estimated irrigation depletions. Earlier surveys estimated that about 2,700 acres might have been irrigated in watershed above the gage at times during the modeling period, but in recent years the acres irrigated probably has been closer to 1,000. Annual irrigation depletions were estimated based on the average irrigation depletions in the watershed during the 2008 and 2009 seasons. These were estimated based on measurements and conversations with landowners and are as follows: May = 3.3 cfs, June = 3.0 cfs, July = 4.3 cfs, August = 1.7 cfs, September = 0 cfs.

A gaging station is operated year-round by the Water Survey of Canada on the Milk River near the Town of Milk River Alberta (Environment Canada Gage #11AA005). Winter flows from this gage were used to fill in the input data for the Milk River at the Western Crossing during the winter when the Western Crossing gaging station was not operational. These winter flows also would include those contributed by the North Fork of the Milk River. Because the Town of Milk River is a relatively short distance downstream of where the two forks of the Milk River join, the winter flow data would also include some winter inflows to the stream below the Forks.

Milk River Gains Between the Western and Eastern Crossings: These natural gains were computed by subtracting the above computed flows for the Milk River at the Western Crossing plus the gaged flow for the North Fork of the Milk River below the St. Mary Canal discharge point (Environment Canada station #11AA025) from the Milk River at the Eastern Crossing gage (USGS station #6134700) and adding estimated depletions to natural flows by Milk River irrigation in Alberta. Alberta irrigation depletions have changed over the years: there has been an increase in acreage during the period from about 4,500 to 8,000 acres, and the method has changed from primarily flood irrigation to mostly sprinkler irrigation that pumps water directly out of the Milk River. The depletion estimates used were gradually adjusted to account for these changes.

<u>Milk River Tributary Inflows: Fresno Dam to mouth of Milk River</u>

Computations of natural flows for the Milk River tributary inflows between Fresno Dam and the confluence with the Missouri River are in the Excel spreadsheet file: *MilkRiverGainsWorksheet*. Milk River tributary inflows are input for the following reaches that correspond to nodes in the model. The gains are a summation of the tributary inflow to the various reaches multiplied by a factor that accounts for other ungaged inflows to that reach. The stations and multipliers used to account for gains by reach are as follows:

1. Gains to Havre (flows for these tributaries * 1.25)
    a. Big Sandy Creek
    b. Beaver Creek
2. Gains to the Ft. Belknap Diversion Dam (flows for this tributary * 1.5)
    a. Little Box Elder Creek
3. Gains to the Paradise Valley Diversion Dam (flows for this tributary)
    a. Clear Creek
4. Gains to the Harlem ID pumping station(flows for these tributaries * 1.25)
    a. Lodge Creek
    b. Battle Creek
5. Gains to the Dodson Diversion Dam (flows for this tributary * 1.5)
    a. Peoples Creek
6. Frenchman River
    a. Frenchman River at International Boundary Flow
7. Beaver Creek
    a. Beaver Creek at Bowdoin * 1.4 to account for Larb Creek flow
8. Gains to Vandalia Diversion Dam (flows for these tributaries * 2.0)
    a. Whitewater River
    b. Rock Creek
9. Gains to the mouth of the Milk River (flows for these tributaries * 1.6)
    a. Buggy Creek
    b. Willow Creek
    c. Porcupine Creek

For the tributary stations listed above, USGS gaged daily average streamflows were used whenever available. However, few of the stations were operational for the entire modeling period, and most of the stations were seasonal gages—that is, they generally were not operated during the winter time. Where data were missing for a gage, values were filled in by statistical correlation to other active stream gaging stations in the region using the U.S. Geological Survey FILLIN program. The *Maintenance of Variance Extension* Type 1 (MOVE.1) method is used by the FILLIN computer program to fill in missing values. Hirsch (1982) showed that the MOVE.1 method, which is similar to regression methods, preserves the statistical characteristics of the actual record better than traditional regression methods. MOVE.1 results in preserving sample estimates of the mean and of the variance from the historical record.

The FILLIN program was used to extend streamflow records to times when a gaging station was not active. Before the program is run, the user compiles a matrix of available streamflow data for the period of interest that includes data for many regional stations that might have overlapping periods of record. The matrix is then put in the FILLIN program and run with the instructions to fill-in missing data for the station of interest. Based on correlation of flow values for stations with overlapping periods of record in the matrix, the missing values are filled in. The filled in values are not all computed through correlation to a single gaging station—multiple stations might have been used to filling in the missing records. One disadvantage of the FILLIN program is that it is an old FORTRAN program that only fills in monthly average flows. The filled in missing monthly flows then need to be disaggregated to daily flows for use as input files to the model.

The flows were disaggregated using the daily flow distribution for the missing period for a nearby gage in the Milk River watershed. For instance, The Rock Creek at International Boundary gage was operational during the entire base period and its daily flow distributions could be used to distribute missing monthly flows for a station like Whitewater Creek, which wasn't operational for much of the base period. The process in this example would be to: (1) compute what percent of the monthly flow of Rock Creek occurred during each day of a month, and (2) apply those daily percentages to each day of the month for the monthly total flow computed for the Whitewater River with the FILLIN program.

Because there are available long-term winter flows for very few stations in the Milk River watershed, missing monthly winter flows were filled in with two daily flow distribution sets. The first was developed based on a compilation of flows for Peoples Creek and Willow Creek and was used for stream in the upper portions of the Milk River below Fresno. The second was based on a compilation of winter flow distributions for Willow Creek and Rock Creek and was used to distribute winter flows for tributaries lower down in the system.

Table 33 lists gaging stations that were used to develop lower Milk River inflow data, either directly or with the FILLIN program. The compilation of Milk River tributary inflow can be found in the EXCEL file: MilkRiverGainsWorksheet.

Table 33. USGS gaging stations used to develop inflow data for tributaries to the Milk River from Fresno Dam to the confluence with the Missouri River.

Station Name	Number	Drainage Area Miles^2	Period of Record
Big Sandy Creek near Havre	06139500	1,805	1946-53; 1984-Present
Beaver Creek near Havre	06140000	87.4	1918-1921
Little Box Elder Creek at mouth, near Havre	06141600	95.9	1986-1992; 1994-1996
Clear Creek near Chinook	06142400	135	1984-Present
Lodge Creek below McRae Creek, at International Boundary	06145500	825	1951-Present
Battle Creek at International Boundary	06149500	997	1917-Present
Battle Creek near Chinook	06151500	1,623	1905-1921; 1984-Present
Peoples Creek near Dodson	06154500	670	1918-1922; 1951-1973; 1982-1988
Peoples Creek below Kuhr Coulee, near Dodson	06154550	675	1918-1921; 1951-1973; 1982-Present
Whitewater Creek near International Boundary	06156000	458	1927-1980
Frenchman River at International Boundary	06164000	2,120	1917-Present
Beaver Creek above Dix Creek, near Malta	06164800	929	1967-1969; 1976-1982
Beaver Creek below Guston Coulee, near Saco	06166000	1,208	1920-1921; 1981-Present
Rock Creek below Horse Creek, near International Boundary	06169500	328	1916-1926; 1956-Present
Rock Creek below McEachern Creek, near International Boundary	06170050	650	1924-1977
Rock Creek near Hinsdale	06171000	1,313	1906-1907; 1912-1920
Buggy Creek near Tampico	06172200	105	1958-1967
Willow Creek near Glasgow	06174000	538	1954-1987
Porcupine Creek at Nashua	06175000	725	1908-1924; 1982-1992
Poplar River at International Boundary[1]	06178000	358	1931-Present

[1]Note: This station is outside of the basin but was used due to the long available record and the proximity of the Poplar River to the Milk River basin.

Crop Irrigation Requirements

Temperature and precipitation data for the observed climate, which were computed as a part of the climate change component of the Basin study, were used with evapotranspiration models and with the above crop mix to estimate the net irrigation requirements for 42 subbasins in the region. The crop mix for each subbasin was prorated based on the acreage in each county, and the crop distributions in Table 34.

Table 34: Irrigated Crops as a percent of Total Irrigated Acres in the Milk River Basin by Geographic Area

Crop	Canada[1]	Glacier County[2]	Blaine County[3]	Phillips County not including Nelson Reservoir Lands[3]	Valley County not including Nelson Reservoir Lands[3]	Nelson Reservoir Lands[4]
Alfalfa	10	25	54	56	55	15
Grass	80	60	25	28	17	80
Small Grains	10	15	21	15	24	5
Corn	0	0	0	1	4	0

1 Source of data: Personal communication, Bob Riewe, Province of Alberta, June 2011.
2 Source of data: Dolan, 2009.
3 Source of data: Average of data for 2002 and 2007, Census of Agriculture – County Data, U.S. Department of Agriculture (USDA), National Agricultural Statistics Service, Phillips and Valley County data adjusted for Nelson Reservoir Lands data
4 Source of data: Personal communication, Malta Irrigation District, April 2011.

The Blaney-Criddle evapotranspiration model was used to estimate monthly net irrigation requirement for each month in the study period as this evapo-transpiration model was the preferred method and used to develop ET rates for earlier modes of the basin. Next, the Hargreaves-Samani evapotranspiration model was used with the temperature, effective precipitation, and crop mix to estimate the daily net irrigation requirement for each subbasin. A daily fraction based on the Hargreaves-Samani evapotranspiration model was then computed and applied to the monthly Blaney-Criddle values to arrive at daily values used in the hydrology model to estimate irrigation demands. These net irrigation requirements were developed for the period 1950 to 2009. These methods are further summarized in the *Milk-St. Mary River System Basin Study: Data and Model Managers User Manual* in Appendix F. These evapotranspiration computation methods are used for both model development and calibration and used when modeling climate change scenarios and alternatives.

These daily ET values then were aggregated to weekly ET values to moderate large daily ET fluctuations that might cause big demand shifts that could in turn cause too large of daily fluctuations in river diversion rates that don't reflect reality. The aggregation was done by averaging the summation of the daily demands for each week during the irrigation season.

Evaporation

Daily evaporation input files were developed for Fresno Reservoir and Nelson Reservoir using data from the evaporation pan at the Fort Assiniboine weather station. Monthly average evaporations, disaggregated evenly to daily values, were used for the years 1959 through 1989. The Fort Assiniboine pan evaporations were multiplied by a factor of 0.74 to adjust the pan evaporation values to what might be expected from a reservoir. For the years 1990-2009, daily evaporation data for each year were used, as obtained from Norm Midtlyng of the U.S. Geological Survey. For Fresno Reservoir, daily precipitation data from the Fort Assiniboine weather station were subtracted from the evaporation values to obtain the net evaporation. For Nelson Reservoir and Lake Bowdoin, daily precipitation data for the Malta 7 weather station were subtracted from the Fort Assiniboine evaporation data. The resulting average annual evaporations for the 1959-2009 period were 22.8 inches for Fresno Reservoir, and 23.0 inches for Nelson Reservoir and Lake Bowdoin. The evaporation input data is contained in the file: MilkReservoirLakeEvaporation. The file: “evaporation data” contains Fort Assiniboine evaporation data from the USGS for the years 1990 through 2009.

Milk River Channel Evaporation in Alberta

An equation was developed for computing evaporation from the Milk River channel in Alberta per-inch of pan evaporation at the Fort Assiniboine weather station. The equation takes the form: $y = 0.00000015x^3 - 0.00030455x^2 + 0.36042969x + 41.89669690$. Where y is the cfs of evaporation loss per inch of pan evaporation for the entire length of the Milk River channel in Canada, and x is the flow of total flow of the Milk River (the natural flow plus imported St. Mary River water). The computations can be found in the file “evaporation data”. The daily Fresno River net evaporation input data were used in RiverWare in the final computation of evaporation.

Future Climate Scenarios

Temperature and Precipitation

Temperatures and Precipitation in the St. Mary River and Milk River basins is expected to change in the future. Warming has been experienced over much of the U.S. during the 20th century and the general warming of the global climate is likely to continue in the 21st century. Reclamation examined climate change in eight western river basins in the 21st century in the *SECURE Water Act Section 9503 (c) - Reclamation Climate Change and Water 2011* (Reclamation, 2011a). One of the eight basins examined was the Missouri River basin, of which the Milk River basin is a part. The report indicated that the annual temperature is projected to increase by 2 to 6° F and annual precipitation would gradually increase over the western upper reaches of the Missouri River basin in the 21st century. Warmer temperatures would affect accumulation of snow in the mountains during the cool season and thus availability of snowmelt to sustain runoff in the spring and summer. Increased precipitation during the cool season would offset increased temperatures somewhat. Increased variability between wetter and drier years is projected.

Reclamation analyzed climate change for the St. Mary River and Milk River basins, producing hydrologic data sets centered on 2030 and 2050 using the Period Change method. The findings are summarized in the report *Climate Change Analysis for the St. Mary and Milk River Systems in Montana* (Reclamation 2010). In the Period Change method, Reclamation started with future climate data sets produced by 112 general circulation models (GCM) simulate future climate changes that affect weather patterns by assuming various rates of some physical parameter, such as greenhouse gas concentrations. A problem with the results from the GCMs is that spatial scale of the output data is too coarse for use in basin studies. Statistical downscaling was used to translate the global-scale output data from the GCMs to the finer scale climate differences applicable at the level of a basin study.

The consensus message of all of these projections was that temperatures in the St. Mary River and Milk River basins are likely to follow a warming trend in the future. However, the rate of warming projected varies among the different GCMs. Projections for precipitation ranged from drier to wetter, but most of the predications were for overall wetter conditions in the basins, with increasing year-to-year variability. Figure 4 contains plots of modeled annual temperatures and precipitation trends. The solid line represents the median change, while the shaded band represents the variability for the 112 climate projections.

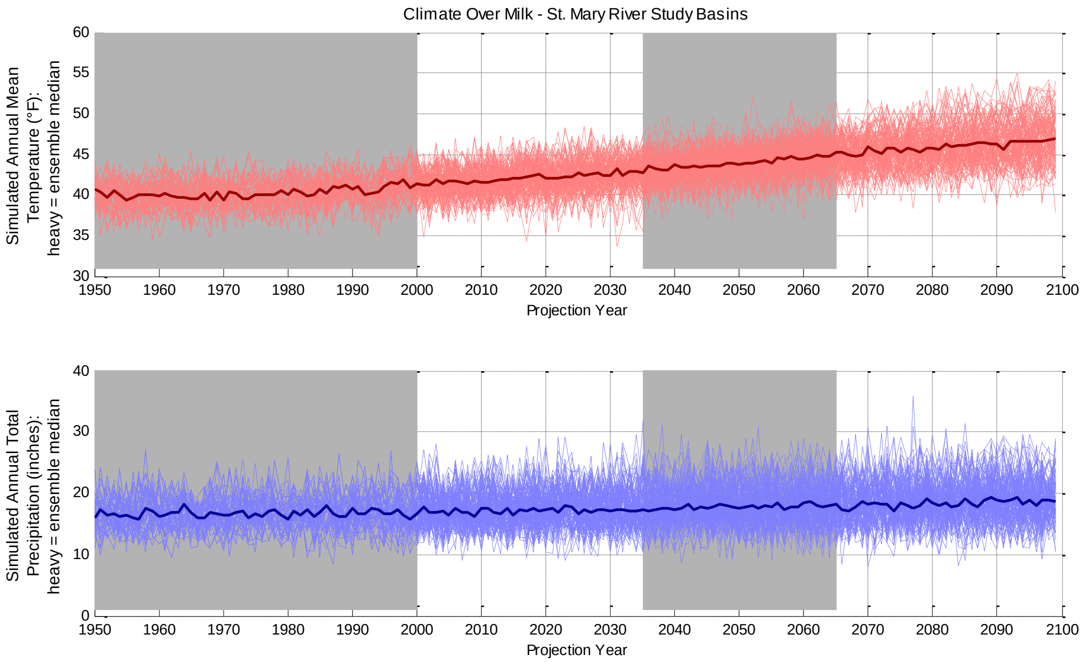


Figure 4: Average Annual Climate Temperature and Precipitation Projections for the Region

To account for the uncertainty in the climate change projections while keeping the number of scenarios manageable, Reclamation grouped the climate change scenarios into four quadrants (that is groups of similar scenarios). Median temperature and precipitation changes were used to define these four groups as depicted in Figure 5. From these groupings, four climate-change threads were produced using the Hybrid Delta Ensemble (HDe) method. The HDe method samples the grouping of climate change projections and uses changes in monthly distributions of temperature and precipitation to capture future variability. The four threads represent projected changes ranging from less to more warming, paired with drier to wetter conditions.

A fifth climate-change thread also was defined, representing the central tendency group of the projected changes. Input data also were produced for a baseline climate thread, which assumes that there will be no climate changes and is based on historic temperature and precipitation data.

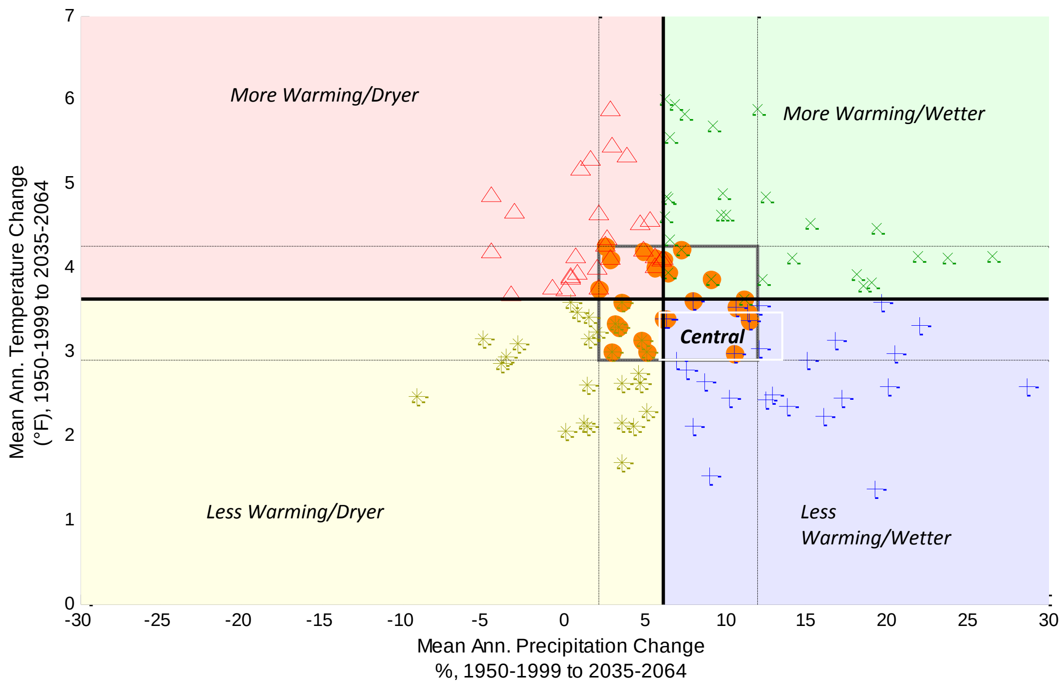


Figure 5: Climate Change Threads, Showing Modeled Changes in Mean Annual Temperature and Precipitation in the Region for Four Quadrant Groupings and a Central Tendency Grouping

Streamflow

A surface water hydrology model was used to translate temperature and precipitation data to streamflow in the region's subbasins. The hydrologic simulation was run using a calibrated version of the National Weather Service River Forecasting Center's SAC-SMA/SNOW-17[1] model of the St. Mary River and Milk River basins. The Sacramento Soil Moisture Accounting (SAC-SMA) and Snow Accumulation and Ablation (SNOW-17) applications use precipitation and temperature on a six hour time series as inputs for computing a runoff time series. The SAC-SMA model simulates physical mechanisms that drive water movement through the soil column (infiltration, percolation, storage, evapotranspiration, baseflow, etc.), while preserving the water balance. The SNOW-17 model simulates physical processes that affect snow runoff data sets from accumulation and snowmelt. Once the projections corresponding to each of the five climate change thread were identified, the Period Change Hybrid Delta Ensemble (*HDe*) method was used to generate temperature and precipitation data to run the *SAC-SMA/SNOW-17* hydrology model for each climate change thread.

The streamflows generated by the SAC-SMA/SNOW-17 surface water runoff hydrology model using temperature and precipitation of the base period 1950-2001 didn't always adequately match the historical gauging station-based data in annual and seasonal volume. This required adjustment of the streamflows developed for the five climate change scenarios to correct the bias between the surface water runoff model historic climate baseline streamflows and the

[1] Combined use of the Sacramento Soil Moisture Accounting and Snow Accumulation and Ablation hydrologic models.

historical flows used in the river system model. The adjustment method is described in Milk-St. Mary River System Basin Study: Technical Service Center Support attached in Appendix H.

Crop Irrigation Requirements

Crop irrigation requirements were computed for the future scenarios using the same methods described in the "Input Data for Model Development and Calibration: Crop Irrigation Requirements" section. The same crop mixes presented in Table 33 were used. The only difference was the predicted future temperatures and precipitation were used in these computations, rather than historic.

Evaporation

Evaporation rates for future climate scenarios were based on monthly ratios of historic evaporation to potential evapotranspiration computed using the Hargreaves Samani method (Table 35). These same ratios were applied to the future daily Hargreaves Samani evapotranspiration rates to estimate future daily evaporation rates from the reservoirs and river channel. More details on the computation of evaporation for future scenarios can be found in the *Milk-St. Mary River System Basin Study: Data and Model Managers Manual* in Appendix H.

Table 35. Ratios of Total Evaporation To Hargreaves Samani Potential Evapotranspiration.

Month	Total Evaporation to Evapotranspiration
1	1.174
2	0.611
3	2.311
4	0.917
5	0.660
6	0.723
7	0.751
8	0.833
9	0.816
10	1.291
11	1.614
12	1.249
Average	1.079

Model Calibration

Hydros Consulting, Inc. evaluated the river system model to quantify and improve the model's ability to simulate irrigation water use and to replicate historical river flows. The calibration focused on physical parameters, such as irrigation efficiencies, surface and groundwater return flows, and water losses. The calibration tested the ability of the model to replicate downstream Milk River flows at the following gauging stations:

- Eastern Crossing
- Harlem
- Dodson (below the Dodson Diversion Dam)
- Juneberg Bridge
- Nashua (mouth of the Milk River).

The model calibration review by Hydros Consulting is summarized in Appendix B.

Data Management Interfaces and Managers

A number of data management interfaces were developed to automate the import to and export of data from the model. RiverWare initialization rules (rules that execute prior to the model running) also were developed to pre-process some model input data prior to a simulation run. Managers were developed to pre-process future climate scenario data outside of RiverWare and to automate the running of these future scenarios.

Data Management Interfaces

Data management interfaces (DMIs) of two types were used in the model: those that import data to the model from text files, and those that import data from or export data to Excel files. Table 36 describes model data that is input or output through DMIs. Some of these DMIs import data directly into the destination model slot; others import that data into data objects that then populate the destination slots through RiverWare initialization rules. More information on the DMIs can be found in Appendix G.

Table 36. St. Mary River Milk River Model DMIs.

DMI	Description	File Type Data Object (if Used)
Annual Areas to Data Objects	Irrigated areas by user by year in acres	Excel File: MilkInputData AnnualAreas
Fallow Acreage Fractions	Fraction of irrigated area that is fallow, by user, by year	Excel File: MilkInputData FallowAcreageFractions
Monthly ET Rates	Monthly crop depletion requirements for each water user in inches	Excel File: MilkInputData MonthlyETRates
Depletion Fractions	Fraction of monthly depletion for each day by user	Excel File: MilkInputData DepletionFractions
Evaporation	Evaporation rates in inches per day	Excel File: MilkInputData
Hydrology	Daily flow input data in CFS	Excel File: MilkInputData
GroundWaterRouting	Daily lagged groundwater return flows from year prior to start year, by user in CFS.[1]	Text File: *.GW_Return_Flow
SurfaceWaterRouting	Initializes surface return flow as zero for first day of model run.	Text File: MilkWaterUsers.SW_Return_Flow
Streamflow Routing	Populates initial inflow data	Text File: *Lag_Time.Inflow

	to stream reaches at a beginning of a run[2].	
Reservoir Storage	Sets the beginning storage for each reservoir in acre-feet	Text File: *_Reservoir.Storage
Standard Output	Exports selected daily	Excel File: MilkOutputData

[1] Groundwater return flows are lagged over a one-year period. This DMI daily groundwater return flows for each water for the year prior to the start of the model run. These are need for the model to solve for total lagged return flows during the first year.

[2] Note: There are time lags built into some model reaches to account for the time it takes for water to move from the headwaters of the St. Mary River to the mouth of the Milk River. This DMI adds initial streamflow data to reaches downstream of reaches with time lags so the model has all the data it needs to solve routed flow during the first week of the simulation.

Initialization Rules

A number of initialization rules were developed to pre-process data and populate model object slots prior to a simulation run. These initialization rules can be found in the model in the RiverWare Initialization Rules Set. Some of these just set a single initial value to a slot so the model has the initial conditions it needs to run. Some key initialization rules are described below.

Initialization Rule: **Set Water User ET Partial Request**

This rule populates the evapotranspiration rate slot for each water user for each day using the Monthly ET data and daily depletion fractions. A supply factor also can be used to set the daily ET rate to a fraction less than the computed amount; or a factor of 1.0 can be used if no adjustment is preferred.

```
FOREACH
        Irrigation Water User
                FOREACH
                        Day of Model Run
                                Evapotranspiration Rate =
                                Monthly ET Rate * Daily Fraction * Supply Factor
                ENDFOREACH
ENDFOREACH
```

Initialization Rule: **Set Fraction of GW Return Flow**

This rule populates the **Fraction GW Return Flow** slot for each day for each water user using set values in the **FractionGWReturnFlow** data object. It simply makes changing these values easier, than going through the model water user objects and making the changes one-by-one.

```
FOREACH
        Day of Model Run
                FOREACH
                        Water User
                                Groundwater Return Flow Fraction =
```

Fraction Specified in **FractionGWReturnFlow** Data Object
ENDFOREACH
ENDFOREACH

Initialization Rule: **Set Minimum Efficiency**

This rule populates the **Minimum Efficiency** slot for each water user for each day using daily efficiencies contained in the **MinimumEfficiency** Data Object. The efficiencies used for water users is seasonally variable, with efficiencies generally higher later in the irrigation when there typically is less water. This sets the minimum efficiency for each water user. Having these values in a data object makes changing the efficiencies easier, than going through the model water user objects and making the changes one-by-one.

FOREACH
    Irrigation Water User
        FOREACH
            Day of Model Run
                Minimum Efficiency =
                Efficiency Specified in the **MinimumEfficiency** Data Object
        ENDFOREACH
ENDFOREACH

Initialization Rule: **Set Irrigated Fallow Adjustment**

This rule populates the **Irrigated Area** slot for each water user for each day using annual irrigated areas contained in the **AnnualAreas** Data Object, and annual fallow acreage fractions found in the **FallowAcreageFractions** data object.

FOREACH
    Day of Model Run
        FOREACH
            Irrigation Water User
                Irrigated Area =
                Irrigated Area from the **AnnualAreas** Data Object *
                (1 – Fraction from the **FallowAcreageFractions** data object)
        ENDFOREACH
ENDFOREACH

Initialization Rule: **Initial Conditions**

This rule sets initial diversion values for several objects on the lower Malta system to zero. It also sets daily depletion requests to zero for water user objects that do not deplete the flows they divert.

Data and Model Managers

Reclamation Technical Services Center developed data and model managers to automate the development of input data and running of the model for the various climate-change traces. These managers were developed using Excel files and Excel macros. The following is a brief description of each the managers. Details on these managers and associated input data can be found in the Milk-St. Mary River System Basin Study: Data and Model Mangers User Manual in Appendix F.

Climate Data Parsing Manager: Application to parse observed and future data in NetCDF binary format, and to transform these parsed data into Excel workbooks.

Delta and HDe Manager: Application to use Delta or HDe method to create five subsets of climate data from the 112 BCSD climate change projections for futures centered on 2030 and 2050.

Blaney-Criddle Model and Manager: Application to facilitates computation of monthly net irrigation requirement using the Blaney-Criddle method for historic conditions and future climate traces, and to automate data input to RiverWare model.

Hargreaves-Samani Model and Manager: Application to facilitates computation of daily net irrigation requirement fractions using the Hargreaves-Samani method, and to automate development of input data to RiverWare model for historic conditions and future climate traces.

Evaporation Manager: Application to compute daily reservoir and river evaporation rates for input to RiverWare model for historic conditions and future climate traces.

Hydrology Manager: Application to compute daily biased-corrected flows as a function of monthly biased corrected flows, daily biased flows, and monthly biased flows for historic conditions and all climate change traces. Automates input of these data to the RiverWare model.

RiverWare Manager: Application to manage RiverWare input data, run RiverWare, and manager RiverWare output data for historic conditions and climate change traces.

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Hirsch, R.M., 1982. *A Comparison of Four Streamflow Record Extension Techniques*. Water Resources Research, v. 18, no. 4; p. 1081-1088.

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Reclamation, 2010. Climate Change Analysis for the St. Mary and Milk River Systems in Montana. Technical Memorandum No. 86-68210-04. Denver, Colorado.

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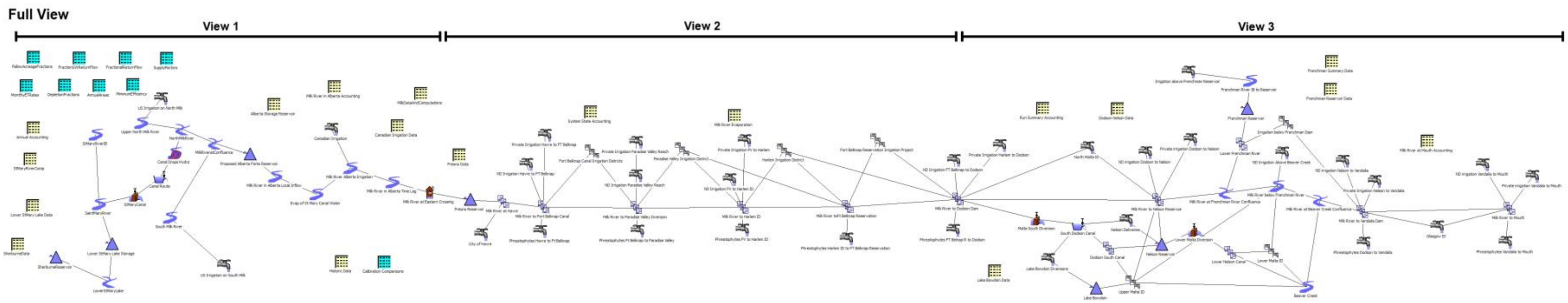
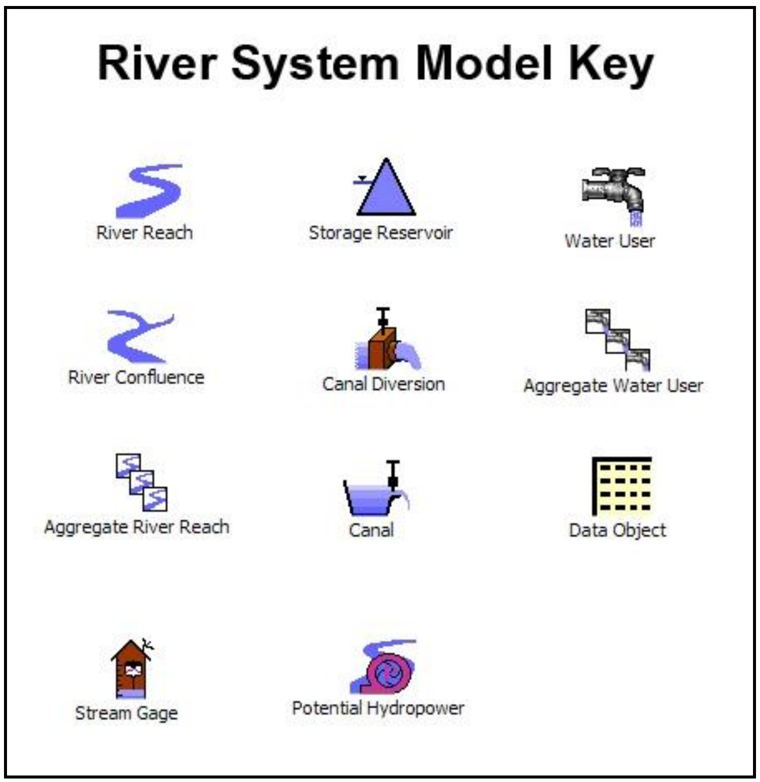
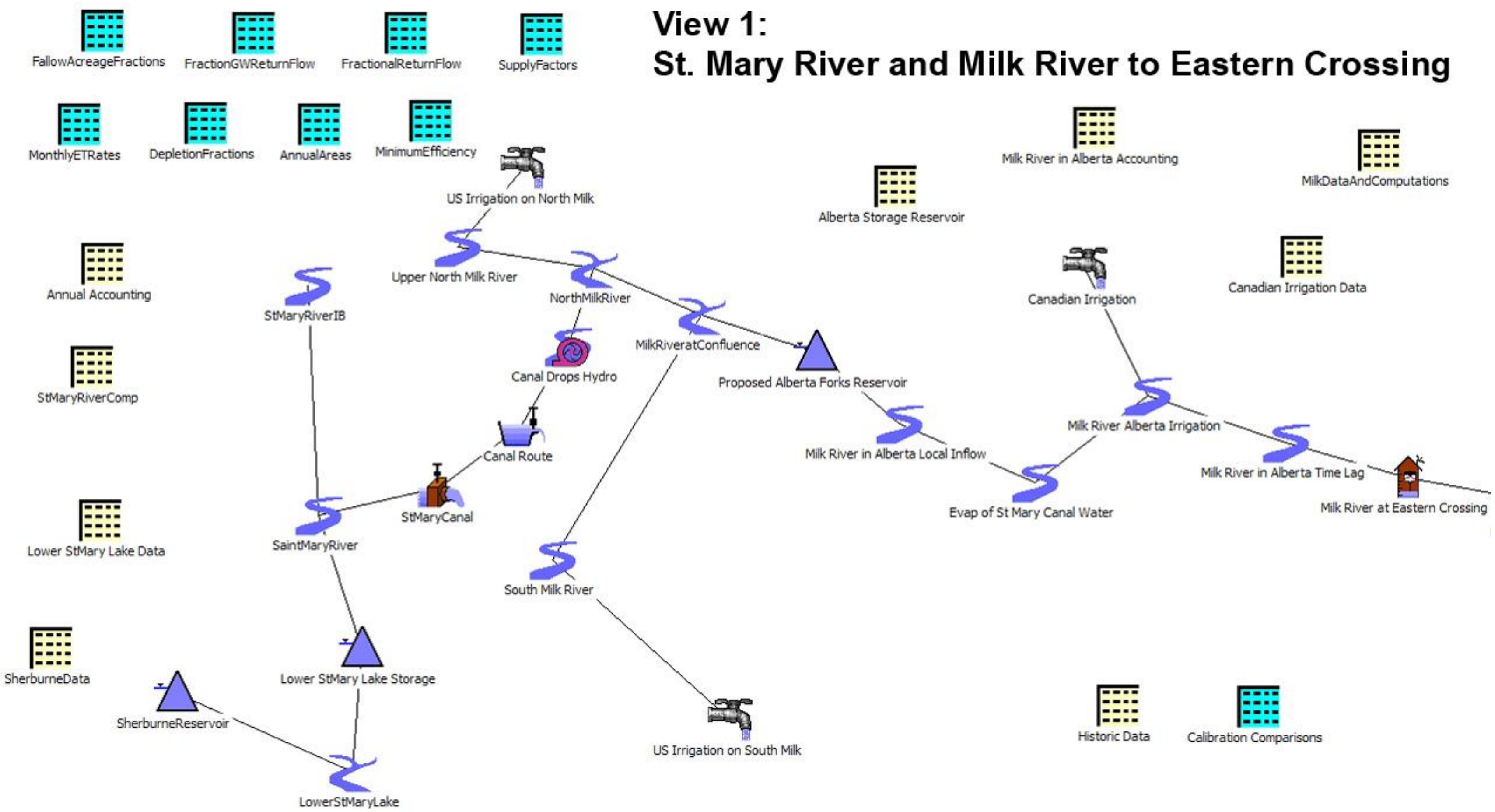
Appendix A
Model Schematic (At Time of River Basin Study)

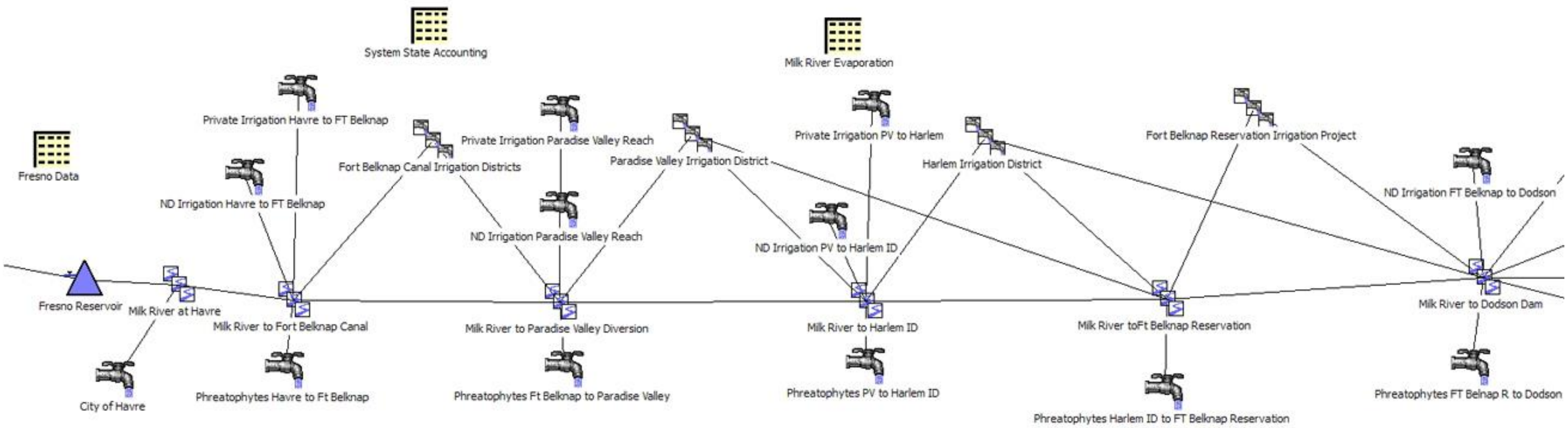

Full View
View 1
View 2
View 3

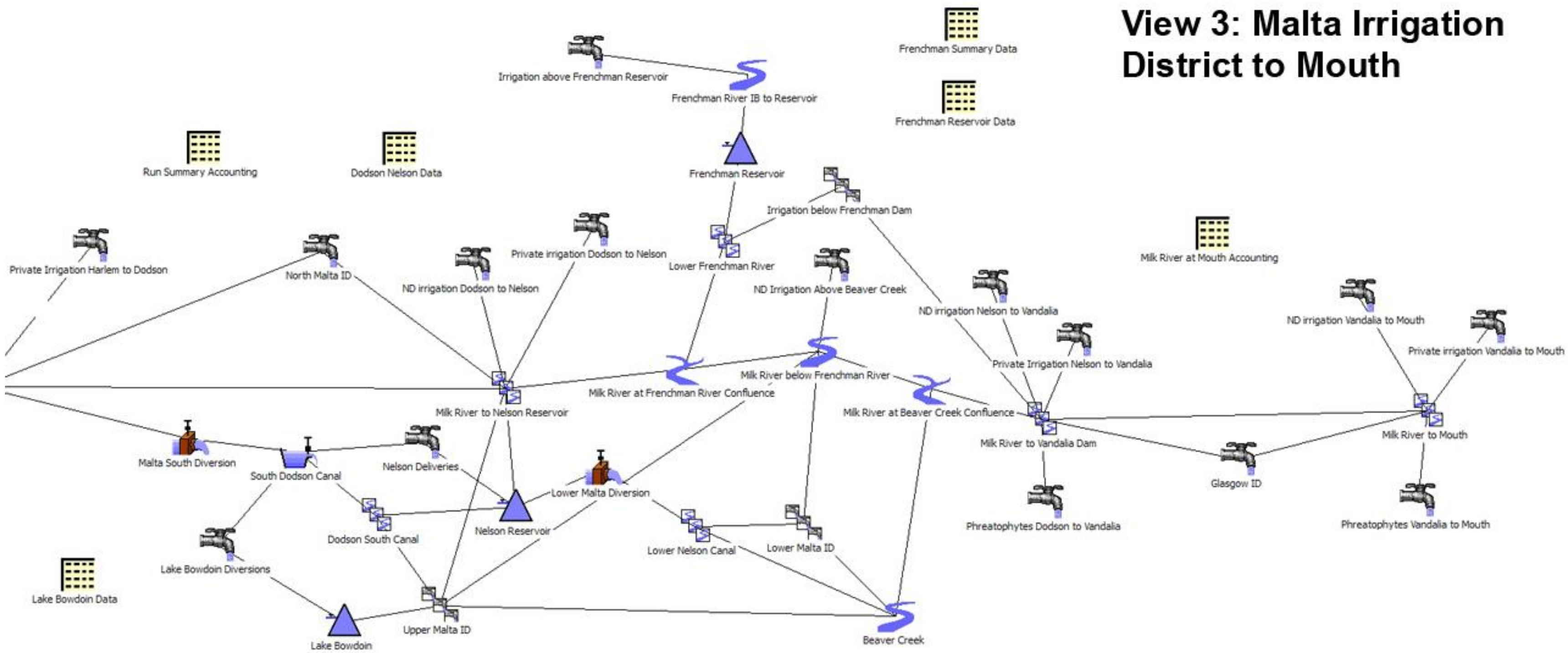

River System Model Key
River Reach
Storage Reservoir
Water User
River Confluence
Canal Diversion
Aggregate Water User
Aggregate River Reach
Canal
Data Object
Stream Gage
Potential Hydropower

View 1:
St. Mary River and Milk River to Eastern Crossing



View 2:
Fresno Reservoir to Dodson Diversion Dam




View 3: Malta Irrigation District to Mouth
Irrigation above Frenchman Reservoir
Frenchman River IB to Reservoir
Frenchman Summary Data
Frenchman Reservoir Data
Run Summary Accounting
Dodson Nelson Data
Frenchman Reservoir
Irrigation below Frenchman Dam
Private Irrigation Harlem to Dodson
North Malta ID
ND irrigation Dodson to Nelson
Private irrigation Dodson to Nelson
Lower Frenchman River
ND Irrigation Above Beaver Creek
ND irrigation Nelson to Vandalia
Milk River at Mouth Accounting
ND irrigation Vandalia to Mouth
Private irrigation Vandalia to Mouth
Private Irrigation Nelson to Vandalia
Milk River below Frenchman River
Milk River at Frenchman River Confluence
Milk River to Nelson Reservoir
Milk River at Beaver Creek Confluence
Milk River to Vandalia Dam
Milk River to Mouth
Malta South Diversion
South Dodson Canal
Nelson Deliveries
Lower Malta Diversion
Glasgow ID
Nelson Reservoir
Dodson South Canal
Lower Nelson Canal
Lower Malta ID
Phreatophytes Dodson to Vandalia
Phreatophytes Vandalia to Mouth
Lake Bowdoin Diversions
Lake Bowdoin Data
Lake Bowdoin
Upper Malta ID
Beaver Creek

Appendix B
Hydros Consulting: Model Calibration Documentation

Memorandum: Historical Model Calibration

To: Larry Dolan, State of Montana DNRC
From: Steve Setzer, Hydros Consulting Inc.
Subject: Summary of Model Calibration Results
Date: February 24, 2012

Hydros completed an evaluation of the RiverWare model of the Milk – St. Mary River system which was developed by the State of Montana DNRC. The objective of this initial evaluation was to quantify and improve the model's ability to replicate historical river flows. We focused on the physical calibration parameters including irrigation efficiencies, surface and groundwater return flows, phreatophyte losses, etc.

In order to eliminate the effects of the operating rules on river flows, the model was modified to use historical data for the following locations:

- Fresno Outflow/Release
- St. Mary Canal Diversion
- Ft. Belknap ID Diversion, Paradise Valley ID Diversion, Harlem ID Diversion, Ft. Belknap Reservation Diversion, Glasgow ID Diversion
- South Malta Canal Diversions

Historical diversion data for the non-district and private irrigators is not available. Therefore, the model estimates the diversion at these locations based on irrigated acreage, crop requirements, efficiencies, and estimated incidental losses. Naturalized inflows are available for all gaged headwaters in the St. Mary and upper Milk River watersheds, and depleted tributary inflows are used for locations downstream of Fresno Reservoir. These were already imported to the model and were not modified for the calibration study. The model was simulated for the period-of-record (1959 to 2009); however, the calibration analysis was limited to the years 1989 to 2009 because these were the only years for which historical irrigation district diversions were available.

The model results were compared with the historical data at the following gage locations:

- Milk River at Eastern Crossing
- Milk River at Harlem
- Milk River at Dodson
- Milk River at Juneberg
- Milk River at Nashua (mouth)

Model results were also visually compared to historic measured diversions and to historic measured surface return flows for the Paradise Valley and Glasgow Irrigation Districts.

A sensitivity analysis was performed to identify the calibration parameters to which the model is most sensitive. Phreatophyte and evaporative losses along the main channel were not significant compared to the total flow at the gages and the model appears to be relatively insensitive to changes in these data. The model appears to be most sensitive to changes in the irrigation district diversions and return flows. As such, we focused our calibration efforts on these areas.

The model results at the Milk River Eastern Crossing compare very well with the historical data (see Table 1 below). This portion of the model is considered calibrated. The majority of the calibration effort focused on the lower Milk River.

Since the goal of the calibration process was to ensure that the model is properly estimating river depletions, it was not necessary to replicate the historical river flows on a daily basis. Additionally, historical data is unavailable at the Harlem and Dodson gages for the months of November through February. As such, the calibration results are based on the total irrigation season volumes for the Harlem and Dodson gages, and total monthly volumes for the Juneberg and Nashua gages.

At each gage we determined the coefficient of determination (R^2), plotted the modeled vs. historical results, and computed a mass balance difference between modeled and historical data. The results are shown in the figures below. The "Baseline Calibration" scenario is the model simulation with historical input data, but with no modifications to the calibration parameters. As shown in Table 1, the modeled flows at Harlem and Dodson gages are greater than historical, implying that the model needed increased depletions in this reach of the river. We accomplished this by reducing the groundwater return flows by 30% for all irrigation diversions between Fresno and Dodson including the irrigation districts, contract pumpers, and private irrigators (in the model, groundwater return flows are the portion of diverted water applied to the fields that enters the alluvial aquifer and returns to the river). The model results based on the reduced groundwater return flows are given in the table and figures below. This shows a better mass balance at the Harlem and Dodson gages.

Overall the model appears to be well calibrated, properly estimates river depletions, and is able to replicate the historical conditions at the gage locations. The R^2 values are acceptable and the mass balance results are within the accuracy level of the gages (USGS reports 5-10% accuracy). Nashua Gage appears to be an exception. However, it is believed that this discrepancy is a result of higher ungaged tributary inflows that are not incorporated into the model. There are several high flow events that the model significantly underestimates. When these are removed from the mass balance calculation, the difference between modeled and historical flows at the Nashua gage improves from -25% to -5%.

Improvements could be made to the model as more irrigation diversion and return flow data becomes available for use in the calibration process. A better understanding of surface-water and groundwater exchanges and losses in the Milk River Valley would also allow for a better calibration.

Table 1: Calibration Results

	Baseline Calibration	Reduced GW Return Flows
Eastern Crossing R2 (monthly volume 1989-2009)	0.99	N/A
Eastern Crossing Mass Balance % Diff	-3%	N/A
Harlem Gage R^2 (total irrigation season volume)	0.97	0.97
Harlem Mass Balance % Diff	11%	5%
Dodson Gage R^2 (total irrigation season volume)	0.89	0.89
Dodson Mass Balance % Diff	17%	5%
Juneberg Gage R^2 (monthly volume)	0.82	0.83
Juneberg Mass Balance % Diff	0.3%	-6.5%
Nashua Gage R^2 (monthly volume)	0.75	0.75
Nashua Mass Balance % Diff	-20%	-25%
Nashua Mass Balance % Diff (Remove High Flow Months)	-5%	-5%

Note: The mass balance % difference is calculated as: (total modeled volume – total historical volume) / total historical volume

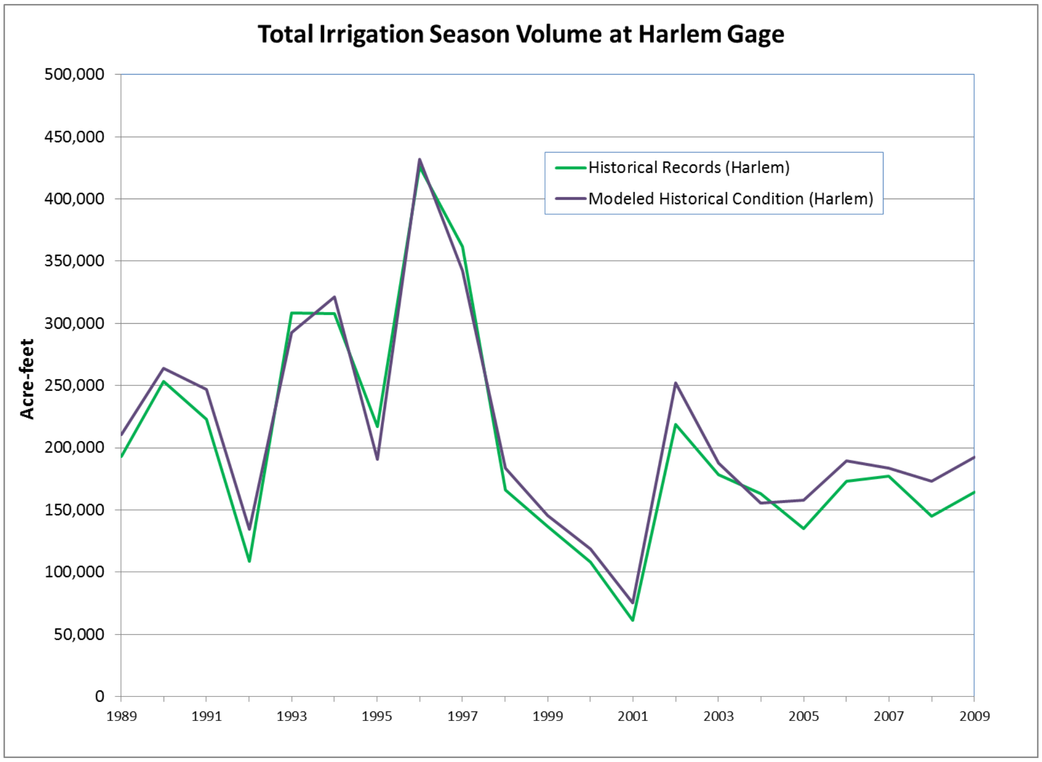


Figure 4: Harlem Gage - Reduced GW Returns

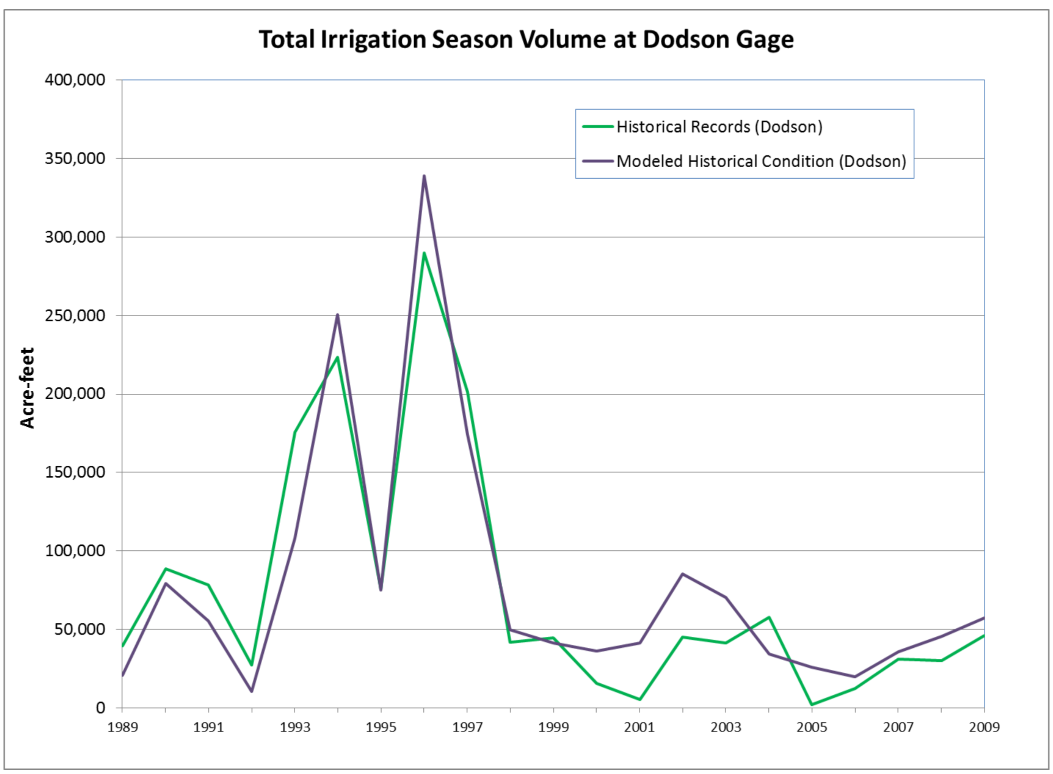


Figure 5: Dodson Gage - Reduced GW Returns

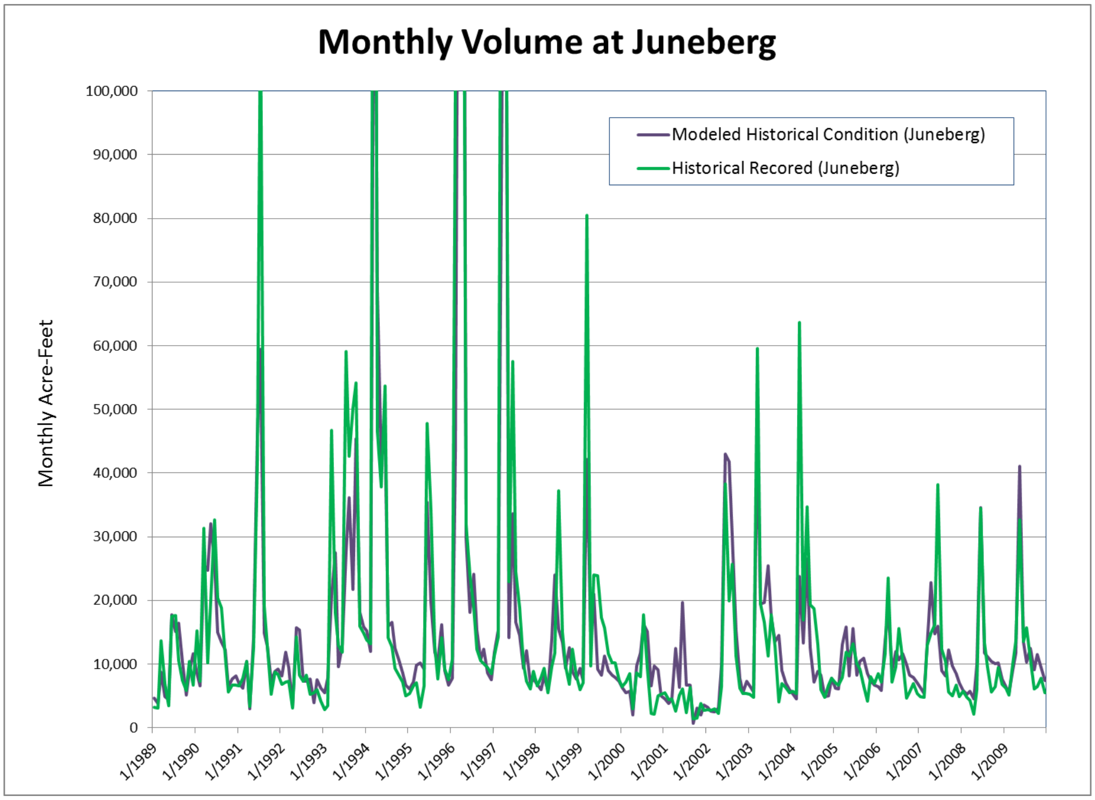


Figure 6: Juneberg Gage - Reduced GW Returns

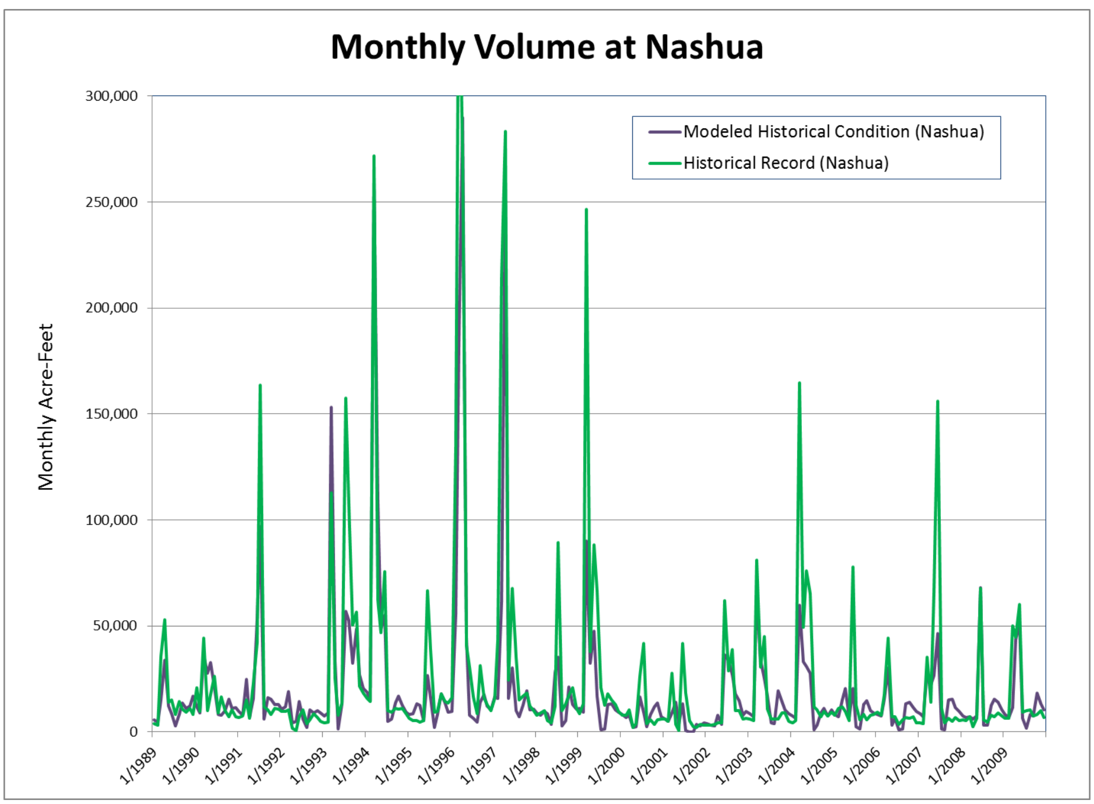


Figure 7: Nashua Gage - Reduced GW Returns

Appendix C
Hydros Consulting Milk: St. Mary RiverWare Model Scenario Creation

Memorandum: Milk – St. Mary RiverWare Model
Scenario Creation

To: Larry Dolan, State of Montana DNRC
From: Steve Setzer, Hydros Consulting Inc.
Subject: Creating Scenario Models from the Baseline Scenario
Date: March 27, 2012

The U.S. Bureau of Reclamation (Reclamation) and the Montana Department of Natural Resources and Conservation (DNRC) conducted a Basin Study of the St. Mary River and Milk River basins in north-central Montana. The purpose was to develop a river system model of the St. Mary River-Milk River watershed to assess the ability of the existing infrastructure to meet future water needs under a changing climate; to evaluate alternative ways of reducing future water shortages; and for future planning and reserved water rights settlement needs. The basins examined in this study supply water to Reclamation's Milk River Project, municipalities, Indian reservations, and to fish, wildlife, and recreational uses.

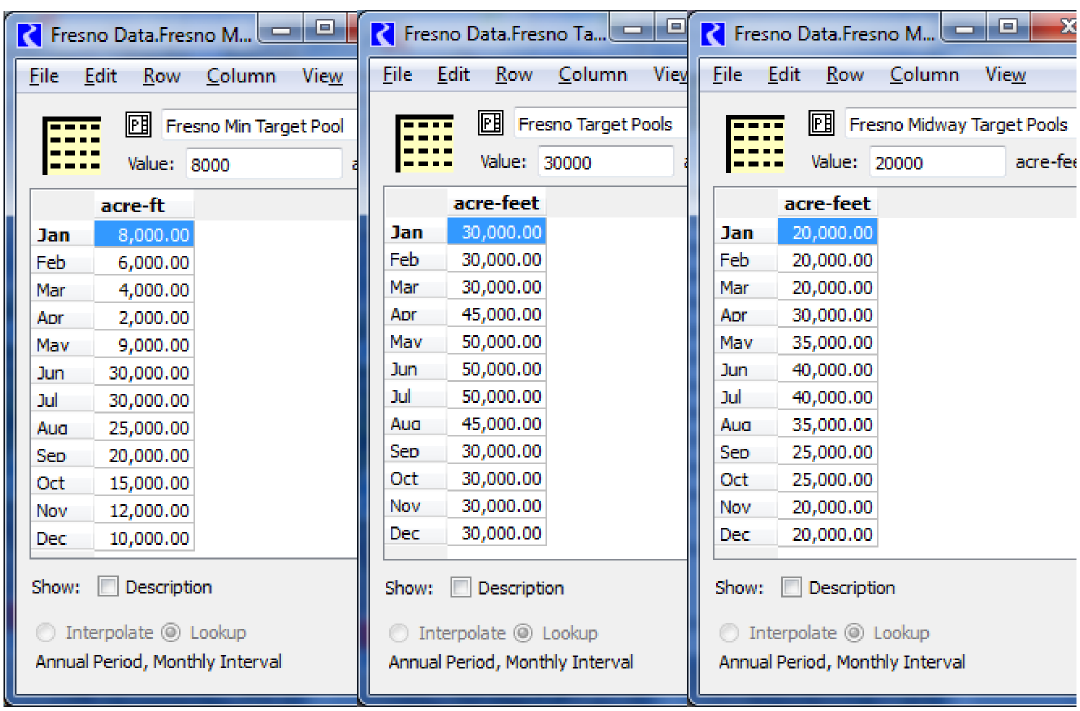
The river system model was developed with RiverWare, a general reservoir and river basin modeling tool developed by CADSWES at the University of Colorado at Boulder. The RiverWare model of the St. Mary River – Milk River system (the Model) simulates operations of the upper St. Mary River system to meet the goals of diverting water through the St. Mary Canal for water needs of the Milk River Project, while meeting international apportionment requirements with Canada. The St. Mary River is linked to the Milk River in the model through the St. Mary Canal. Operations of the Milk River system in the model are simulated to distribute the imported St. Mary River water and Milk River natural flow to various irrigation districts, contract users, and the Tribes of the Fort Belknap Reservation using the reservoirs and irrigation canals on the Milk River. The Model was used to simulate the operations of the St. Mary River-Milk River system under baseline conditions and for five future climate scenarios.

Hydros Consulting Inc. (Hydros) is working as a contractor for the DNRC under Contract Number WM-HC-123. As part of the work performed under this contract, Hydros has assisted the DNRC and Reclamation with the final development and calibration of the model, and simulations of alternatives under the historic climate and the five future climate scenarios. This memorandum explains how to run the model for the alternatives evaluated in the St. Mary and Milk River Basin Study Report. Following is a brief description of each of the alternatives followed by the steps required to create the alternative from the core baseline model (the model with existing operational criteria and infrastructure).

***Scenario:* Increase Fresno Reservoir Storage**

This scenario explores the option of increasing the maximum pool elevation, or the spillway crest, on Fresno Reservoir by 5 feet. This scenario assumes that the extra storage is used to meet downstream irrigation demands on the Milk River.

1. Increase all pool elevation values in the Unregulated Spill Table slot on the Fresno Reservoir object by 5 feet. As a result, the spillway crest is set at 80 ft (which corresponds to an actual crest elevation of 2,580 above MSL).
2. Change the Fresno Max Pool slot on the Fresno Data object to 90,000 acre-feet. This is the storage associated with the new maximum pool elevation (spillway crest, 80 ft).
3. Change the Fresno Spring Target slot on the Fresno Data object to 60,000 acre-feet.
4. Change the October Target slot on the Fresno Data object to 70,000 acre-feet, or 10,000 acre-feet higher than the Fresno Spring Target.
5. The Fresno Min Target Pool, Fresno Target Pools, and Fresno Midway Target Pools periodic slots need to be adjusted via trial-and-error to properly operate Fresno Reservoir. In order to fully maximize the increased storage to meet irrigation demands, the values in these slots should remain as close to possible as the values used in the baseline scenario. The following values were used in the study:



6. Add a new row to the Elevation Volume Table slot on the Fresno Reservoir object to incorporate the new max pool elevation of 80 feet with the corresponding storage value.

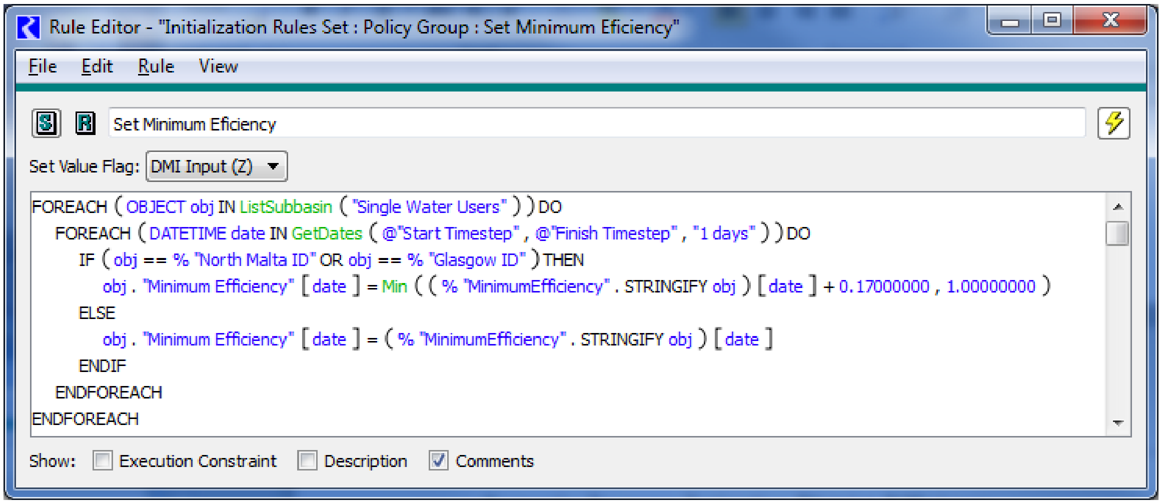
Adjust adjacent values to "smooth" the elevation-volume curve in this area. The following values were used for this study:

Pool Elevation ft	Storage acre-feet
18.00	-100,000.00
18.00	0.00
22.00	66.75
25.00	133.51
30.00	299.05
34.00	1,338.39
38.00	3,420.41
42.00	6,323.49
46.00	9,897.44
50.00	14,116.88
54.00	18,979.16
58.00	24,506.29
62.00	30,804.41
66.00	38,176.59
70.00	47,411.18
74.00	58,811.22
75.00	62,000.00
78.00	80,000.00
80.00	90,000.00
82.00	96,000.00
86.00	107,947.29
90.00	129,255.45

Scenario: **Canal and On-Farm Water Use Efficiency Improvements**

This scenario explores increased efficiency (canal and on-farm) for several irrigation districts on the Milk River. These include Fort Belknap ID, Paradise Valley ID, Harlem ID, North Malta ID, Upper Malta ID, Lower Malta ID, and Glasgow ID.

1. The Minimum Efficiency values must be increased by 0.17 for each of the irrigation districts listed above. This is accomplished through the Set Minimum Efficiency initialization rule (accessed under Policy – Initialization Rules Set in the RiverWare main menu). There is a line of code for each of the irrigation districts that sets the Minimum Efficiency for each of the sub-elements. These lines were changed so that 0.17 was added to each efficiency value referenced by the rule on the Minimum Efficiency data object. North Malta ID and Glasgow ID are exceptions, since they do not have sub elements and are not set explicitly by the initialization rule. See the logic below for these irrigation districts:



2. The values in the Max Efficiency slots on each of the irrigation districts listed above were also increased by 0.17. This was done manually for each object and each sub-object.

Scenario: **Expanded Frenchman Reservoir**

This scenario explores increasing the available storage at Frenchman Reservoir. The extra storage is used to more reliably meet the irrigation demands on the Frenchman River below the dam. Also, the extra storage may be used to mitigate shortages on the Milk River below the confluence with the Frenchman River.

1. Change the Current Max Storage slot on the Frenchman Reservoir Data object to 50,000 acre-feet.
2. Change the Release Extra for Milk Diverters On Off Switch on the Frenchman Reservoir Data object to 1.0. This triggers the rules to release stored water from Frenchman Reservoir to meet shortages on the Milk River.
3. Set the Min Storage for Extra Milk Release slot on the Frenchman Reservoir Data object to 7,500 acre-feet. This is the threshold value above which Frenchman Reservoir will release stored water to mitigate shortages on the Milk River.

Scenario: **New Storage on Milk River in Alberta**

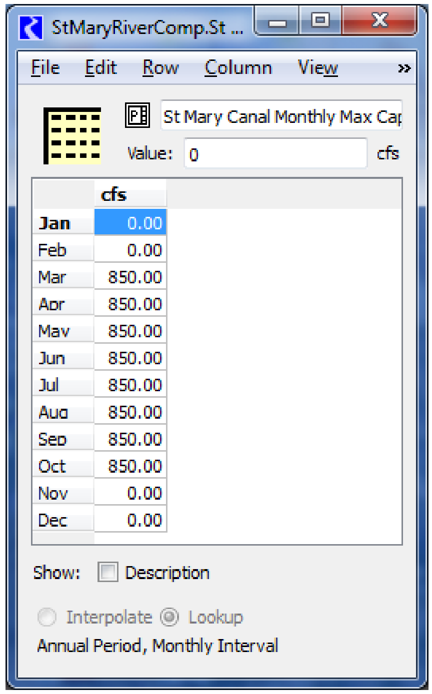
This scenario explores the proposed Alberta Forks Reservoir and its effects on the Milk River. The Alberta Forks Reservoir may store Canada's share of the Milk River natural flow. It operates to meet the Canadian Irrigation demands and ensures that the US share of Milk River natural flow plus the St. Mary Canal water reaches the Eastern Crossing.

1. Set the Alberta Reservoir On Off Switch on the Alberta Storage Reservoir data object to 1.0. This enables the operation of the proposed Alberta Forks Reservoir.
2. Set the Override Canadian Irrigated Area On Off Switch on the Canadian Irrigation Data object to 1.0. This allows the model operator to override the irrigated area imported through the DMIs into the AnnualAreas data object.
3. Specify the irrigated area associated with the Canadian Irrigation object by setting the appropriate value in the Canadian Irrigated Area when Overridden slot on the Canadian Irrigation Data object. A value of 26,000 acres was used for the study.
4. Disable the Annual Accounting (which in the baseline model is used to simulate the Letter of Intent Accounting for the St. Mary River Basin) by setting the Annual Balancing slot on the Annual Accounting object to 0.0.
5. Disable the Letter of Intent Accounting by setting the Milk River LOI On Off Switch on the Milk River in Alberta Accounting object to 0.0.

***Scenario:* Rehabilitate St. Mary Canal for Increased Capacity**

This scenario models the St. Mary Canal with the capacity increased to 850 cfs. The Sherburne Reservoir operating policy is adjusted to meet a September 15 target level so that Sherburne does not draw down too early in the summer with the expanded canal capacity.

1. On the Sherburne Data object, set the Enable Sept 15 Target Switch to 1.0. The target level used for the study is 8,000 acre-ft. This is set on the September 15 Target slot on the Sherburne Data object.
2. Change the CanalMin3 slot on the StMaryRiverComp object to 600 cfs.
3. Increase the St. Mary Canal capacity to 850 cfs by doing the following:
    a. Change the StMCanalCapacity slot on the StMaryRiverComp object to 850 cfs.
    b. Change the spring ramp rates on the StMaryRiverComp object as follows:
        i. CanalMaxWeek1: 250 cfs
        ii. CanalMaxWeek2: 450 cfs
        iii. CanalMaxWeek3: 650 cfs
        iv. CanalMaxWeek4: 850 cfs
    c. Change the values on the St Mary Canal Monthly Max Capacities slot on the StMaryRiverComp object as follows:



d. Change the Max Diversion slot on the StMaryCanal diversion object to 850 cfs.

Appendix D

Hydros Consulting: Model and Ruleset Enhancements to Finalize Baseline Scenario and Develop Future Climate Scenarios

Memorandum: Model and Ruleset Enhancements to Finalize Baseline Scenario and Develop Future Climate Scenarios

To: Larry Dolan, State of Montana DNRC
From: Steve Setzer, Hydros Consulting Inc.
Subject: Model and Ruleset Enhancements to Baseline Scenario and Future Climate Scenarios
Date: April 18, 2012

The U.S. Bureau of Reclamation (Reclamation) and the Montana Department of Natural Resources and Conservation (DNRC) conducted a Basin Study of the St. Mary River and Milk River basins in north-central Montana. The purpose was to develop a river system model of the St. Mary River-Milk River watershed to assess the ability of the existing infrastructure to meet future water needs under a changing climate; to evaluate alternative ways of reducing future water shortages; and for future planning and reserved water rights settlement needs. The basins examined in this study supply water to Reclamation's Milk River Project, municipalities, Indian reservations, and to fish, wildlife, and recreational uses.

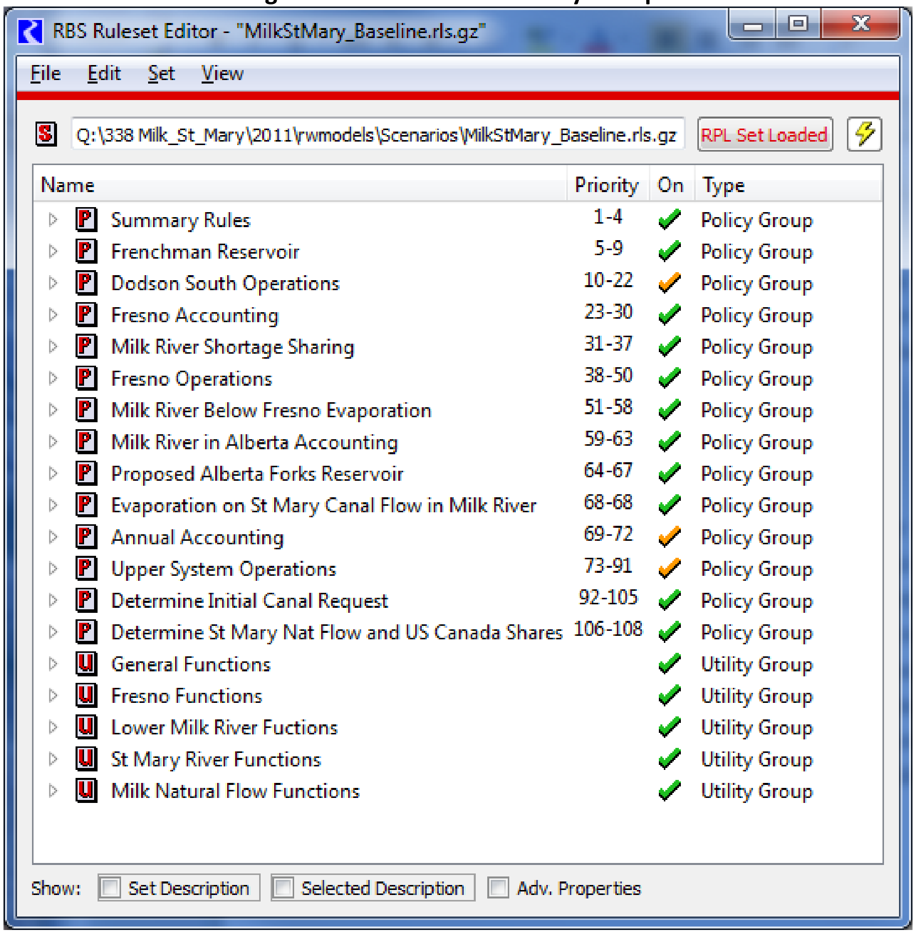
The river system model was developed with RiverWare, a general reservoir and river basin modeling tool developed by CADSWES at the University of Colorado at Boulder. The RiverWare model of the St. Mary River – Milk River system (the model) simulates operations of the upper St. Mary River system to meet the goals of diverting water through the St. Mary Canal for water needs of the Milk River Project, while meeting international apportionment requirements with Canada. The St. Mary River is linked to the Milk River in the model through the St. Mary Canal. Operations of the Milk River system in the model are simulated to distribute the imported St. Mary River water and Milk River natural flow to various irrigation districts, contract users, and the Tribes of the Fort Belknap Reservation using the reservoirs and irrigation canals on the Milk River. The model was used to simulate the operations of the St. Mary River-Milk River system under baseline conditions and for five future climate scenarios.

Hydros Consulting Inc. (Hydros) is working as a contractor for the DNRC under Contract Number WM-HC-123. As part of the work performed under this contract, Hydros has assisted the DNRC and Reclamation with the final development and calibration of the model, and the simulation of alternatives under the historic climate and the five future climate scenarios. This memorandum describes the improvements made to the model and ruleset as part of the modeling tasks described in the contract. The model improvements discussed in this document begin with the version of the model after the completion of the model calibration work. Changes to the model as part of the historical calibration are described in a separate document titled *Memorandum: Historical Model Calibration*.

Ruleset Policy Group Order

The order of policy groups within the ruleset was changed so that upstream rule groups execute before downstream rule groups. This improves model/ruleset efficiency by reducing unnecessary rule iteration within each timestep. Execution constraints were added to all rules so that each rule executes only once per timestep. Rules in the *Dodson South Operations* group were excluded as these have not yet been improved for efficiency. Also, the rules in the *Milk River Shortage Sharing* group did not receive execution constraints as these rules need to be allowed to iterate to reach a solution. The addition of execution constraints improves efficiency, speeds up simulation time, and makes it easier to add/modify rules in the future. However, because of this restriction on rule execution, the positioning of rules and policy groups within the ruleset is now critical. The following screen capture shows the new positioning of policy groups within the ruleset. Rules that were no longer being used and had been disabled were deleted from the ruleset.

Figure 12: New Order of Policy Groups

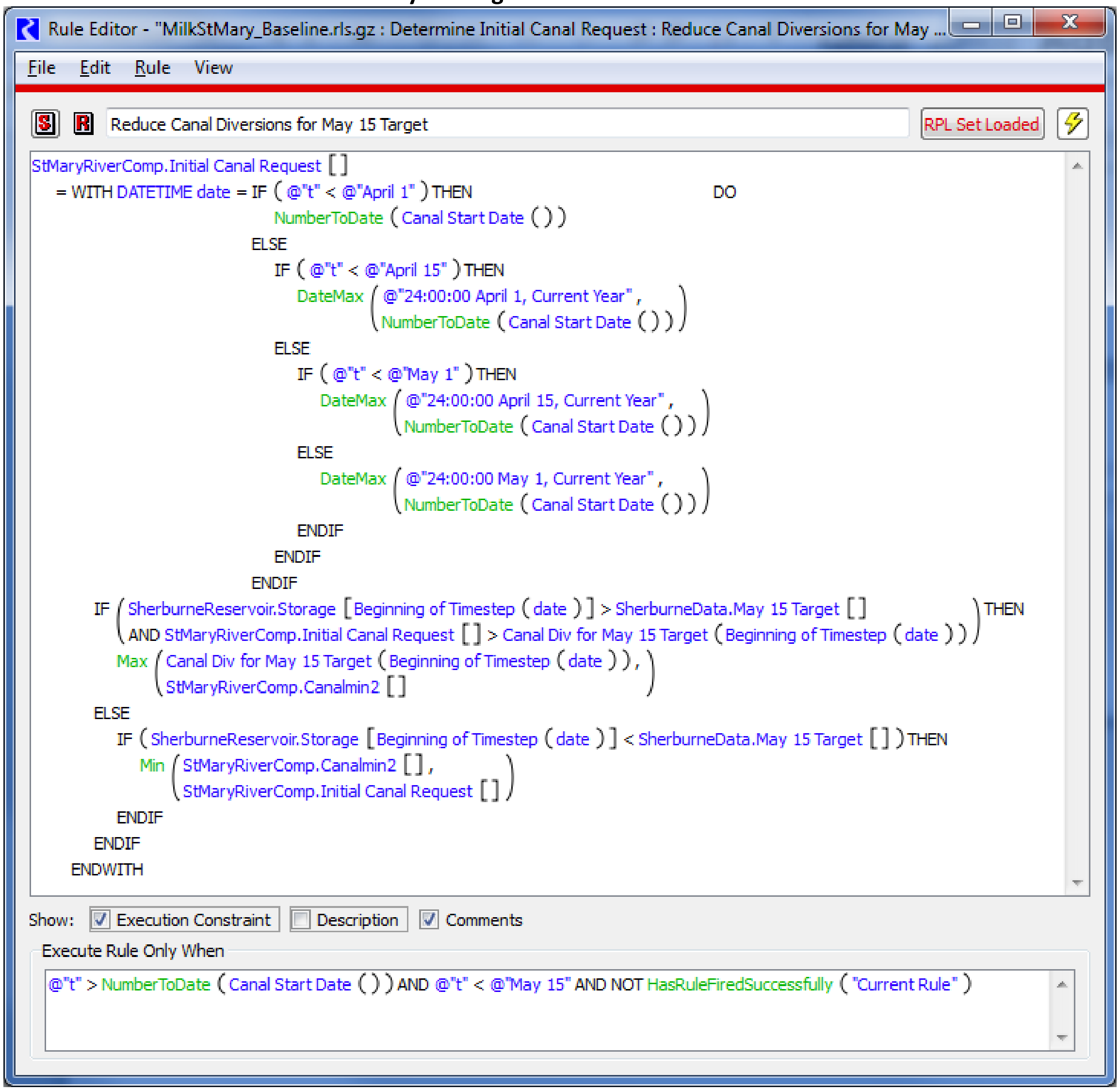


Sherburne Reservoir and St. Mary Canal Rules

Two new rules were added to the *Determine Initial Canal Request* policy group: *Reduce Canal Diversions for May 15 Target* and *Reduce Canal Diversions for September 15 Target*.

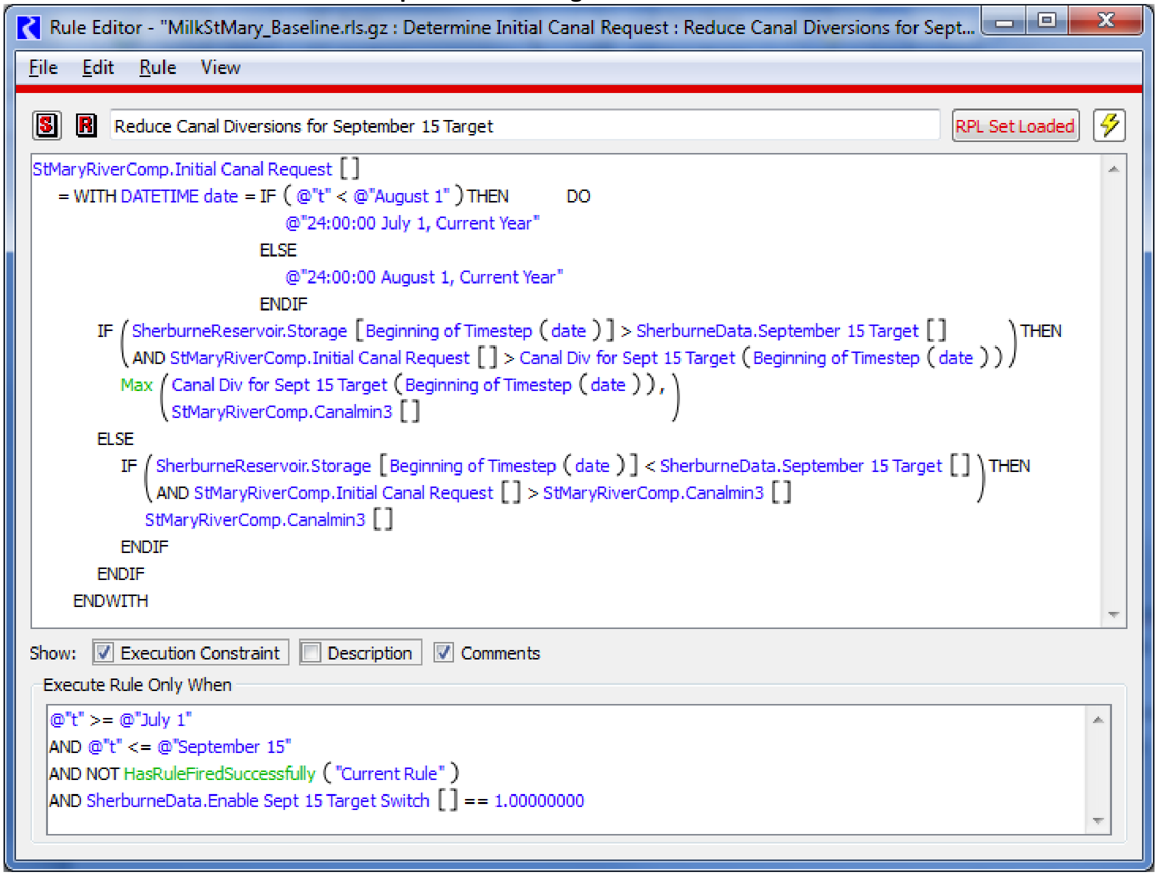
The *Reduce Canal Diversions for May 15 Target* rule is show in Figure 13 below. The purpose this rule is to limit the situation where Sherburne Reservoir is drawn down below the May 15 target value prior to May 15 due to high canal diversion rates early in the season. The rule estimates the daily average diversion through the St. Mary Canal that would allow Sherburne Reservoir to hit the May 15 Target value on May 15. If the initial canal request computed by previous rules is greater than this value, the rule reduces the initial canal request to the value estimated above without going below the value specified in the Canal Min 2 slot. The rule first computes its estimate of the average daily canal diversion on the canal start date and then re-computes the estimate on April 1, April 15, and May 1.

Figure 13: Reduce Canal Diversions for May 15 Target



The *Reduce Canal Diversions for September 15 Target* rule is show in Figure 14 below. The purpose this rule is to limit the situation where Sherburne Reservoir is drawn down below the September 15 target level prior to September 15 due to high canal diversion rates. This rule is active only when the Enable Sept 15 Target Switch is set to one (this rule and the associated switch were added for the Rehabilitate St. Mary Canal for Increased Capacity Alternative). The rule estimates the daily average diversion through the St. Mary Canal that would allow Sherburne Reservoir to hit the September 15 Target value on September 15. If the initial canal request computed by previous rules is greater than this value, the rule reduces the initial canal request to the value estimated above without going below the value in the Canal Min 3 slot. The rule first computes its estimate on July 1 and re-computes its estimate on August 1.

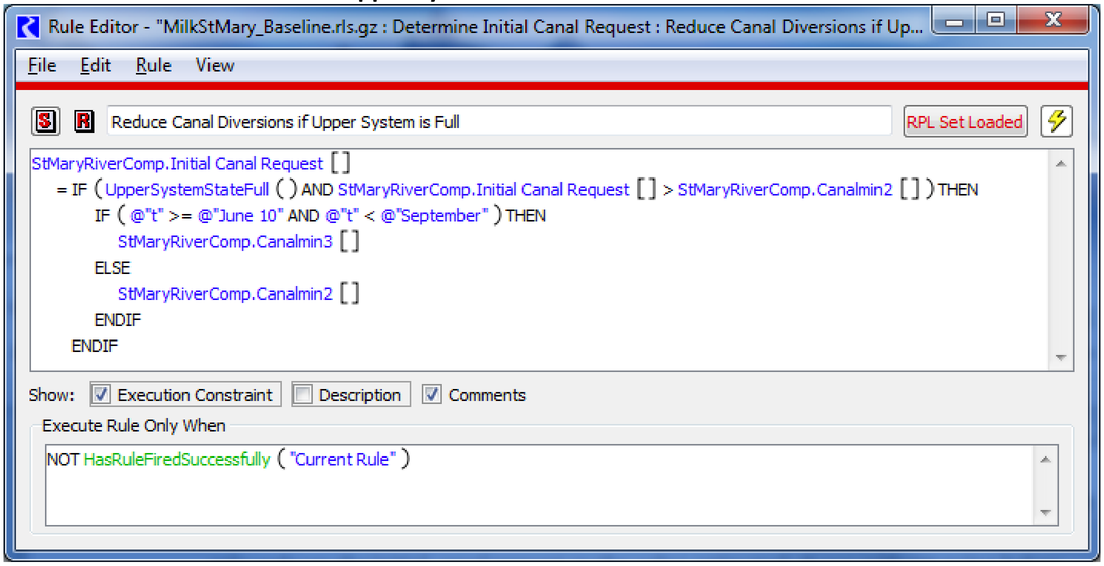
Figure 14: Reduce Canal Diversion for September 15 Target



Changes to Existing Rules:

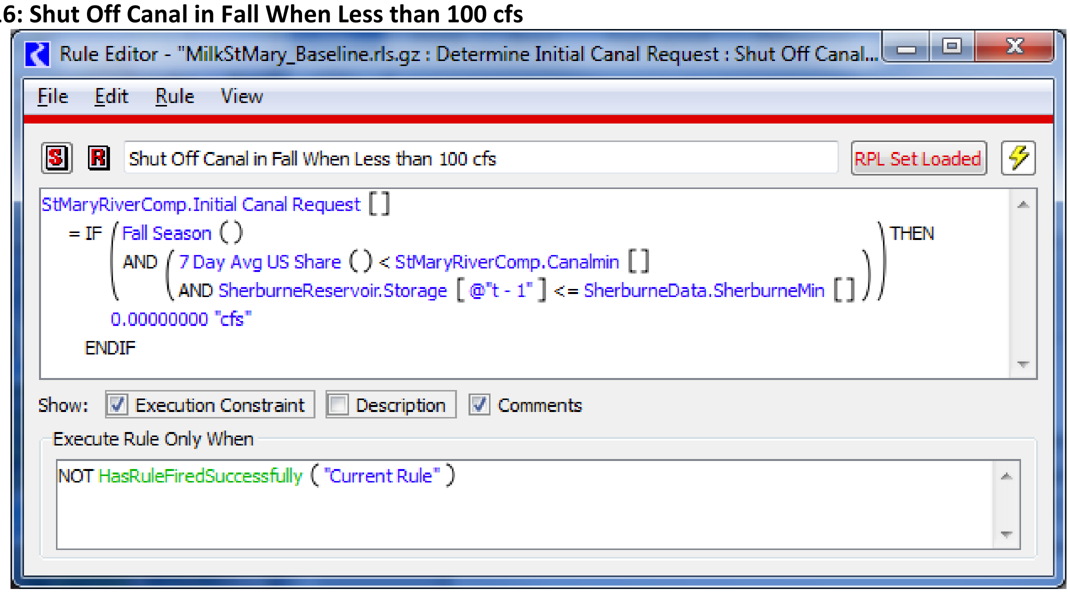
The *Reduce Canal Diversions if Upper System is Full* rule was modified to limit the reduction in canal diversion after June 10. Before June 10, if the upper system is full, the St. Mary canal request is reduced to Canal Min 2 (currently 350 cfs). After June 10, if the upper system is full, the canal request is reduced to Canal Min 3 (currently 550 cfs).

Figure 15: Reduce Canal Diversions if Upper System is Full



Logic in the *Shut Off Canal in Fall When Less than 100 cfs* rule was updated to use a 7-day rolling average of the US Share of the St. Mary natural flow. Previously, this rule shut off the canal in fall as soon as the US Share dropped below 100 cfs and Sherburne Reservoir was at or below the minimum. However, in some years there was a single day where the US Share was just below 100 cfs followed by several more weeks where the US Share was greater than 100 cfs. A 7-day average is now used to avoid shutting down the canal in a situation like this.

Figure 16: Shut Off Canal in Fall When Less than 100 cfs



Miscellaneous St. Mary Canal Changes:

The value for Canal Max Week 1, which is the week one spring ramp up rate, was increased from 50 cfs to 200 cfs to be more consistent with historical operations.

Evaporation of St. Mary Canal Water in the Milk River

The RiverWare objects between the Proposed Alberta Forks Reservoir and the Milk River at Eastern Crossing were re-organized for clarity and to simplify the operations of Alberta Forks Reservoir. The local inflow and incremental evaporation were split into two separate objects as shown in Figure 17 below: Milk River in Alberta Local Inflow and Evap of St. Mary Canal Water. The Milk River in Alberta Time Lag object was moved below the Canadian Irrigation diversion point. This facilitates the development of operational rules for Alberta Forks Reservoir to meet the Canadian Irrigation demands.

As shown in

Figure 18, the rule that computes evaporation of water from the St. Mary Canal, previously titled *Incremental Evaporation*, was renamed *Evaporation on St. Mary Canal Flow in Milk River* and was moved from the Milk River Evaporation group into a separate policy group that executes before the Proposed Alberta Forks Reservoir rules. The logic of the Evaporation on St. Mary Canal Flow in Milk rule was simplified after it was realized that the previous equations contained redundancies. The new logic shown in Figure 19 results in the same evaporation values as the previous version of the rule but is more concise and is easier to understand.

Figure 17: New Objects Between Alberta Forks and Eastern Crossing

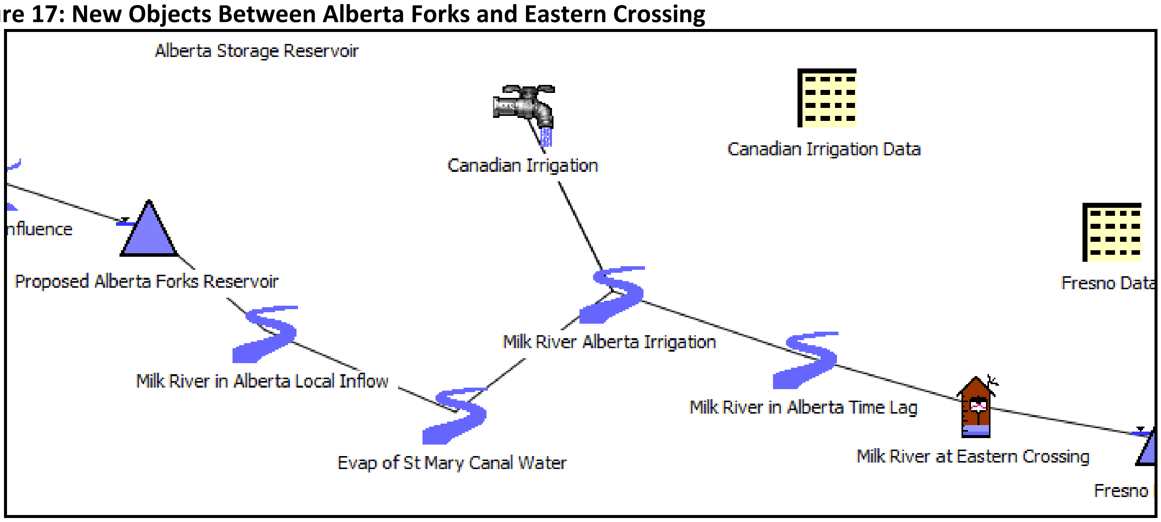


Figure 18: Evaporation on St Mary Canal Flow in Milk River

Name	Priority	On	Type
Milk River Below Fresno Evaporation	51-58	✔	Policy Group
Milk River in Alberta Accounting	59-63	✔	Policy Group
Proposed Alberta Forks Reservoir	64-67	✔	Policy Group
Evaporation on St Mary Canal Flow in Milk River		✔	Policy Group
Evaporation on St. Mary Canal Flow in Milk River	68	✔	Rule
Annual Accounting	69-72	✔	Policy Group
Upper System Operations	73-91	✔	Policy Group

Figure 19: Evaporation on St. Mary Canal Flow in Milk River

```
Evaporation on St. Mary Canal Flow in Milk River                RPL Set Loaded
# This rule must execute before the Alberta rules.  In other words,
# it must be lower priority.
Evap of St Mary Canal Water.Variable GainLoss [ ]
   = IF ( 0.18700000 * NorthMilkRiver.Inflow2 [ ] * - ( MilkDataAndComputations.Channel Evaporation [ ] ) > 0.00000000 "cfs" ) THEN
        0.00000000 "cfs"
     ELSE
        0.18700000 * NorthMilkRiver.Inflow2 [ ] * - ( MilkDataAndComputations.Channel Evaporation [ ] )
     ENDIF
```

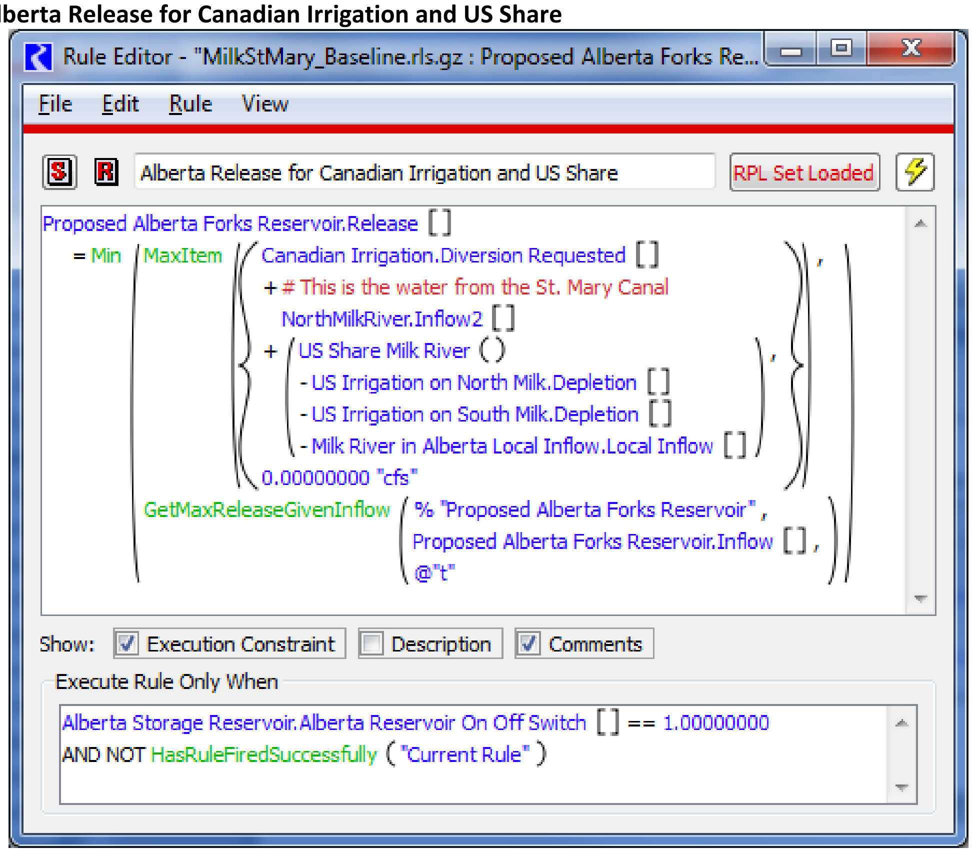
Proposed Alberta Forks Reservoir

New rules were developed to operate the Proposed Alberta Fork Reservoir. The function of this reservoir in the model is to store the Canadian Share of Milk River natural flow, meet the Canadian Irrigation demands, and ensure the required flows reach the Eastern Crossing. The model operator enables these rules by setting the Alberta Reservoir On Off Switch to one (1.0) on the Alberta Storage Reservoir data object. The rules previous were deleted and replaced by the new rules described below. The exception is the *Minimum Release from Alberta Reservoir* rule which has remained unchanged and ensures that the Alberta Forks Reservoir is releasing at least the minimum flow. This rule now executes last in the *Proposed Alberta Forks Reservoir* policy group.

The first rule that executes in this group is the *Initialize Alberta Set Outflow to Inflow* rule. This rule sets the Alberta Forks Reservoir release to the current inflow value and is active regardless of whether or not the Alberta Reservoir On Off Switch has been activated. In other words, this rule ensures that Alberta Forks Reservoir acts as a pass through object when the reservoir is not enabled in the model.

The *Alberta Release for Canadian Irrigation and US Share* rule is shown in Figure 20 below. This rule ensures that the Canadian Irrigation demands are being met and that the required flows reach the Eastern Crossing. As an automatic consequence of this policy, any portion of the Canada Share of the Milk River natural flow that is not needed for the Canadian Irrigation demand is stored in the reservoir. The required release from Alberta Forks Reservoir is the Canadian Irrigation diversion request, plus St. Mary Canal water, plus the total US Share of the Milk River natural flow minus depletions by U.S. irrigation on the North and South Milk River. This required release is reduced by the amount of local inflow accruing between Alberta Forks Reservoir and the Eastern Crossing as these inflows can be used to meet the US Share required at the Eastern Crossing. The Milk River in Alberta Time Lag occurs below the Canadian Irrigation diversion point, so the rule logic does not need to account for this time lag. Also, since the requirement at the Eastern Crossing for St. Mary Canal water accounts for a reduction due to evaporation, the rule logic needs to pass the total flow from the St. Mary Canal. Evaporation of this water will occur below Alberta Forks Reservoir and the proper amount will reach the Eastern Crossing.

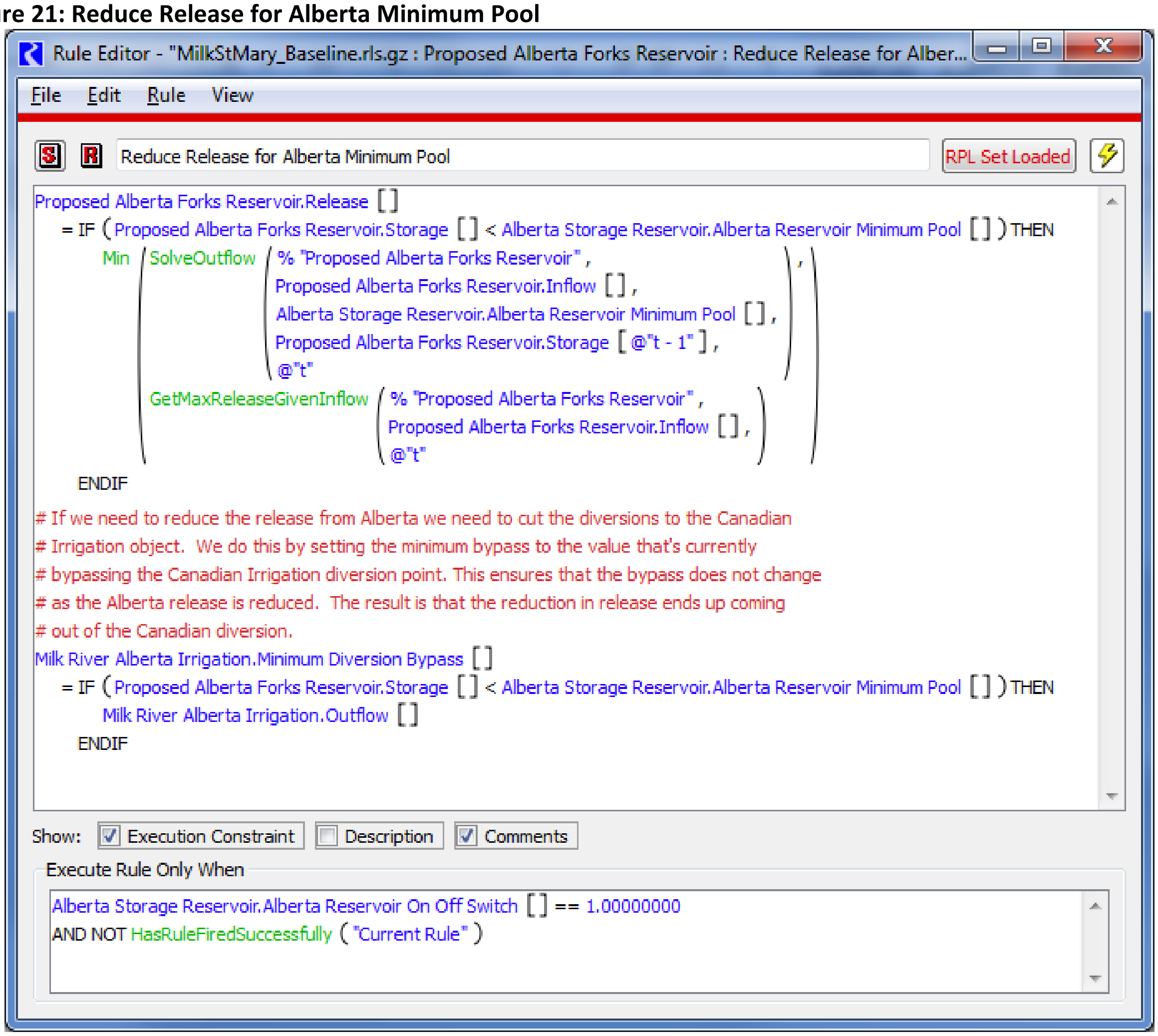
Figure 20: Alberta Release for Canadian Irrigation and US Share



The *Reduce Release for Alberta Minimum Pool* rule reduces deliveries to the Canadian Irrigation object when the Alberta Forks Reservoir reaches the minimum pool. This rule must execute after the *Alberta Release for Canadian Irrigation and US Share* rule so that it may refer to the

Alberta Forks Reservoir storage value and the flow bypassing the Canadian Irrigation object as a result of the release computed by the *Alberta Release for Canadian Irrigation and US Share* rule. If the Alberta Forks Reservoir storage will drop below the minimum pool, the release is cut back to exactly meet/maintain the minimum pool. Any reduction in the release needs to be transferred to the Canadian Irrigation diversion to ensure that the required flow at the Eastern Crossing is maintained. This is accomplished through the second rule assignment which sets the Minimum Diversion Bypass to the flow that was bypassing the Canadian Irrigation object (and reaching the Eastern Crossing) before the reduction in release determined by this rule (i.e. the flow that was bypassing the Canadian Irrigation object and reaching the Eastern Crossing after the *Alberta Release for Canadian Irrigation and US Share* rule had executed). **<u>Note</u>**: when multiple assignments occur within a RiverWare rule, both assignments take place simultaneously at the end of the rule execution. Therefore, a slot assignment made by the first assignment statement will not affect the state of the model or slots referred to by the second assignment statement.

Figure 21: Reduce Release for Alberta Minimum Pool



An override switch was added to the Canadian Irrigation Data object for the “New Storage on Milk River in Alberta Alternative” for the Reclamation Basin Study. When the Override Canadian Irrigation Area On Off Switch is set to one (1.0), the value in the Canadian Irrigated Area when Overridden slot is used for the annual acreage on the Canadian Irrigation object.

Fresno Operations Policy Group

Several improvements were made to the rules in the *Fresno Operations* policy group to streamline performance, improve efficiency, and more accurately reflect real-world operations. These improvements include:

- Deleted unused and/or disabled rules
- Changed the order of execution of all rules and added an execution constraint so that each rule executes once per timestep
- Removed unused slots from the Fresno Data object
- Reduced Fresno storage to account for sedimentation
- Re-designed the fall operations associated with the October target
- Re-designed the logic to cut back releases in the late summer and/or fall if the storage drops below 15,000 acre-ft
- Added logic to the winter release rules to improve the ability to reach the Spring Target value by March 1
- Added two levels of winter releases; 45 cfs for normal operations and 25 cfs for low storage levels (below the Fresno Min Target Pool)
- Increased the value in the Convergence Percentage slot on Fresno Reservoir to 0.0005 to avoid convergence problems and the associated warning messages which occurred in the previous version of the model

Reduced Storage for Sedimentation

The maximum storage for Fresno Reservoir was reduced from 92,880 acre-ft to 62,000 acre-ft to account for reduced storage due to accumulated sediment. Several slots on the Fresno Data object and the Fresno Reservoir object were updated as a result:

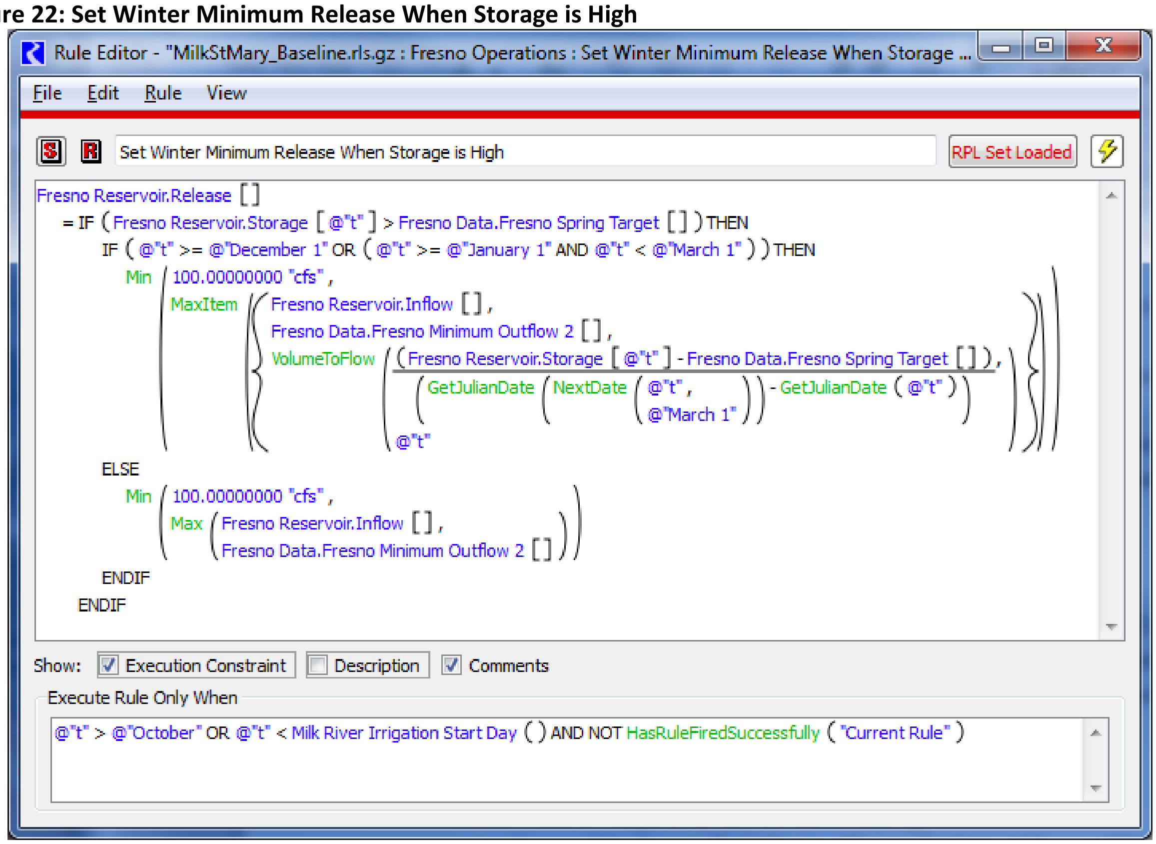
- Fresno Max Storage was set to 62,000 acre-ft
- Fresno Spring Target was set to 32,000 acre-ft
- October Target was set to 42,000 acre-ft
- Fresno Min Target Pool, Fresno Target Pools, and Fresno Midway Target Pools were all adjusted via trial-and-error to tune Fresno operations.

- Each value in the Elevation Volume Table was scaled to 66.7% of the original values so that the storage at 75 ft is 62,000 acre-ft and the storage values for all other pool levels were reduced proportionally.

Winter Releases to Meet Spring Target on March 1

Logic was added to the *Set Winter Minimum Release When Storage is High* rule to draw down Fresno Reservoir to the Spring Target by March 1. However, due to winter operational constraints, the release is limited to the winter maximum release of 100 cfs. Therefore, if winter inflows are high, Fresno Reservoir may be higher than the spring target on March 1. The rule logic is shown in Figure 22 below. At each timestep beginning on December 1, the rule estimates the release required to draw the reservoir down to the spring target. This is a daily average release computed as the difference in storage between the current level and the spring target level divided by the number of days until March 1. Before December 1, this rule passes the inflow if the current storage is greater than the Spring Target. Restrictions are placed such that the daily release will not go below 45 cfs or above 100 cfs.

Figure 22: Set Winter Minimum Release When Storage is High



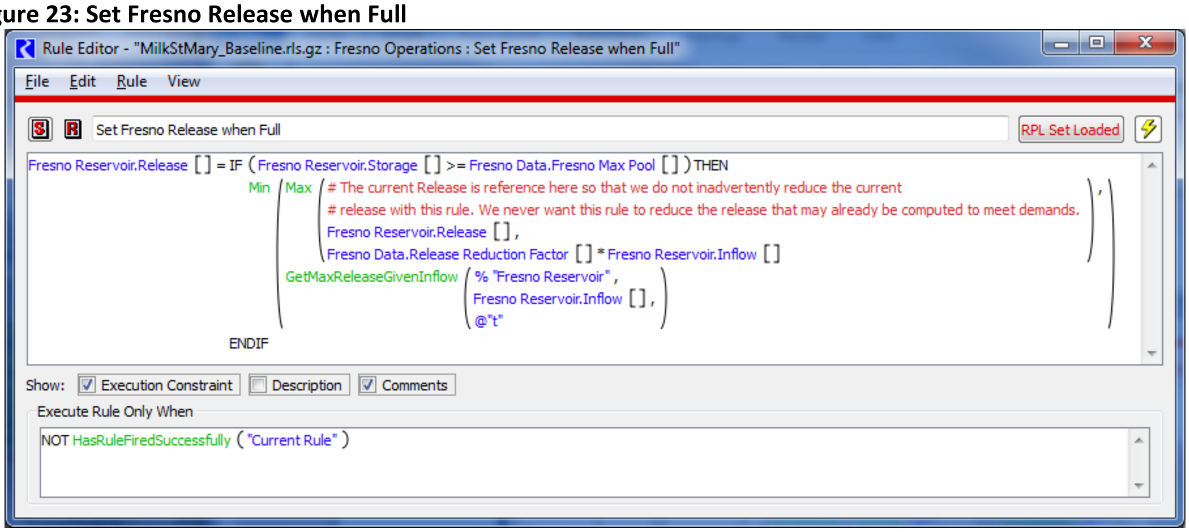
Fresno Winter Flow Function

The *Fresno Winter Flow* function was modified to include two levels of winter releases defined by the Fresno Minimum Outflow 2 and Fresno Minimum Outflow 3 slots on the Fresno Data object. The normal winter flow is 45 cfs (Fresno Minimum Outflow 2). When the storage drops below the Fresno Min Target Pool (periodic slot on the Fresno Data object) the winter release is reduced to 25 cfs (Fresno Minimum Outflow 3). This change was made to better reflect historical operations.

Set Fresno Release When Full

The *Set Fresno Release When Full* rule was modified to fix an error in the logic whereby the release from Fresno was, under certain conditions, being reduced below the level required to meet demands even though Fresno Reservoir was full. The new logic is shown in Figure 23 below. Note that the new logic will not allow the release to be reduced below the value already determined by lower priority rules. In other words, this rule will only increase the release if needed.

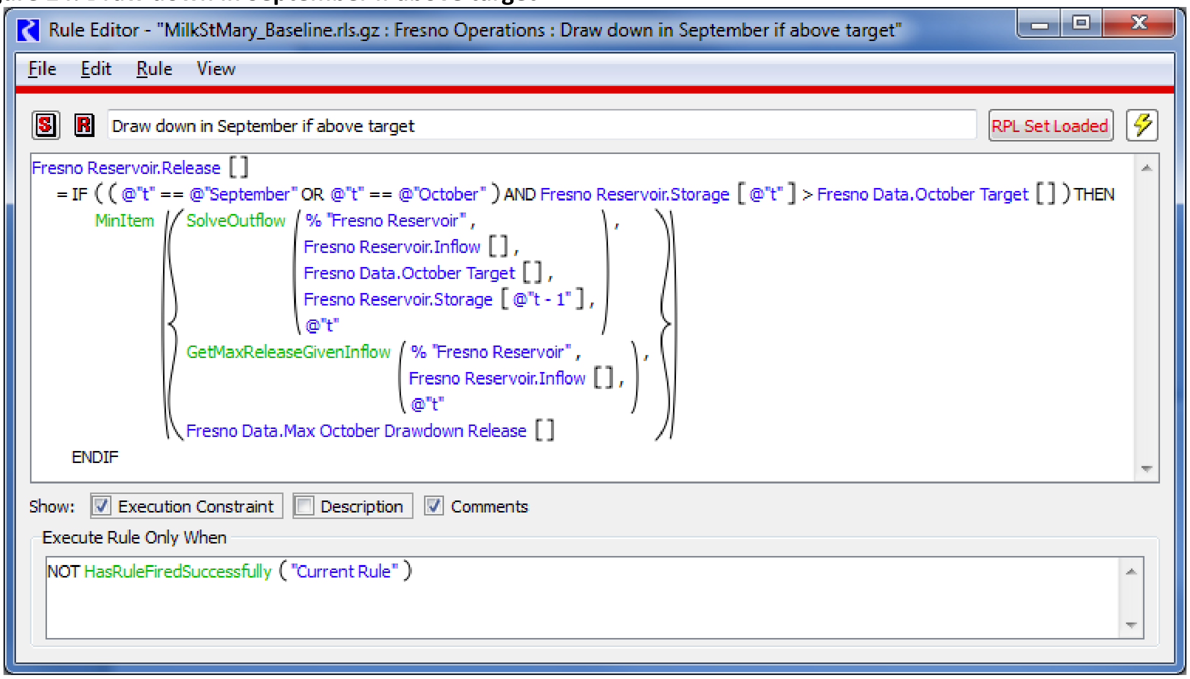
Figure 23: Set Fresno Release when Full



Releases for October Target

The *Draw down in September if above target* rule releases extra water from Fresno Reservoir in September and October if the storage is greater than the October Target (defined in the October Target slot on the Fresno Data object). This rule was improved to better represent real world operation in the months of September and October. Figure 24 shows the new logic associated with this rule. During September and October, if the Fresno storage is greater than the October Target, the release from Fresno is set to the value required to bring the storage down to the target level. This is limited to the physical maximum release and the Max October Drawdown Release defined on the Fresno Data object. In most cases, the Max October Drawdown Release will be the limiting factor. As the storage approaches the October Target, the rule will adjust the release to exactly hit the target value.

Figure 24: Draw down in September if above target



Release Reduction in Late Summer/Fall

The operating policy that reduces releases late in the irrigation season when the Fresno Reservoir drops too low was improved to better match historical operations and to better represent future alternatives involving expanded storage at Fresno Reservoir.

Figure 25 and Figure 26 below show the two rules that control these operations. The first rule, *Late Summer Fall Release Reduction Flag*, sets a flag for the reminder of the irrigation season if Fresno Reservoir drops below the Winter low pool (15,000 acre-ft) any time after August 1. The next rule, *Reduce Release for Late Summer Fall if Flagged*, executes only when the flag has been set by the previous rule (i.e. only if Fresno storage has dropped below 15,000 acre-ft on any day after August 1). If the flag has been set, the release will be reduced so that Fresno Reservoir is passing inflows only, unless the release for demands is less than the inflow, in which case the release to meet demands is maintained. In either case, this rule will not allow the release to go below the Minimum Outflow 2 (45 cfs).

Figure 25: Late Summer Fall Release Reduction Flag

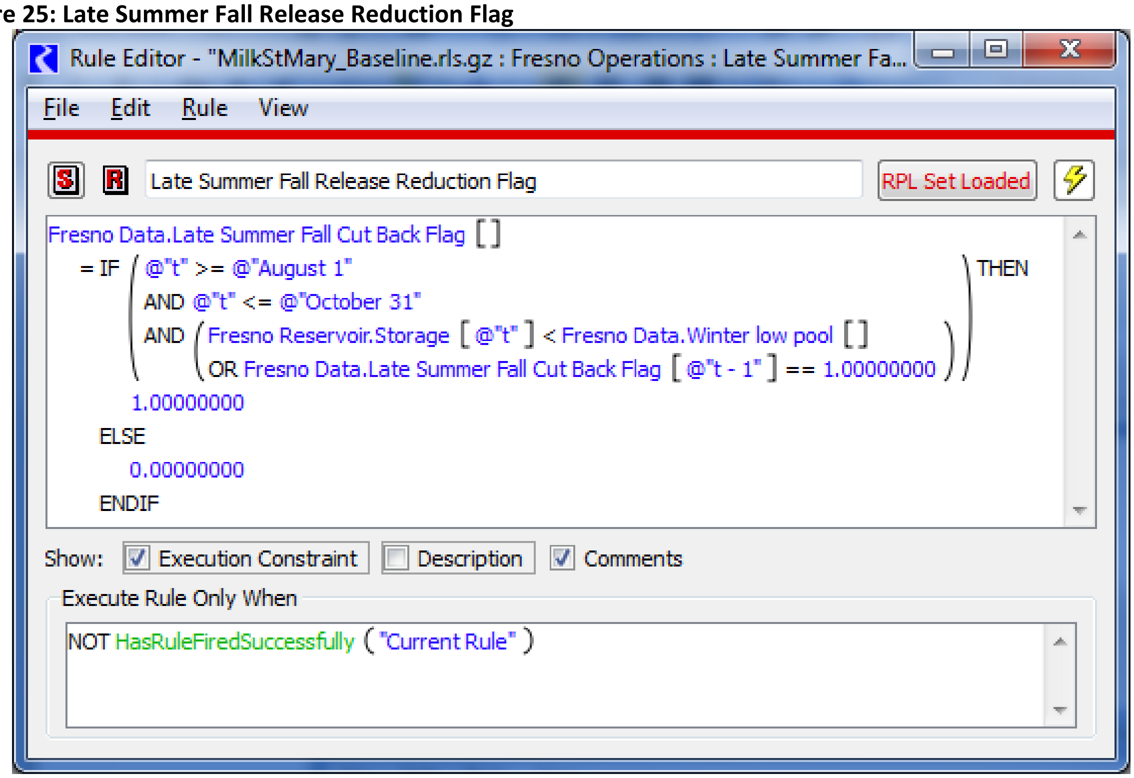
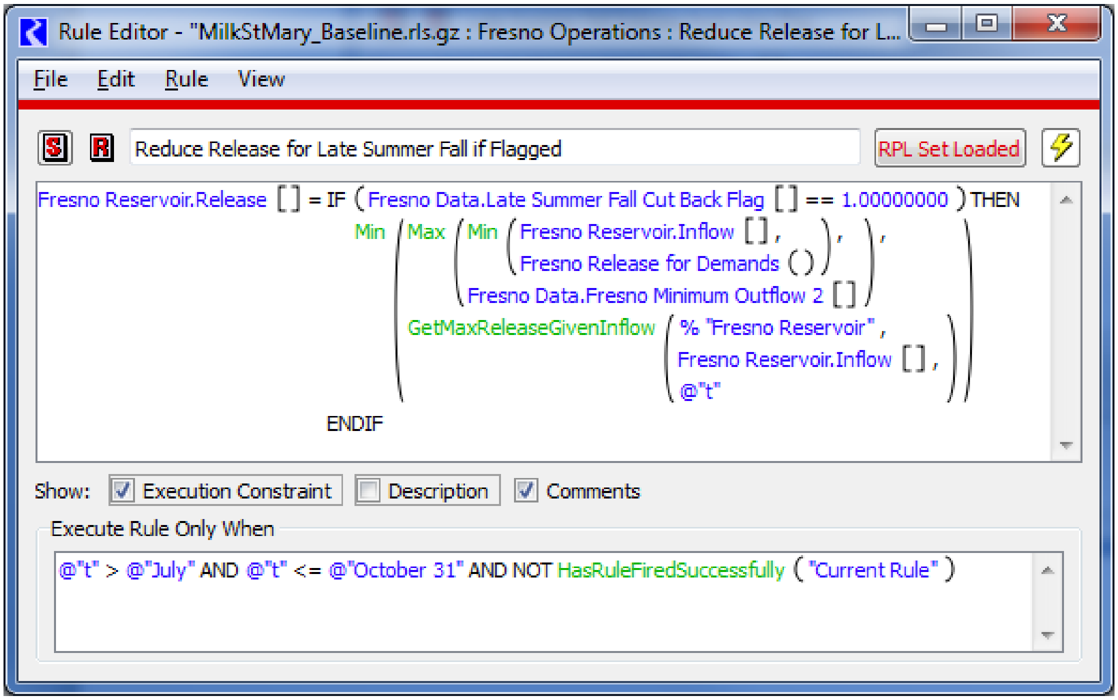


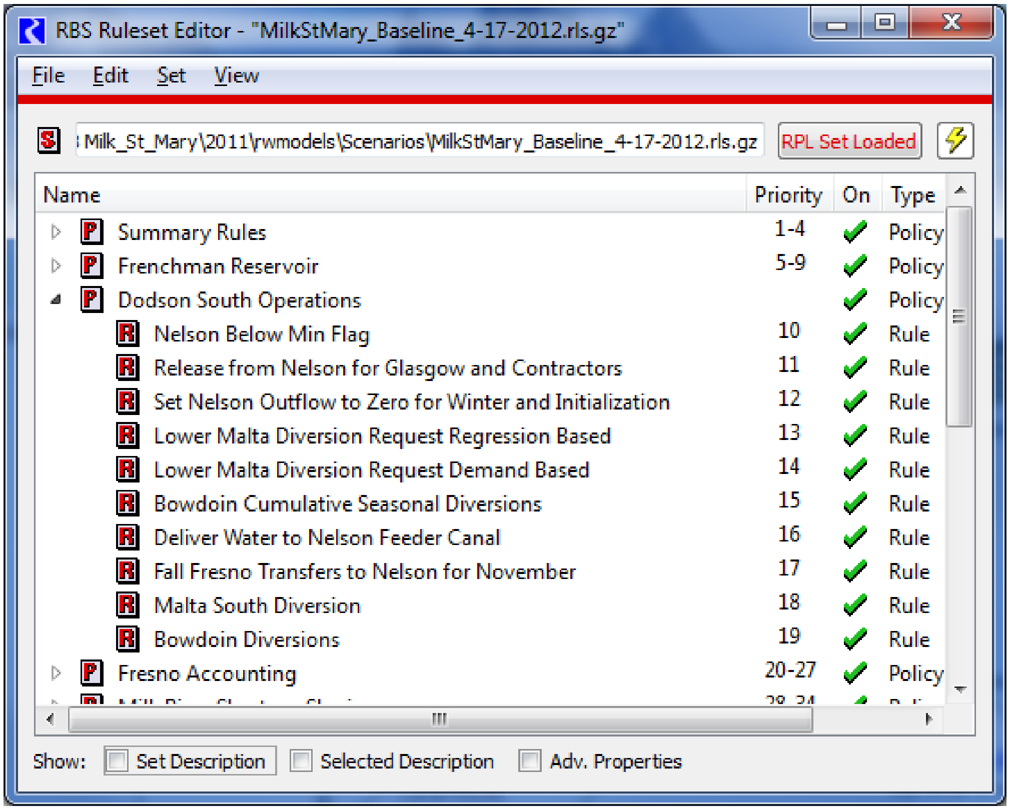
Figure 26: Reduce Release for Late Summer Fall if Flagged



Dodson South Operations Policy Group

Several improvements were made to the rules in the *Dodson South Operations* policy group to streamline performance, improve efficiency, and more accurately reflect real-world operations. Unused or disabled rules were deleted and the remaining rules were re-prioritized and re-named as shown in Figure 27 below. The rules were constrained to execute once per timestep (except the *Nelson Below Min Flag* rule). Therefore, the order/priority of rules within the policy group is now critical.

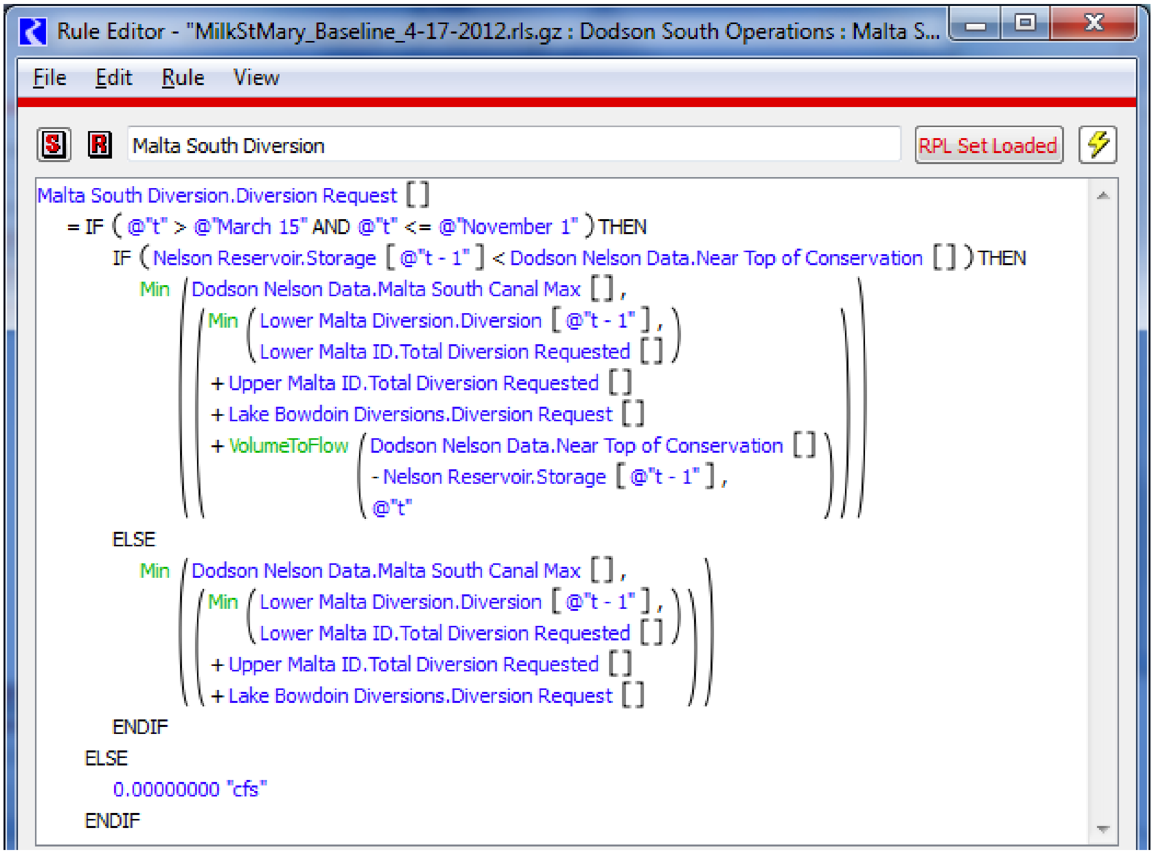
Figure 27: Dodson South Operations



Malta South Diversion Rule

The Malta South Diversion rule was re-written as shown in the figure below. The rule now diverts available water from the Milk River up to the Malta South Canal capacity based on the Upper and Lower Malta irrigation district demands, the Lake Bowdoin demands and the Nelson storage level. When Nelson Reservoir is full (Near Top of Conservation), the canal diverts enough to meet demands only and will not divert extra to store in Nelson.

Figure 28: Malta South Diversion Rule

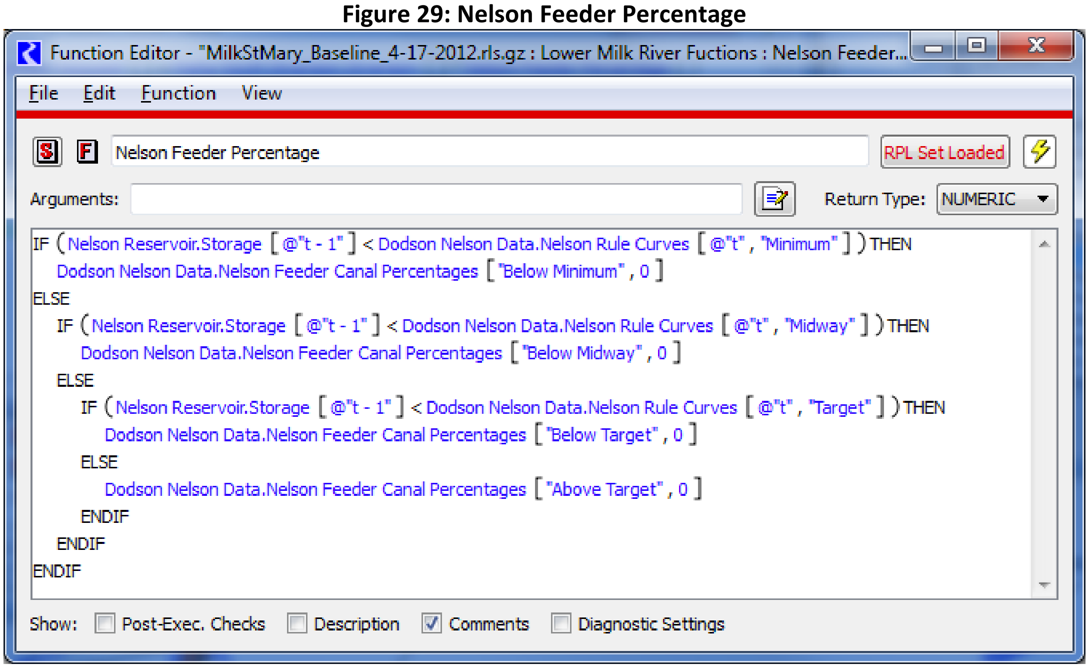


Deliver Water to Nelson Feeder Canal

The rule to deliver water through the Nelson feeder canal was enhanced to use a diversion percentage that varies with Nelson storage. A new function was added that computes the Nelson feeder canal diversion percentages (see

Figure 29 below). The percentage values are located on the Nelson Feeder Canal Percentages slot on the Dodson Nelson Data object.

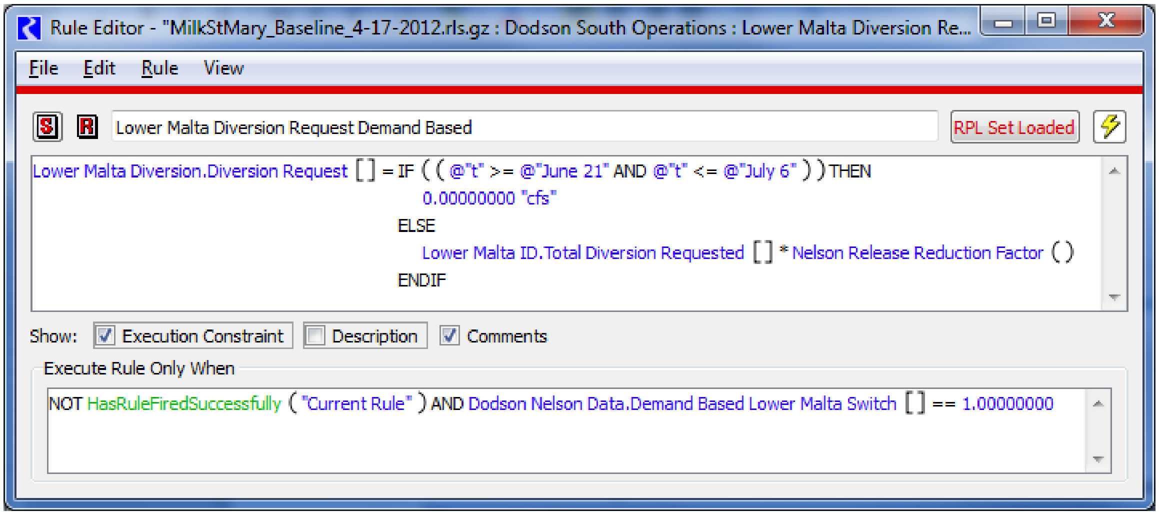
Figure 29: Nelson Feeder Percentage



Lower Malta Diversion Request Demand Based

A new rule was added to compute the Lower Malta Canal flows based on the Lower Malta Irrigation District demands. The previous rule used a regression equation relating the canal flow to Nelson storage. Both rules are still active and are controlled through the Demand Based Lower Malta Switch located on the Dodson Nelson Data object. When this slot is set to 1.0, the demand based rule is used. When this slot is set to zero, the previous regression based rule is used.

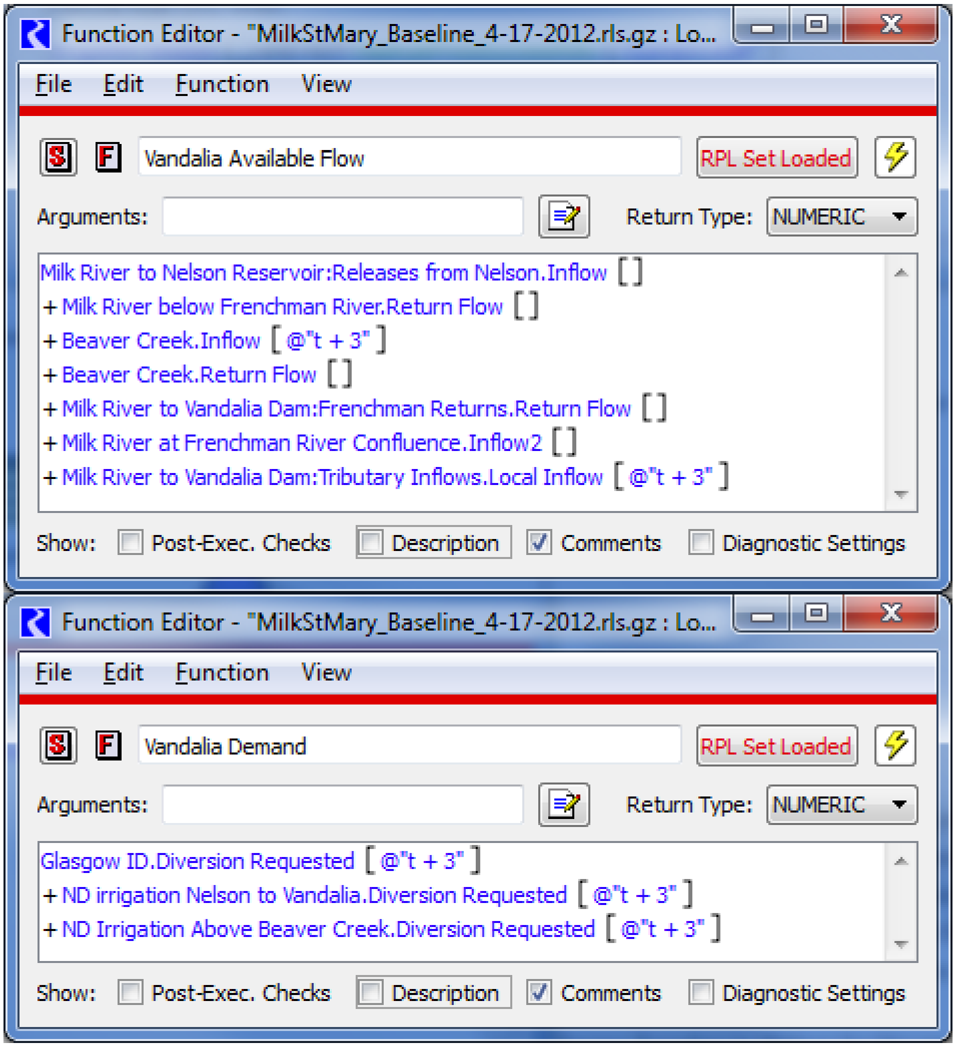
Figure 30: Lower Malta Diversion Request Demand Based



Release from Nelson for Glasgow and Contractor

The rule that determines the outflow from Nelson Reservoir during the irrigation season was updated to better estimate the demand and available flow at Vandalia Dam. The Vandalia Available Flow function was updated to account for all inflow and return flow points between Nelson and Vandalia. Since there is a three-day lag time between Nelson and Vandalia in the model, the best estimate of available flow is the flow that will be at Vandalia three days in the future, since the model is releasing from Nelson to meet the demand/orders three days three days from the current. The first term in the function, Milk River to Nelson Reservoir:Releases from Nelson.Inflow represents the flow rate in the Milk River at the point where the Nelson release enters the river. This is just above the point where the 3-day lag time is applied in the model, so this is the best estimate of the main channel flow that will reach Vandalia Dam three days from the current. Tributary inflows downstream from this point are reference at time t+3, as these are user input values and are available to the rule logic on the current timestep. All return flows are referenced at the current timestep because they have not yet been calculated at time t+3 in the model. Therefore, the return flow estimate will be three days "early". However, because the return flows do not vary greatly from day to day, this is considered to be a good estimate.

Figure 31: Vandalia Available Flow and Demand



Nelson Outflow Oscillations – Nelson Below Min Flag

The logic which determines the Nelson Reduction Factor was organized into a single function (see

Figure 32 below). A flag was added to the Dodson Nelson Data object that tracks whether Nelson Reservoir has been drawn down below the minimum level defined by the Nelson Rule Curves. This was added to avoid oscillation in the releases when the Nelson storage reaches the minimum level. Prior to this change, the model would alternate between a release of zero and a large positive value as the pool elevation alternated above and below the minimum value. To fix this, two new slots and a new rule were added. The Nelson Below Min Flag slot was added to track the value of the flag. When this value is 1.0, it means that Nelson has gone below the minimum level and has not yet recovered above the minimum value plus a user defined "buffer" value. The buffer is a user input value on the Nelson Oscillation Buffer Space slot. Once the storage rises above the minimum value plus the buffer value, the flag is re-set to zero and Nelson may begin releasing again.

Figure 32 shows the Nelson Release Reduction Factor function that determines whether the release from Nelson will be cut-off when the pool falls below the minimum or if the flag has been set to 1.0. Figure 33 shows the Nelson Below Min Flag rule which tracks and sets the flag used to avoid oscillation.

Figure 32: Nelson Release Reduction Factor

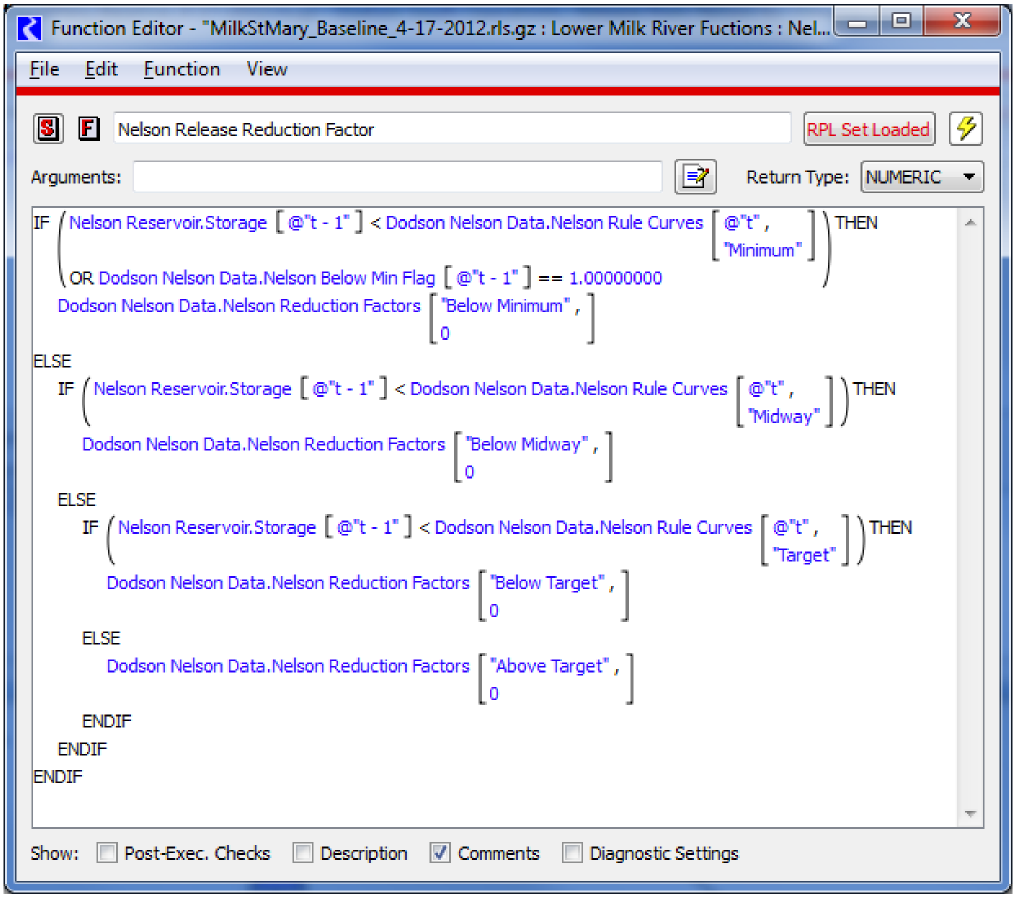
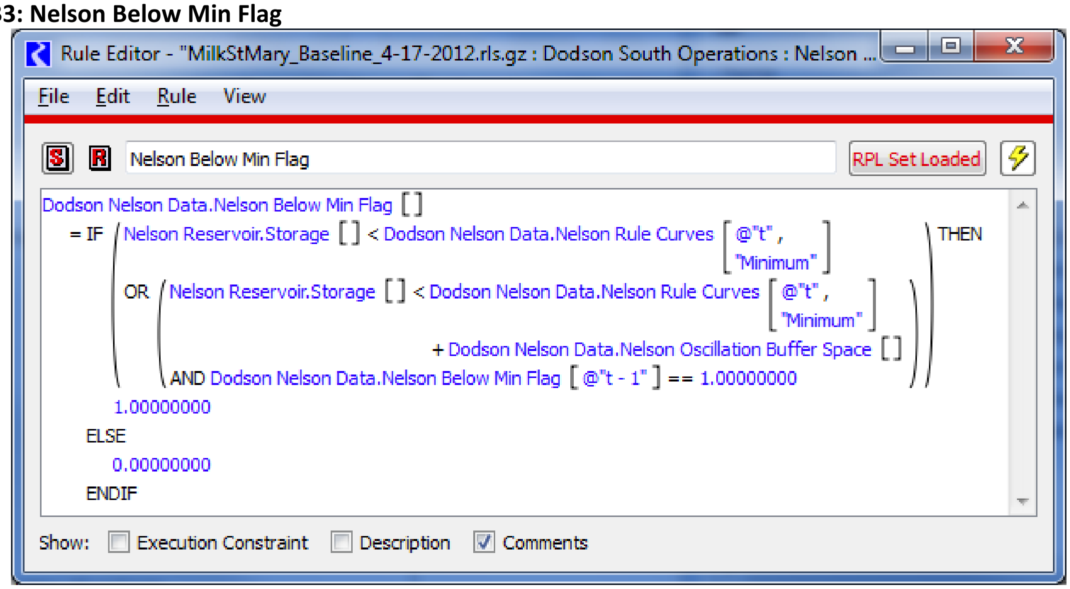


Figure 33: Nelson Below Min Flag



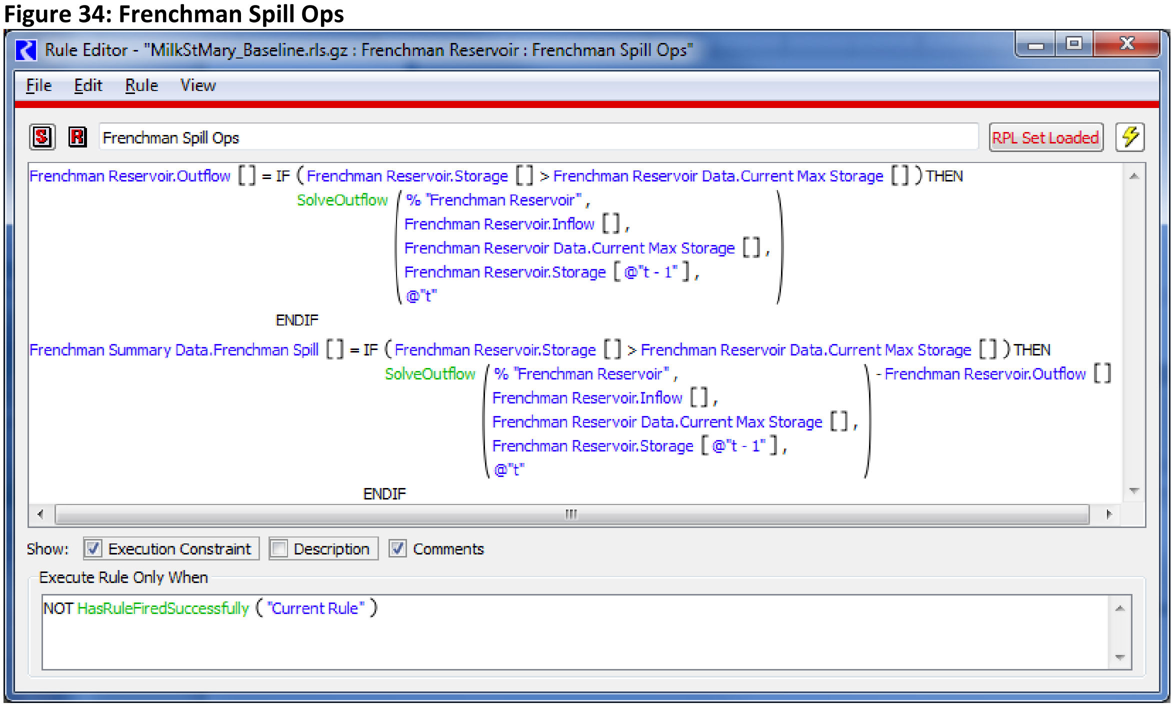
Frenchman Reservoir

The Frenchman Reservoir rules were re-designed to improve performance and efficiency and to allow the simulation of an alternative used in the Reclamation Basin Study with increased storage at Frenchman Reservoir.

Flexible Maximum Storage

In order to facilitate the simulation of alternate maximum storages, the Frenchman Reservoir object was re-configured to remove the physical constraints associated with the spillway and release structures. The Max Release table was modified to remove any restrictions on release and the Unregulated Spill method was disabled. Spill is now controlled by the rules according to the user input Current Max Storage on the Frenchman Reservoir Data object. This allows the model operator to change the max storage value without reconfiguring the associated max release and spill tables. Figure 34 below shows the new spill policy. If the storage goes above the Current Max Storage, Frenchman Reservoir immediately spills all water stored above the max storage. The amount spilled is stored in the Frenchman Spill slot on the Frenchman Summary Data object for reference.

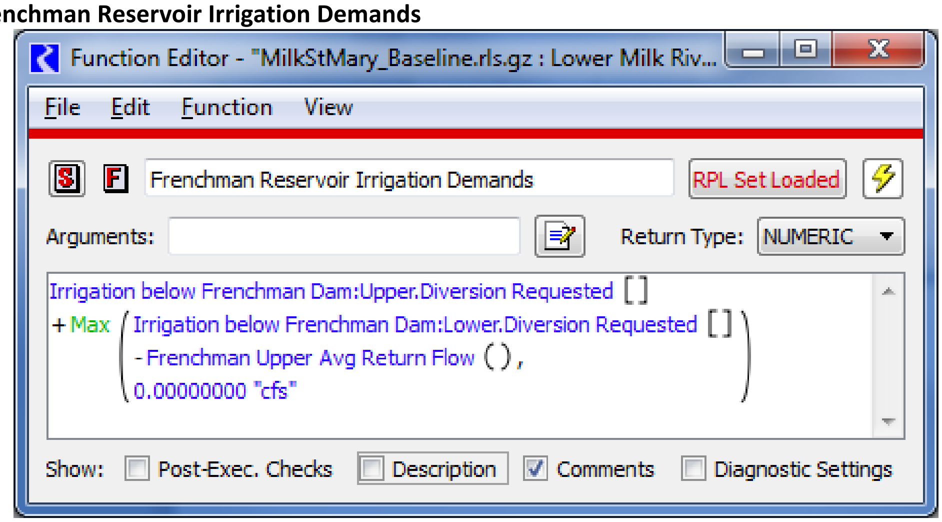
Figure 34: Frenchman Spill Ops



Releases to Meet Irrigation Demands

The rules to meet irrigation demands on the Frenchman River were improved to reduce shortages and avoid oscillation in the Frenchman Reservoir pool elevation around the minimum storage level. The *Frenchman Reservoir Irrigation Demands* function was modified as shown in Figure 35 below. The irrigation demands are the diversion requested for the upper Frenchman diversion object plus the diversion requested for the lower Frenchman diversion object minus the 3-day average return flow from the upper object. In this way the lower object can make use of the return flows from the upper object and reduce the demand on Frenchman Reservoir.

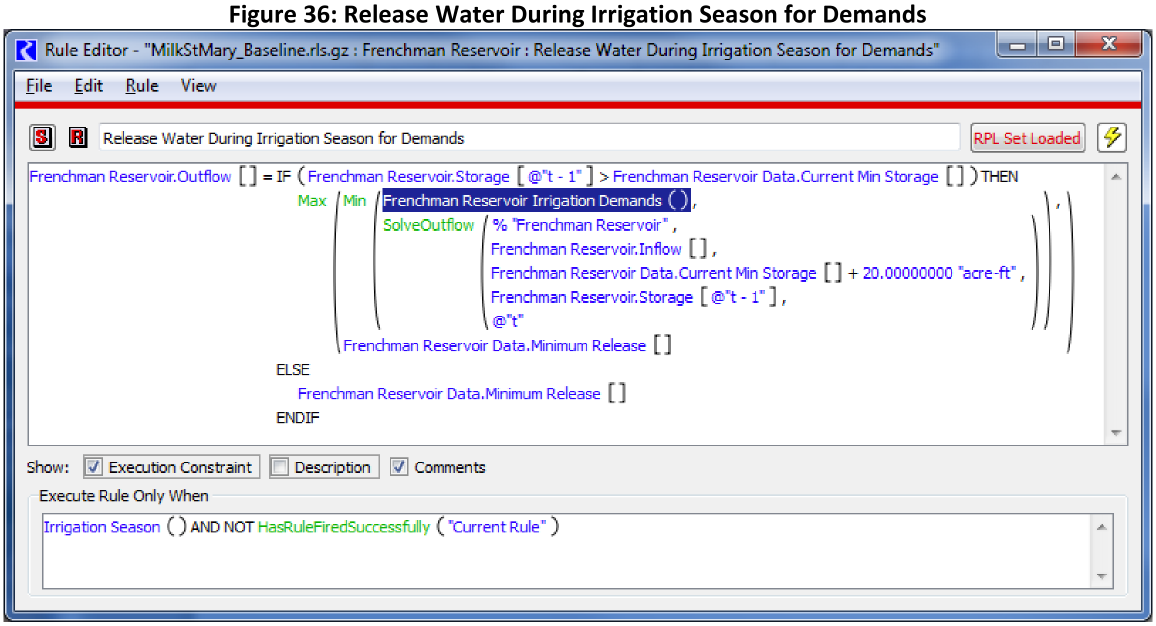
Figure 35: Frenchman Reservoir Irrigation Demands



The *Release Water During Irrigation Season For Demands* rule is show in

Figure 36 below. This rule will execute during the irrigation season only when the storage in Frenchman Reservoir is greater than the Current Min Storage defined on the Frenchman Reservoir Data object. If the storage is greater than this value, the rule will release the minimum of the value returned by the *Frenchman Reservoir Irrigation Demands* function and the release that would draw down the reservoir to 20 acre-ft above the minimum storage level. The inclusion of a 20 acre-ft “buffer” above the minimum storage value avoids oscillations that would occur if the reservoir were drawn down to exactly the minimum storage value. In all cases, the rule logic ensures that at least the minimum release is maintained.

Figure 36: Release Water During Irrigation Season for Demands

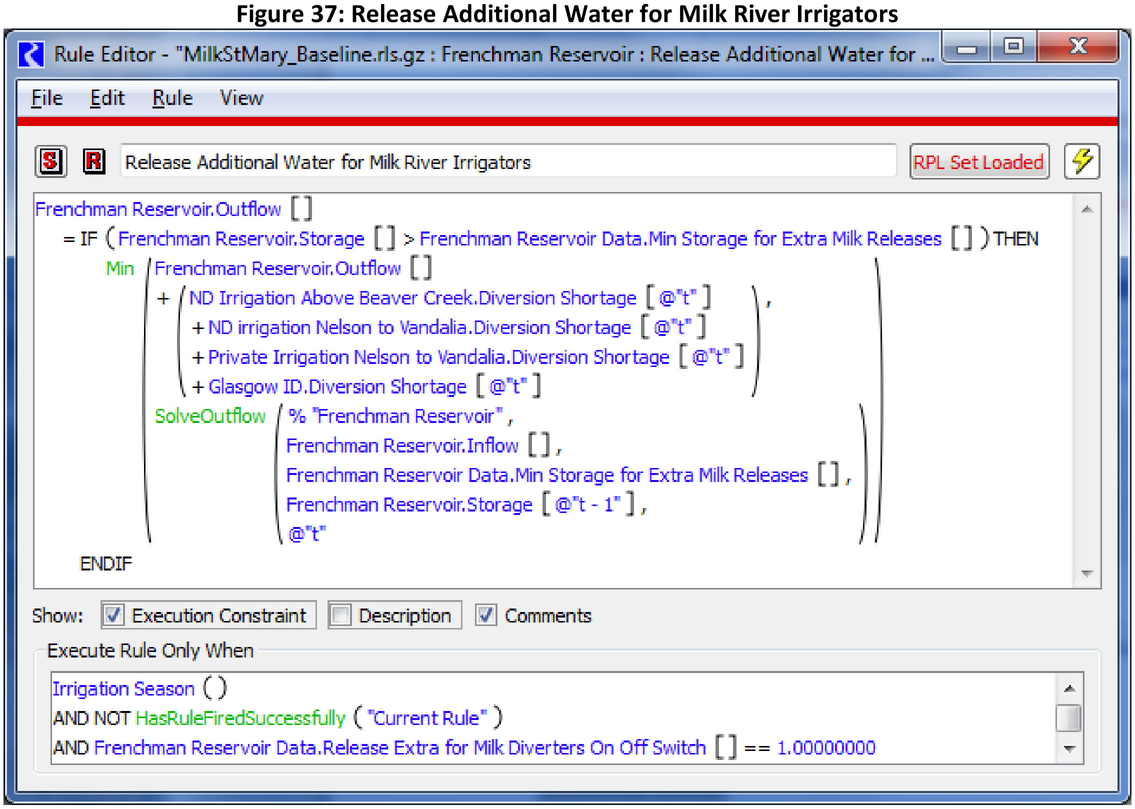


The rule shown in

Figure 37 below was added for Reclamation Basin Study alternative which explores increased storage at Frenchman Reservoir. This rule executes only when the Release Extra For Milk Diverters On Off Switch has been set to one (1.0). When this switch is active, and the current storage is greater than the value defined in the Min Storage for Extra Milk Releases slot, the *Release Additional Water for Milk River Irrigators* rule will increase the release from Frenchman

Reservoir to meet irrigation shortages on the Milk River below the confluence with the Frenchman River. These include the following Milk River diverters: ND Irrigation Above Beaver Creek, ND irrigation Nelson to Vandalia, Private Irrigation Nelson to Vandalia, and Glasgow ID. The rule logic places a limit on the release so that the Frenchman Reservoir storage will not go below the Min Storage for Extra Milk Releases as a result of the increased release for Milk River diverters.

Figure 37: Release Additional Water for Milk River Irrigators



Miscellaneous

Following are miscellaneous changes that were made to the model and rules as part of the scope of work.

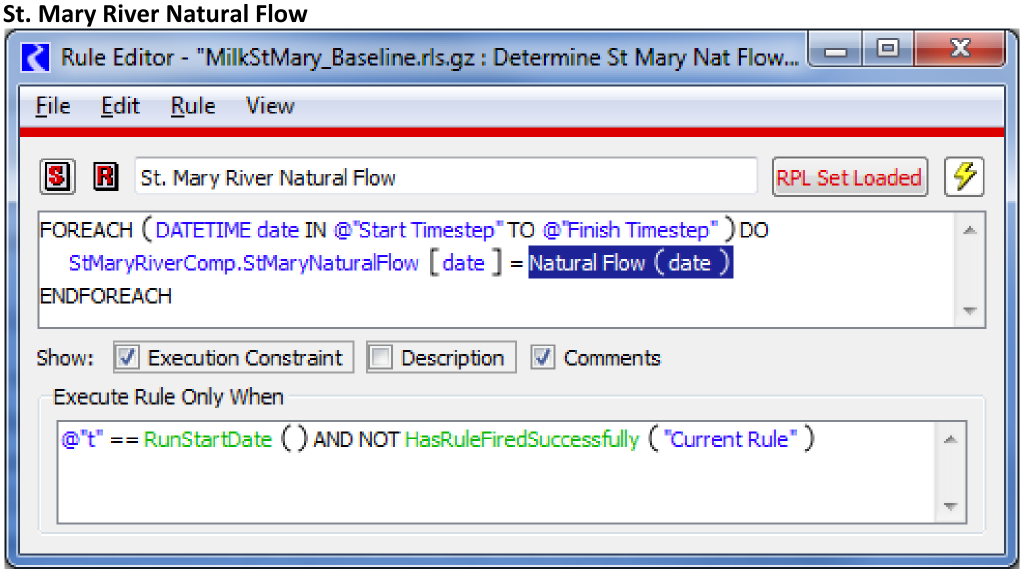
City of Havre Demands

Demands for the City of Havre were increased to 2,600 acre-ft/year. The values in the Periodic Diversion Request slot on the City of Havre water user object were proportionally increased to reach the 2,600 AF annual total.

St. Mary Natural Flow Rules

The rules which compute the St. Mary River natural flow and the associated US and Canada Shares were modified to compute values for the entire model run on the first model timestep. This was done to facilitate the implementation of operating rules for the St. Mary Canal to meet the May 15 and September 15 targets at Sherburne Reservoir. These operational rules for the St. Mary Canal need to estimate the natural flow that will occur between the current operating day and the target day. Prior to this change, the natural flow was computed for each timestep at the beginning of the timestep. This precluded any operating rules from determining the natural flow at future dates. The screen capture below gives an example of the new logic used for *St. Mary River Natural Flow*, *US Share*, and *Canada Share* rules.

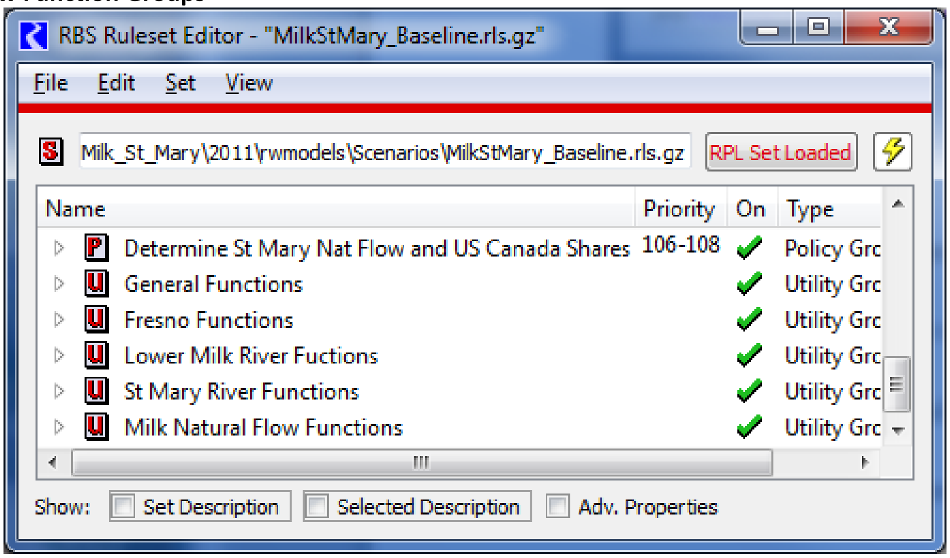
Figure 38: St. Mary River Natural Flow



Function Reorganization

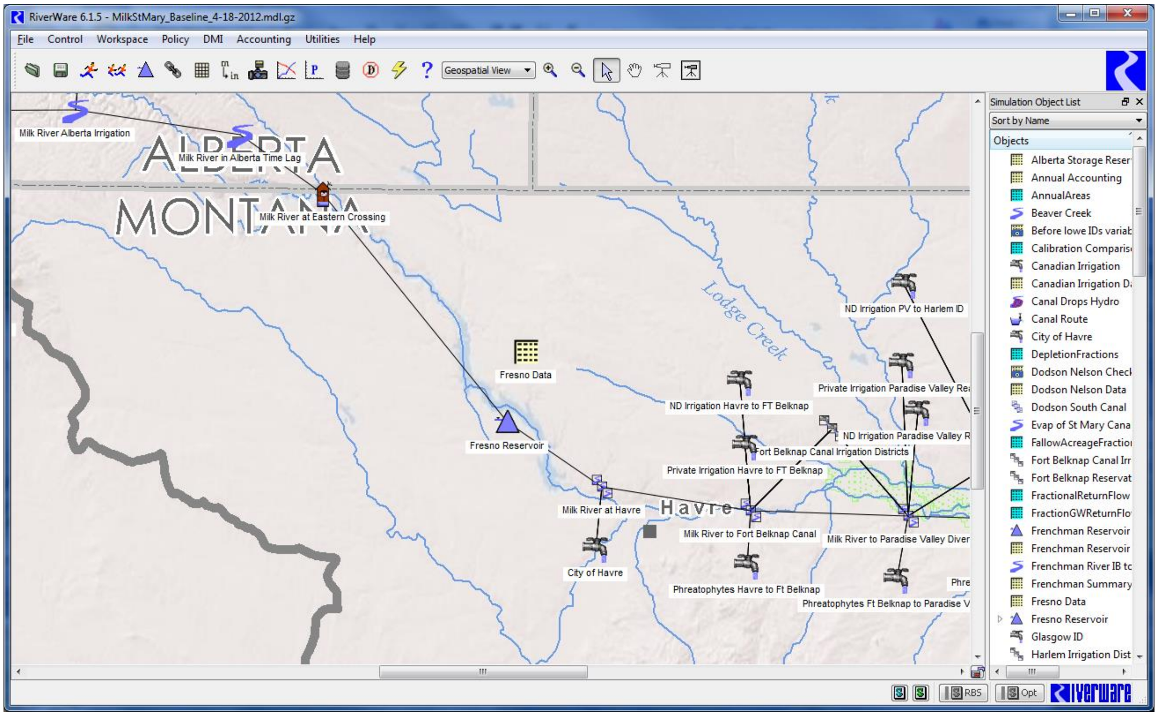
The ruleset functions were re-organized for improved reference. Each function was placed into one of the Utility Groups shown in Figure 39 below. Within each group the functions are organized alphabetically.

Figure 39: New Function Groups



Background Image

A background image was added to the model under the Geospatial View. In order to view the background image, the model user must have a copy of the RW_Background_Map.jpg file. An environment variable named MILK_STMARY_RW_MAP_DIR must be created and the RW_Background_Map.jpg file must be stored in the directory to which this environment variable points. The environment variable must be created before starting RiverWare. To add an environment variable, right-click on the Computer icon and select Properties. Then go to Advanced system settings and Environment Variables.


RiverWare 6.1.5 - MilkStMary_Baseline_4-18-2012.mdl.gz
File Control Workspace Policy DMI Accounting Utilities Help
Geospatial View
ALBERTA
MONTANA
Milk River Alberta Irrigation
Milk River in Alberta Time Lag
Milk River at Eastern Crossing
Lodge Creek
Fresno Data
Fresno Reservoir
ND Irrigation PV to Harlem ID
ND Irrigation Havre to FT Belknap
Private Irrigation Havre to FT Belknap
Fort Belknap Canal Irrigation Districts
Milk River at Havre
Havre
Milk River to Fort Belknap Canal
Milk River to Paradise Valley Diver
City of Havre
Phreatophytes Havre to Ft Belknap
Phreatophytes Ft Belknap to Paradise V
Simulation Object List
Sort by Name
Objects
Alberta Storage Reser
Annual Accounting
AnnualAreas
Beaver Creek
Before Iowe IDs variab
Calibration Comparis
Canadian Irrigation
Canadian Irrigation D
Canal Drops Hydro
Canal Route
City of Havre
DepletionFractions
Dodson Nelson Check
Dodson Nelson Data
Dodson South Canal
Evap of St Mary Cana
FallowAcreageFractio
Fort Belknap Canal Irr
Fort Belknap Reservat
FractionalReturnFlow
FractionGWReturnFlo
Frenchman Reservoir
Frenchman Reservoir
Frenchman River IB to
Frenchman Summary
Fresno Data
Fresno Reservoir
Glasgow ID
Harlem Irrigation Dist
RBS
Opt
RiverWare

Appendix E
Hydros Consulting: Documentation of Model and Ruleset Enhancements Developed Under Amendments to Contract WM-HC-123

Memorandum: Documentation of Model and Ruleset Enhancements Developed Under Amendment to Contract WM-HC-123

To: Larry Dolan, State of Montana DNRC
From: Steve Setzer, Hydros Consulting Inc.
Subject: Documentation of Model and Ruleset Enhancements Developed Under Amendment to Contract WM-HC-123
Date: September 21, 2012

Hydros Consulting Inc. (Hydros) is working as a contractor for the State of Montana Department of Natural Resources and Conservation (DNRC) under Contract Number WM-HC-123. In May, 2012 an addendum to the contract added the following modeling tasks:

Task 10.0: Enhance the model so that canal and field efficiencies, and return flows from both of these losses, can be tracked separately for the larger water users. This will be done for the following irrigation districts: Fort Belknap, Alfalfa Valley, Zurich, Paradise Valley, Harlem, North Malta, Upper Malta, Lower Malta, Glasgow, and Fort Belknap Reservation Irrigation Project.

Task 11.0: Enhance the ability of the model to equitably distribute available water and to share shortages between Milk River Project users. This also would include limiting diversions by junior water users to flow that remains after Milk River Project and Fort Belknap Indian Irrigation Project water rights are satisfied.

Task 12.0: Add the capability to the model to simulate a potential off-stream water storage reservoir for the Fort Belknap Indian Community Compact Settlement. The reservoir to be simulated would have a capacity of 60,000 acre-feet, with a maximum diversion of 520 cfs of Milk River natural flow. The reservoir would be simulated to irrigate up to 18,000 acres, and to provide an additional 4,000 acre-feet per year for other uses. The water supply will be simulated as a pumped diversion from the Milk River, with a lift of 180 feet.

This memorandum describes the improvements made to the model and ruleset to implement the modeling tasks described in the contract addendum.

Task 10.0: Separate Canal and Field Efficiencies

The model schematic was enhanced to include additional objects for each irrigation unit so that the canal losses and on-farm losses are modeled separately. The screen capture below shows the new structure for a sample irrigation unit.

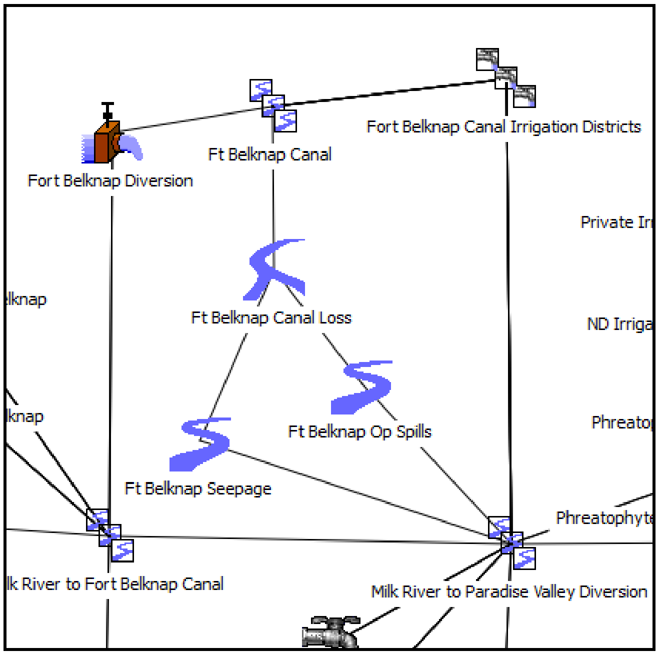


Figure 40: Model Structure for Separate Canal and On-Farm Efficiency

The previously used total efficiencies in the model were segregated into field and canal loss components. The Water User efficiency modifications were made using values provided by Larry Dolan at the DNRC. To account for canal seepage losses, seepage fractions were added to the new canal Reach Objects, which are used to represent the delivery canals. The canal losses were split into operational spills (direct flow back to surface water) and seepage to groundwater using a Bifurcation Object. The resulting losses are each routed through a Reach Object so that the operational spills to surface water and seepage to groundwater may use different sets of routing coefficients. Overall, the new method, which accounts for both canal and field efficiency components, results in overall efficiencies for each water user object that correspond to the total efficiencies used in the previous version of the model.

Several rules, functions, and expression slots needed to be enhanced to accommodate this change. These include the following:

- Run Summary Accounting object:
  - The Total Irrigation Diversions expression was modified to include distribution canal losses for the Dodson South canal. This now results in some of the deliveries intended to fill Nelson reservoir being counted as irrigation diversions.

  - Fort Belknap ID Total Diversions, Paradise ID Total Diversions, Harlem ID Total Diversions, Belknap Reservation Total Diversions, Malta North Canal Diversion Summary, and Glasgow ID Diversions were all modified to look at the Diversion slot on the new Diversion Object which is directly connected to the Milk River. Previously these expression slots referred to the compilation of diversions for Aggregate Water User Objects which no longer correspond to the river head-gate diversions.
- A data object called "Average Irrigation District Efficiencies" was added. This object contains expression slots to calculate the average efficiency on each timestep for each of the eight distribution canals (canal and on-farm efficiency).
- Vandalia Demand function: Glasgow diversion requests were adjusted for canal losses.
- Lower Malta Diversion Request Demand Based rule: Lower Malta depletion volumes were adjusted for canal losses.
- Malta South Diversion rule: Lower Malta and Upper Malta diversions requested were adjusted for canal losses.
- FBIIP Diversion function: changed so that it now refers to diversions from the Milk River rather than from the canal by water users.
- Diversion Request Routing rule: added so that the diversions requested by groups of water users are routed to the diversion object connected to the Milk River after having been adjusted for the canal losses in the corresponding distribution canal, and checked to ensure that they don't exceed the canal capacity. This rule sets the diversion requests for the entire period of simulation at the first timestep so that the Fresno Release for Irrigation Demand rule can use forecasted diversion requests.
- Total Lower Milk Return Flows function: altered so that it includes the return flows from canal losses.
- Total Lower Milk Efficiency Adjusted Diversions function: added to recreate the original effect of the Total Lower Milk Irrigation Demands function now that the Depletion Requested slots on some of the Lower Milk River Subbasin objects are no longer adjusted to account for canal capacities. This is now calculated directly in this function by multiplying the Diversion Requested by the "Average Irrigation District Efficiency" which includes both the canal and on-farm losses. Also, because the Diversion Requested and Depletion Requested slot values may be reduced from shortage sharing, this function refers to the original diversion/depletion requested values stored on the Original Irrigation Diversion Requests and Original Irrigation Depletion Requests data objects.
- No Irrigation in January initialization rule: added to set diversion requests for January to zero so that the water users near Ft Belknap dispatch in the correct chronological order.
- A function called Average Irrigation District Efficiency was added that looks up the value on the corresponding "Average Irrigation District Efficiencies" slot for a given day if the day is in the past, or otherwise returns the value from the day before the current timestep.

Task 11.0: Shortage Sharing Rules

In order to better model the equitable distribution of available water, the previous shortage sharing rules were deleted and replaced with new rules. The screen capture below shows the new rules and new policy groups (*Fresno to Dodson Shortage Sharing* and *Nelson to Vandalia Shortage Sharing*).

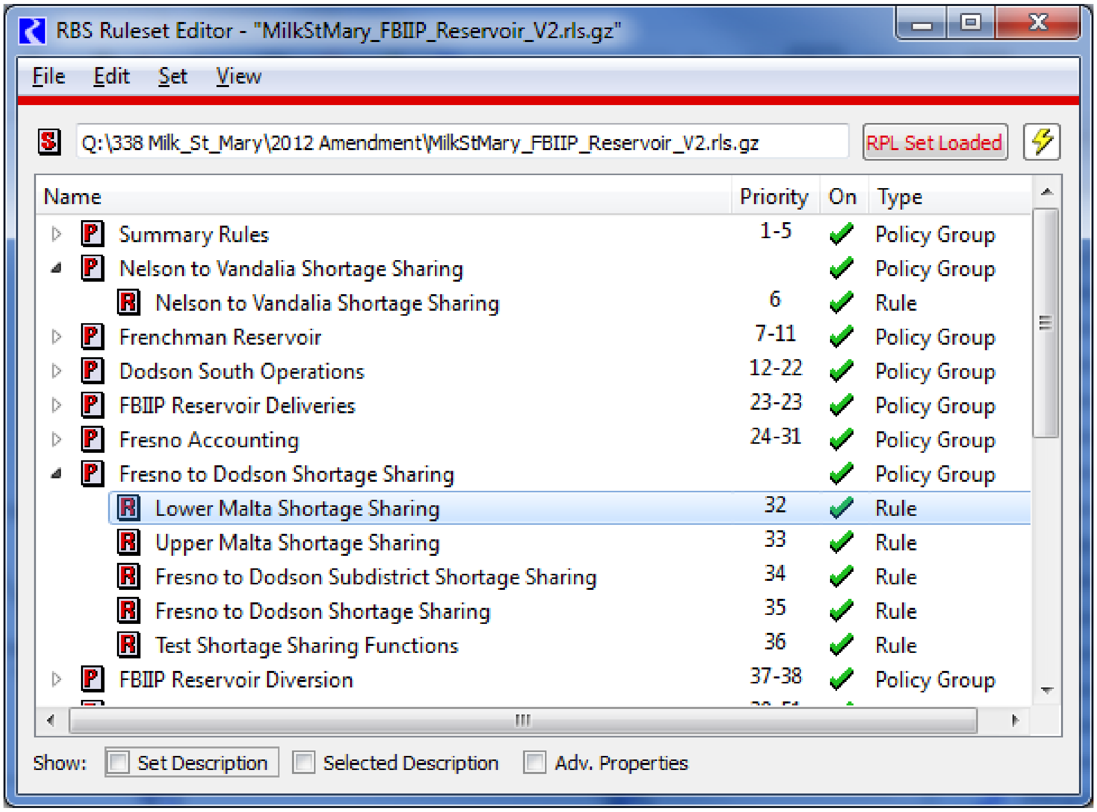


Figure 41: Shortage Sharing Rules and Policy Groups

Record Original Diversion Depletion Requests: This rule was added to the Initialization Rules Policy Group (within the MilkStMary ruleset, not the RiverWare internal initialization rules). This function records all of the Diversion Requested and Depletion Requested values to data objects called Original Irrigation Diversion Requests and Original Irrigation Depletion Requests. This was done because the shortage sharing rules may reduce the Diversion Requested and Depletion Requested values in order to ensure equitable shortage sharing. It is useful for the model to keep track of the original values for computing shortage, etc. The appropriate rules and expression slots were updated to refer to the Original Diversion/Depletion Requested values.

Test Shortage Sharing Functions: This rule writes the result of each of the shortage sharing functions to a data object. This rule is used for testing purposes only and may be deleted when testing is complete. The Test Shortage Sharing data object may also be deleted.

Fresno to Dodson Shortage Sharing: This rule performs the equitable distribution of available water, or shortage sharing, by reducing the Diversion Requested values for each of the private and project water users. For those irrigation projects that are served by a canal via a Diversion Object in the model, only the Diversion Request slot needs to be reduced. For those users that are modeled as a Water User object connected directly to the river, both the Diversion Requested slot and possibly the Depletion Requested slot need to be reduced. The Depletion Requested value needs to be reduced such that the maximum efficiency is not violated. The private demands are reduced first until they are completely curtailed. Any remaining shortage is then applied to the project demands. Both the private demands and project demands are reduced *pro rata* such that their percent reduction is the same. In other words, all private users are reduced by the same percentage and all project users are reduced by the same percentage, but the private users will always be fully curtailed before any project users are curtailed. Any water users that are not in the private or project subbasins (such as the Fort Belknap Indian Reservation) will never be curtailed; however, their demands may not be fully met if the release from Fresno is insufficient.

Fresno to Dodson Subdistrict Shortage Sharing: This rule sets the Minimum Diversion Bypass slot on each of the distribution canals (AggReach Objects in the model) such that each subdistrict receives the same amount of water, *pro rata*, based on their irrigated acreage and the total diversion at the river head-gate. This happens for the Fort Belknap, Paradise Valley, Harlem, and Fort Belknap Reservation Irrigation Projects.

Upper Malta Shortage Sharing: This rule sets the Minimum Diversion Bypass slot on the Dodson South Canal object so that each of the Upper Malta subdistricts receive the same amount of water, *pro rata*, based on their irrigated acreage and the total Upper Malta diversion.

Lower Malta Shortage Sharing: This rule sets the Minimum Diversion Bypass slot on the Lower Nelson Canal object so that each of the Lower Malta subdistricts receive the same amount of water, *pro rata*, based on their irrigated acreage and the total Lower Malta diversion.

Nelson to Vandalia Shortage Sharing: This rule controls the shortage sharing for water users between the Nelson release location at the Milk River and Vandalia Dam. Since these are all project users, they can all be shorted *pro rata*, based on the available water and the irrigated area of each project. For Water User objects that are connected directly to the river, the Depletion Requested slot may need to be reduced to ensure that the maximum efficiency is not violated.

Task 12.0: Proposed Reservoir at Fort Belknap Reservation

The model was enhanced to include a potential off-stream storage reservoir at the Fort Belknap Reservation Irrigation Project. The diversion point for the off-stream storage reservoir (*FBIIP Reservoir*, see Figure 42 below) is located just downstream from the existing diversion for the Ft. Belknap Reservation IP Diversion object. In the model schematic, it appears that the FBIIP Reservoir diversion is upstream of the diversion for the existing acreage, but this was done to simplify the appearance of the schematic. If the Milk River to Ft Belknap Reservation object (AggReach Object) is opened, the model user will notice that the FBIIP Reservoir diversion point is downstream from the from the diversion point for the existing acreage. This allows the existing acreage to have priority over the off-stream storage reservoir when diverting available Milk River natural flow.

The FBIIP Reservoir is used to store the portion of the Fort Belknap Indian Irrigation Project's (FBIIP) share of the Milk River natural flow that is not required by the existing FBIIP acreage. The maximum daily natural flow allocation to the FBIIP is set by the model user on the FBIIP Accounting object (see Figure 43). Note that the FBIIP Reservoir may be enabled and disabled through the FBIIP Reservoir On Off Switch slot.

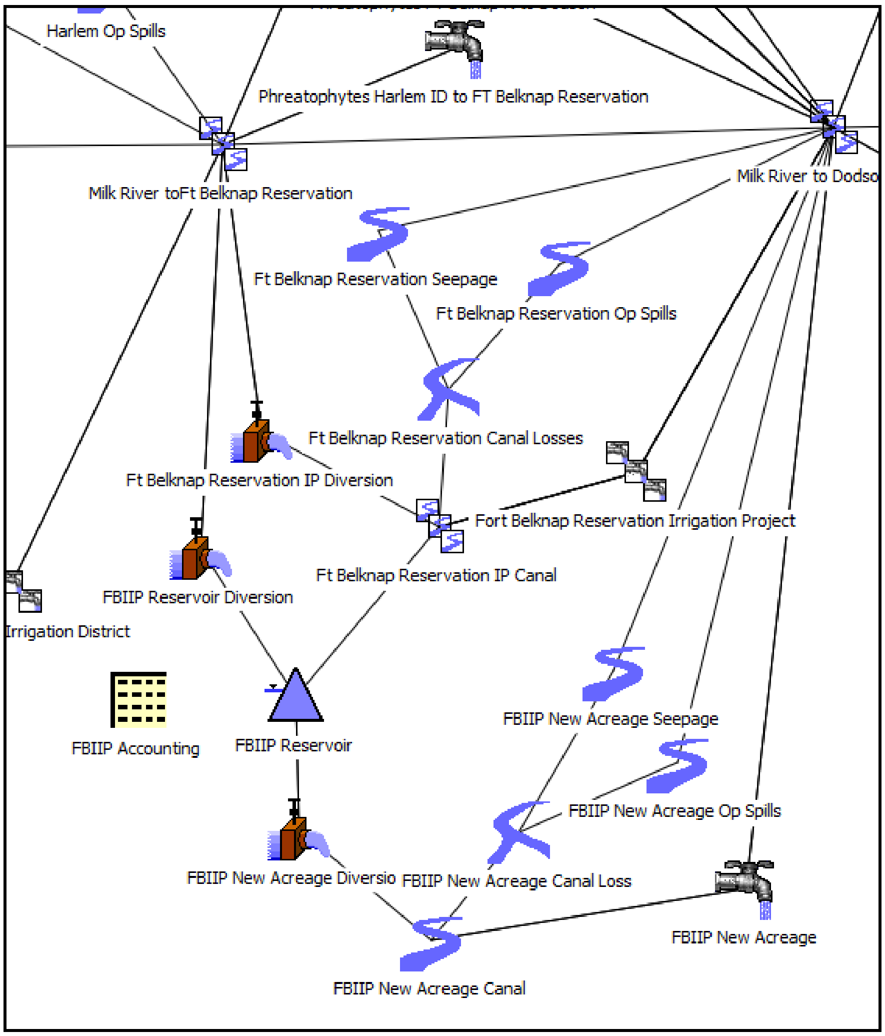


Figure 42: FBIIP Reservoir and New Acreage

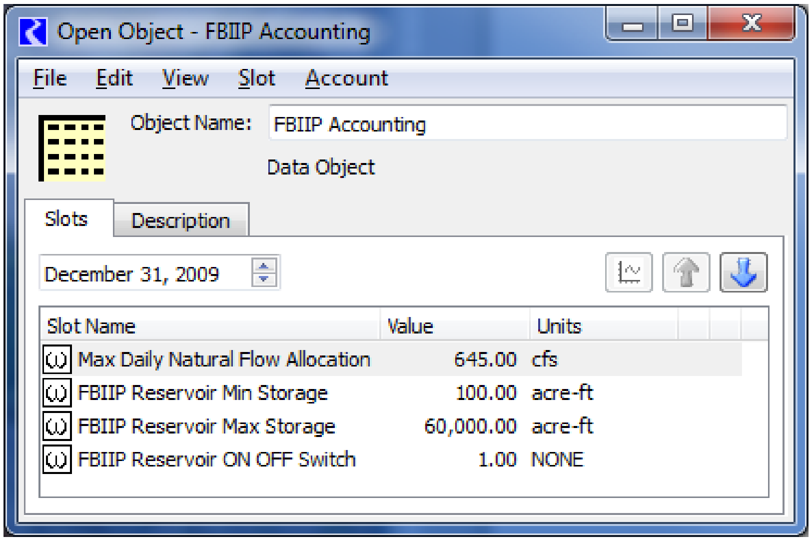


Figure 43: FBIIP Data

In addition to the off-stream reservoir, a new Water User object and the associated delivery canals were added to represent new FBIIP acreage (18,000 acres). Water stored in the FBIIP Reservoir will first be used to meet the requirements of the new acreage. Any remaining storage may be used to augment deliveries to the existing FBIIP acreage (limited to the 170 cfs capacity of the existing canal). The delivery canal from the FBIIP Reservoir to the new acreage was configured to have a capacity of 1000 cfs, such that canal capacity will not be a limitation (the crop requirements of the new acreage are below 1000 cfs daily). The distribution canal was implemented in the same manner as the existing distribution canals such that losses occur due to operation spills and seepage to groundwater. A bifurcation object is used to split the canal losses into the surface and groundwater portions. These are then routed separately according to the surface water routing coefficients and groundwater routing coefficients. These are the same routing coefficients used to route the operational spills and groundwater seepage from the delivery canal to the existing FBIIP acreage. All return flows are linked to the Milk River to Dodson Dam object and accrue just below the return flows from the existing FBIIP acreage.

Figure 44 below shows the rules and policy groups associated with the new FBIIP Reservoir. The two rules in the *FBIIP Reservoir Diversion* policy group must execute before the shortage sharing rules and the Fresno accounting rules. This is required so that the shortage sharing rules ensure that the full allocation is made available to the FBIIP Reservoir and the existing FBIIP acreage.

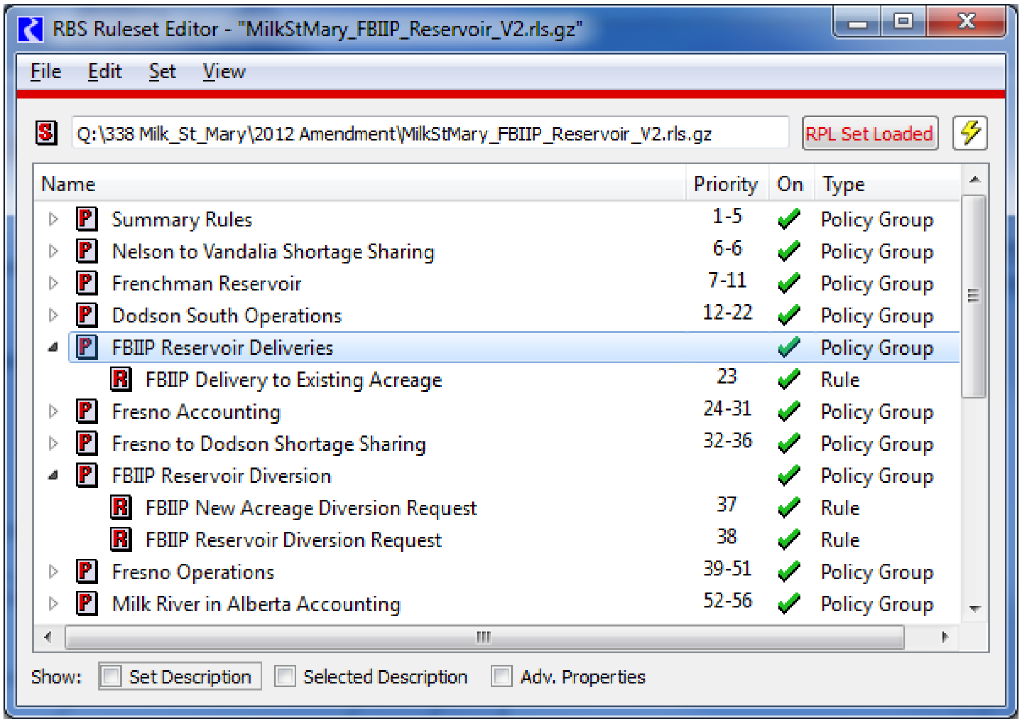


Figure 44: FBIIP Reservoir Rules

FBIIP Reservoir Diversion Request: This rule sets the Diversion Request by the FBIIP Reservoir from the Milk River. This diversion is active from March 1 to October 31. The Diversion Request is set to the MINIMUM of the following four items:

1. The Milk River natural flow accruing through tributary inflows between Fresno Reservoir PLUS the FBIIP plus the Milk River natural flow at the Eastern Crossing MINUS the diversion requirement of the existing FBIIP acreage.
2. The maximum daily natural flow allocation as defined on the FBIIP Accounting data object MINUS the diversion requirement of the existing FBIIP acreage.
3. The maximum diversion capacity of the FBIIP Reservoir, currently set to 520 cfs.
4. The volume of empty space available for storage in the FBIIP Reservoir (maximum storage level is 60,000 AF).

FBIIP New Acreage Diversion Request: This rule sets the diversion from the FBIIP Reservoir to the FBIIP New Acreage object. This is set to the MINIMUM of the following three items:

1. The FBIIP New Acreage diversion requirement increased to cover the canal losses that occur between the reservoir and the new acreage.
2. The maximum capacity of the diversion canal between the FBIIP Reservoir and the FBIIP New Acreage water user object. This is currently set to 1000 cfs so as not to be a limitation.
3. The available water stored in the FBIIP Reservoir.

FBIIP Delivery to Existing Acreage: This rule augments the existing FBIIP acreage if the daily allocation of Milk River natural flow is insufficient to meet the diversion requirement. This occurs after stored water is delivered to the new FBIIP acreage. The Outflow slot of the FBIIP Reservoir is linked to the Return Flow slot on the Ft Belknap Reservation IP Canal:Canal Losses object. This is the point in the delivery canal just below the location where canal losses are removed. Essentially this water goes directly to satisfy the existing FBIIP acreage on the Fort Belknap Reservation Irrigation Project object. The delivery from the FBIIP Reservoir to augment the demands of the existing acreage is set to the MINIMUM of the following three items:

1. The sum of the Diversion Shortage slots on the Milk River Unit and White Bear Unit (existing acreage). This is the diversion request that is not met by direct diversion of Milk River natural flow.
2. The remaining water stored in the FBIIP Reservoir (deliveries to the new acreage have already been removed).
3. The remaining space in the Ft Belknap Reservation IP Diversion canal (the existing delivery canal from the river to the existing FBIIP acreage). This is currently 170 cfs MINUS the water already in the canal from the river.

Appendix F
Milk-St. Mary River System Basin Study: Data and Model Managers Manual

RECLAMATION

Managing Water in the West

Milk-St. Mary River System Basin Study

Data and Model Managers Manual

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Milk-St. Mary River System Basin Study

Data and Model Managers Manual

Introduction

A set of data and model managers (managers) were developed using Excel and Excel macros to support the Milk-St.Mary River System Basin Study (MSMRSBS). The managers are contained in several Excel 2007 macro workbooks. These workbooks contain worksheets and macros for automating the generation of climate change data, depletion computations, management of bias corrected hydrology, and managing RiverWare model runs. The hydrologic scenarios supported by the managers are five Ensemble Hybrid Delta (HDe) traces for two futures (2030 and 2050) plus the observed trace that is associated with all climate change traces. In addition, the RiverWare manager can run the existing historic trace.

The managers perform the functions tabulated and explained below. Figure 1 is a flow chart of data and model paths provided by the managers. Circles represent data stores (workbooks) and boxes represent applications on Figure 1.

1. Processing of climate change and observed data from NetCDF format into workbooks by timestep and parameter.
2. Computation of HDe traces for two futures and posting to workbooks by timestep and parameter.
3. Computation of monthly crop irrigation requirements (CIR's) and daily CIR fractions.
4. Computation of daily reservoir and river net evaporation rates.
5. Managing RiverWare model runs including creating of input data files by scenario, running model in batch mode, and posting model output to output scenarios workbooks.

Except for the RiverWare output file, workbooks are organized by parameter, climate change scenario, and future (if applicable). The scenarios in each file are labeled in Table 1.

Table 1. Climate change scenarios and worksheets in parameter workbooks.

Climate Change Scenarios	
Worksheet	Scenario
S0	Observed Data
S1	Lower Temperature Lower Precipitation
S2	Lower Temperature Higher Precipitation
S3	Higher Temperature Lower Precipitation
S4	Higher Temperature Higher Precipitation
S5	Central

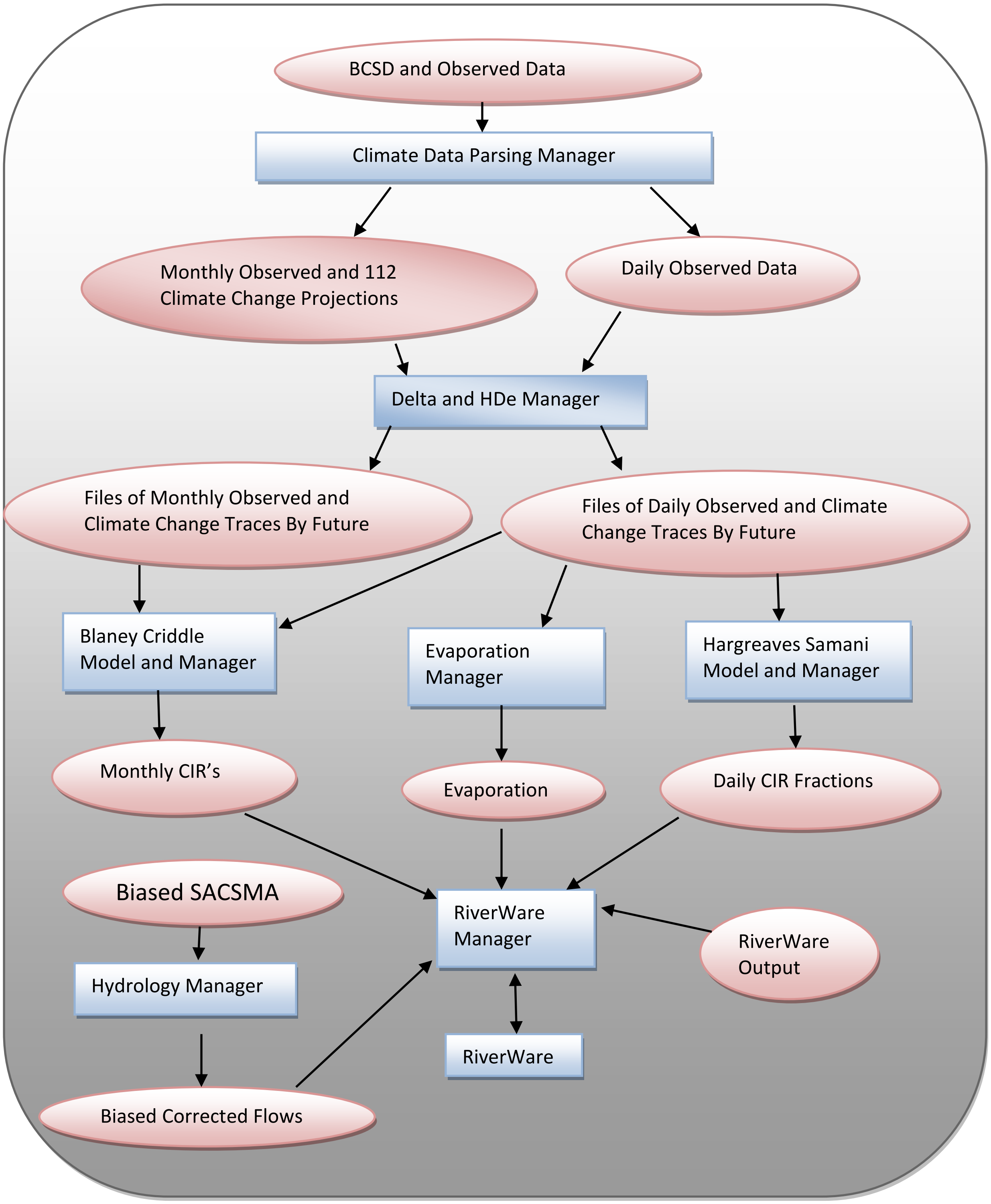


Figure 1. Milk data stores, managers, and models.

Getting Started

The manager workbooks mostly only contain data to support the given manager. All time series data are in binary files (NetCDF climate change data), text files (some SACSMA data) and workbooks. Typically, a given manager uses the Setup worksheet and/or a control worksheet. The setup worksheet is used to specify simulation periods, futures, scenarios, and folders and to run code associated with the manager. The control worksheet contains fully specified file paths associated with the choices selected on the setup worksheet. In some cases, these functionalities are combined on one worksheet. Examples of each manager's setup and control worksheets are provided later.

Input and output template workbooks were created to support the managers. These workbooks consist of header worksheets, data worksheets, and scenario indices. The header worksheets support data management interfaces (DMI 's), aggregations, and statistic computations. The data worksheets are time series scenario worksheets as noted in Table 1.

Using the managers consist of following steps:

1. Copy managers and template files to desired directories.
2. Create folders and environment needed to support the managers (Environmental Variables).
3. Install ET models.
4. Copy RiverWare model and ruleset to desired directory.
5. Download and unzip supporting software.
6. Open Excel and install necessary Add-In's.
7. Setup or obtain necessary supporting data.
8. Open desired managers and run applications.
9. Evaluate input and output data.

Managers Setup

The managers require a number of Office 2007 resources, environmental variables, RiverWare, and Excel Add-In's. Office 2007 includes multiple ways to enable user to run macros. See Excel help for additional information under "Trust Center", "Macros", and "Add-Ins". The simplest way to enable macros is to press "Trust Center" under "Excel Options", select "Trust Center Settings", and select "Enable all macros …" under "Macro Settings."

Environmental Variables

Three environmental variables are used by the manager or RiverWare Data Management Interfaces (DMI's). Environmental variables are useful for making applications more platform independent. Environmental variables used by the manager or RiverWare DMI's are listed below.

1. MILK_SOURCE_DIR - path to mother directory of MSMRSBS data and models. For example - "C:\fieldProjects\Milk". Required and suggested subdirectories of MILK_SOURCE_DIR are noted below.

2. RIVERWARE_DMI_DIR - path to mother directory of all RiverWare traditional DMI's. This environmental variable is required to run all conventional RiverWare DMI's. See RiverWare help file DMI.pdf for additional information. For example, "C:\dmidata".

3. RIVERWARE_HOME - path to version of RiverWare. For example - "C:\Program Files\CADSWES\RiverWare 6.0.5"

It is suggested that you create the directories associated with the MSMRSBS and managers as you create the environmental variables in the order above. After creating directory MILK_SOURCE_DIR, create folders "data" and "rwmodels". Under the "data" directory, create folders "climatechange" and "simulated". The managers can reside anywhere and can even be renamed. It is suggested that the managers reside in folder MILK_SOURCE_DIR\runScripts. The templates associated with the managers should reside in the same directory as the managers.
Create environmental variables using the System Properties utility. Convention is to name environmental variables in all capital letters. Under "Start", right click by "My Computer" ("Computer" on Windows 7 or Vista), and select "Properties" to see the dialog shown on Figure 2. Press "Environmental Variables" on the "Advanced" tab to see the dialog shown on Figure 3. Press "New" under user variables and enter the name and value of the environmental variable in the dialog shown on Figure 4. Press Ok on all dialogs as you exit them to create the environmental variable. Environmental variables are not known to applications until the application is re-instantiated. Therefore, exit Excel and reload it after creating the environmental variables for them to be known to the managers.

The climate data parser uses a DLL whose location is in the user's PATH environmental variable. File VbNc.dll can either be copied to an existing folder in user's PATH or be copied to where the managers are stored and that folder should be specified in the value of PATH. If an existing PATH variable exists, append it by adding a “:” and the path to the DLL. If not, press “New” and enter the path as shown on Figure 3.

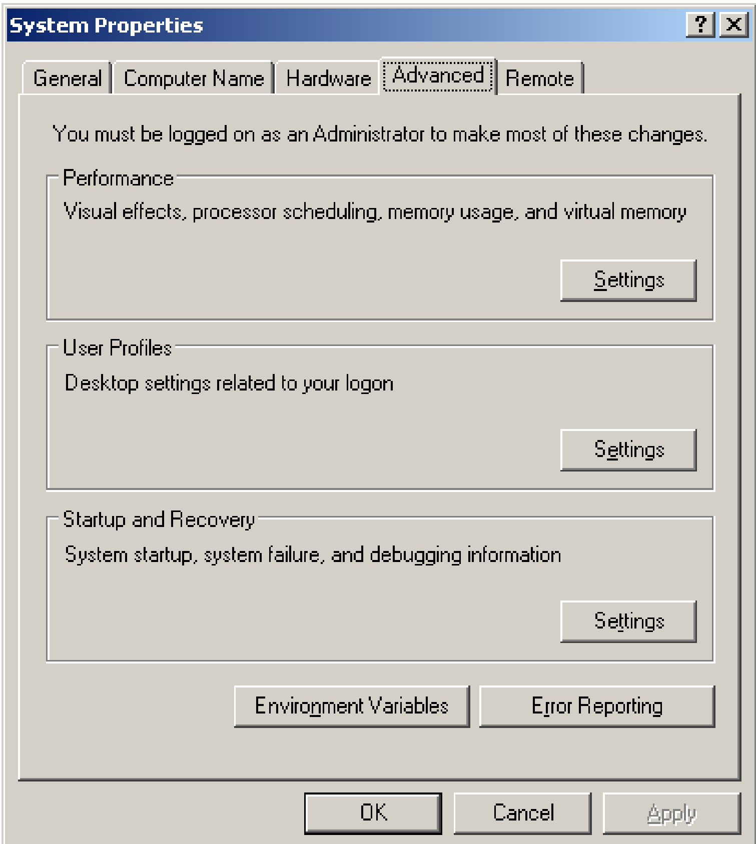


Figure 2. System Properties Dialog.

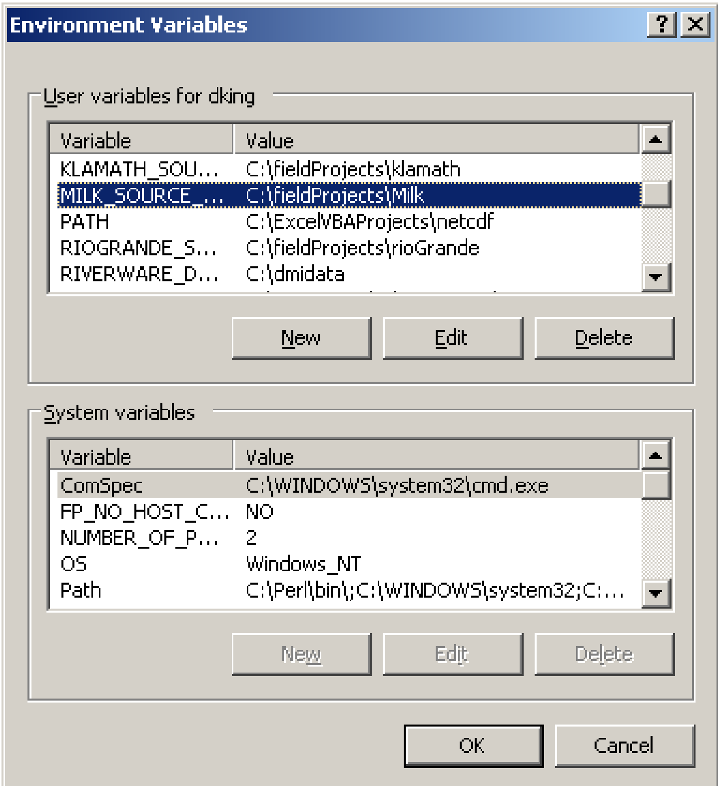


Figure 3. Environmental Variables Dialog.

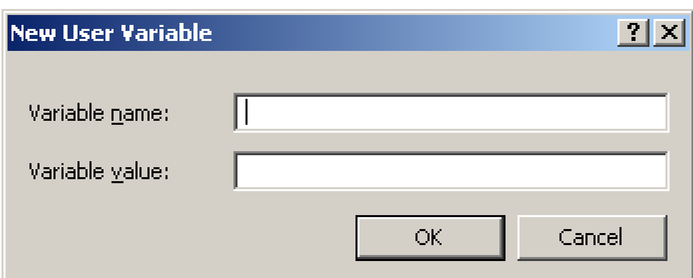


Figure 4. New User Variable Dialog.

Add-Ins and Supporting Software

The managers require Excel 2007 or newer. You must have Add-In's enabled and you must have the Developer tab visible in Excel. To make the Developer tab visible, check the "Show Developer tab in the Ribbon" option on the "Popular" tab of "Excel Options".

The time series data and DMI's used by the managers are specified using Header worksheets. These worksheets are equivalent to the Header worksheet created by RiverWare's XlWriter program that creates Excel output from RiverWare output. RiverWare's original Header worksheet was modified to specify DMI's and provide inormation for other utilities. Do not edit the data on any worksheet with a "Header" prefix nor any data on the data worksheet that the Header worksheet references. All multiple scenario workbooks are patterned after RiverWare Multiple Run Manager (MRM) output files. The observed trace is separated from the climate change traces. Most workbooks have two headers – "HeaderObs" and "HeaderCC" where the "HeaderCC" maps the climate change worksheets.

The managers require that two Office provided Add-In's be installed. Press the "Add-Ins" tab of "Excel Options", and then press the "Go" button at the bottom to see the dialog shown on Figure 5. Check the "Analysis ToolPak" and "Analysis ToolPak –VBA" boxes and "OK" to install these Add-In's. These Add-In's are used extensively by many applications and may already be installed.

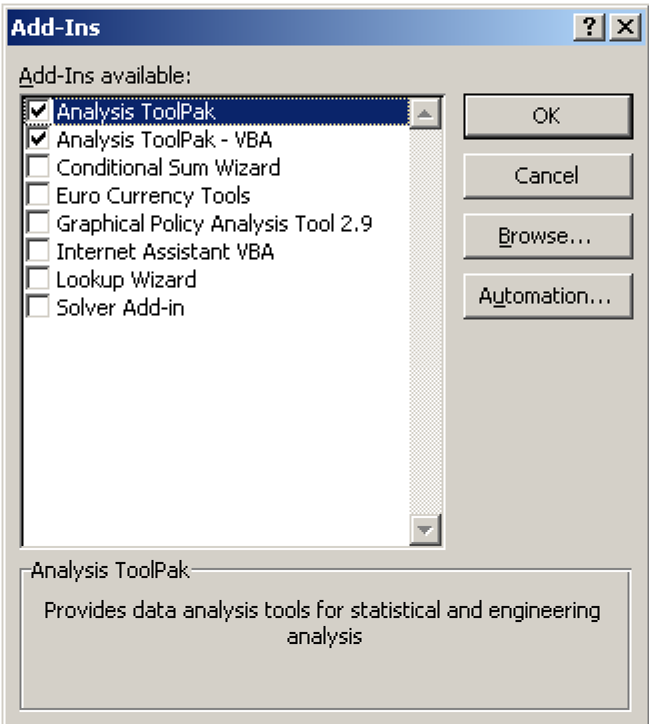


Figure 5. Excel Add-Ins Dialog.

The managers run the ET models and RiverWare in batch mode. The MSMRSBS RiverWare model at time of this document used RiverWare 6.0.5. As noted above, the RiverWare version must be specified using environmental variable "RIVERWARE_HOME". It is recommended that the PC have 4GB of memory and be set up to make to 3 GB available to applications. See RiverWare document "Performance.pdf" for additional information.

Some of the DMI's are run using the Data Utilities Toolkit (DUT). The DUT includes a number of aggregation, statistical, and DMI utilities. Both Add-In (.xlsa) and workbook (.xlsm) versions of the DUT exist. The DUT has a graphical user interface but DMI's can be run in batch mode from other Excel workbooks. The DUT is available at:

ftp://ftp.usbr.gov/tsc/jrieker/warsmp/dmiutils/dutaddin.zip

Managers Overview

The managers have two primary functions

1. Manage input and output data for data computations and model runs.

2. Manage data computation and model runs by climate change scenario and future.

A list of managers developed or used by the MSMRSBS are listed in Table 2.

Table 2. MSMRSBS Data and Model Managers.

Workbook	Description
DataUtilitiesToolkit.xlam or DataUtilitiesToolkit.xlsm	Data Utilities Toolkit - Various data management utilities oriented to data in RiverWare XlWriter format.
NetCDFBCSDManager.xlsm or MilkNetCDFBCSDManager.xlsm	Application to parse BCSD and Mauer observed data in NetCDF binary format and transform into Excel workbooks.
ClimateChangeAdjustsmentsManager MilkCCAdjustmentsManager.xlsm	Application to use Delta or HDe method to create five subsets of climate data from the 112 BCSD climate change projections.
BlaneyCriddleManager or MilkwaterUsersBlaneyCriddleManager.xlsm	Application to manage Blaney-Criddle monthly ET model runs using climate change scenarios.
HargreavesSamaniManager or MilkWaterUsersHargreavesSamaniManager.xlsm	Application to manage Hargreaves-Samani daily ET model runs using climate change scenarios.
MilkEvaporationManager.xlsm	Application to compute reservoir and river evaporation rates by climate change scenarios.
MilkDailyHydrologyManager.xlsm	Application to compute daily biased corrected flows as a function of monthly biased corrected flows, daily biased flows, and monthly biased flows for all climate change scenarios.
MilkRiverWareManager.xlsm	Application to manage RiverWare input data, run RiverWare, and manager RiverWare output data by climate change scenarios.

The managers operate using NetCDF binary files, SACSMA text file, workbooks, ET executables, RiverWare, RiverWare model and ruleset, environmental variables, DMI information specified in the workbooks, DMI information specified in the managers, and the file specifications on the controller worksheets. The workbooks used by the managers are described in Table 3. Most of the file names are automatic and are a function of the manager, parameter, specified folders, scenario, and future. Some file specifications such as the RiverWare base model and ruleset can be specified by user. These specifications do not require, but can be specified using environmental variables. Using a "$" in front of an environmental variable's name is a flag to the applications that an environmental variable is being used.

Table 3. Milk Climate Change Workbooks.

DailyObservedTemplate.xlsx	Template for storing daily observed (Maurer) data.
MonthlyBCSDTemplate.xlsx	Template for storing monthly BCSD and observed data.
BCSDCellsTemplate.xlsx	Template for setting up BCSD cells.
DailyCCTemplate.xlsx	Template for storing daily climate change data (HDe output).
MonthlyCCTemplate.xlsx	Template for storing monthly climate change data (HDe output).
BCMonthlyCropReportTemplate.xlsx	Template for posting of monthly crop CIR's for comparison of scenarios.
Annual2030RWOutput.xlsx	2030 future annual RiverWare output.
Annual2050RWOutput.xlsx	2050 future annual RiverWare output.
Daily2030RWOutput.xlsx	2030 future daily RiverWare output.
Daily2050RWOutput.xlsx	2050 future daily RiverWare output.
DailyCC2030Hydrology.xlsx	2030 future daily hydrology.
DailyCC2050Hydrology.xlsx	2050 future daily hydrology.
MilkEvapNodes2030DailyCCETP.xlsx	2030 daily potential evapotranspiration for evaporation nodes.
MilkEvapNodes2030DailyCCNetEvap.xlsx	2030 daily net evaporation for evaporation nodes.
MilkEvapNodes2030DailyCCPrcp.xlsx	2030 daily precipitation for evaporation nodes.
MilkEvapNodes2030DailyCCTMax.xlsx	2030 daily maximum temperature for evaporation nodes.
MilkEvapNodes2030DailyCCTMin.xlsx	2030 daily minimum temperature for evaporation nodes.
MilkEvapNodes2030DailyCCTotalEvap.xlsx	2030 daily total evaporation for evaporation nodes.
MilkEvapNodes2030MonthlyCCPrcp.xlsx	2030 monthly precipitation for evaporation nodes.
MilkEvapNodes2030MonthlyCCTAvg.xlsx	2030 monthly average temperature for evaporation nodes.
MilkEvapNodes2050DailyCCETP.xlsx	2050 daily potential evapotranspiration for evaporation nodes.
MilkEvapNodes2050DailyCCNetEvap.xlsx	2050 daily net evaporation for evaporation nodes.
MilkEvapNodes2050DailyCCPrcp.xlsx	2050 daily precipitation for evaporation nodes.
MilkEvapNodes2050DailyCCTMax.xlsx	2050 daily maximum temperature for evaporation nodes.
MilkEvapNodes2050DailyCCTMin.xlsx	2050 daily minimum temperature for evaporation nodes.
MilkEvapNodes2050DailyCCTotalEvap.xlsx	2050 daily total evaporation for evaporation nodes.
MilkEvapNodes2050MonthlyCCPrcp.xlsx	2050 monthly precipitation for evaporation nodes.

MilkEvapNodes2050MonthlyCCTAvg.xlsx	2050 monthly average temperature for evaporation nodes.
MilkEvapNodesCellsData.xlsx	Evaporation nodes cells data.
MilkEvapNodesDailyObserved.xlsx	Evaporation nodes daily oberved data.
MilkEvapNodesHDeMethodComputations.xlsx	Evaporation nodes HDe workbook.
MilkEvapNodesMonthlyBCSDPrcp.xlsx	Evaporation nodes monthly BCSD and observed precipitation.
MilkEvapNodesMonthlyBCSDTAvg.xlsx	Evaporation nodes monthly BCSD and observed average temperatures.
MilkWaterUsers2030DailyCCNIR.xlsx	2030 future daily net irrigation requirements for water user nodes.
MilkWaterUsers2030DailyCCPrcp.xlsx	2030 future daily precipitation for water user nodes.
MilkWaterUsers2030DailyCCTMax.xlsx	2030 future daily maximum temperature for water user nodes.
MilkWaterUsers2030DailyCCTMin.xlsx	2030 future daily minimum temperature for water user nodes.
MilkWaterUsers2030DailyCIRFractions.xlsx	2030 future daily CIR fractions for water user nodes.
MilkWaterUsers2030FrostDates.xlsx	2030 future frost dates for water user nodes.
MilkWaterUsers2030MonthlyCCDepletion.xlsx	2030 future monthly depletion for water user nodes.
MilkWaterUsers2030MonthlyCCNIR.xlsx	2030 future monthly net irrigation requirement for water user nodes.
MilkWaterUsers2030MonthlyCCPrcp.xlsx	2030 future monthly precipitation for water user nodes.
MilkWaterUsers2030MonthlyCCTAvg.xlsx	2030 future monthly average temperatures for water user nodes.
MilkWaterUsers2050DailyCCNIR.xlsx	2050 future daily net irrigation requirements for water user nodes.
MilkWaterUsers2050DailyCCPrcp.xlsx	2050 future daily precipitation for water user nodes.
MilkWaterUsers2050DailyCCTMax.xlsx	2050 future daily maximum temperature for water user nodes.
MilkWaterUsers2050DailyCCTMin.xlsx	2050 future daily minimum temperature for water user nodes.
MilkWaterUsers2050DailyCIRFractions.xlsx	2050 future daily CIR fractions for water user nodes.
MilkWaterUsers2050FrostDates.xlsx	2050 future frost dates for water user nodes.
MilkWaterUsers2050MonthlyCCDepletion.xlsx	2050 future monthly depletion for water user nodes.
MilkWaterUsers2050MonthlyCCNIR.xlsx	2050 future monthly net irrigation requirement for water user nodes.
MilkWaterUsers2050MonthlyCCPrcp.xlsx	2050 future monthly precipitation for water user nodes.

MilkWaterUsers2050MonthlyCCTAvg.xlsx	2050 future monthly average temperatures for water user nodes.
MilkWaterUsersCellsData.xlsx	Water users nodes cells data.
MilkWaterUsersDailyObserved.xlsx	Water user nodes daily observed data.
MilkWaterUsersHDeMethodComputations.xlsx	Water user nodes HDe workbook.
MilkWaterUsersMonthlyBCSDPrcp.xlsx	Water user nodes monthly BCSD and observed precipitation.
MilkWaterUsersMonthlyBCSDTAvg.xlsx	Water user nodes monthly BCSD and observed average temperatures.
Monthly2030RWOutput.xlsx	2030 future daily RiverWare output.
Monthly2050RWOutput.xlsx	2050 future daily RiverWare output.
MonthlyCC2030Hydrology.xlsx	2030 future hydrology.
MonthlyCC2050Hydrology.xlsx	2050 future hydrology.
MilkInputData.xlsx	RiverWare input data workbook.
MilkInputDataTemplate.xlsx	RiverWare input data template.
MilkOutputData.xlsx	RiverWare output data workbook.
MilkOutputTemplate.xlsx	RiverWare output data template.
MilkHistoricInputData.xlsx	Historic data RiverWare input data workbook.
MilkHistoricOutputData.xlsx	Historic data RiverWare output data workbook.

Managers Application

The following sections provide information and instructions on using all of the managers. To the extent possible, the managers use a common look and feel. In addition, to avoid excessive file navigation, most files are automatically named based on the specific manager's function and a minimum of user input. Although this reduces user flexibility to some extent, it also reduces user inputs. The user can always rename a given file for archiving purposes after runs are completed.

Climate Data Parsing Manager

The climate data parsing manager parses observed and climate data from NetCDF files into Excel workbooks. NetCDF files are a binary format used extensively for climate data. Observed and climate change projections for 1/8 degree cells are obtained at:

gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#Data%3A%20Subset%20Request

Bias corrected spatially disaggregated (BCSD) climate change data are available at this site for 112 projections. The data are monthly average temperatures and monthly precipitation.

The manager parses data from the NetCDF files for a set of target nodes specified by the user with one of two methods – the closest cell or the weighted four closet cells. The WWCRADS used the latter approach. When a target node exactly corresponds to source cell, the output values will be the same using either approach. Output of the climate data parsing manager are three daily observed workbooks containing maximum temperature, minimum temperature, and precipitation and two workbooks containing monthly observed and 112 BCSD traces of average temperatures and precipitation. The flow of data is shown on Figure 6.

The manager's menu is shown on Figure 7 which is located on the "Controller" worksheet in the manager workbook. Use the following steps to process a data set:

1. Specify BCSD climate change and monthly observed data, and if used, daily observed data on the website. Be sure to specify NetCDF format.

2. Download and unzip data after email notification.

3. Specify if daily and wind data are being processed.

4. Specify folders and files either using the buttons provided or directly on the 'Contoller' worksheet.

5. Open BCSD cells template and specify target latitudes and longitudes on worksheet 'TargetNodes', then copy equations of columns E through R for specified number of for specified number of output nodes/cells. An example "TargetNodes" worksheet is shown on Figure 7.

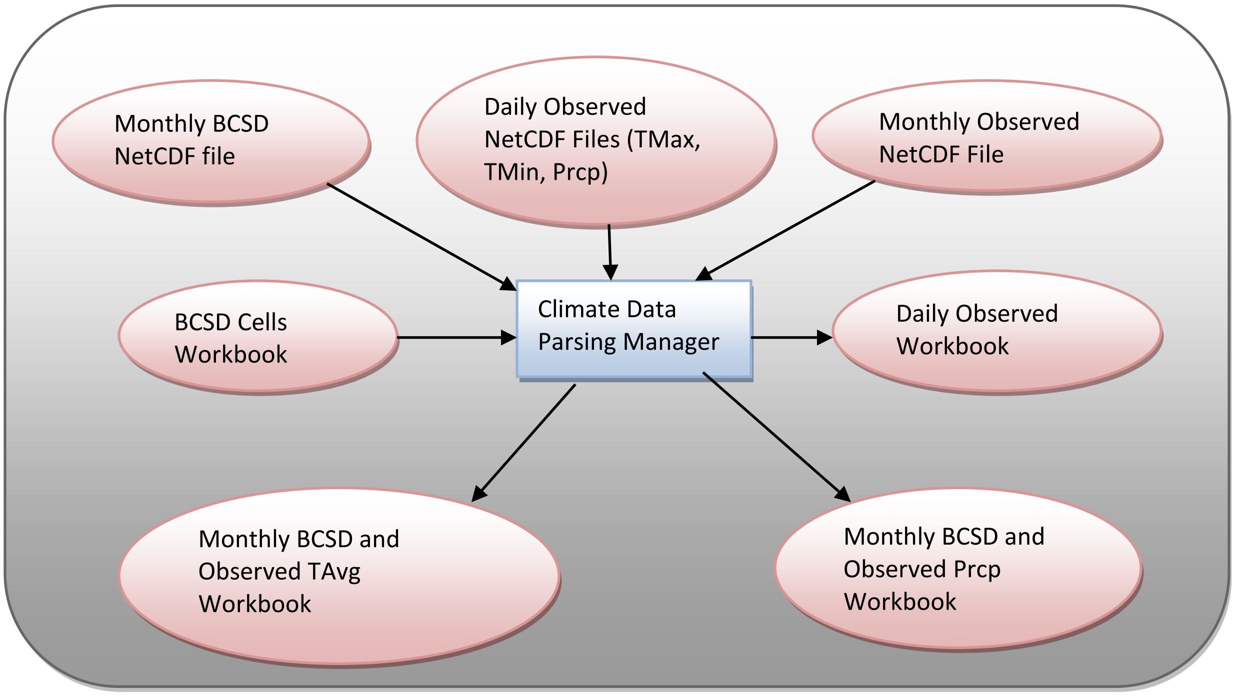


Figure 6. Climate Data Parsing Manager Data Paths.

6. Specify slot (site) numbers for output workbooks. These need to be continuous in cells and data workbooks but not all cells need to exist in the netCDF files. Those can be done in groups to create a continuous dataset in the output workbooks before running the D/HDe application. Because the application has memory limitations, it may be necessary to pull multiple sets of NetCDF data and post data to a common set of output files. The target node names and slot numbers will correspond to the object names posted to the output files as shown on Figure 9.

7. Import downloaded cell latitudes and longitudes using button 'Inventory Cell Lat Longs' which get posted to worksheet 'SourceCells'.

8. Double check equations on 'TargetNodes' worksheet and review cell locations on worksheet 'GridCellPlots'. An example gird cells plot is shown on Figure 10.

9. Post desired data using method of choice (closest or weighted) to output workbooks. Be sure to use the same method for all output. A cell that coincides with a target node will use that cells values regardless of method selected.

Log file ncdfparser.log can be used to troubleshoot runs that failed. Multiple setups can be stored on new worksheets in this workbook and copied to the controller worksheet for a given application. BCSD queries should be limited to five squares degrees or 320 cells. Multiple BCSD queries can be parsed to create one set of workbooks. Maximum practical workbook size limits the number of target cells to around 130 cells.

BCSD NetCDF Manager	
Specify Templates Folder	Revise All Specifications
Inventory Cell Lat Longs	Revise NetCDF Specifications
Open User Cells Workbook	Revise Output WB Specifications
Post Closest Cells of BCSD Data To WB	Post Weighted Cells of BCSD Data To WB
Post Closest Cells of Observed Monthly To WB	Post Weighted Cells of Observed Monthly To WB
Post Closest Cells of Observed Daily To WB	Post Weighted Cells of Observed Daily To WB
Open Monthly Temperatues WB	Open Monthly Precipitation WB
Open Daily Observed WB	Open All Output Workbooks

Item	Specification
Daily Data Flag (TRUE or FALSE)	TRUE
Wind Flag (TRUE or FALSE)	FALSE
Templates Folder	C:\ExcelVBAProjects\ClimateChange\
Output Folder	C:\warsmp\climatechange\netcdf\
Output Prefix	My
Climate Change NetCDF Path	C:\warsmp\climatechange\netcdf\bcsd\Extraction_TavgPrcp.nc
Observed Monthly NetCDF Path	C:\warsmp\climatechange\netcdf\1_8obs\Extraction_TavgPrcp.nc
Observed Daily Precipitation NetCDF Path	C:\warsmp\climatechange\netcdf\1_8obs_daily\milk_pr_subset.nc
Observed Daily Max Temperature NetCDF Path	C:\warsmp\climatechange\netcdf\1_8obs_daily\milk_tasmax_subset.nc
Observed Daily Min Temperature NetCDF Path	C:\warsmp\climatechange\netcdf\1_8obs_daily\milk_tasmin_subset.nc

Figure 7. Climate Data Parsing Manager Controller Worksheet.

Target Node Name	Target Slot Number	Latitude	Longitude	Used With Current Group of Cells	Closest Cell Distance	Closest Cell Number	Closest Cell Weight	2nd Closest Cell Distance	2nd Closest Cell Number	2nd Closest Cell Weight	3rd Closest Cell Distance	3rd Closest Cell Number	3rd Closest Cell Weight	4th Closest Cell Distance	4th Closest Cell Number	4th Closest Cell Weight
Node 1	1	48.9730	-113.0470	TRUE	0.039	4	0.72986	0.091	7	0.13274	0.115	5	0.08265	0.141	8	0.05476
Node 2	2	48.8910	-112.8900	TRUE	0.066	5	0.41171	0.090	6	0.22270	0.092	2	0.21609	0.110	3	0.14950
Node 3	3	49.0625	-113.0313	TRUE	0.031	7	0.90000	0.094	8	0.10000	0.129	4	0.00000	0.156	5	0.00000
Node 4	4	48.8125	-112.9375	TRUE	0.000	2	1.00000	0.125	1	0.00000	0.125	1	0.00000	0.125	1	0.00000
Node 5	5	48.7000	-112.9500	FALSE	0.113	2	0.46759	0.159	1	0.23668	0.178	3	0.18981	0.238	5	0.10592
Node 6	6	48.8125	-112.8000	FALSE	0.013	3	0.97781	0.126	6	0.00968	0.138	2	0.00808	0.186	5	0.00442
Node 7	7	48.6250	-112.7000	FALSE	0.219	3	0.44131	0.303	2	0.23045	0.332	6	0.19128	0.393	5	0.13696

Figure 8. Example "TargetNodes" Worksheet.

Name	Owner	Description	Creation Date	Number of Runs	Number of Slots	Number of Timesteps	Orientation	Source Book	Source Path	Source Header
N/A			5/11/2011 7:39	5	4	600	Runs	N/A	N/A	N/A
Run #	**Start**	**End**	**Timestep Unit**	**Unit Quantity**	**Timesteps**	**Consecutive**	**Index Sequential**		**Worksheet**	**DMI Path**
Run0	1/1950	12/1999	month	1	600	0	0		S1	
Run1	1/1950	12/1999	month	1	600	0	0		S2	
Run2	1/1950	12/1999	month	1	600	0	0		S3	
Run3	1/1950	12/1999	month	1	600	0	0		S4	
Run4	1/1950	12/1999	month	1	600	0	0		S5	
Slot #	**Object Type**	**Object Name**	**Slot Name**	**Units**	**Scale**	**Separator**	**Station**	**Paramete**	**DMI Flag**	**DMI Scale**
Slot0		Node 1	Precipitation	inches/month	1	.				
Slot1		Node 2	Precipitation	inches/month	1	.				
Slot2		Node 3	Precipitation	inches/month	1	.				
Slot3		Node 4	Precipitation	inches/month	1	.				

Figure 9. Example Multiple Run Header Worksheet.

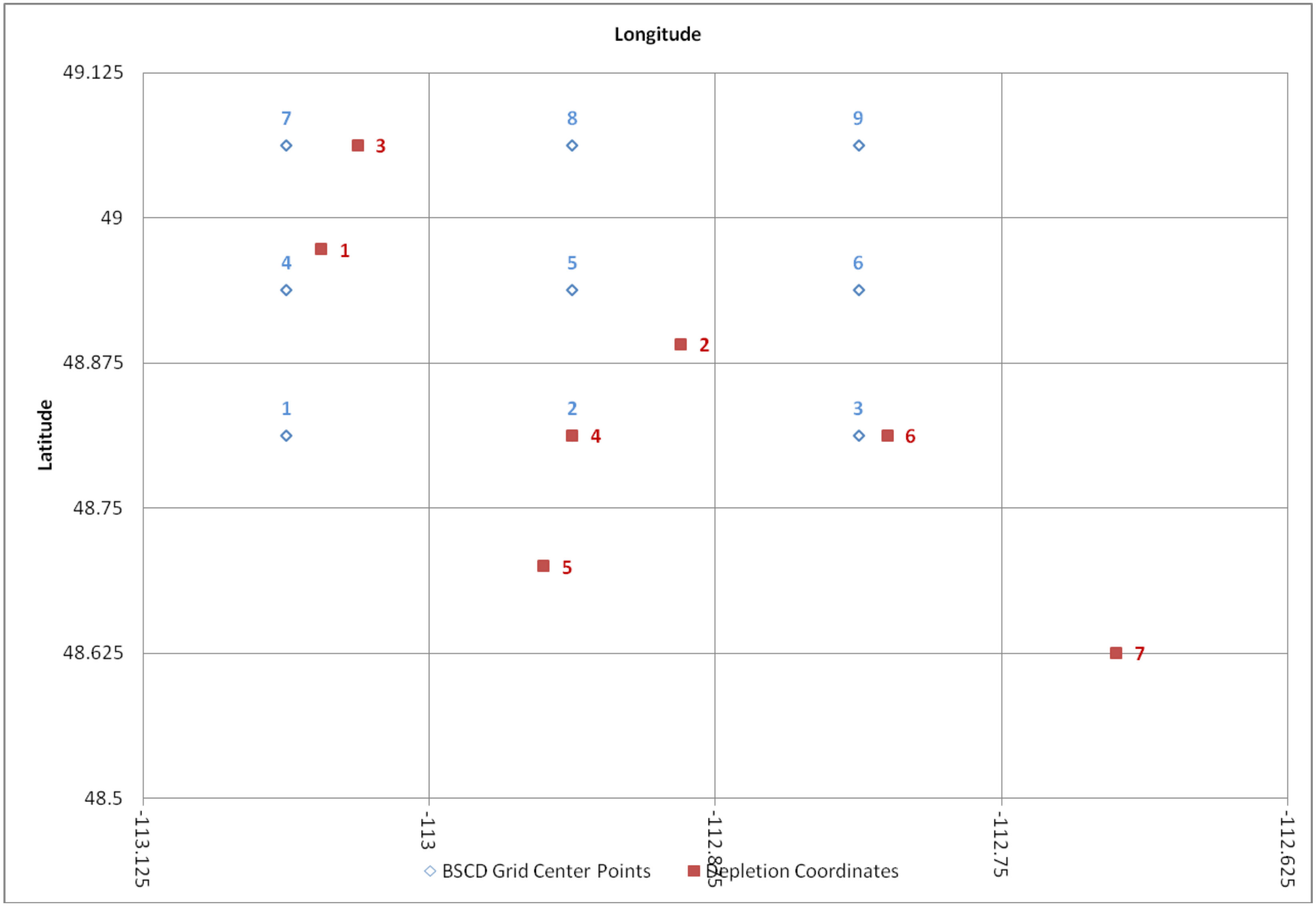


Figure 10. Example Grid Cells Plot.

Delta and HDe Manager

The delta and HDe manager processes the 112 BCSD projections into the five quadrants of climate change scenarios listed in Table 1 for up to three futures (the MSMRSBS used two futures to be consistent with SACSMA runs). This manager also transforms the observed trace into the same format. The MSMRSBS used the HDe method.

Output of the manager for each future are three daily workbooks containing observed and five HDe traces of maximum temperature, minimum temperature, and precipitation and two monthly workbooks containing observed and five HDe traces of average temperature and precipitation. The flow of data is shown on Figure 11.

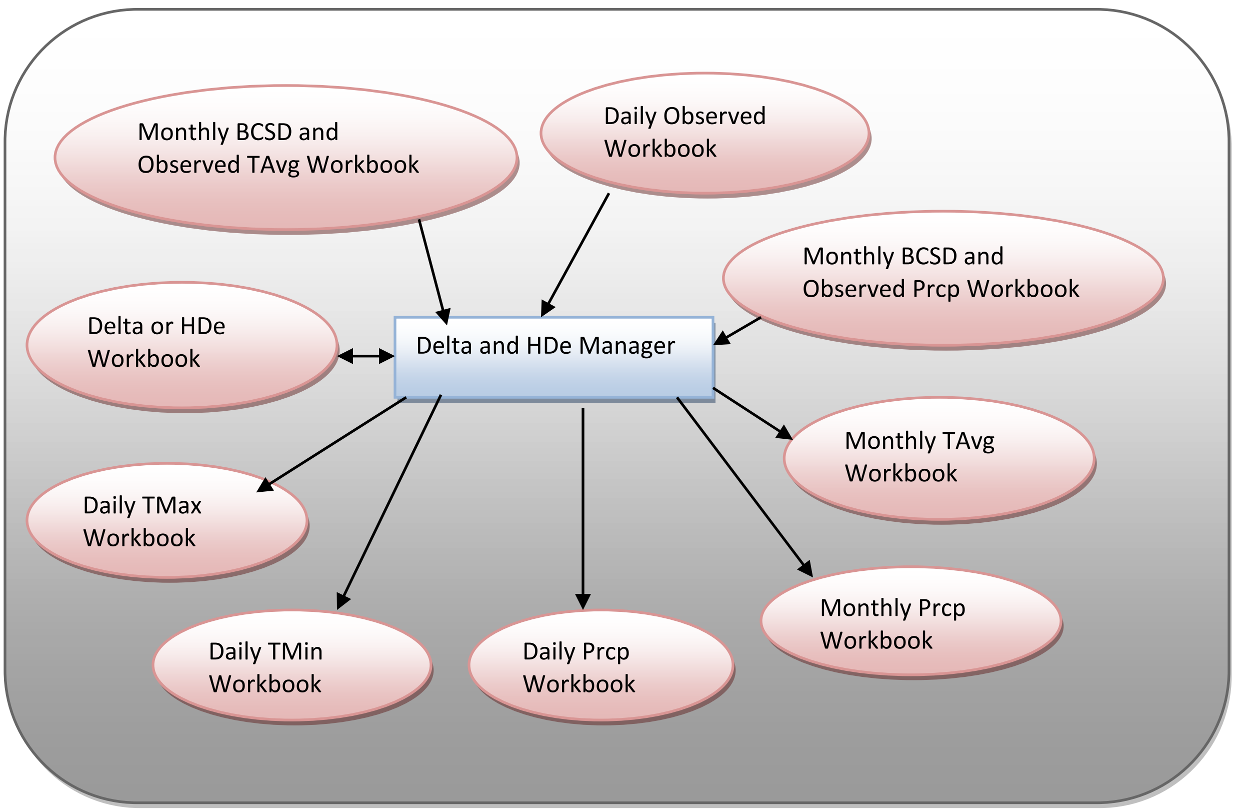


Figure 11. Delta and HDe Manager Data Paths.

The Delta and HDe manager requires several user specifications on the "Controller" worksheet of the manager workbook as shown on Figure 12. Each quadrant of climate data for the Delta method is sampled from a single climate projection. These can be selected automatically or manually. However, manual selection requires the user to run all nodes and futures individually.

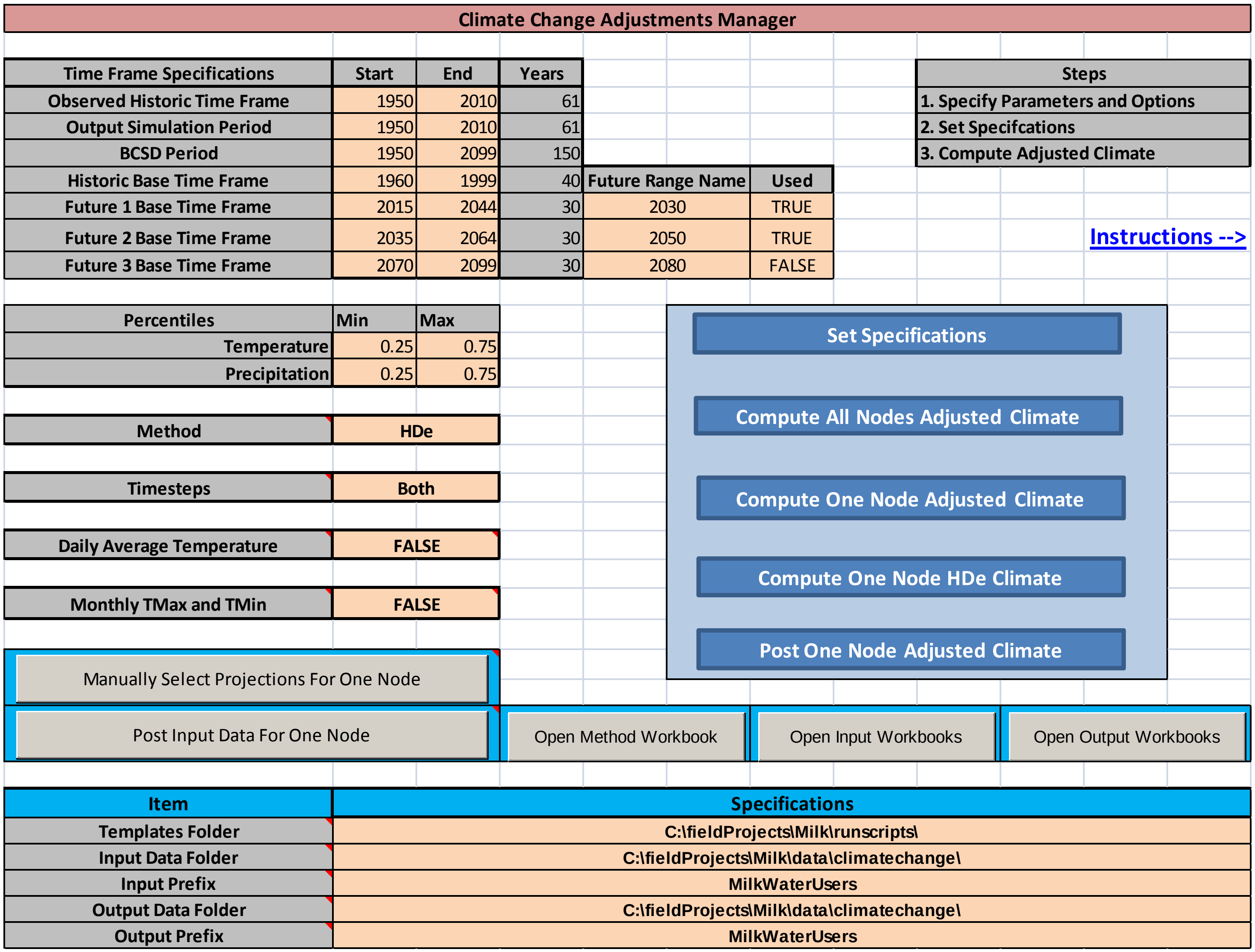


Figure 12. Delta and HDe Manager Menu.

The Ensemble Hybrid Delta (HDe) method computes climate change traces for each quadrant using the criteria specified on the “Controller” worksheet with an ensemble of projections from each quadrant. After specifying the desired method and data on the ”Controller” worksheet, set the specifications at the bottom of the worksheet using the “Set Specifications” button or manually entering the values. Then process one node for future or all nodes for one future. Each future needs to be run separately and output files will be named automatically using the future in the name (see Table 3 for example filenames).

The method workbooks can be opened but will always contain data of last node and setup that was run. Therefore, to view data of a specific node, use the one node, one future approach before viewing the method workbook. The “Controller” worksheet information are posted to the “UserInput” worksheet of the method workbook and the climate data are posted to the “TCalcs”, “PCalcs”, and “Observed” worksheets. Adjustment factors and adjusted values are one worksheet “MonthlyFactors”. The manager applies the adjustment factors to the observed data for the simulation period specified on the “Controller” worksheet and posts the results to the output workbooks.

HDe computations are memory and CPU intensive. It can take several hours to compute one future for a set of nodes. Currently, all computations are done in the workbooks. In addition, maximum practical workbook size limits the number of BCSD target cells to around 130 cells. However, the HDe output workbooks are considerably smaller and can be merged up to around practical limit of around 260 nodes.

Blaney Criddle Manager

The Blaney Criddle manager facilitates computation of monthly net irrigation requirement (NIR) and/or depletions. The manager can compute one scenario for one future, all scenarios for one future, or all scenarios for all futures. Output of the manager for each future are workbooks containing observed and five HDe traces of monthly crop irrigation requirement (CIR aka NIR) and optionally, crop irrigation demand as a flow. In addition, files of spring and fall frost dates are produced if user selects the frost dates options. The flow of data is shown on Figure 13.

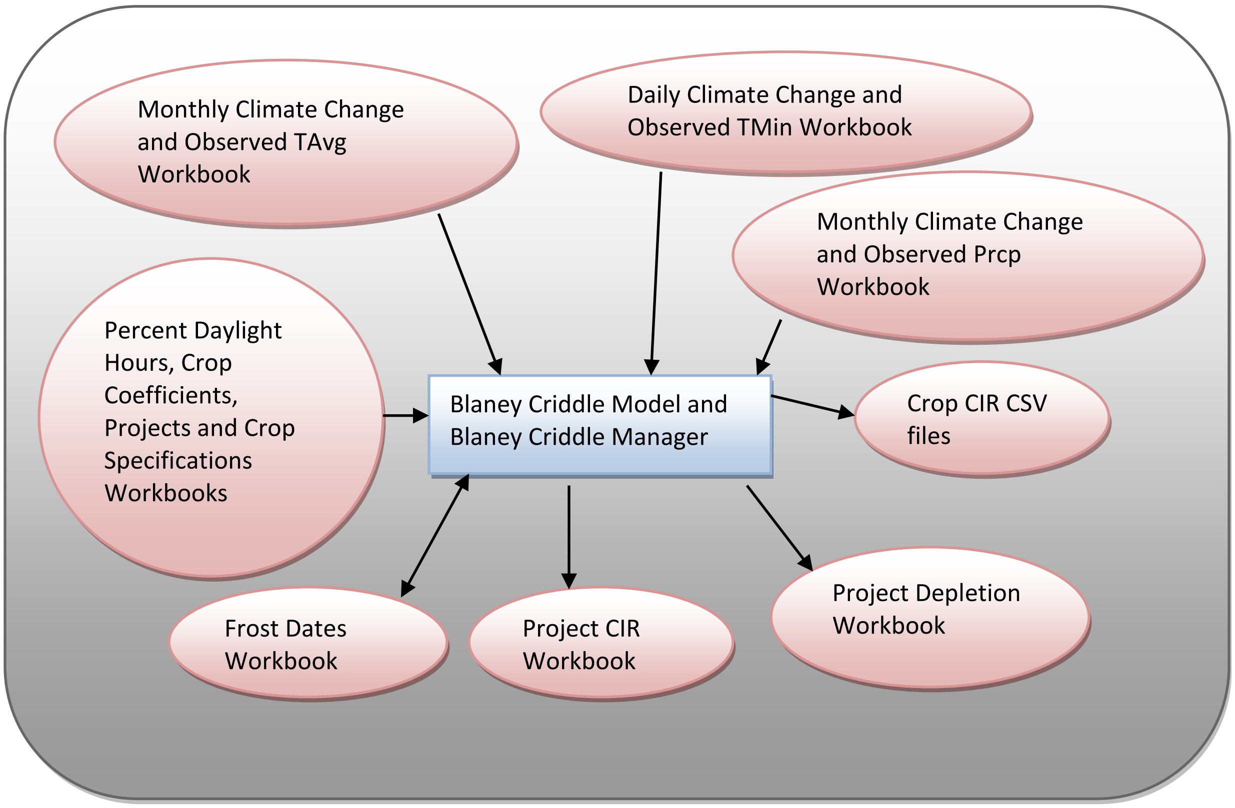


Figure 13. Blaney Criddle Manager Data Paths.

The Blaney Criddle manager handles the climate change scenarios and runs the Blaney Criddle model in batch mode. Download the Blaney Criddle model at:

ftp://ftp.usbr.gov/tsc/jrieker/utilities/blaneycriddle/bc4.0install.zip

If Net Framework 4 or Windows Installer 4.5 do not exist on users PC, the install will require admin rights. Otherwise, the install can be done without admin rights. It is recommended that an initial install be done using an admin account, then uninstall Blaney Criddle and reinstall it without an admin account. Then future updates can be installed without admin rights.
To do the install, unzip file bc4install.zip maintaining the directory structure to a temporary folder. Then run “setup.exe” in folder “c:\vbnetprojects\deployments\BlaneyCriddle4.0”. Net Framework 4 and Windows Installer 4.5 are installed from a Microsoft site, requiring an

internet connection, and can take some time. The Blaney Criddle install is very quick. The model will attempt to run after the install and request the name of a control file. You can either navigate to the example control file contained in bc4install.zip or the Blaney Criddle Manager. After specifying the name of the control file, user is prompted for name of worksheet that contains control specifications. The name of the control worksheet in the example control file is “control”. The name of the control worksheet in the manager is “BCControl”. An example “BCControl” worksheet is shown on Figure 14.

1950	Start Year		**<--- Blaney Criddle control specifications are lines 1 through 17, columns 1 though 3.**
1999	End Year		**Future Being Run**
1	Crop Mix Type: 0 is variable; 1 is constant		2020
1	Effective Precipitation Method: 1 is SCS; 2 is USBR		
1	Blaney Criddle Method: 1 is modified; 2 is original		
0	Frost Data Source: 0 is estimated; 1 is user provided		See file specification below.
0	Cropping Pattern Type: 0 is fraction; 1 is acres		
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	Projects	Projects data. Can reside in another workbook.
xls	C:\warsmp\climatechange\netcdf\My2020MonthlyCCTAvg.xlsx	S5	Average temperature data.
xls	C:\warsmp\climatechange\netcdf\My2020MonthlyCCPrcp.xlsx	S5	Precipitation data.
N/A			Frost data file. Enter 1 in cell A6 to use. Enter N/A as file type (column 1) and nothing as file path to not use. Frost dates are computed on the fly using data in daily minimum temperatures file. Therefore, they can only be used if those data exist.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	PercDaylightHrs	Percennt daylight hours as a function of latitude. Can reside in another workbook.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	BCCropCoefs	Blaney Criddle Crop Coefficients. Can reside in another workbook.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	Fractions	Cropping Pattern as percent or acres. Can reside in another workbook.
text	C:\warsmp\climatechange\netcdf\My2020bcreport.txt		Automatic output. Summary of Blaney Criddle run.
xls	C:\warsmp\climatechange\netcdf\My2020MonthlyCCNIR.xlsx	S5	Project net irrigation requirement. Optional output. Enter N/A as file type (column 1) and nothing as file path to exclude.
N/A			Project depletions. Optional output but requires acres on 'Total' lines of 'Fractions' worksheet. Enter N/A as file type (column 1) and nothing as file path if not used.

Figure 14. Blaney Criddle Manager “BCControl” worksheet.

The Blaney Criddle model uses several required and one optional input. Some output is automatic but project CIR’s and depletions are optional outputs – user should specify one or the other or both. The primary input choice to make is whether to use user provided frost dates or estimated frost dates. If daily minimum temperatures are available, it is recommended that user provided frost dates option be used. If that approach is used, the Blaney Criddle manager computes the frost dates before running the Blaney Criddle model.

Percent daylight hours as a function of latitude are provided with the install and the manager (worksheet “PercDaylightHours”) as are crop curve files (worksheet “BCCropCoefs”). Example crop specifications are provided on worksheet “Fractions” in the manager workbook and shown on Figure 15. Cropping patterns can be provided as either fractions or areas in acres and a constant crop mix or a variable crop mix can be used.

The remaining input is the projects data worksheet. This is a list of depletion nodes and data associated with those. The terms project, node, unit, and water user are used synonymously in this discussion. An example data set is on the “Projects” worksheet in the manager workbook and a specification for one project is shown on Figure 16.

Year	Unit	Crop Name	Acres Percent	Crop Number	Spring Frost Flag	Fall Frost Flag	Wakeup Temperature	Shutdown Temperature	Begin Month	Begin Day	End Month	End Day	Growing Season	Node Number
9999	Node 1	ALFALFA	0.4059	1	0	1	50	28	1	1	10	20	365	1
9999	Node 1	PASTURE	0.4752	2	0	2	45	45	1	1	12	31	365	1
9999	Node 1	CORN_GRAIN	0.0396	11	0	2	55	32	5	13	10	11	140	1
9999	Node 1	ORCHARD_WO_COVER	0.0793	3	0	2	50	45	1	1	12	31	365	1
9999	Node 1	Total	5900.0000	1.0000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1
9999	Node 2	ALFALFA	0.5600	1	0	1	50	28	1	1	10	20	365	2
9999	Node 2	PASTURE	0.3000	2	0	2	45	45	1	1	12	31	365	2
9999	Node 2	CORN_GRAIN	0.0500	11	0	2	55	32	5	13	10	11	140	2
9999	Node 2	ORCHARD_WO_COVER	0.0900	3	0	2	50	45	1	1	12	31	365	2
9999	Node 2	Total	4000.0000	1.0000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	2
9999	Node 3	ALFALFA	0.5600	1	0	1	50	28	1	1	10	20	365	3
9999	Node 3	PASTURE	0.3000	2	0	2	45	45	1	1	12	31	365	3
9999	Node 3	CORN_GRAIN	0.0500	11	0	2	55	32	5	13	10	11	140	3
9999	Node 3	ORCHARD_WO_COVER	0.0900	3	0	2	50	45	1	1	12	31	365	3
9999	Node 3	Total	3000.0000	1.0000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	3
9999	Node 4	ALFALFA	0.5600	1	0	1	50	28	1	1	10	20	365	4
9999	Node 4	PASTURE	0.3000	2	0	2	45	45	1	1	12	31	365	4
9999	Node 4	CORN_GRAIN	0.0500	11	0	2	55	32	5	13	10	11	140	4
9999	Node 4	ORCHARD_WO_COVER	0.0900	3	0	2	50	45	1	1	12	31	365	4
9999	Node 4	Total	5000.0000	1.0000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	4

Figure 15. Example Blaney Criddle crop specifications worksheet.

Node 1	Node 1 Big Sky Montana	Description		
Node 1	Node 1	Net Irrigation Requirement	inches	
Node 1	Node 1	Crop Demand	acre-feet/month	
Node 1	3	Application Depth		
Node 1	0	Mean Elevation	A value of 0.0 is a flag to not use this functionality	
Node 1	14080103	HUC		
Node 1	Big Sky	County		
Node 1	Montana	State		
Node 1	48.9730	Latitude		
Node 1	1	Number of temperature stations		
Node 1	1	Number of precipitation stations		
Node 1	100	Node 1	Average Temperature	F
Node 1	100	Node 1	Precipitation	inches

Figure 16. Example Blaney Criddle project specifications worksheet.

The example project data shows the climate stations using the same names as the depletion nodes. This is not required as long as the climate station names match those in the climate data files. Typically, the climate station names are associated with an existing meteorological station whereas the project names are associated with depletion units. The manager workbook includes a "Nodes" worksheet. This worksheet is not used by the manager or by the model but was used to facilitate setting up the project and crop specifications.

The percent daylight hours, crop coefficients, crop specifications, and project specifications do not have to reside in the manager workbook. If they will reside elsewhere, edit the appropriate file paths and worksheets on the "BCControl" worksheet. However, do not edit the time series file paths and worksheets because those are automatically generated from data on the "Setup" worksheet and the future being run.

After specifying these data (the non time series data), set up the simulation period and futures on the "Setup" worksheet as shown on Figure 17. Then set the specifications using the "Set Specifications" button or manually entering the values at the bottom of the worksheet. Finally, compute project CIR's and/or depletions which can be done for one scenario and one future, all scenarios and one future, or for all scenarios and all futures. To run one scenario for one future, use the scroll bar to select the scenario and press "Run One Blaney Criddle". To run all scenarios for one future, set all of the "Used" futures except one to false and press "Run All

Blaney Criddle”. To run all scenarios for all futures, set all desired futures to “True” and press “Run All Blaney Criddle”.

Blaney Criddle Manager							
Depletion Period	Start Year	1950	End Year	1999		Future Range Name	Used
Worksheet	Climate Change Scenario					2030	TRUE
S0	Observed					2050	TRUE
S1	Lower Temperature Lower Precipitation					2080	FALSE
S2	Lower Temperature Higher Precipitation				Steps		
S3	Higher Temperature Lower Precipitation				1. Set up period, projects and crops		
S4	Higher Temperature Higher Precipitation				2. Set specifcations		
S5	Central				3. Compute depletions		
Scenario To Run	Set Specifications				Import Crop CIR's		
S5							
S0, S1, S2, S3, S4, S5	Run One Blaney Criddle				Open Input Workbooks		
	Run All Blaney Criddle				Open Output Workbooks		

Item	Specifications
Templates Folder	C:\ExcelVBAProjects\ClimateChange\
Input Data Folder	C:\fieldprojects\Milk\data\climatechange\
Input Prefix	MilkWaterUsers
Output Data Folder	C:\fieldprojects\Milk\data\climatechange\
Output Prefix	MilkWaterUsers

Figure 17. Blaney Criddle Manager Menu.

The primary intended output of the Blaney Criddle model is project CIR’s and/or depletions. However, crop by crop CIR’s are posted to CSC files. These files include crop evapotranspiration, effective precipitation, and crop irrigation requirement. A workbook for analyzing these data can be generated using the “Import Crop CIR’s” button.

Hargreaves Samani Manager

The Hargreaves Samani manager facilitates computation of daily CIR and CIR fractions. The manager can compute one scenario for one future, all scenarios for one future, or all scenarios for all futures. Output of the manager for each future are workbooks containing observed and five HDe traces of daily project CIR[2] and CIR fractions. The CIR fractions are the ratio of the 7-day running average CIR divided by the equivalent monthly CIR. The flow of data is shown on Figure 18.

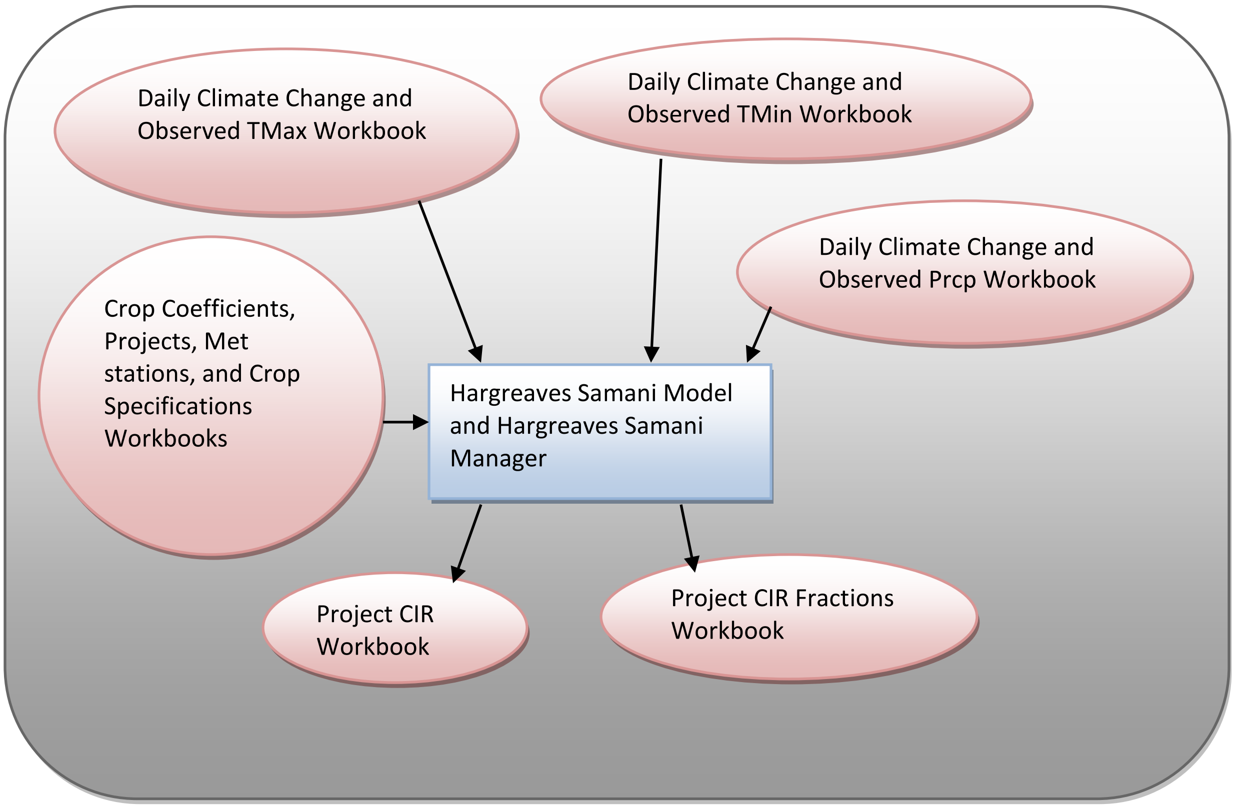


Figure 18. Hargreaves Samani Manager Data Paths.

The Hargreaves Samani manager handles the climate change scenarios and runs the Hargreaves Samani model in batch mode. Download the Hargreaves Samani model at:

ftp://ftp.usbr.gov/tsc/jrieker/utilities/hargreavessamani/hs4.0install.zip

If Net Framework 4 or Windows Installer 4.5 do not exist on users PC, the install will require admin rights. Otherwise, the install can be done without admin rights. It is recommended that

[2] Due to memory PC memory issues, manager was unable to post daily 7-day running average CIR's but should be able to with some adjustments to Hargreaves Samani code. The same memory issues necessitated running every scenario and future individually.

an initial install be done using an admin account, then uninstall Hargreaves Samani and reinstall it without an admin account. Then future updates can be installed without admin rights.

To do the install, unzip file bc4install.zip maintaining the directory structure to a temporary folder. Then run “setup.exe” in folder “c:\vbnetprojects\deployments\Hargreaves-Samani4.0”. Net Framework 4 and Windows Installer 4.5 are installed from a Microsoft site, requiring an internet connection, and take some time. The Hargreaves Samani install is very quick. The model will attempt to run after the install and request the name of an Access database. You can either navigate to the example database contained in hs4install.zip or one provided with the Hargreaves Samani Manager.

The name of the control worksheet in the manager is “HSControl”. An example “HSControl” worksheet is shown on Figure 19.

1/1/1950	Start Date	Hargreaves Samani control specifications are line 1 through 12, columns 1 though 3.	
12/31/1999	End Date	2020	<-- Future Being Run
accdb	C:\warsmp\climatechange\netcdf\HSET_MyDB.accdb	N/A	Hargreaves Samani Access database. Future and scenario independent.
xls	C:\warsmp\climatechange\netcdf\My2020DailyCCTMax.xlsx	S5	Daily maximum temperature data.
xls	C:\warsmp\climatechange\netcdf\My2020DailyCCTMin.xlsx	S5	Daily minimum temperature data.
xls	C:\warsmp\climatechange\netcdf\My2020DailyCCPrcp.xlsx	S5	Precipitation data.
xls	C:\warsmp\climatechange\netcdf\My2020DailyCCNIR.xlsx	S5	Net irrigation requirement.
xls	C:\warsmp\climatechange\netcdf\My2020DailyCIRFractions.xlsx	S5	CIR Fractions.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	HSRunList	Hargreaves Samani runs (nodes) list. Can reside in another workbook.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	HSCropMix	Hargreaves Samani crops mix. Can reside in another workbook.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	HSMets	Hargreaves Samani weather (Met) stations list. Can reside in another workbook.
xls	C:\ExcelVBAProjects\ClimateChange\BlaneyCriddleManager.xlsm	HSCrops	Hargreaves Samani crops. Can reside in another workbook.

Figure 19. Hargreaves Samani Manager “HSControl” worksheet.

The Hargreaves Samani model uses several required and optional inputs. Hargreaves Samani crop curves are specified on worksheet “HSCrops”. Example crop mix specifications are provided on worksheet “HSCropMix” in the manager workbook and shown on Figure 20. Cropping patterns can be provided as a constant crop mix or a variable crop mix can be used.

The next input is the run description worksheet. The run descriptions are a list of is a list of depletion nodes, a mapping to MET stations, starting and ending dates, and some switches. The terms run description, project, node, unit, and water user are used synonymously in this discussion. An example data set is on the “RunDesc” worksheet in the manager workbook and which is shown on Figure 21. Note that this worksheet includes several switches. The example switches are setup as they should be for climate change computations.

The last input is the MET stations worksheet. This is a list of MET stations used by a run with elevation, latitude and longitude. Example “HSMets” worksheet is shown on Figure 22. The example project data shows the climate stations using different names than the depletion nodes. This is not required but was done to facilitate troubleshooting. The “RunDesc” names should match the climate station names in the climate data files. The manager workbook includes a “Nodes” worksheet. This worksheet is not used by the manager or by the model but was used to facilitate setting up the project and crop specifications.

The Hargreaves-Samani model uses an Access database for all input and output data. The manager post all input to the database and queries all output from the database. The non-time series data on worksheets “HSRunList”, “HSCropMix”, “HSMets”, and “HSCrops” should be posted to the database using the “Post Nodes and Crops” button on the “Setup” worksheet as shown on Figure 23. Before posting these data, populate the worksheets with desired data and set the specifications by pressing “Set Specifications” or manually entering them at the bottom of the “Setup” workshop.

Project	Crop	Percent	Starting Temperature Flag	Starting Fixed Date Flag	Ending Temperature Flag	Ending Fixed Date Flag
Node 1	ALFALFA	0.4059	TRUE	FALSE	TRUE	FALSE
Node 1	PASTURE	0.4752	TRUE	FALSE	TRUE	FALSE
Node 1	CORN_GRAIN	0.0396	TRUE	FALSE	TRUE	FALSE
Node 1	ORCHARD_WO_COVER	0.0793	TRUE	FALSE	TRUE	FALSE
Node 2	ALFALFA	0.5600	TRUE	FALSE	TRUE	FALSE
Node 2	PASTURE	0.3000	TRUE	FALSE	TRUE	FALSE
Node 2	CORN_GRAIN	0.0500	TRUE	FALSE	TRUE	FALSE
Node 2	ORCHARD_WO_COVER	0.0900	TRUE	FALSE	TRUE	FALSE
Node 3	ALFALFA	0.5600	TRUE	FALSE	TRUE	FALSE
Node 3	PASTURE	0.3000	TRUE	FALSE	TRUE	FALSE
Node 3	CORN_GRAIN	0.0500	TRUE	FALSE	TRUE	FALSE
Node 3	ORCHARD_WO_COVER	0.0900	TRUE	FALSE	TRUE	FALSE
Node 4	ALFALFA	0.5600	TRUE	FALSE	TRUE	FALSE
Node 4	PASTURE	0.3000	TRUE	FALSE	TRUE	FALSE
Node 4	CORN_GRAIN	0.0500	TRUE	FALSE	TRUE	FALSE
Node 4	ORCHARD_WO_COVER	0.0900	TRUE	FALSE	TRUE	FALSE

Figure 20. Example Hargreaves Samani crop mix worksheet.

RunDesc	MetStaName	Project	StartDate	EndDate	Variable Mix Flag	Last Run Flag	Depletions Flag	Acres Fractions Flag	CIR Table Flag	CIR Fractions Flag	Irrigation Depth
Node 1	Met 1	Node 1	1/1/1950	12/31/1999	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	1
Node 2	Met 2	Node 2	1/1/1950	12/31/1999	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	1
Node 3	Met 3	Node 3	1/1/1950	12/31/1999	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	1
Node 4	Met 4	Node 4	1/1/1950	12/31/1999	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	1

Figure 21. Example Hargreaves Samani run descriptions worksheet.

StationID	StationName	Station Notes	Elevation	Latitude Degrees	Latitude Minutes	Longitude Degrees	Longitude Minutes
Met 1	Met 1	Node 1	3558.00	48	58	113	2
Met 2	Met 2	Node 2	2390.00	48	53	112	53
Met 3	Met 3	Node 3	2413.00	49	3	113	1
Met 4	Met 4	Node 4	2365.00	48	48	112	56

Figure 22. Example Hargreaves Samani MET stations worksheet.

The non time series data do not have to reside in the manager workbook. If they will reside elsewhere, edit the appropriate file paths and worksheets on the “HSControl” worksheet. However, do not edit the time series file paths and worksheets because those are automatically generated from data on the “Setup” worksheet and the future being run.

After specifying the non time series data, set up the simulation period and futures on the “Setup” worksheet as shown on Figure 23. Finally, compute project CIR’s and/or depletions which can be done for one scenario and one future, all scenarios and one future, or for all scenarios and all futures. To run one scenario for one future, use the scroll bar to select the scenario and press “Run One Hargreaves Samani”. To run all scenarios for one future, set all of the “Used” futures except one to false and press “Run All Hargreaves Samani”. To run all scenarios for all futures, set all desired futures to “True” and press “Run All Hargreaves Samani”. Due to Access and PC limitations, it may not be possible to run a large number of nodes. In those cases, each scenario and future will have to be run individually.

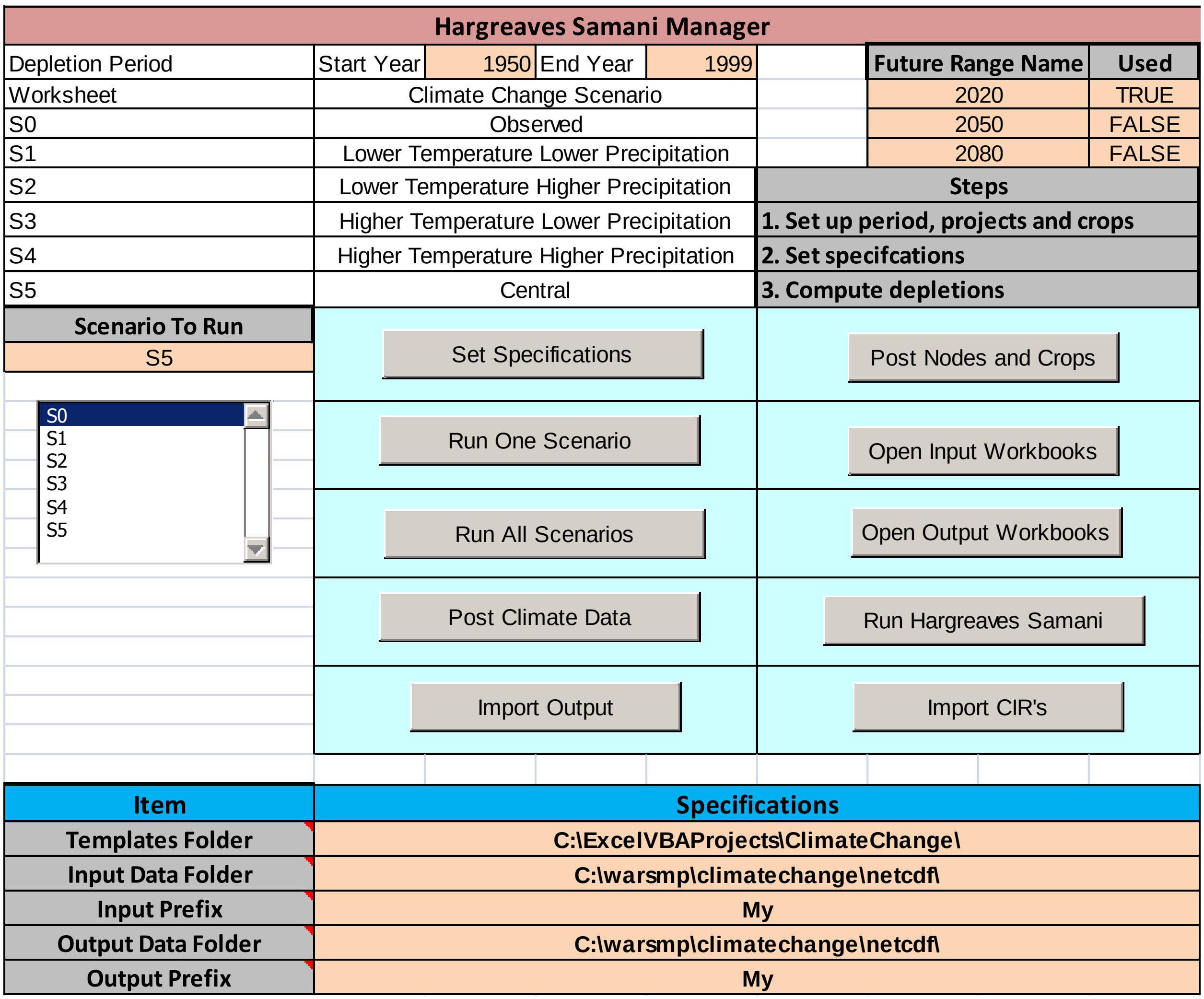


Figure 23. Hargreaves Samani Manager Menu.

Evaporation Manager

The evaporation manager computes daily evaporation rates used by the RiverWare model to compute reservoir and river evaporation. The manager can compute one scenario for one future, all scenarios for one future, or all scenarios for all futures. Output of the manager for each future are workbooks containing observed and five HDe traces of daily Hargreaves Samani evapotranspiration potential (ETP), total evaporation, and net evaporation.   The flow of data is shown on Figure 24.

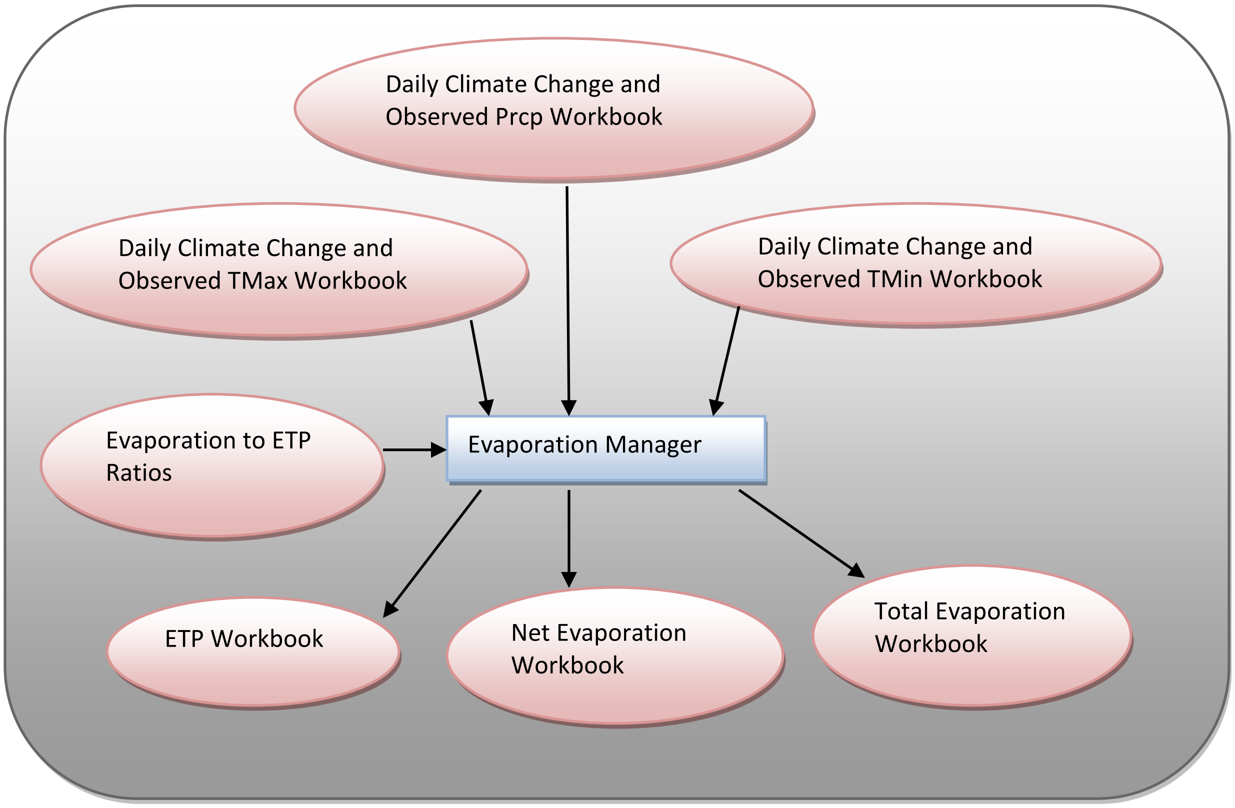


Figure 24. Evaporation Manager Data Paths.

The manager's control worksheet is shown on Figure 25. The values on the worksheet are specified automatically using information specified on the "Setup" worksheet shown on Figure 26.

1/1/1950	Start Date		**Evaporation control specifications are line 1 through 8, columns 1 though 3.**
12/31/1999	End Date	2030	**<-- Future Being Run**
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCTMax.xlsx	S0	Maximum temperature data.
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCTMin.xlsx	S0	Minimum temperature data.
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCPrcp.xlsx	S0	Precipitation data.
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCETP.xlsx	S0	Hargreaves-Samani evapotranspiration data.
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCTotalEvap.xlsx	S0	Total Evaporation data.
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCNetEvap.xlsx	S0	Net Evaporation data.

Figure 25. Evaporation Manager "EvapControl" worksheet.

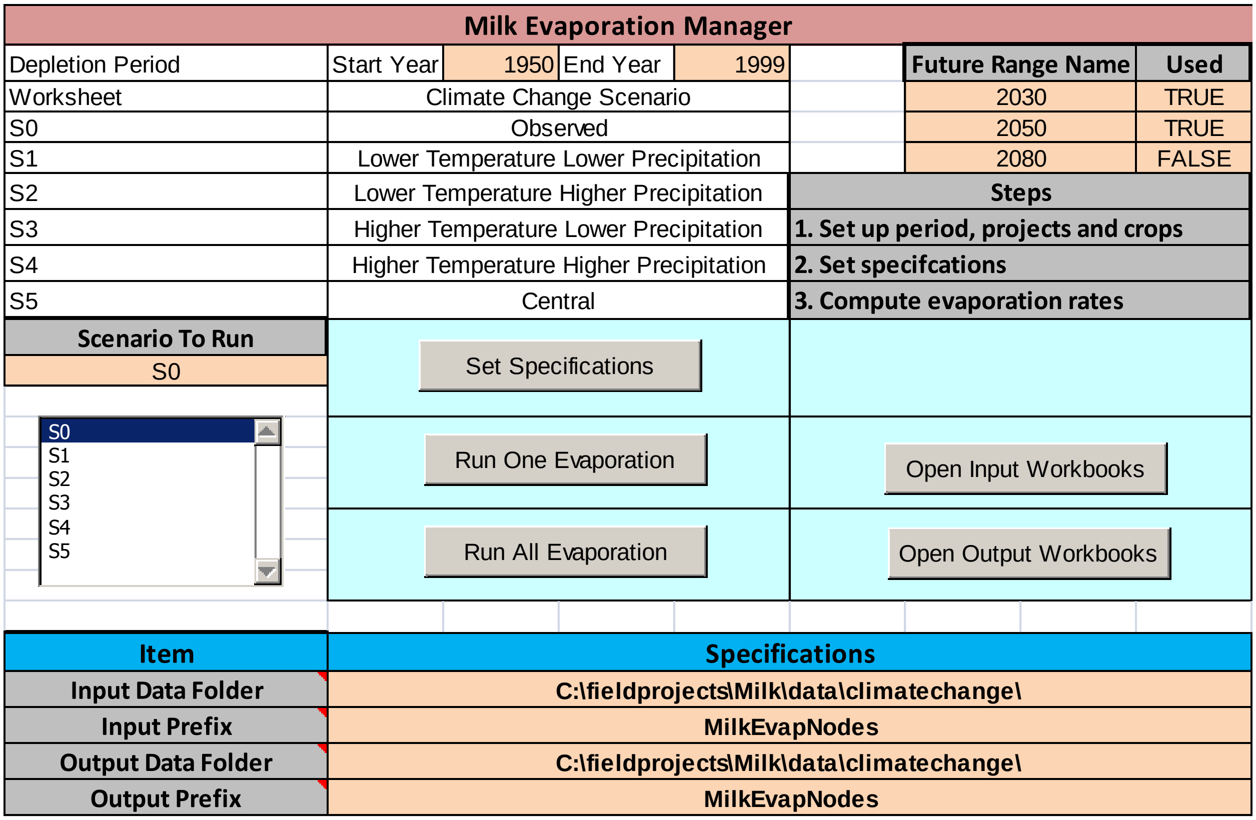


Figure 26. Evaporation Manager main menu.

The manager uses data on the “Ratios” worksheet to compute total evaporation as a function of the Hargreaves Samani potential evapotranspiration. The ratios are shown in Table 4.

Table 4. Ratios of Total Evaporation To Hargreaves Samani Potential Evapotranspiration.

Month	Total Evaporation to Evapotranspiration
1	1.174
2	0.611
3	2.311
4	0.917
5	0.660
6	0.723
7	0.751
8	0.833
9	0.816
10	1.291
11	1.614
12	1.249
Average	1.079

The manager uses data on the “Nodes” worksheet to specify the latitude, longitude, and elevation of the MET stations. The latitude is used by Hargreaves-Samani to estimate the solar radiation. Example node data are shown on Figure 27.

Fresno Reservoir Evaporation	Fresno Reservoir Evaporation	48.634	-109.977	2530
Nelson Reservoir Evaporation	Nelson Reservoir Evaporation	48.49	-107.556	2222
Lake Bowdoin Evaporation	Lake Bowdoin Evaporation	48.4	-107.661	2209
Frenchman Reservoir Evaporation	Frenchman Reservoir Evaporation	48.704	-107.231	2260
Alberta Milk River Reservoir Evaporation	Alberta Milk River Reservoir Evaporation	49.13	-112.376	3558
River Evaporation: Fresno to Ft. Belknap Canal	River Evaporation: Fresno to Ft. Belknap Canal	48.568	-109.516	2465
River Evaporation: Ft. Belknap Canal to Paradise ID	River Evaporation: Ft. Belknap Canal to Paradise ID	48.589	-109.302	2420
River Evaporation: Paradise ID to Harlem ID	River Evaporation: Paradise ID to Harlem ID	48.578	-109.119	2380
River Evaporation: Harlem ID to Ft. Belknap Reservation	River Evaporation: Harlem ID to Ft. Belknap Reservation	48.531	-108.869	2354
River Evaporation: Ft. Belknap Reservation to Dodson	River Evaporation: Ft. Belknap Reservation to Dodson	48.444	-108.526	2310
River Evaporation: Dodson to Nelson Reservoir	River Evaporation: Dodson to Nelson Reservoir	48.366	-107.839	2250
River Evaporation: Nelson Reservoir to Vandalia	River Evaporation: Nelson Reservoir to Vandalia	48.405	-107.052	2145
River Evaporation: Vandalia to Mouth	River Evaporation: Vandalia to Mouth	48.16	-106.58	2080
River Evaporation: Milk River in Alberta	River Evaporation: Milk River in Alberta	49.151	-112.083	3444

Figure 27. Example Evaporation Manager node specifications.

After populating the “Nodes” worksheet, specify the simulation period and futures on the “Setup” worksheet, then set the specifications by pressing the “Set Specifications” button or manually entering them at the bottom of the worksheet. Finally, computation of project evaporations can be done for one scenario and one future, all scenarios and one future, or for all scenarios and all futures. To run one scenario for one future, use the scroll bar to select the scenario and press “Run One Evaporation”. To run all scenarios for one future, set all of the “Used” futures except one to false and press “Run All Evaporation”. To run all scenarios for all futures, set all desired futures to “True” and press “Run All Evaporation”.

Hydrology Manager

The hydrology manager computes daily bias corrected flows rates used by the RiverWare model as a function of daily biased flows, monthly biased corrected flows and monthly biases flows. It also translates total flows to local flows. The manager computes all scenarios for all futures as one process. Output of the manager for each future are workbooks containing observed and five HDe traces of daily flows. The flow of data is shown on Figure 28.

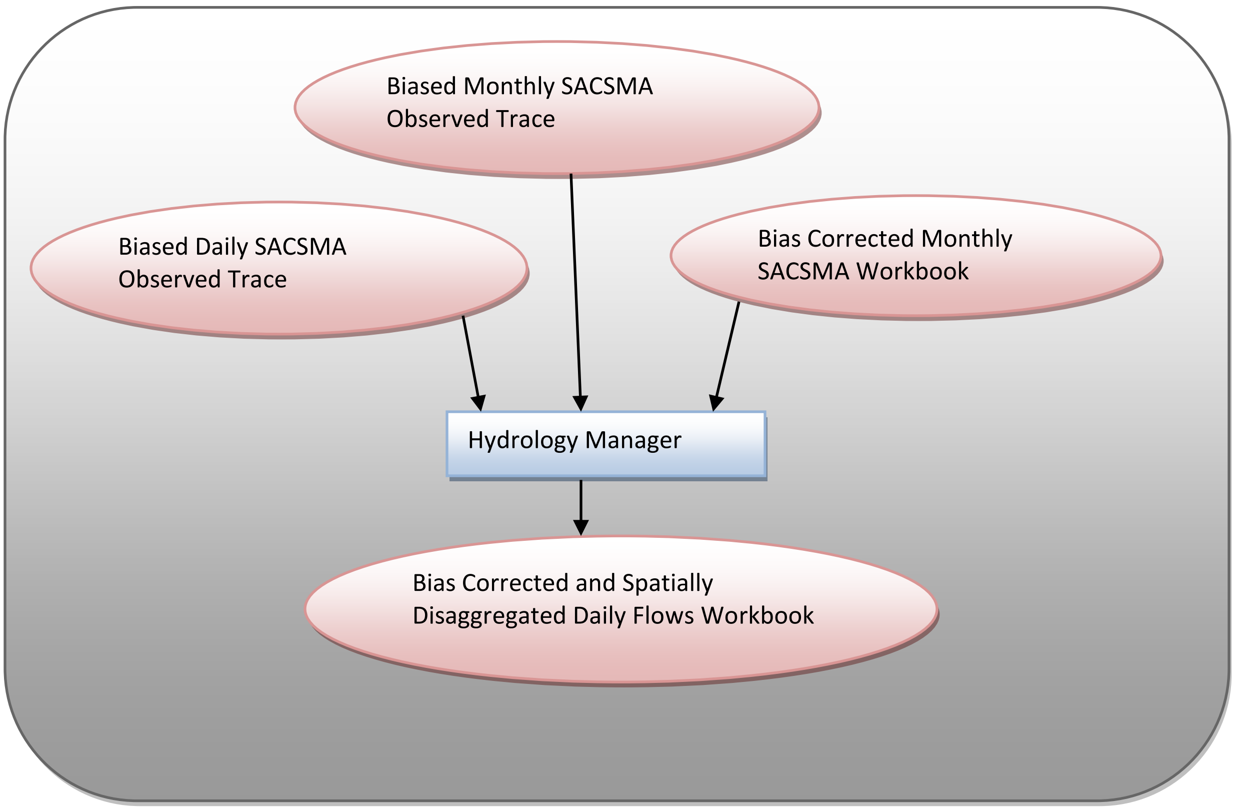


Figure 28. Hydrology Manager data paths.

The hydrology manager computes daily bias corrected flows as:

daily bias corrected flow = daily biased observed flow
/ monthly biased observed flow
× monthly biased corrected flow

The monthly biased corrected flows are posted to the multiple run workbook using DUT DMI's from text files.

RiverWare Manager

The RiverWare manager pulls data from the hydrology, evaporation, monthly CIR, and daily CIR fractions workbooks, posts the data to the model's input file, runs the model in batch mode, pulls model output from the model's output file, and post model results to the output MRM that is associated with the future and scenario. The manager can compute one scenario for one future, all scenarios for one future, or all scenarios for all futures. The flow of data is shown on Figure 29.

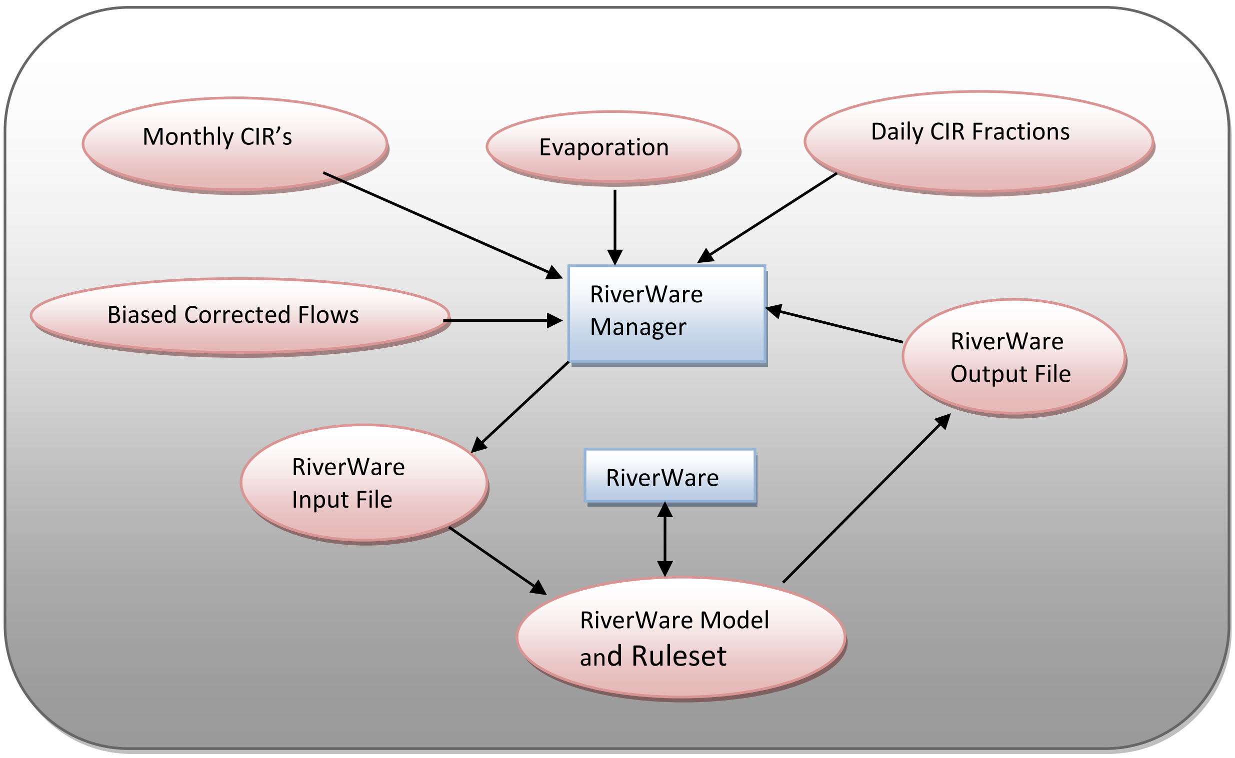


Figure 29. RiverWare manager data paths.

The manager's setup worksheet is shown on Figure 30 and an example control worksheet ("RWControl") is shown on Figure 31. After specify the simulation period (assuming calendar years), the future periods and which future periods are to be simulated, press 'Set Specifications' to set the specifications. These can also be entered manually. All specifications on the control worksheet are automatically generated from information on the setup worksheet. The future of a given run is posted to the control worksheet by the application.

To run one scenario and one future, use the scroll bar to specify the scenario, then press 'Run One Scenario'. To run all scenarios for one future, set all futures except one to 'False' and press 'Run All Scenarios'. To run all scenarios for all futures, set all desired futures to "True" (only 2030 and 2050 are used by the MSMRSBS) and press 'Run All Scenarios'.

RiverWare Manager						
Simulation Period	Start Year	1950	End Year	1999	Future Range Name	Used
Worksheet	Climate Change Scenario				2030	TRUE
S0	Observed				2050	TRUE
S1	Lower Temperature Lower Precipitation				2080	FALSE
S2	Lower Temperature Higher Precipitation				Steps	
S3	Higher Temperature Lower Precipitation				1. Set up period.	
S4	Higher Temperature Higher Precipitation				2. Set specfcations	
S5	Central				3. Run RiverWare	
Scenario To Run	Set Specifications				Run Historic	
S0						
S0 S1 S2 S3 S4 S5	Run One Scenario				Open Input Workbooks	
	Run All Scenarios				Open Output Workbooks	

Item	Specifications
Templates Folder	C:\fieldprojects\Milk\runscripts\
Scenario Data Folder	C:\fieldprojects\Milk\data\climatechange\
Depletions Prefix	MilkWaterUsers
Evaporation Prefix	MilkEvapNodes
RiverWare Data Folder	C:\fieldprojects\Milk\data\simulated\
Base RiverWare Model	C:\fieldprojects\Milk\rwmodels\MilkStMary.mdl.gz
RiverWare RuleSet	C:\fieldprojects\Milk\rwmodels\MilkStMary.rls.gz

Figure 30. RiverWare manager setup worksheet.

1950	Start Year		**RiverWare file specifications are lines 1 through 10, columns 1 though 3.**
1999	End Year	2030	**<-- Future Being Run**
mdl	C:\fieldprojects\Milk\rwmodels\MilkStMary2030_S0.mdl.gz		
rls	C:\fieldprojects\Milk\rwmodels\MilkStMary.rls.gz		RiverWare ruleset
xls	C:\fieldprojects\Milk\data\climatechange\DailyCC2030Hydrology.xlsx	S0	Scenario hydrology data
xls	C:\fieldprojects\Milk\data\climatechange\MilkEvapNodes2030DailyCCNetEvap.xlsx	S0	Scenario evaporation data
xls	C:\fieldprojects\Milk\data\climatechange\MilkWaterUsers2030MonthlyCCNIR.xlsx	S0	Scenario monthly crop net irrigation requirements
xls	C:\fieldprojects\Milk\data\climatechange\MilkWaterUsers2030DailyCIRFractions.xlsx	S0	Scenario daily cir fractions
xls	C:\fieldprojects\Milk\data\simulated\MilkInputData.xlsx		RiverWare input data workbook
xls	C:\fieldprojects\Milk\data\simulated\MilkOutputData.xlsx		RiverWare output data workbook
xls	C:\fieldprojects\Milk\data\climatechange\Daily2030RWOutput.xlsx	S0	Scenarios output data workbook

Figure 31. RiverWare manager control worksheet.

The RiverWare manager creates a RiverWare Command Language (RCL) file for each model run. An example RCL produced by the manager is shown on Figure 32. The date and duration specifications tell the model the period of the run. The “SyncObj !Acct !ExDiffTS “ command tells RiverWare to synchronize the daily timestep slots including accounting slots with the run period. The “InvokeDMI” commands tell the model to run various DMI’s. After input DMI’s are run, the ruleset is loaded, the model is run and saved, and output DMI "Standard Output" is invoked. The traditional RiverWare DMI's are non-executing DMI's. These data are processed by the manager and posted to RiverWare DMI files in appropriate directories. All scenario and future dependent data are Excel DMI's. The output files as well as aggregation files of the same contain statistics and plots to help analyze data and model runs.

```
OpenWorkspace "C:\\fieldprojects\\Milk\\rwmodels\\MilkStMary2050_S5.mdl.gz"
SetRunInfo #RunInfo !InitDate "12-31-1949 24:00" !Duration "18262 DAYS"
SyncObj !Acct !ExDiffTS
InvokeDMI {GroundWaterRouting}
InvokeDMI {SurfaceWaterRouting}
InvokeDMI {StreamflowRouting}
InvokeDMI {ReservoirStorage}
InvokeDMI {Hydrology}
InvokeDMI {Monthly ET Rates}
InvokeDMI {Depletion Fractions}
InvokeDMI {Annual Areas to Data Object}
InvokeDMI {Evaporation}
SaveWorkspace "C:\\fieldprojects\\Milk\\rwmodels\\MilkStMary2050_S5.mdl.gz"
LoadRules "C:\\fieldprojects\\Milk\\rwmodels\\MilkStMary.rls.gz"
StartController
SaveWorkspace "C:\\fieldprojects\\Milk\\rwmodels\\MilkStMary2050_S5.mdl.gz"
InvokeDMI {Standard Output}
Close Workspace
```

Figure 32. Example RiverWare Command Language file.

A log file is produced by RiverWare that can be used to monitor progress of a run and to troubleshoot a run upon completion. In addition, the manager writes messages to the Excel status bar. During RiverWare runs or large file I/O, these messages are often not refreshed or even visible. The RiverWare manager tells RiverWare to create log file milkbatchrun.log in the model directory. An example RiverWare log file is shown in Figure 33. Other than warning messages, if you see content that looks significantly different than the example, the model run is probably a bad run. Note that the RiverWare log file includes the model segment's run time.

```
_REQINFO_:   "Using the Resource Database "C:\\Program
Files\CADSWES\RiverWare 6.0.5\riverwareDB"."
_REQINFO_:   "Model File Information: "
_REQINFO_:   "Last saved on: 07-16-2011 18:55:35."
_REQINFO_:   "Last saved by "Dave King" using "RiverWare 6.0.5"."
_REQINFO_:   "------ Inline Rulebased Simulation and Accounting RUN STARTED --
----"
_REQINFO_:   ""MilkStMary2050_S5.mdl.gz at 21:58 July 16, 2011""
_REQINFO_:   "----------------------------------"
_REQINFO_:   "------ Inline Rulebased Simulation and Accounting RUN FINISHED --
----"
```

Figure 33. Example RiverWare model run log.

The RiverWare manager includes an option to run RiverWare using the historic data of the original model using the 1959 through 2009 period. Press 'Run Historic' to do this model run. Input data for this run are obtained from file $MILK_SOURCE_DIR\data\historic\MilkHistoricInputData.xlsx and are posted to file $MILK_SOURCE_DIR\data\historic\MilkHistoricOutput.xlsx.

Data File Contents, Analyses, and Aggregations

Most of MRM (scenario) workbooks consist of time series worksheets “S0”, “S1”, “S2”, S3”, “S4”, and “S5 and header worksheets “HeaderObs” and “HeaderCC”. Additional data may exist in some workbooks specific to a manager. Data on the time series worksheets are organized in the default “Runs” orientation for RiverWare XlWriter output to Excel where columns are slots and worksheets are scenarios. The DUT and the managers expect all time series data to have the date in the first column in all workbooks.

The DUT was used to aggregate daily RiverWare output to monthly and annual. RiverWare scenario workbooks include summary statistics and monthly averages that were generated using DUT. DUT could be used to compute similar data for the other data parameters. The wakeup menu of DUT is shown on Figure 34.

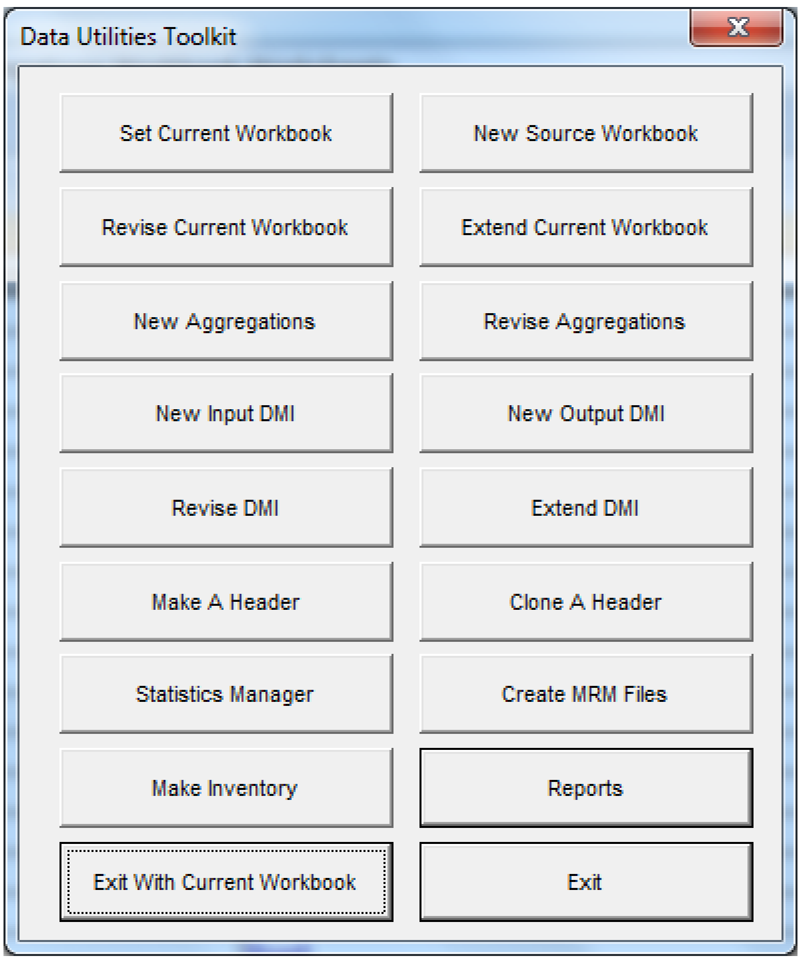


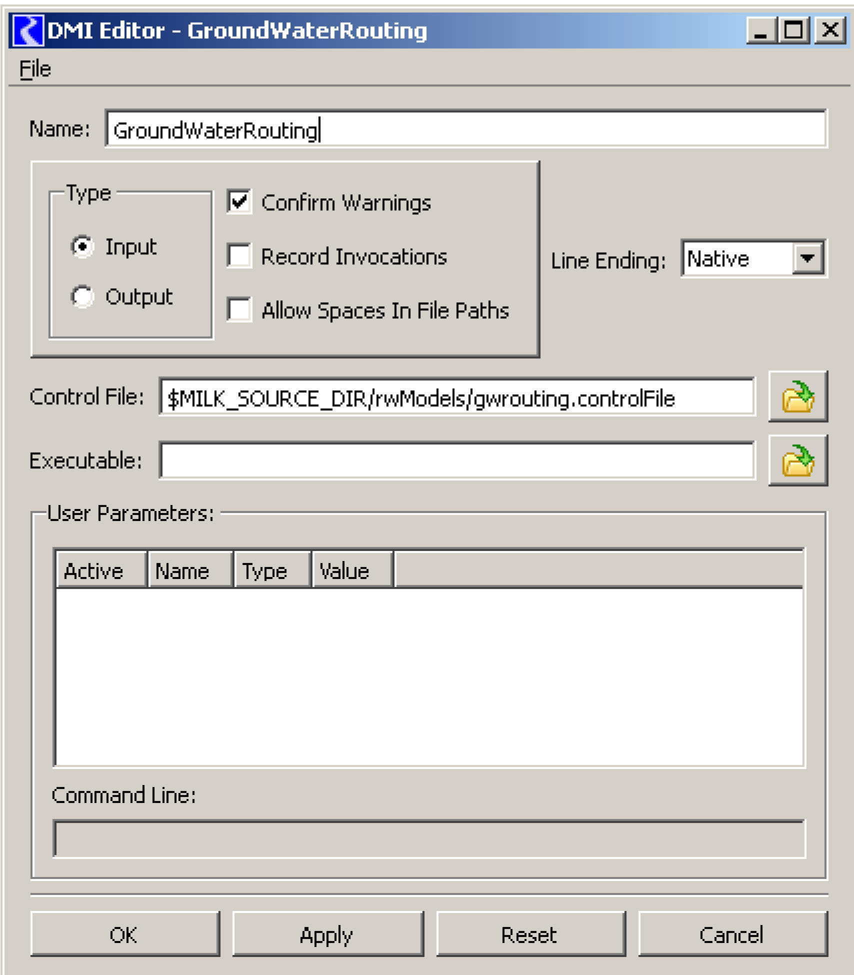
Figure 34. Data Utilities Toolkit main menu.

Appendix G
Milk-St. Marys RiverWare Model, DMI and Excel Output Information

DMI and Excel Output Information

RiverWare DMI"s consists of two types – traditional and database. For many years, the only way to get time-series data into RiverWare was using traditional DMI's which use a control file to specify the objects and slots that you are processing and an optional executable. Excel output could be generated through the output manager. More recently, three database types were added including Excel. The DMI's that we added consist of 3 non-executing DMI's for the initial routing and 5 Excel database DMI's. In addition, we created 4 traditional Excel output manager exports.

All of the DMI's and Excel output were created using environmental variable MILK_SOURCE_DIR. Using environmental variables allows some machine independence. The actual value of MILK_SOURCE_DIR can be whatever you want it to be on your pc but everything downhill of MILK_SOURCE_DIR has to be the same. For instance, on my pc, the value of MILK_SOURCE_DIR is "c:\fieldprojects\MILK". I use c:\fieldprojects as the mother directory of all my field related work. Milk is the directory that I created specific to this project. Under Milk, I have two main directories related to modeling which are data and rwModels. Under data, I have historic and simulated. If you open the DMI dialog, select the GroundWaterRouting DMI, and press the edit button (just right of the run button), you'll see following:



The $ in front of the control file specification tells RiverWare that the first part of the specification is an environmental variable (env). The rest of the specification is what is downhill of the env. The three routing control files have to reside in directory $MILK_SOURCE_DIR/rwModels (which is also where I have my copies of the models and rules but is coincidental). I used non executing DMI's for these because all that I did was post your previous values, rename the files as needed, and changed the dates as needed using a text editor.

All traditional DMI's require that another env exist that has to be named RIVERWARE_DMI_DIR (MILK_SOURCE_DIR is just a name that I made up). RIVERWARE_DMI_DIR specifies the mother directory of all the model's traditional DMI"s. All DMI's correspond to subdirectories of RIVERWARE_DMI_DIR. Therefore, DMI GroundWaterRouting corresponds to directory RIVERWARE_DMI_DIR/GroundWaterRouting. This is where RiverWare will look for the object.slot files if you use wildcarding to specify the file path. The data file can exist elsewhere if you fully specify the file path in the control file. In the case of the surface water return flows, I used one file for all of them. In that case, the control file uses a wild card to specify the base path (the ~ automatically tells it to use the DMI path) but used the same data file name for the file specifications.

On my pc, the value of RIVERWARE_DMI_DIR is c:\dmidata. I placed the DMI files for the three routing DMI's in file dmidata.zip at:

ftp://ftp.usbr.gov/tsc/jrieker/Milk/

The 3 control files are at:

ftp://ftp.usbr.gov/tsc/jrieker/Milk/rwmodels/

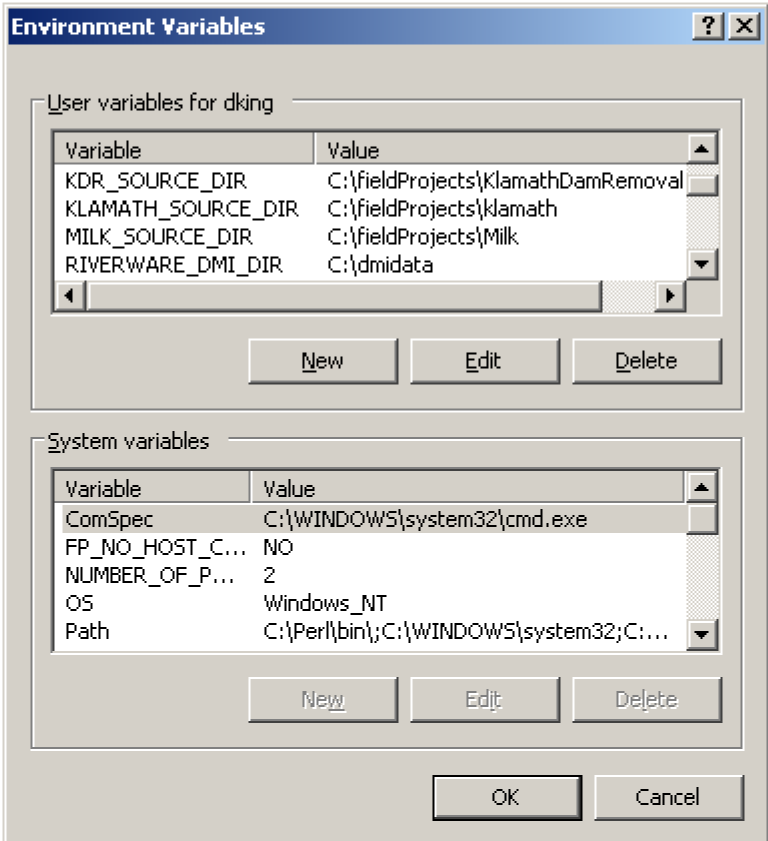
If you download these files, save the control files in rwModels under your Milk mother directory, unzip the zip file and create the env variables, you can run these DMI's. To create the env's (make sure that you exit RiverWare first), right click on MyComputer, select Properties, select Advanced, and select Environmental Variables which brings up dialog below. Use New user variables to create MILK_SOURCE_DIR and RIVERWARE_DMI_DIR. The directories have to exist before you create the env's.

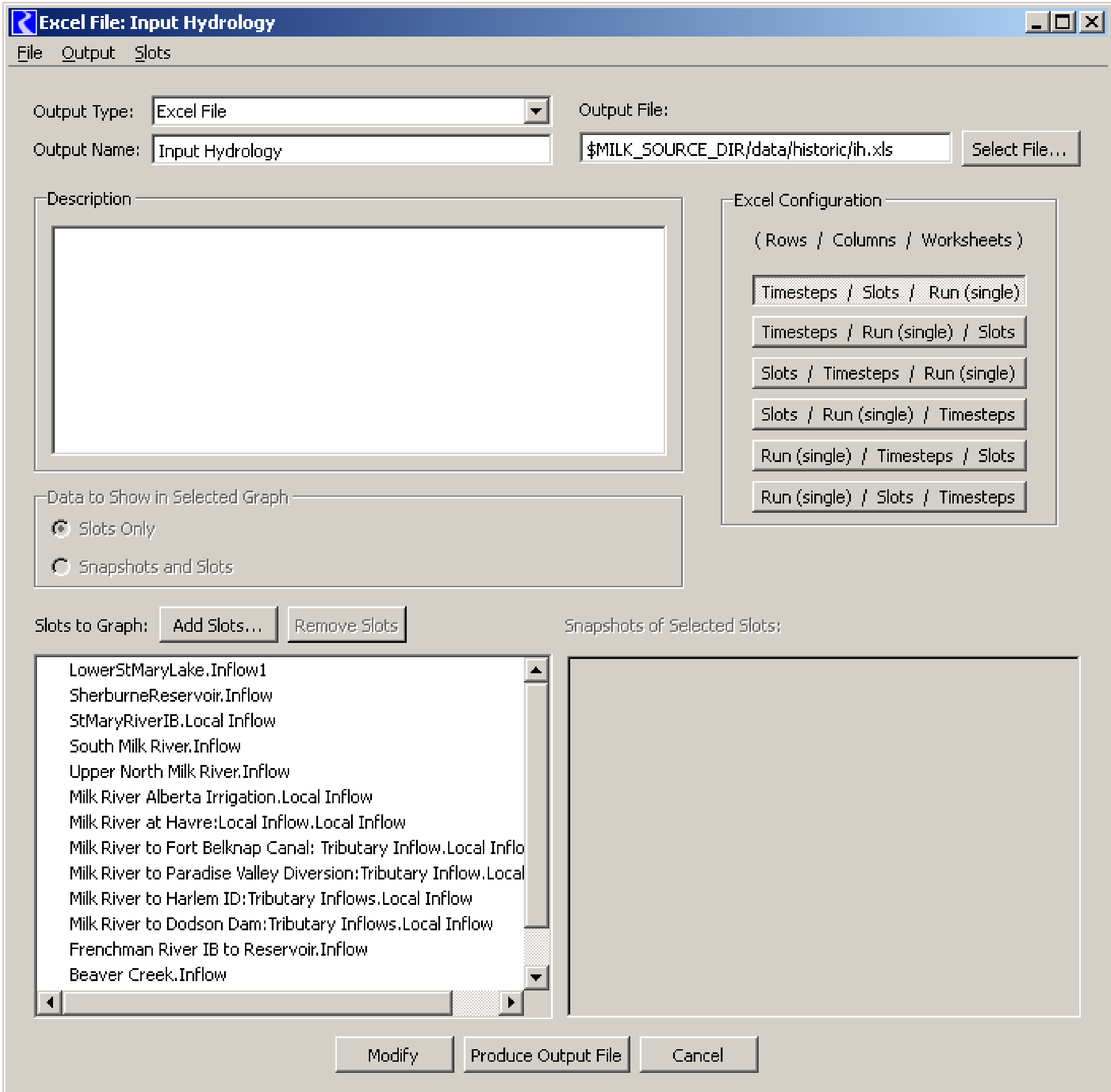
Excel output via the output manager is the fastest way to get data to Excel, both in setting it up and in execution. However, this approach can not be used to post data to an existing Excel file. Therefore, any Excel file that has additional content like aggregations and plots can not be revised using the output manager Excel output. Therefore, I always specify these with a scratch file, then import the data into my working file either by cutting and paste or using an Excel vba macro that I wrote. The four Excel outputs in the model were used to compute example data for the other DMI's but can be used in the climate change runs to get output from those runs. An example specification is shown below. One of these post data to MILK_SOURCE_DIR/data/historic and the other three post data to MILK_SOURCE_DIR/data/simulated. Files associated with these output can be picked up at:

ftp://ftp.usbr.gov/tsc/jrieker/Milk/data/historic/

and

ftp://ftp.usbr.gov/tsc/jrieker/Milk/data/simulated/


Environment Variables
User variables for dking
Variable
Value
KDR_SOURCE_DIR
C:\fieldProjects\KlamathDamRemoval
KLAMATH_SOURCE_DIR
C:\fieldProjects\klamath
MILK_SOURCE_DIR
C:\fieldProjects\Milk
RIVERWARE_DMI_DIR
C:\dmidata
New
Edit
Delete
System variables
Variable
Value
ComSpec
C:\WINDOWS\system32\cmd.exe
FP_NO_HOST_C...
NO
NUMBER_OF_P...
2
OS
Windows_NT
Path
C:\Perl\bin\;C:\WINDOWS\system32;C:...
New
Edit
Delete
OK
Cancel



We just started using Excel database DMI's. Previously, we had back door ways to get Excel data into RiverWare without cutting and pasting. Anyways, we created those DMI's to test the computation of daily et's from monthly et's and daily fractions. I set these DMI's up to pull data from the 'historic' directory. Files associated with these DMI's can be picked up at:

ftp://ftp.usbr.gov/tsc/jrieker/Milk/data/historic/

We will clone these DMI's for the climate change runs with the climate change et's and fractions in either directory 'simulated' or 'et'. See dmi.pdf RiverWare help file for specifics on creating Excel database DMI's and DMI's in general.

Appendix H
Milk-St. Marys River System Basin Study Technical Services Center Support

RECLAMATION

Managing Water in the West

Milk-St. Mary River System Basin Study

Technical Service Center Support

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Milk-St. Mary River System Basin Study

Technical Service Center Support

Introduction

This document reports work done by the Technical Service Center (TSC) to support the Milk-St. Mary River System Basin Study (MSMRSBS), one of several basin studies that are associated with the WaterSMART program. TSC previously developed hydrologic flows and a climate change analysis in the basin[3]. The objective of this phase of TSC support was to provide assistance to the Montana Area Office in automating and implementing daily and monthly ET computations, hydrologic data computations, and management of hydrologic planning model runs for historic and climate change scenarios. A second objective is to review the hydrologic planning model. Working with Montana Area Office, GP Regional Office, and state of Montana staff, TSC staff assisted in development of software, data management interfaces, and other tools needed to support the Milk River Basin Study.

The tasks performed by TSC were:

1. Development of observed and five climate change traces for two futures to support computation of irrigation depletion, reservoir evaporation, and river evaporation.
2. Computation of project irrigation requirements.
3. Computation of reservoir and river evaporation rates.
4. Computation of bias corrected flows.
5. Extension of RiverWare hydrologic decision model to support climate change scenarios.
6. Development of applications (data managers) to support all of the above.
7. Review of RiverWare hydrologic model and documentation.

The following sections provide additional detail on these tasks.

Climate Data Development

Climate data were developed for the 2010 study by climate change scenario for computation of depletions that input data to the Sacramento Soil Moisture Accounting (SACSMA) watershed model. However, those climate data were not available for computation of irrigation and evaporation nodes for current phase because the data and adjustment factors were discarded. Even if the data were available, the SACSMA nodes do not correspond directly with the irrigation and evaporation nodes. Therefore, a new data set was developed for the 45 water user nodes are listed in Table 1 and 14 reservoir and river nodes listed in Table 2.

[3] Technical Memorandum No. 86-68210-2010-04, August, 2010.

Table 1. RiverWare model water user nodes.

RiverWare Node	Met Data Decimal Latitude	Met Data Decimal Longitude	Met Data Elevation
Canadian Irrigation	49.13	-112.376	3558
Fort Belknap Canal Irrigation Districts:Alfalafa Valley ID	48.590	-109.169	2390
Fort Belknap Canal Irrigation Districts:Fort Belknap ID	48.614	-109.337	2413
Fort Belknap Canal Irrigation Districts:Zurich ID	48.573	-108.922	2365
Fort Belknap Reservation Irrigation Project:Milk River Unit	48.45	-108.596	2320
Fort Belknap Reservation Irrigation Project:White Bear Unit	48.421	-108.393	2300
Glasgow ID	48.207	-106.664	2090
Harlem Irrigation District:East Portion	48.503	-108.717	2343
Harlem Irrigation District:West Portion	48.53	-108.825	2352
Irrigation above Frenchman Reservoir	48.855	-107.25	2330
Irrigation below Frenchman Dam:Lower	48.552	-107.26	2170
Irrigation below Frenchman Dam:Upper	48.612	-107.255	2205
Lower Malta ID: Milk Returns	48.513	-107.37	2195
Lower Malta ID: Beaver Creek	48.419	-107.259	2175
ND irrigation Dodson to Nelson	48.366	-107.839	2250
ND Irrigation FT Belknap to Dodson	48.444	-108.526	2310
ND Irrigation Havre to FT Belknap	48.568	-109.516	2465
ND irrigation above Beaver Creek	48.536	-107.366	2170
ND irrigation Nelson to Vandalia	48.405	-107.052	2145
ND Irrigation Paradise Valley Reach	48.589	-109.302	2420
ND Irrigation PV to Harlem ID	48.578	-109.119	2380
ND irrigation Vandalia to Mouth	48.16	-106.58	2080
North Malta ID	48.363	-108.084	2260
Paradise Valley Irrigation District:East Portion	48.548	-108.995	2365
Paradise Valley Irrigation District:West Portion	48.563	-109.076	2367
Phreatophytes Dodson to Vandalia	48.552	-107.26	2170
Phreatophytes Ft Belknap to Paradise Valley	48.589	-109.302	2420
Phreatophytes FT Belnap R to Dodson	48.444	-108.526	2310
Phreatophytes Harlem ID to FT Belknap Reservation	48.531	-108.869	2354
Phreatophytes Havre to Ft Belknap	48.568	-109.516	2465
Phreatophytes PV to Harlem ID	48.578	-109.119	2380
Phreatophytes Vandalia to Mouth	48.16	-106.58	2080
Private irrigation Dodson to Nelson	48.366	-107.839	2250
Private Irrigation Harlem to Dodson	48.444	-108.526	2310
Private Irrigation Havre to FT Belknap	48.579	-109.857	2500
Private Irrigation Nelson to Vandalia	48.538	-107.508	2190
Private Irrigation Paradise Valley Reach	48.589	-109.302	2420
Private Irrigation PV to Harlem	48.578	-109.119	2380
Private irrigation Vandalia to Mouth	48.405	-107.052	2145
Upper Malta ID:Lower	48.548	-107.574	2200
Upper Malta ID:Beaver Returns	48.376	-107.572	2215
Upper Malta ID:Upper	48.348	-107.963	2253
Upper Malta ID:Bowdoin Returns	48.372	-107.758	2250
US Irrigation on North Milk	48.973	-113.047	4200
US Irrigation on South Milk	48.891	-112.89	4240

Table 2. RiverWare model reservoir and river evaporation nodes.

RiverWare Node	Met Data Decimal Latitude	Met Data Decimal Longitude	Met Data Elevation
Fresno Reservoir Evaporation	48.634	-109.977	2530
Nelson Reservoir Evaporation	48.49	-107.556	2222
Lake Bowdoin Evaporation	48.4	-107.661	2209
Frenchman Reservoir Evaporation	48.704	-107.231	2260
Alberta Milk River Reservoir Evaporation	49.13	-112.376	3558
River Evaporation: Fresno to Ft. Belknap Canal	48.568	-109.516	2465
River Evaporation: Ft. Belknap Canal to Paradise ID	48.589	-109.302	2420
River Evaporation: Paradise ID to Harlem ID	48.578	-109.119	2380
River Evaporation: Harlem ID to Ft. Belknap Reservation	48.531	-108.869	2354
River Evaporation: Ft. Belknap Reservation to Dodson	48.444	-108.526	2310
River Evaporation: Dodson to Nelson Reservoir	48.366	-107.839	2250
River Evaporation: Nelson Reservoir to Vandalia	48.405	-107.052	2145
River Evaporation: Vandalia to Mouth	48.16	-106.58	2080
River Evaporation: Milk River in Alberta	49.151	-112.083	3444

The data scenarios consist of observed and five quadrants of climate change data as listed in Table 3. The climate change data were developed for two futures, 2030 and 2050. This was done to be consistent with the 2010 study. The Ensemble Hybrid Delta (HDe) method of the developing the traces was used where an ensemble of climate projections is assembled from period monthly distributions of a given quadrant. The quadrants are defined by the intersections of 112 Bias Corrected Spatially Disaggregated (BCSD) monthly average temperatures and precipitation changes as shown on Figure 1.

Table 3. Climate Change Scenarios.

Observed
Lower Temperature Lower Precipitation
Lower Temperature Higher Precipitation
Higher Temperature Lower Precipitation
Higher Temperature Higher Precipitation
Central

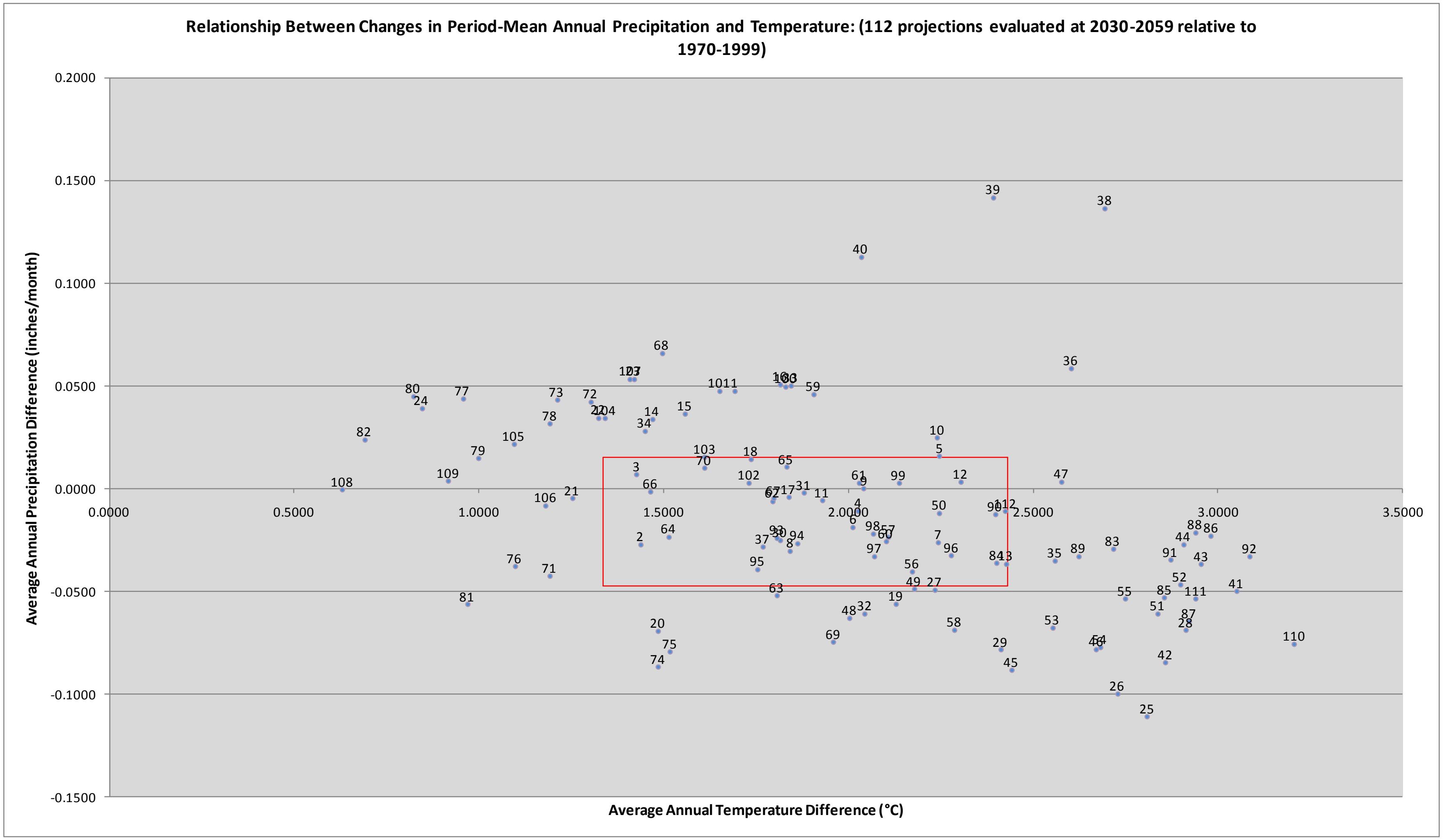


Figure 1. Example BCSD data set quadrants.

The monthly observed and 112 BCSD traces were obtained from the BCSD web site[4]. The daily observed trace was available in-house but will be available on the web site in the near future. The data consist of observed and BCSD monthly average temperature and monthly precipitation and daily observed maximum temperature, minimum temperature, and precipitation at 1/8 degree cells. The period of the data are 1950 through 1999. Data are available for individual cells in a text format or for sets of cells in NetCDF format. NetCDF is a binary format used extensively for large data sets. Because of the number of nodes involved in the MSMRSBS and to support the needs of other studies, an Excel Visual Basic For Applications (aka VBA) data manager was developed to parse NetCDF data and post it to Excel workbooks. The NetCDFBCSDManager computes the BCSD and observed data using either the closest BCSD cell to the target cell or the weighted average of the four closest BCSD cells. The latter approach was used for the MSMRSBS.

Another Excel VBA data manager, the ClimateChangeAdjustmentsManager, was developed to do the HDe computations and to apply the adjustment factors to obtain five scenarios for two futures. It processes the nodes in batches and posts the output to workbooks in a format usable by the depletion models. The data were processed in two batches – one for the water users and one for the evaporation nodes.

Depletion Computations

The Milk basin has historically used the Blaney-Criddle method of computing irrigation depletions. However, the decision model uses a daily timestep. At the time that this work was scoped, Reclamation did not have access to a PC based Penman-Monteith ET model but did have a daily Hargreaves-Samani ET model. The Hargreaves-Samani ET model has been used by Reclamation in the San Juan basin for several years to disaggregate Blaney-Criddle depletions to daily. This approach was used to support the MSMRSBS. The steps of this approach are:

1. Compute monthly Blaney-Criddle project irrigation requirements in inches/month.

2. Compute daily Hargreaves-Samani project irrigation requirements in inches/day.

3. Compute 7-day running average daily project irrigation requirements in inches/day.

4. Compute daily project crop requirement fractions as a function of 7-day running average daily requirements and equivalent monthly requirements.

5. Compute daily Blaney-Criddle project irrigation requirements as a function of the monthly Blaney-Criddle project irrigation requirement and the Hargreaves-Samani based daily fractions.

Step 1 is done using the Blaney-Criddle data manager and model. Steps 2 through 4 are done using the Hargreaves-Samani data manager and model. Step 5 is done in the RiverWare model. Running average daily values are used to compute the daily fractions to smooth the demand

---

[4] gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#Data%3A%20Subset%20Request

curve because daily requirements can be erratic. The SCS method of computing effective precipitation is used by both the Blaney-Criddle and Hargreaves-Samani models. A constant cropping pattern provided by the clients was used.

Bias Corrections of SACSMA Flows

SACSMA produces spatially aggregated flows whereas the decision model uses spatially disaggregated flows. Daily historic flows from the existing decision model were spatially and temporally aggregated for use in the bias correction process. Then the biased corrected monthly flows by climate scenario were temporally and spatially disaggregated to obtain daily flows for use in the decision model. These computations are managed by the hydrology manager. SACSMA nodes used in the decision model and bias correction computations are listed in Table 4.

Table 4. SACSMA nodes used in RiverWare model and bias correction computations.

Node	Description
SBUM8	Sherburne Reservoir
PDBM8	South Milk River
NFMM8	Upper North Milk River
CCMM8	Milk River to Paradise Valley Diversion:Tributary Inflow
FRDM8	Frenchman River IB to Reservoir
BCHM8	Beaver Creek
SMYM8	LowerStMaryLake
SMBM8	StMaryRiverIB
ERNM8	Milk River at Milk River Alberta
HAVM8	Milk River at Havre
HRLM8	Milk River at Harlem
DMRM8	Milk River At Dodson Dam
INSM8	Milk River to Vandalia Dam
NSHM8	Milk River to Mouth

Simulated flows for St. Mary's Milk basins were adjusted using a quantile mapping bias correction methodology. For this analysis, biases are characterized using a quantile map. The quantile map features two empirical cumulative distribution functions (CDFs), one of simulated flows during bias identification period (1960-2002) and another of reference observed flows during this period. The CDFs are constructed at a given runoff location, first on a month-specific basis to characterize bias in monthly mean flows and then on an annual basis to characterize bias in annual mean flow. All CDFs are smoothed non-parametrically. After defining these maps, simulated runoff bias correction ensues. The quantile maps are interpreted to reveal SAC-SMA runoff simulation bias for a given simulated runoff magnitude. For more details on the methodology refer to the "West-Wide Climate Risk Assessment" report[5].

[5] Technical Memorandum No. 86-68210-2011-01, March, 2011.

Figures 2 through 5 show example bias correction outputs for two example basins with low and high biases. Low bias stations have simulation outputs that match both the annual volume and seasonal timing well. High bias stations fail to capture either the seasonal flow patterns or the annual runoff volume. Figure 2 shows monthly observed (black line), simulated (red line), and bias-corrected simulated (cyan line) flow volumes for water years 1960–2002 for node SBUM8. Figure 3 shows monthly mean volume (left panel) and annual mean volumes (right panel) including bias-corrected simulated flow (BCF) calculated from water years 1960–2002 for node SBUM8. Figure 4 shows monthly observed (black line), simulated (red line), and bias-corrected simulated (cyan line) flow volumes for water years 1960–2002 for node ERNM8. Figure 5 shows monthly mean volume (left panel) and annual mean volumes (right panel) including bias-corrected simulated flow (BCF) calculated from water years 1960–12002 for node ERNM8.

Extension of RiverWare Decision Model

The RiverWare model that was obtained from the clients did not have data management interfaces (DMI's) for moving data in and out of the model. Furthermore, the period (1959 through 2009) did not correspond to the common period of the climate change depletions data and biased corrected flows (1950 through 1999). In addition, it was discovered that the initial conditions for streamflow and return flow routing were incorrect. The following adjustments were made to the model to support the MSMRSBS:

Created DMI's to specify initial routing conditions with corrected slots[6].

Created DMI's to specify reservoir initial storages.

Created data object slots and initialization rules to populate minimum efficiency, return flow fractions and ground water fractions of water user.

Created data object slots and initialization rules to populate evapotranspiration rate slots of water users from monthly irrigation requirement and daily requirement fraction.

Added initialization rules to support dynamic period specifications.

Used minimum outflow of 0.0 on gain and evaporation reaches to keep river whole.

Created data object slots and modified rules that compute river evaporation losses.
Created output DMI with standard model output.

Developed data manager to manager RiverWare input and output and model runs by climate change scenarios.

[6] A slot is a RiverWare term for one parameter of an object.

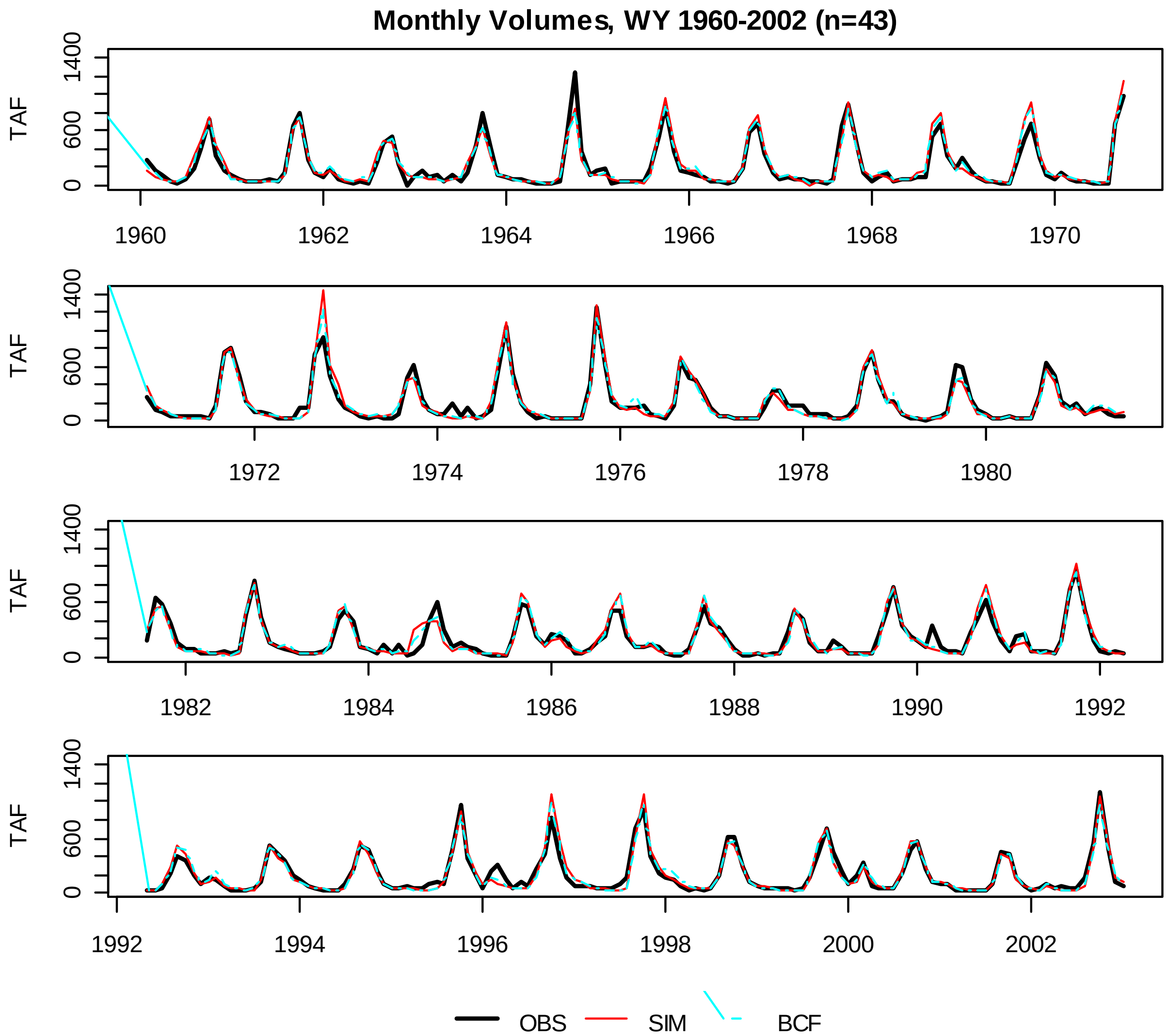


Figure 2. Historical Simulated Runoff, Small-Bias Example: Monthly Time Series Before and After Bias Correction.

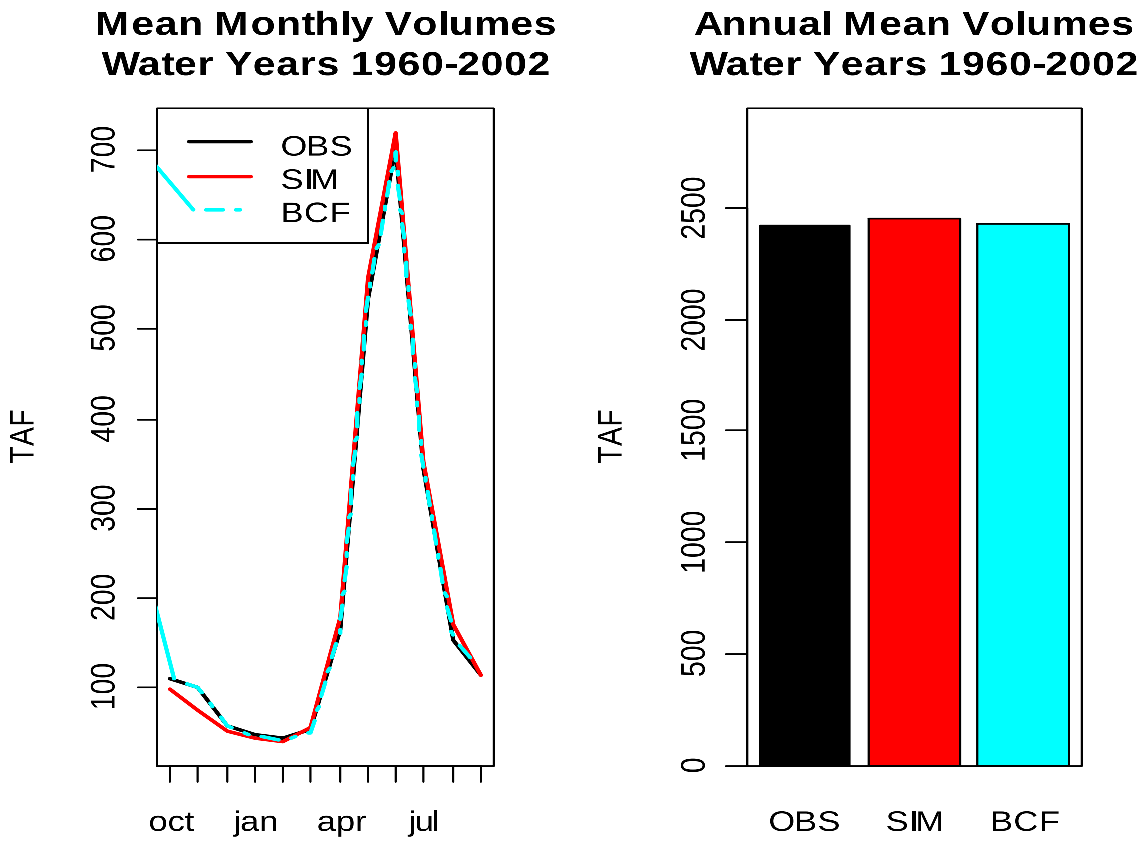


Figure 3. Historical Simulated Runoff, Small-Bias Example: Monthly and Annual Means Before and After Bias Correction.

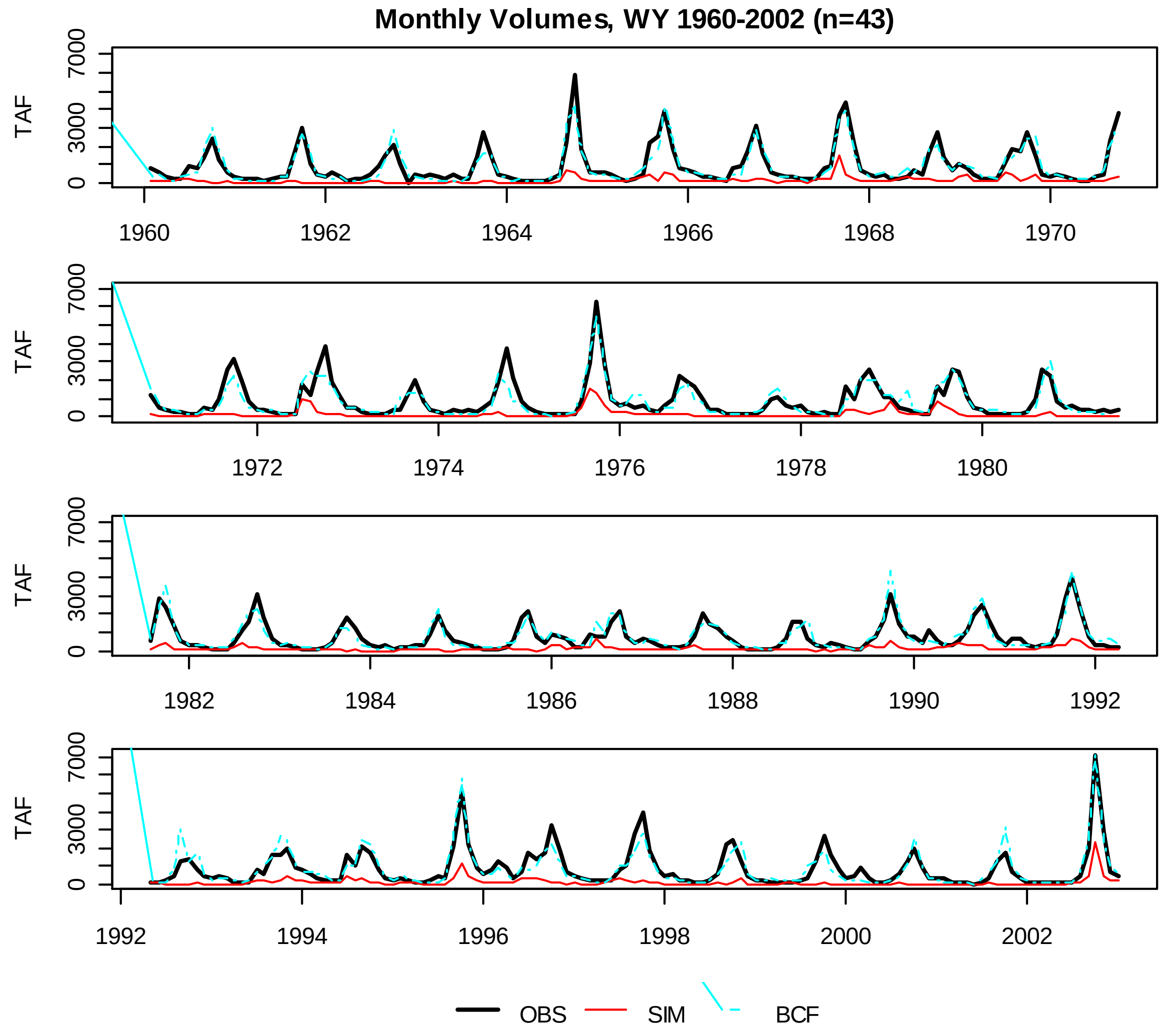


Figure 4. Historical Simulated Runoff, Large-Bias Example: Monthly Time Series Before and After Bias Correction.

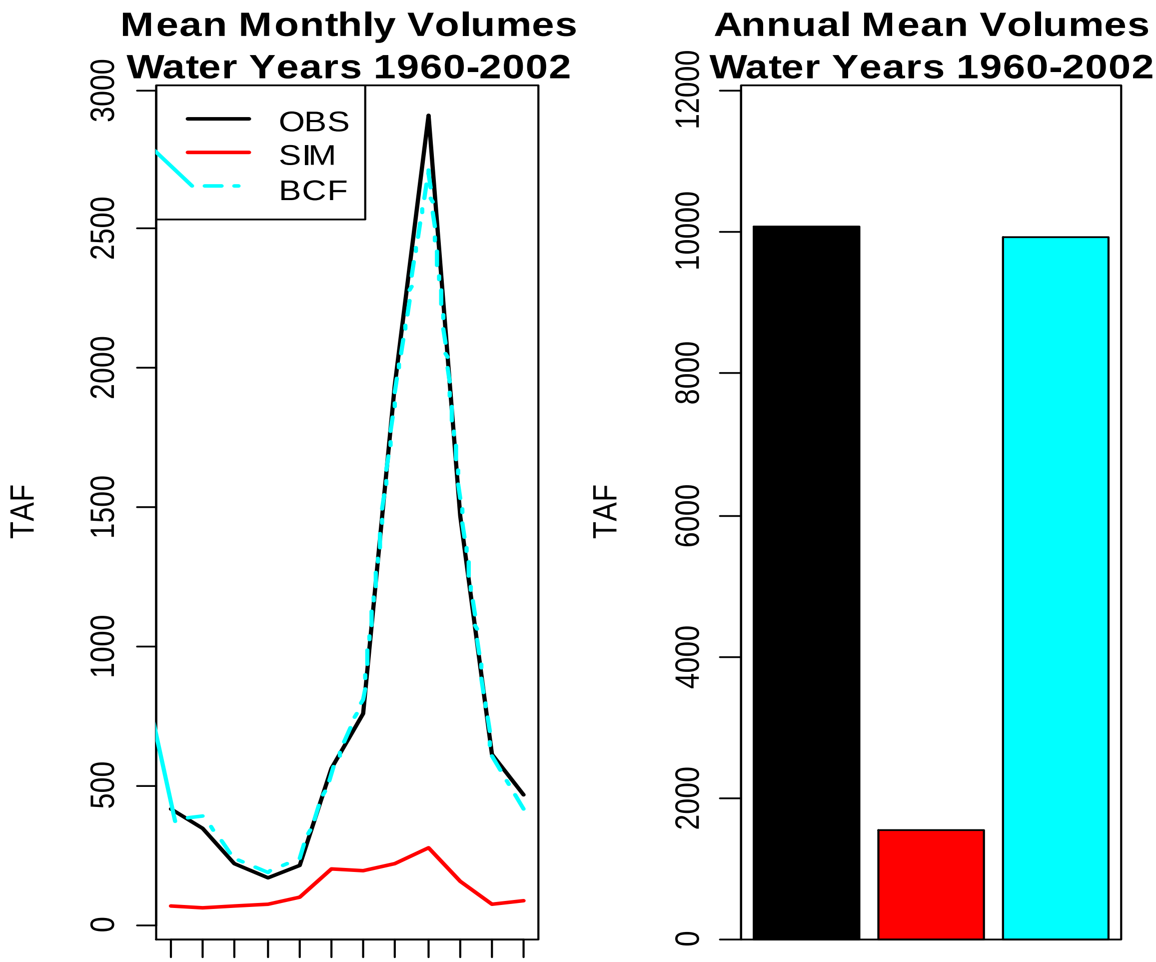


Figure 5. Historical Simulated Runoff, Large-Bias Example: Monthly and Annual Means Before and After Bias Correction.

Supporting Applications

The tasks required to support the MSMRSBS required development or adaptation of a number of data managers. Specific ones are noted in this document. A list of managers developed or used by the MSMRSBS are listed in Table 5. The DUT was an existing manager used to support the study. The NetCDF BCSD manager, Climate Change Adjustments Manager, and Blaney Criddle manager were developed for use throughout Reclamation. The other managers were developed specifically for the study. A user manual of all managers was provided to the clients.

Table 5. MSMRSBS Data and Model Managers.

Workbook	Description
DataUtilitiesToolkit.xlam or DataUtilitiesToolkit.xlsm	Data Utilities Toolkit - Various data management utilities oriented to data in RiverWare XlWriter format.
NetCDFBCSDManager.xlsm or MilkNetCDFBCSDManager.xlsm	Application to parse BCSD and Mauer observed data in NetCDF binary format and transform into Excel workbooks.
ClimateChangeAdjustsmentsManager MilkCCAdjustmentsManager.xlsm	Application to use Delta or HDe method to create five subsets of climate data from the 112 BCSD climate change projections.
BlaneyCriddleManager or MilkwaterUsersBlaneyCriddleManager.xlsm	Application to manage Blaney-Criddle monthly ET model runs using climate change scenarios.
HargreavesSamaniManager or MilkWaterUsersHargreavesSamaniManager.xlsm	Application to manage Hargreaves-Samani daily ET model runs using climate change scenarios.
MilkEvaporationManager.xlsm	Application to compute reservoir and river evaporation rates by climate change scenarios.
MilkDailyHydrologyManager.xlsm	Application to compute daily biased corrected flows as a function of monthly biased corrected flows, daily biased flows, and monthly biased flows for all climate change scenarios.
MilkRiverWareManager.xlsm	Application to manage RiverWare input data, run RiverWare, and manager RiverWare output data by climate change scenarios.

RiverWare Model and Documentation Review

Sufficient resources were only available to do a cursory review of the model. Enough time was spent with the model to design the changes needed to support the MSMRSBS and to formulate a few recommendations. Two drafts of the model documentation were reviewed. Model and documentation review and recommendations were provided to clients by email on April 25, 2011, July 21, 2011, and September 2, 2011. The clients have discussed the possibility of a more extensive peer review by TSC of the model and study.

The model is comprehensive, well documented, and a viable tool for analyzing affects of climate change in the basin and to support the objectives of the MSMRSBS. The one shortcoming in the model is historic hydrology. The team should consider naturalizing flows downstream of Fresno Reservoir. If this is done, climate change flows would have to have bias corrections revised. TSC will be conducting a more comprehensive review of entire study by 01/31/2012.