predicted significant growth for Calgary and other Irrigation districts. The data supplied by Alberta Environment was transcribed from model input and other sources. The full model data set was not provided. As a result, the assumptions underlying the data provided were not always clear. The demand data sets were thus distributed to the Modeling and Data Committee for review. As a consequence of this review, Calgary demands were modified to better reflect current (viz. future) demands and return flows. To correct for both circumstances, demands were increased by a factor of 2.7122 at the Bearspaw water treatment plant (Bearspaw WTP) and by a factor of 5.2614 at the Glenmore water treatment plant (Glenmore WTP). These ratios were found by comparing average actual WTP diversion against the SSRB demand dataset. Similarly, irrigation demands were adjusted to account for return flows. The WID demands also required a scaling factor to represent more current demand levels (0.588). BRID was similarly adjusted (factor = 0.9). Following correction, the demand sets were reviewed and approved by the Modeling and Data Committee members, which included highly knowledgeable staff from the appropriate organizations.

SECTION 3. OPERATIONS

GENERAL OASIS OPERATIONS DESCRIPTION

At its most basic, an OASIS model is driven by weights on variables (flow and/or storage); positive weights encourage actions while negative weights discourage them. Further, the weights are ordinal; a variable with a higher weight is given preference over one with a lower weight, regardless of the magnitude of the difference. Thus, in a very simple, two-variable model, the solution will be the same whether the difference in the two weights is 0.1 or 100. Of course, as a model becomes more complex – the BROM is quite large and complex – the more complex it becomes to set the weights appropriately.

The weight operations simulated in this model are summarized below in table form. The "Priority, Weight" column indicates the order in which the flows and storages are satisfied. Note that the Priority values are not part of the data read by OASIS; they are simply to help the user understand the hierarchy.

BOW RIVER OPERATIONS MODEL WEIGHTS

Traditionally, demand weights are recorded in the statdata.mdb file as model inputs. In order to support a simpler transition between WRMM emulation and BROM operations in the future, however, these weights are instead applied to deliveries to demands in the file set_demands.ocl. The list of demands and their associated weights can be found in the file _znode_lists.ocl, as set_demands.ocl refers only substitutes. In many cases, weights described below are the added values of both the demand's specific weight and the value for passing through each ID's diversion channel. The weights on channel flow maintain the hierarchy between WID, EID, and BRID licenses.

Again, priority is not reflected anywhere in the model, it merely reflects the underlying hierarchy that the model uses the weight system to generate. In many cases (e.g. releases from TAU reservoirs to meet senior downstream licenses), the weights below are overridden by operational targets that force the release (or storage) of water in reservoirs and limit withdrawals.

OASIS Node Number, Name	Priority, Weight	Category	Notes
205, Calgary Div	0, 0	Future Node, no effect on model	Will reflect Calgary diversions before release from Bearspaw. Currently set to 0 due to lack of data.
065, Minnewanka Reservoir	1, 1500	TAU Reservoir Storage	Stored water in the TAU reservoirs. Increased storage is only allowed if there is enough inflow to meet the WID, EID, and BRID minimum licenses. TAU does not have to release storage to meet these flows, however, instead sending natural inflow or 1250 cfs (whichever is greater) at Bearspaw. See inflow_projections.ocl
080, Spray Reservoir	1, 1500	TAU Reservoir Storage	See above
130, Upper Kananaskis Reservoir	1, 1500	TAU Reservoir Storage	See above
145, Lower Kananaskis Reservoir	1, 1500	TAU Reservoir Storage	See above
155, Barrier Reservoir	1, 1500	TAU Reservoir Storage	See above
185, Ghost Reservoir	1, 1500	TAU Reservoir Storage	See above

OASIS Node Number, Name	Priority, Weight	Category	Notes
01, BRID1	2, 0	Instream Objective	Although weight is zero, this instream target is met through target on Bassano flows
02, BRID2	2, 0	Instream Objective	See above
03, BRID3	2, 0	Instream Objective	See above
04, BRID4	2, 0	Instream Objective	See above
05, BRID5	2, 0	Instream Objective	See above
06, Red Deer River	2, 0	Instream Objective	See above
17, JNonIrr OM/B confl and SSask. Jlic to MedHat	2, 0	Instream Objective	See above
30, BRID6	2, 1170	Instream Objective	Instream Objective flow past Bassano. Met via target statement on arc 320.560 in inflow_projections.ocl.
216, Bearspaw WTP	3, 900	Calgary Demand	Water treatment plant demands for the City of Calgary. Return flows are estimated at 83%
240, Glenmore WTP	3, 900	Calgary Demand	See above
212, Bow Senior Irrigation, Bearspaw to WID diversion	4, 890	River Demands	These are demands that cannot be met by any storage and are totally reliant on river flow. Discussions with ID representatives implied that they rarely, if ever, place calls on these users since their demands are so small. Thus they are met before the ID demands.
214, Bearspaw to WID diversion (major)	4, 890	River Demands	See above
215, Bearspaw to WID diversion (minor)	4, 890	River Demands	See above
221, Bow Senior Irrigation, WID diversion to Bonnybrook	4, 890	River Demands	See above
222, Bow Junior Irrigation, WID diversion to Bonnybrook	4, 890	River Demands	See above
224, Calgary (major)	4, 890	River Demands	See above
225, Calgary (minor)	4, 890	River Demands	See above
251, Bow Senior Irrig, Bonnybrk to Highwd confl	4, 890	River Demands	See above
252, Bow Junior Irrig, Bonnybrk to Highwd confl	4, 890	River Demands	See above
254, B JIrrig, PineCreek/Bonnybrk to Highwd Confl maj	4, 890	River Demands	See above
255, B JIrrig, PineCreek/Bonnybrk to Highwd Confl min	4, 890	River Demands	See above
281, Bow Junior Irrigation, Highwood to Carseland	4, 890	River Demands	See above
282, Bow Senior Irrigation, Highwood to Carseland	4, 890	River Demands	See above
284, Bow NonIrrig Highwood/Bow Conf to Carseland major	4, 890	River Demands	See above
285, Bow NonIrrig Highwood/Bow Conf to Carseland minor	4, 890	River Demands	See above
291, Bow Senior Irrigation, Carseland to Bassano	4, 890	River Demands	See above
292, Bow Junior Non Irrigation, Carseland to Bassano	4, 890	River Demands	See above
295, Carseland (minor)	4, 890	River Demands	See above
321, Bow Senior Irrigation, Bassano to mouth	4, 890	River Demands	See above
322, Bow Junior Irrigation, Bassano to mouth	4, 890	River Demands	See above
322, Bow Junior Irrigation, Bassano to mouth	4, 890	River Demands	See above

OASIS Node Number, Name	Priority, Weight	Category	Notes
324, Bow Junior NonIrrig, Bassano to mouth (major)	4, 890	River Demands	See above
325, Bow Junior NonIrrig, Bassano to mouth (minor)	4, 890	River Demands	See above
331, Siksika Irrigation Diversion Expansion	4, 890	River Demands	See above
332, Siksika Irrigation Existing	4, 890	River Demands	See above
333, Siksika Bow Expansion	4, 890	River Demands	See above
261, Chestermere Lake (minor)	5, 660	WID Protected Demands/License	These demands are only met up to the licensed priority diversion (see below)
263, WID Irrigation Block1	5, 660	WID Protected Demands/License	See above
264, WID Irrigation Block2	5, 660	WID Protected Demands/License	See above
266, WID Irrigation Block3	5, 660	WID Protected Demands/License	See above
268, WID Irrigation Block4	5, 660	WID Protected Demands/License	See above
269, WID Irrigation Block5	5, 660	WID Protected Demands/License	See above
524, EID Irrig Block, N. Branch below Crawling Valley	6, 640	EID Protected Demands/License	These demands are only met up to the licensed priority diversion (see below)
525, EID Irrig Block, N. Branch above Crawling Valley	6, 640	EID Protected Demands/License	See above
527, EID Irrigation Block1	6, 640	EID Protected Demands/License	See above
530, EID Irrigation Block, below Snake Lake	6, 640	EID Protected Demands/License	See above
537, EID Irrigation Block2	6, 640	EID Protected Demands/License	See above
538, EID Irrigation Block, East Branch below Kitsim	6, 640	EID Protected Demands/License	See above
539, EID Irrigation Block3	6, 640	EID Protected Demands/License	See above
540, EID Irrigation Block, below Lake Newell	6, 640	EID Protected Demands/License	See above
541, EID Irrigation Block4	6, 640	EID Protected Demands/License	See above
542, EID Irrigation Block, below Rock Lake	6, 640	EID Protected Demands/License	See above
543, EID Irrigation Block5	6, 640	EID Protected Demands/License	See above
549, EID Irrigation Block, below Tilley B	6, 640	EID Protected Demands/License	See above
336, BRID Irrigation Block, Headworks	7, 620	BRID Protected Demands/License	These demands are only met up to the licensed priority diversion (see below)
341, BRID Irrigation Block, McGregor Lake	7, 620	BRID Protected Demands/License	See above
348, BRID Irrigation Block1	7, 620	BRID Protected Demands/License	See above
349, BRID Irrigation Block2	7, 620	BRID Protected Demands/License	See above
351, BRID Irrigation Block3	7, 620	BRID Protected Demands/License	See above
355, BRID Irrigation Block4	7, 620	BRID Protected Demands/License	See above

OASIS Node Number, Name	Priority, Weight	Category	Notes
356, BRID Irrigation Block5	7, 620	BRID Protected Demands/License	See above
360, BRID Irrigation Block6	7, 620	BRID Protected Demands/License	See above
524, EID Irrig Block, N. Branch below Crawling Valley	8, 430	EID Remaining Demand	Any remaining EID Demand beyond their license
525, EID Irrig Block, N. Branch above Crawling Valley	8, 430	EID Remaining Demand	See above
527, EID Irrigation Block1	8, 430	EID Remaining Demand	See above
530, EID Irrigation Block, below Snake Lake	8, 430	EID Remaining Demand	See above
537, EID Irrigation Block2	8, 430	EID Remaining Demand	See above
538, EID Irrigation Block, East Branch below Kitsim	8, 430	EID Remaining Demand	See above
539, EID Irrigation Block3	8, 430	EID Remaining Demand	See above
540, EID Irrigation Block, below Lake Newell	8, 430	EID Remaining Demand	See above
541, EID Irrigation Block4	8, 430	EID Remaining Demand	See above
542, EID Irrigation Block, below Rock Lake	8, 430	EID Remaining Demand	See above
543, EID Irrigation Block5	8, 430	EID Remaining Demand	See above
549, EID Irrigation Block, below Tilley B	8, 430	EID Remaining Demand	See above
260, Chestermere Reservoir (below lower rule)	9, 460	WID Reservoir Storage	Chestermere is not allowed to be drawn down, so extra water is immediately routed to refill any loss.
261, Chestermere Lake (minor)	10, 440	WID Remaining Demand	Any remaining WID Demand beyond their license
263, WID Irrigation Block1	10, 440	WID Remaining Demand	See above
264, WID Irrigation Block2	10, 440	WID Remaining Demand	See above
266, WID Irrigation Block3	10, 440	WID Remaining Demand	See above
268, WID Irrigation Block4	10, 440	WID Remaining Demand	See above
269, WID Irrigation Block5	10, 440	WID Remaining Demand	See above
336, BRID Irrigation Block, Headworks	11, 420	BRID Remaining Demand	Any remaining BRID Demand beyond their license
341, BRID Irrigation Block, McGregor Lake	11, 420	BRID Remaining Demand	See above
348, BRID Irrigation Block1	11, 420	BRID Remaining Demand	See above
349, BRID Irrigation Block2	11, 420	BRID Remaining Demand	See above
351, BRID Irrigation Block3	11, 420	BRID Remaining Demand	See above
355, BRID Irrigation Block4	11, 420	BRID Remaining Demand	See above
356, BRID Irrigation Block5	11, 420	BRID Remaining Demand	See above
360, BRID Irrigation Block6	11, 420	BRID Remaining Demand	See above
523, Crawling Valley Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above
532, Snake Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above
535, Rock Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above
536, Newell Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above
547, Cowocki Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above

OASIS Node Number, Name	Priority, Weight	Category	Notes
548, Tilley Reservoir (Below Lower Rule)	13, 310	EID Reservoir Storage	See above
262, Langdon Reservoir	14, 325	WID Reservoir Storage	Remaining extra water is used to refill ID reservoir storage, starting with WID, then EID, then BRID
340, McGregor Reservoir (Below Lower Rule)	15, 305	BRID Reservoir Storage	See above
342, Travers Reservoir (Below Lower Rule)	15, 300	BRID Reservoir Storage	See above
344, Little Bow Reservoir (Below Lower Rule)	15, 300	BRID Reservoir Storage	See above
347, Badger Reservoir (Below Lower Rule)	15, 300	BRID Reservoir Storage	See above
352, Lost Lake Reservoir (Below Lower Rule)	15, 300	BRID Reservoir Storage	See above
357, Scope Reservoir (Below Lower Rule)	15, 300	BRID Reservoir Storage	See above
523, Crawling Valley Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
532, Snake Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
535, Rock Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
536, Newell Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
547, Cowocki Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
548, Tilley Reservoir (Between Upper/Lower Rule)	17, 260	EID Reservoir Storage	See above
260, Chestermere Reservoir (Between upper/lower rule)	16, 275	WID Reservoir Storage	See above, (For a small period of time, Chestermere has a limited volume available for use to the WID.)
340, McGregor Reservoir (Between Upper/Lower Rule)	18, 255	BRID Reservoir Storage	See above, (McGregor has a slightly higher weight so that its level is high enough for irrigators that pull directly from the lake)
342, Travers Reservoir (Between Upper/Lower Rule)	19, 250	BRID Reservoir Storage	See above
344, Little Bow Reservoir (Between Upper/Lower Rule)	19, 250	BRID Reservoir Storage	See above
347, Badger Reservoir (Between Upper/Lower Rule)	19, 250	BRID Reservoir Storage	See above
352, Lost Lake Reservoir (Between Upper/Lower Rule)	19, 250	BRID Reservoir Storage	See above
357, Scope Reservoir (Between Upper/Lower Rule)	19, 250	BRID Reservoir Storage	See above
507, Little Bow Irrigation, Travers to mouth	20+, 190	Downstream/Offstream Demands	The remaining demands are downstream, offstream, or otherwise met by flows outside of the Bow system. Thus these demands are met last.
571, Irrigation (Senior) South Sask from Oldman/Bow confluence to Medicine Hat	20+, 180	Downstream/Offstream Demands	See above
582, , Irrigation (Senior) South Sask from Medicine Hat to border	20+, 180	Downstream/Offstream Demands	See above
572, Irrigation (Future) South Sask from Oldman/Bow confluence to Medicine Hat	20+, 140	Downstream/Offstream Demands	See above
573, Irrigation (Junior) South Sask from Oldman/Bow confluence to Medicine Hat	20+, 140	Downstream/Offstream Demands	See above
574, JNonIrr OM/B confl and SSask. Jlic to MedHat majr	20+, 140	Downstream/Offstream Demands	See above

OASIS Node Number, Name	Priority, Weight	Category	Notes
581, , Irrigation (Junior) South Sask from Medicine Hat to border	20+, 140	Downstream/Offstream Demands	See above
583, , Irrigation (Future) South Sask from Medicine Hat to border	20+, 140	Downstream/Offstream Demands	See above
584, Medicine Hat (major)	20+, 140	Downstream/Offstream Demands	See above
508, Little Bow South of Travers (minor)	20+, 80	Downstream/Offstream Demands	See above
575, JNonIrr OM/B confl and SSask. Jlic to MedHat minr	20+, 80	Downstream/Offstream Demands	See above
585, Medicine Hat (minor)	20+, 80	Downstream/Offstream Demands	See above

SECTION 4. BOW RIVER OPERATIONS MODEL SPECIFIC OPERATIONS

DIVERSION LICENSE OPERATIONS

Similar to WRMM, the BROM uses irrigation district diversion limits that are dependent on river flow and timing. They follow the logic below provided by Alberta Environment and clarified by irrigation district stakeholders.

WID:

- When natural flow is equal to or below 155 m³/s, the river is termed to be in LOW STAGE and the maximum diversion is 450 cfs (12.743 m³/s).
- When the natural flow is equal to or above 300 m³/s, it is termed to be in FLOOD STAGE and the maximum diversion is 750 cfs (21.238 m³/s).
- When the natural flow is between the above two values (i.e. between 155 and 300 m³/s), the river is in HIGH STAGE and the maximum diversion is 600 cfs (16.990 m³/s)

EID:

- When the natural flow is equal to or below 183 m³/s in weeks 18 to 39 (May 1 to Sept 30), the river is in LOW STAGE and the maximum diversion is 1,000 cfs (28.317 m³/s).
- When the natural is above Low Stage, the maximum diversion permitted is 3,000 cfs (84.951 m³/s).
- Outside of May 1 to Sept 30 the maximum diversion is 1,000 cfs.

BRID:

- BRID diversion limit is effectively 1460 cfs at all times.

IMPORTANT DEVIATIONS FROM WRMM IN LOWER BOW OPERATIONS

The WRMM models strict license priority water allocation. In OASIS, we have attempted to instead create a model that better reflects current operations and allows for greater variation in potential operational changes. To that end, there are a number of significant specific changes in the way the BROM operates (in addition to the above changes in weights). These operational rules are the result of numerous discussions with stakeholders from the irrigation districts and the City of Calgary.

1. Water Use Among Junior Licensees

In the WRMM scenario provided for use in the SSRB model, the junior licenses are assumed to have expanded significantly over current use. In several cases, these expanded demands exceeded the users' annual license limitations. In the absence of stakeholder input to speak for individual demand node use, we were unable to scale these demands as occurred with the Irrigation Districts. Since these demands are very small compared to Irrigation District use, however, model it was decided to sate these demands fully regardless of license limit in the BROM.

2. Water Use Among Senior Licensees

Irrigation diversions will generally not call for water that would lead to shortages in demands that cannot be met by storage. For example, BRID has significant storage reserves that can be used to meet demands during periods of low flows. In such a situation, rather than call for extra water to meet their demands from Bow river flows (that would in turn cause shortages in river dependent junior licenses), the BRID demands will be met from storage and the junior license needs will be maintained. This is accomplished using the weighting system described above.

Among the IDs, however, there is also a general recognition of the importance of demands that cannot be met by storage within their districts. The BRID Headworks, for example, cannot withdraw from McGregor reservoir and is thus wholly dependent on river flow. As such, if the EID has enough water to meet its own river-dependent demands without reaching its 1000 cfs license, the EID will allow the extra licensed water to be used for the BRID Headworks and meet its remaining demands from storage. In our code, under low flow circumstances, the IDs divert the lesser of their license or their river dependent demands first. After these "protected demands" are met, the remaining river flow is divvied up according to license seniority (WID -> EID -> BRID). License diversions are determined according to logic described by Alberta Environment according to the following logic:

For WID:

- When river flow is equal to or below 155 cms, the river is termed to be in LOW STAGE and the maximum diversion is 450 cfs (12.743 cms)
- When the river is equal to or above 300 cms, it is termed to be in FLOOD STAGE and the maximum diversion is 750 cfs (21.238 cms)
- When the river is between the above two values (i.e. between 155 and 300 cms), the river is in HIGH STAGE and the maximum diversion is 600 cfs (16.990 cms)

For EID:

- When the river is equal to or below 183 cms in weeks 18 to 39 (May 1 to Sept 30), the river is in LOW STAGE and the maximum diversion is 1,000 cfs (28.317 cms).
- When the river is above Low Stage, the maximum diversion permitted is 3,000 cfs (84.951 cms).

The OCL code for this is found in "inflow_projections.ocl."

3. Langdon Reservoir

Langdon Reservoir is not modeled in WRMM. In the BROM, data for this reservoir and its operations are carried over from the SSRB implementation. It is an 8340 cubic decameter reservoir that can be filled and drained completely (i.e. there is no dead storage for this reservoir in the model). Rule curve operations for this model are derived from conversations with WID stakeholders. License limitations for diversions under "normal" and "low flow" conditions are not yet modeled.

4. McGregor Reservoir

Discussions with BRID implied that changes were necessary to correctly model the dead storage portion of McGregor reservoir in the BRID. The WRMM established dead storage at a level of 871.74 M as there are irrigators who cannot draw from the reservoir when it falls below that level. BRID staff indicated that the district will draw the reservoir down much farther to 863.5 M and cut off the 2,000 acres that irrigate directly from the reservoir. This change is reflected in the input dataset for the BROM with the shutoff reflected in the file set_demands.ocl. In BRID, McGregor is drawn down in preference to Travers.

5. Carseland Diversion Limitations

BRID staff also described additional limitations at the Carseland diversion structure. At very high Bow River flows, the structure is unable to fully divert due to debris and damage. Similarly, at very low flows in the summer weeds and aquatic vegetation prevent full diversion. The OCL code for this can be found in "set_diversion_limits.ocl." This code remains in the model but is deactivated based on guidance from BRID.

In the BROM the flows and reductions of interest are as follows:

- At Bow flows above 230 cms, diversion flows are problematic and reduced 10%.
- At Bow flows above 400 cms, safety booms break and diversion flows are reduced 50%.
- At Bow flows above 600 cms, diversion becomes unmanageable and must be shut off entirely.
- During the summer (July 15 – September 15) at Bow flows below 55 cms, weeds affect diversion and reduce it by 50%.

6. Siksika Expansion

Discussions with BRID staff also indicated the fact that expansions to current Siksika demand cannot be met fully from canal flows. At maximum only 4000 hectares on the Siksika Reservation can be irrigated from the Carseland diversion. The remaining 7431 hectares in the expansion must be met directly off of Bow River flows. This change was reflected in raw input and model structural changes rather than an OCL file. In the BROM Siksika is thus represented as three separate demands with the following irrigated areas.

From Carseland:

- Siksika existing (OASIS node 332): 1988 ha
- Siksika expansion (OASIS node 331): 2012 ha

From Bow:

- Siksika expansion (OASIS node 333): 7431 ha

7. BRID Headworks Pass-by Flow

The final BRID refinement noted in conversation was the minimum pass-by flow required for the BRID headworks to withdraw from the Carseland diversion. The Headworks are not currently able to draw water from the diversion when flows are below 500 cfs (14.16 cms). There has been an attempt to reduce this minimum flow to 300 cfs (8.5 cms), but the structural improvements failed to improve flow requirements. This value can be changed in the OCL constants table of the OASIS user-interface, and is reflected in the OCL files "set_maxQ_ann_limits.ocl" and "set_diversion_limits.ocl."

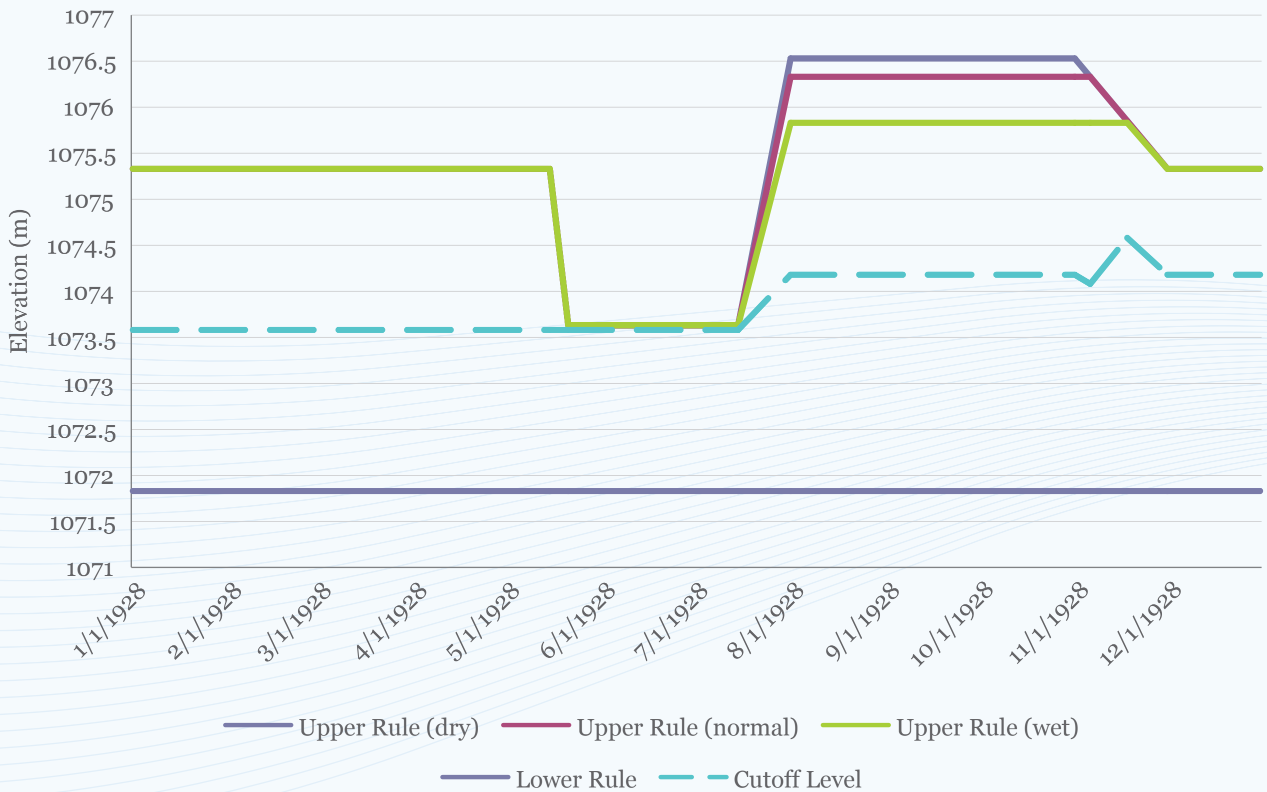
8. Glenmore Reservoir

Glenmore Reservoir did not exist in either the SSRB or WRMM models. Instead, it was represented by a time series of expected WTP production. The addition of Glenmore allows the use of storage in meeting Calgary WTP demands. Most of Calgary's demands can be met from either the Glenmore or Bearspaw treatment plants, according to Calgary staff. Node 239 (WTP Intermediate) allows for such flows.

Glenmore follows an inflow dependent rule curve. Conditions are determined on August 1, when 3-day lagged inflows are used to establish whether the season has been wet, normal, or dry (>75th percentile, >25th percentile, <25th percentile respectively). Stoplog devices are placed in the reservoir to increase maximum storage during the period Aug 1 to Dec 1, at 0.5, 1.0, and 1.2m above crest (see Figure 1). These devices are unable to withstand flood forces, however. Thus, if the 3 day flows during this period ever exceed the 90th percentile the stoplogs are removed. Additionally, for the low period (May 21 – July 15) Glenmore may fill above the Upper Rule to crest in order to keep flood releases through Calgary below 180 cms. In addition to the rule curve, Glenmore attempts to maintain a minimum flow of 1.5 cms (52 cfs) through the plant. The model maintains this flow unless reservoir stage falls more than halfway below the upper rule for Glenmore reservoir.

In addition, and in order to avoid drawing Glenmore unusually low, when the reservoir drains below the cutoff level, flow is reduced to a season dependent minimum flow – 120 cfs in winter (Aug 16 – July 14) and 400 cfs in summer (July 15 – Aug 15). Glenmore operational OCL can be found in the file "Glenmore_Ops.ocl."

FIGURE 2 - Glenmore Rule Curves



9. Time of Travel

Channel Routing

Without channel routing causing the lagging and attenuating of flow, water that enters the upper end of the basin can leave the lower end of the basin in the same day. Obviously, this is unrealistic. Alberta Environment has done SSARR (Streamflow Synthesis and Reservoir Routing – US Army Corps of Engineers) modeling on the Bow. The SSARR channel routing method is unusual in that we have not found it described in any hydrology text, and it is very difficult to implement in OASIS. The Muskingum method of channel routing is more common and has been implemented multiple times in OASIS. Thus, we used the SSARR routing parameters as a basis for computing Muskingum parameters

SSARR Method

The SSARR method uses three equations:

$$T_s = \frac{KTS}{Q^n}$$

$$T = T_s * N$$

Once these two equations are used to establish the value of Ts, the following equation is used to compute the outflow from the reach.

$$O_2 = O_1 + \Delta t * \frac{\left[\frac{(I_1 + I_2)}{2} - O_1\right]}{T_s + \Delta t}$$

Where:

Ts = time of storage per phase (time)
KTS = calibration constant determined by trial and error
Q = discharge (volume per unit time)
n = coefficient, usually between -1 and 1 determined by trial and error
T = travel time
N = number of phases
I1 = previous time-step's inflow into the stream reach
I2 = current time-step's inflow into the stream reach
O1 = previous time-step's outflow from the stream reach
O2 = current time-step's outflow from the stream reach
Δt = length of time step

The Muskingum method uses one equation:

$$O_2 = C_0 * I_2 + C_1 * I_1 + C_2 * O_1$$

Where:

I1 = previous time-step's inflow into the reach
I2 = current time-step's inflow into the reach
O1 = previous time-step's outflow from the stream reach
O2 = current time-step's outflow from the stream reach
Ci = fitted coefficients

Conversion Method

AE provided SSARR parameters (see the table below) for the 10 reaches shown. For each reach we used the SSARR parameters to compute an "observed" outflow hydrograph from the observed inflow hydrograph. Then we used the solver function in Excel to compute the Muskingum parameters. The solver was set up to minimize the sum of the absolute values of the residuals (Muskingum-computed outflows minus the SSARR-computed outflows. The observed inflow hydrograph used in this analysis was 846 days long (daily time step), which gives a significant number of both low flows and high flows. The results are summarized in the table below.

River	Stream Reach	Reach Number	SSARR Parameters			Muskingum Parameters		
			N	n	KTS	Co	C1	C2
Ghost	Waiparous Cr. conf to Ghost Res.	1	1	0.2	15.5	0.835	0.165	0
Bow	Banff to Canmore	2	1	0.2	12.26	0.866	0.134	0
	Canmore to Horseshoe Plant	3	1	0.2	17.16	0.822	0.178	0
	Horseshoe Plant to Ghost Res	4	1	0.2	24.51	0.751	0.249	0
	Ghost Res to Bearspaw Res	5	3	0.3	5.92	0.806	0.194	0
	Bearspaw Reservoir to Calgary	6	1	0.3	5.9	0.516	0.484	0
	Elbow R. conf. to Highwood conf.	7	3,3	0.2, 0.3	7	0.669	0.331	0
	Highwood River conf to Carseland	8	2	0.2	7	0.851	0.149	0
	Carseland to Bassano	9	2, 15	0.45, 0.24	8, 10	0.253	0.68	0.067
	Bassano to conf with Oldman R.	10	30	0.4	2	0.873	0.127	0

UPPER BOW/TRANSALTA OPERATIONS

1. Inter-day Reservoir Operations

The BROM includes and respects the seasonal pattern of Full Storage Levels for all TAU reservoirs. Seasonal elevation targets for power generation are not available. In the absence of such data, power generation targets were set as the average elevations of each reservoir on particular calendar dates. These were computed from historical records. The BROM attempts to closely match those average historical levels, called "Normal Curves," for each reservoir (included in Section 6 of this Appendix). When system inflows are unable to maintain such elevations, reductions in storage are balanced evenly across all reservoirs (i.e. insofar as it is possible, all reservoirs will remain at the same proportional level below the Normal Curve. If Spray is 10% below "Normal," for example, expect to see Barrier also at 10% below normal). Each reservoir has a spillway modeled, though the BROM assigns a penalty (negative weight) for their use. The code for these curves can be found in TAU_Gen_Flows.ocl. Lake Minnewanka is excepted from the balancing because of its recreational importance and its location in the National Park. As a result Lake Minnewanka is the last reservoir to be drawn below its normal curve. For Lower Kananaskis data was not available for the entire year. Guidance from SRD, based on prior FREWG study, was used to fill in the period between September and April.

2. Minimum Releases from Bearspaw Reservoir

Under shortage situations, TAU is not required to release any water in excess of:

» 350 cfs continuous flow from Ghost and
» Up to the natural flow at Bearspaw when and only when senior licenses downstream are not being met.

Notwithstanding, TAU has historically maintained a minimum release of about 1250 cfs from Bearspaw reservoir. In attempting to model the real circumstances, rather than the legal circumstances, the BROM assumes that TAU will continue to maintain a minimum flow of either 1250 cfs unless it is required to maintain a higher flow under condition 2 above. When senior licenses cannot be met with a flow of 1250 cfs at Bearspaw, the BROM requires TAU to release enough water to meet the ID minimum licensed diversions and downstream flow targets, but only up to the Alberta Environment calculated natural flow. TransAlta is allowed to capture natural flow in excess of the required release. The model logic that determines when case 2 applies and how much water to release under the current low flow circumstances is made in main.ocl. Specific Bearspaw flow targets are set in TAU_Gen_Flows.ocl.

3. Power Generation and Ancillary Services

It is important to remember that OASIS is a daily model, not an hourly one. BROM calculates daily releases before attempting to determine power revenue on a given day. A "second solve" is needed to determine revenue. Only intra-day (and not inter-day) reservoir releases for power generation are optimized. As described above, the model assumes that maintaining historical average elevations in the reservoirs is a reasonable way to approximate seasonal and inter-day power operations. Utilizing datasets of historical prices, projected prices, and probability of call on ancillary services, BROM optimizes the revenue gained from turbine operation *within a given day* with a total daily flow predetermined in the previous solve.

SECTION 5. SIMULATION OF DAILY STREAM FLOW FROM WEEKLY AVERAGE FLOW

UPPER BOW RIVER SYSTEM, ALBERTA, CANADA

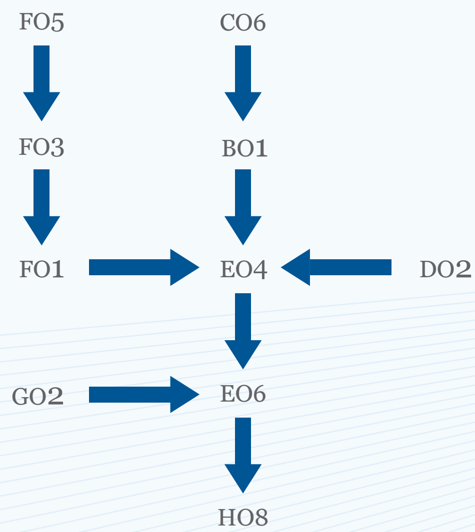
Version 2

» Negative local inflows retained except at headwater nodes.
» Corrected from version 1 for input data of average weekly flow rate, not flow sum.

HydroLogics | September 14, 2010

Average weekly flow rates of naturalized flows were provided to HydroLogics for a period between 1928 and 2001 (1928–1995 for Elbow). A schematic of the flow system is shown below in Figure 1.

FIGURE 1: Upper Bow River System Gages



LOCAL INFLOWS AND ELIMINATION OF NEGATIVE INFLOWS IN HEADWATER NODES

Weekly, local inflow was estimated by subtracting upstream inflow from the weekly flow sum at each gage location. One negative local inflow was observed in D02 (Cascade River near Banff). This deficit was "passed forward in time". It was set to zero and the deficit was held until subsequent inflows were sufficient to fill it.

SIMULATION OF DAILY LOCAL INFLOWS

The sets of 52 weekly local inflow sums were used to generate simulations of daily local inflow. Weeks were 7 days in length, with the exception of the last week in December, which was assumed to have 8 days in order to reach 365 total days for each year. Leap years were assumed to contain a week of 8 days at the end of February.

The long-term average of local inflow in log-space was estimated at each site. This long-term average was used to generate sequences of log-normally distributed simulated flow values. Weekly sets of these values were then scaled such that their sum was equal to the weekly local inflow sum. A standard deviation in log-space was selected such that the resulting coefficient of variation of non-zero flow in real-space ranged between 1.1 and 1.5 at all locations. Negative values for average daily inflow that resulted from negative weekly inflow sums were retained in the output flow sequence. Example daily simulations are shown below.

FIGURE 2: Daily flow simulation (H08) Bow River at Bearspaw Reservoir, 1999

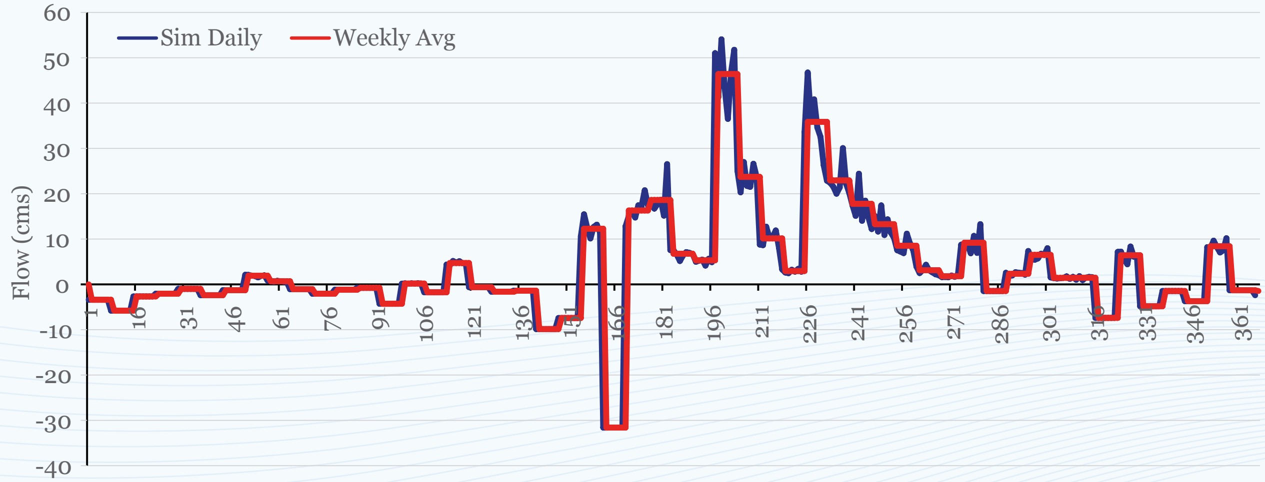


FIGURE 3: Daily flow simulation Elbow, 1990

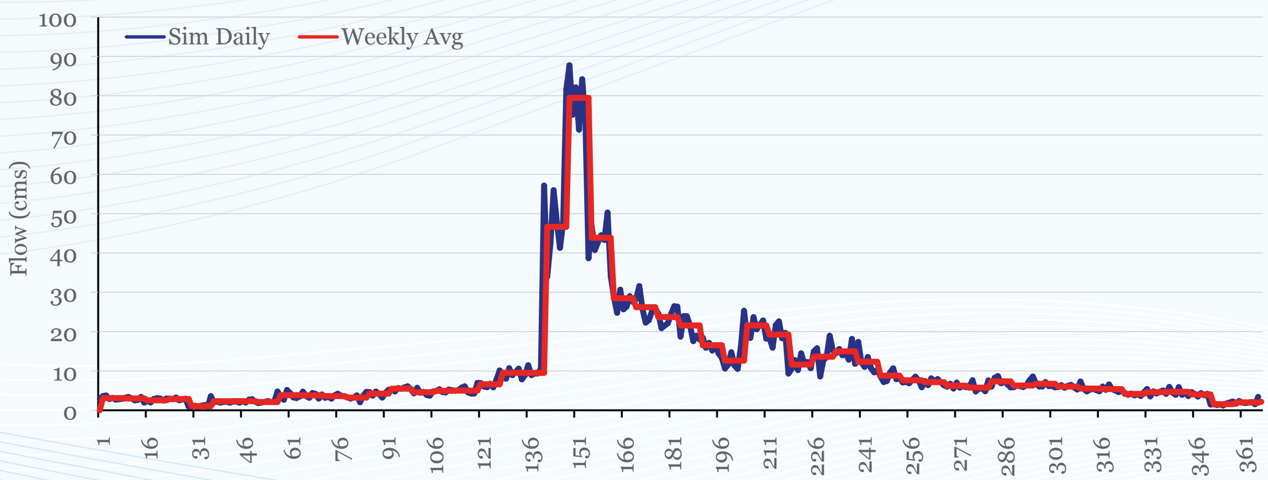
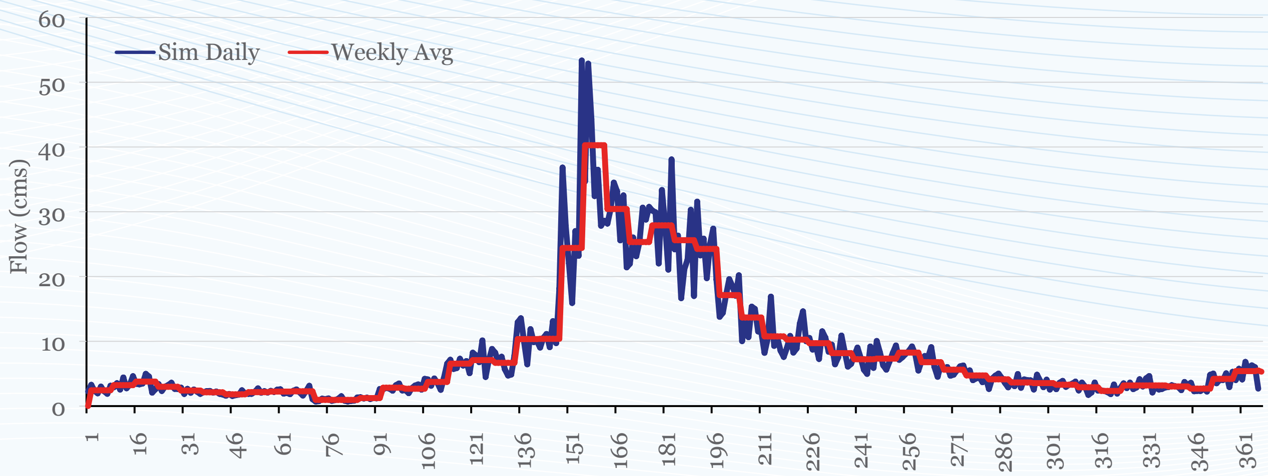
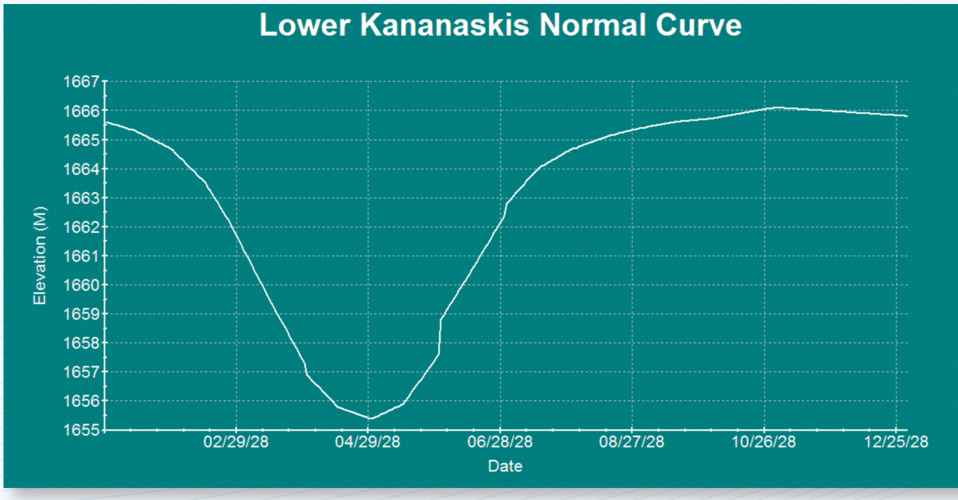
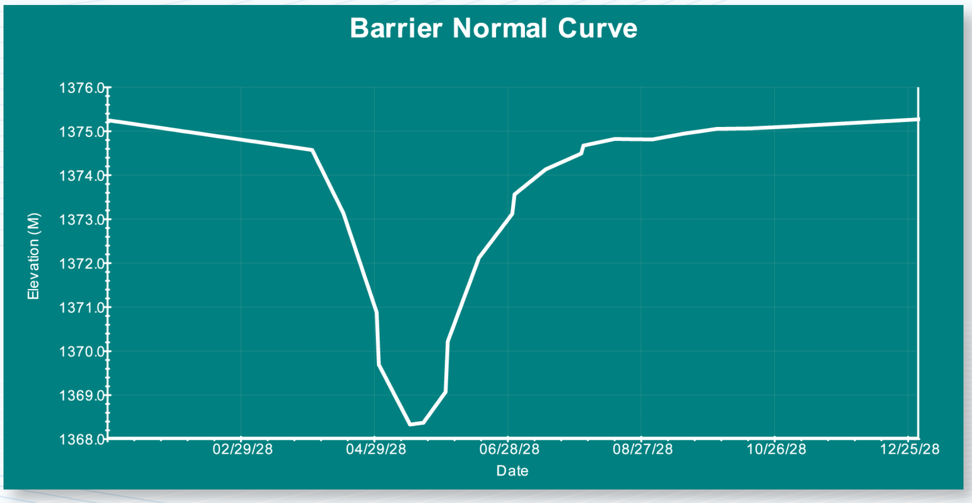


FIGURE 4: Daily flow simulation (D02) Cascade River near Banff, 1930




Lower Kananaskis Normal Curve
Elevation (M)
1667
1666
1665
1664
1663
1662
1661
1660
1659
1658
1657
1656
1655
02/29/28
04/29/28
06/28/28
08/27/28
10/26/28
12/25/28
Date


Barrier Normal Curve
Elevation (M)
1376.0
1375.0
1374.0
1373.0
1372.0
1371.0
1370.0
1369.0
1368.0
02/29/28
04/29/28
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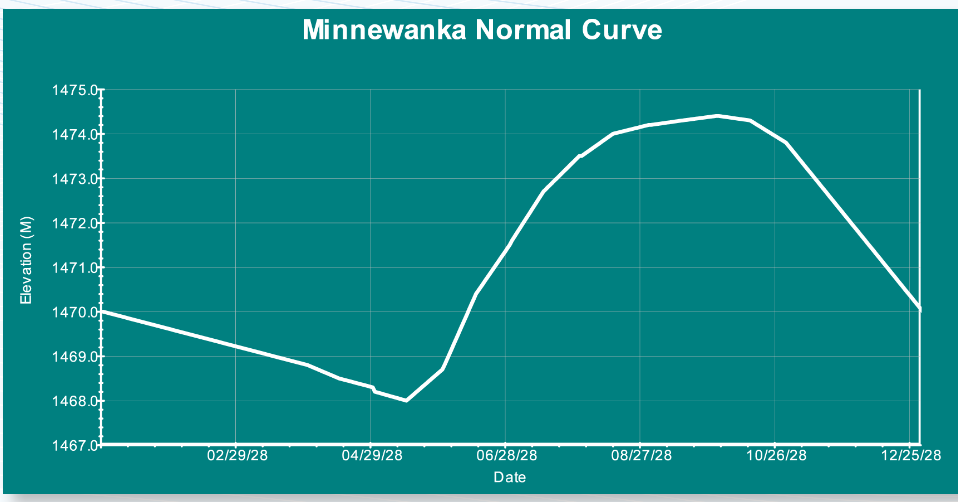
08/27/28
10/26/28
12/25/28
Date


Minnewanka Normal Curve
Elevation (M)
1475.0
1474.0
1473.0
1472.0
1471.0
1470.0
1469.0
1468.0
1467.0
02/29/28
04/29/28
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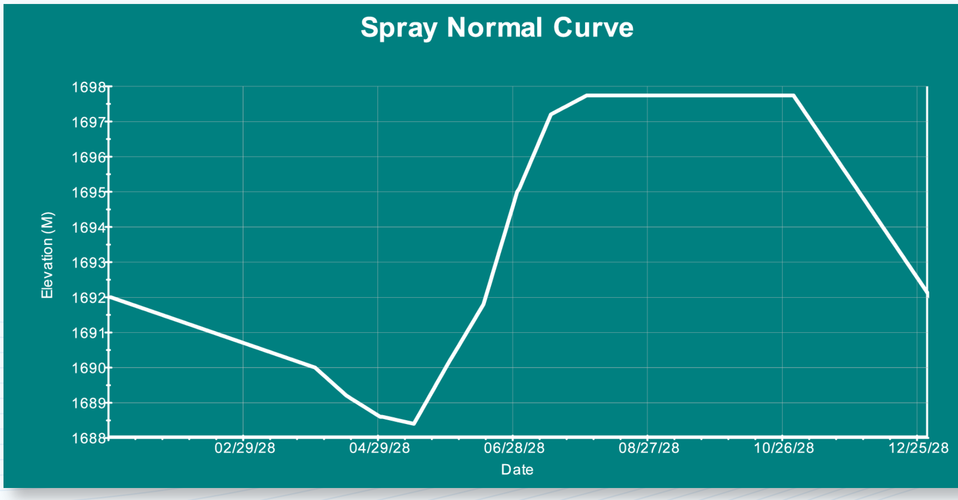
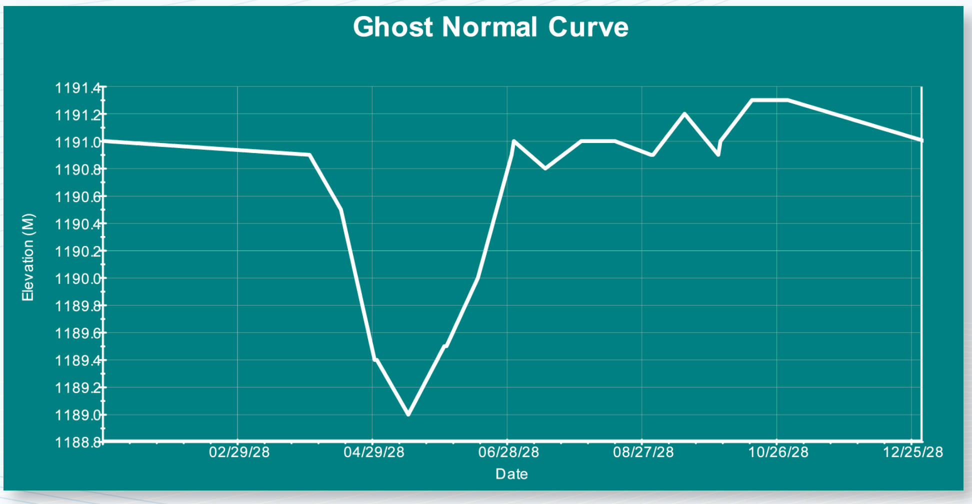
08/27/28
10/26/28
12/25/28
Date


Spray Normal Curve
Elevation (M)
1698
1697
1696
1695
1694
1693
1692
1691
1690
1689
1688
02/29/28
04/29/28
06/28/28
08/27/28
10/26/28
12/25/28
Date


Ghost Normal Curve
Elevation (M)
1191.4
1191.2
1191.0
1190.8
1190.6
1190.4
1190.2
1190.0
1189.8
1189.6
1189.4
1189.2
1189.0
1188.8
02/29/28
04/29/28
06/28/28
08/27/28
10/26/28
12/25/28
Date

APPENDIX C
Bow River Operational Model Scenarios

The following BROM alternatives evaluated each build on one another from the foundation of the Current Operations Base Case. They are presented in order.

SCENARIO 1: STABILIZED LOWER KANANASKIS LAKE AND KANANASKIS RIVER

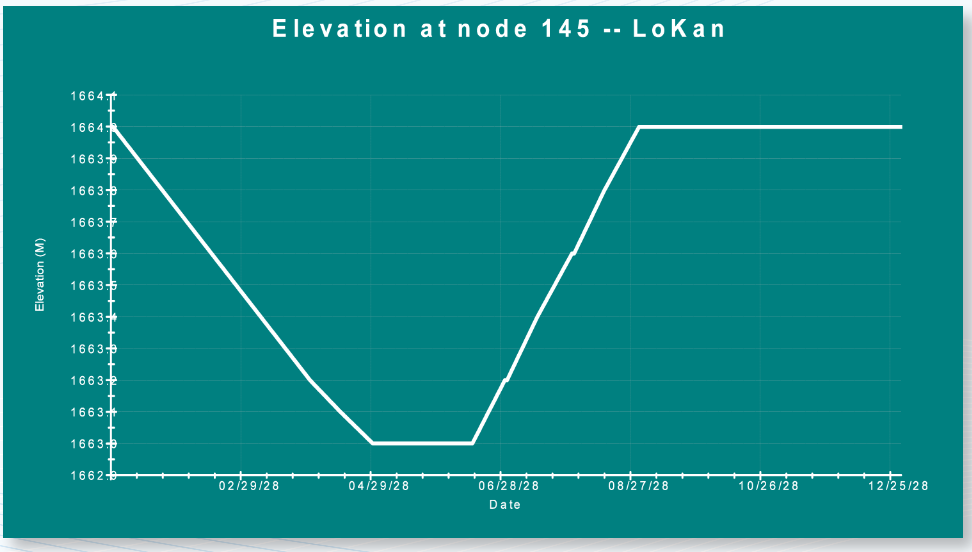
In the first alternative, the changes from the Base Case are:

Langdon Reservoir

» Langdon Reservoir, per discussions with WID representatives, has been doubled in size from 8340 CDM (6750af) to 16680 CDM (13,500af). It remains entirely live storage.

Lower Kananaskis Lake

» "Normal Curve" has been redesigned to allow for only 1 meter in rise and fall from elevations of 1663m to 1664m.
» The reservoir is not allowed to use its spillway unless the elevation rises above full supply level (FSL).



Lower Kananaskis River

» River flows through Kananaskis river are held more steady. Maximum variation day-to-day is a factor of 2x, while minimum variation day-to-day is a factor of 0.5x.
» River flow is also assumed to be held steady in the power generation and revenue calculations
» Intra-day variation in flow is limited to 3x. (Note: this only affects power revenue)

SCENARIO 2: WATER BANK AT 40,000 ACRE FEET

Scenario 2. Water Bank at 40,000 acre feet includes all changes in Scenario 1. Stabilized Lower Kananaskis Lake and Kananaskis River, and adds the following:

Purchased Storage

» 40,000 acre feet of TransAlta reservoir storage are "purchased" for use in improving Bassano flows.
» This water is released only to increase Bassano flows
» The 40,000 acre feet is refilled with a proportional amount of natural inflows to the TAU system (Purchased Storage / Total TAU Storage above Ghost * inflow above Ghost)

» When the purchased water is called upon, it is released in equal proportions from each TAU reservoir above Bearspaw.

SCENARIO 3. WATER BANK AT 60,000 ACRE FEET

Scenario 3. Water Bank at 60,000 acre feet is identical to the Scenario 3. Water Bank at 40,000 acre feet except:

Purchased Storage

» 60,000 acre feet of TransAlta reservoir storage are "purchased" for use in improving Bassano flows, instead of the previous 40,000 acre feet.

SCENARIO 4. INTEGRATED SCENARIO

Scenario 4. Integrated Operations adds the following changes to Scenario 3. Water Bank at 40,000 acre feet:

Purchased Storage

» 60,000 acre feet of TransAlta reservoir storage are "purchased" for use in improving Bassano flows, instead of the previous 40,000 acre feet.

Restored Spray Reservoir

» 61,000 acre feet are added to Spray Reservoir. This is reflected as an increase in the FSL level, maximum reservoir storage.

» Spray's Normal Curve has been stretched to include the additional storage. It splits the difference between the old Normal Curve and what the Normal Curve would be if it had 61,000 acre feet added to it. This preserves both the raised high stages and the old low stages. See graph below.

FIGURE 2: Revised Normal Curves for Spray Reservoir