— APPENDIX C—

Extended Deschutes Surface Water Distribution Model – Users Manual Version October 31, 2002

Extended Deschutes Surface Water Distribution Model: Development and Assumptions

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1. BACKGROUND

The Extended Deschutes Surface Water Distribution Model (Extended Model) was created to analyze flow scenarios for the Deschutes River Basin BA. The Extended Model combined the products of three separate models and studies: 1) The Upper and Middle Deschutes Basin Surface Water Distribution Model, 2) The Crooked River Surface Water Distribution Model, and 3) a spreadsheet analysis of the White River. Model output reflects the October 31, 2002 version of the model.

The Upper and Middle Deschutes Basin Surface Water Distribution Model was developed by the Oregon Water Resources Department (OWRD). The scope of this model extends from the headwaters of the Deschutes and Little Deschutes Rivers to the Deschutes River Below Bend (RM 164.3). Diversions and creek inflows as far downstream as Tumalo Creek (RM 160.2) are also provided in the model. Documentation for this model is found in the *Upper and Middle Deschutes Basin Surface Water Distribution Model.*[1] This model was extended by Reclamation to the Deschutes River near Madras (RM 100.1).

The Crooked River Surface Water Distribution Model was developed by Reclamation from 1997 through 2001. The scope of the model is from the Crooked River above Prineville Dam (RM 70.5) and from Ochoco Creek above Ochoco Dam (RM 10.6) to the Crooked River Near Terrebonne gage (RM 27.7). Modeled Terrebonne flows were incorporated into the Extended Deschutes Model. Documentation for this model is included in Section 2, "Crooked River Surface Water Distribution Model."

A White River spreadsheet analysis determined effects from the operation of the Wapinitia Project. A discussion of this analysis is contained in *Effects of Wasco Dam Storage on White River Flows.*[2]

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[1] La Marche, J. 2001. *Upper and Middle Deschutes Basin Surface Water Distribution Model*. Surface Water Open File Report #SW02-001. Oregon Water Resources Department. Available in PDF.
[2] Mellema, M. 2002. *Effects of Wasco Dam Storage on White River Flows.* Unpublished Report. U.S. Bureau of Reclamation, Pacific Northwest Regional office.

Flow effects at the Deschutes River at Moody (RM 1.4) were determined by applying the calculated flow effects due to the Wapinitia Project and the modeled flow effects at the Deschutes River Near Madras to historic (observed) flows Near Moody.

2. CROOKED RIVER SURFACE WATER DISTRIBUTION MODEL

The model was constructed using Modsim.[1] The model was developed to demonstrate Prineville and Ochoco Reservoir contents, irrigation deliveries, and Crooked River flows that would be likely to occur under alternate allocation and distribution scenarios. Historic monthly inflows to Prineville and Ochoco Reservoirs for the years 1962-1999 enter the reservoirs and are distributed according to defined operations criteria.

Due to the lack of diversion data, modeled requests for diversions are based on estimated crop irrigation requirements and distribution and delivery efficiencies. If adequate flow is not available or if the diverter does not have a storage or natural flow right to that water, the full request can not be diverted, and a shortage occurs.

The Crooked River Surface Water Distribution Model was used to determine surface water and groundwater contributions from the Crooked River into Lake Billy Chinook. The modeled contributions were incorporated as gains and losses into the Extended Deschutes Basin Surface Water Distribution Model.

The following discussion describes the assumptions used in developing the Crooked River Surface Water Distribution Model and in extending the Upper and Middle Deschutes Surf ace Water Model.

Model Scope

The most upstream nodes of the model include inflow to Prineville and Ochoco Reservoirs. The most downstream node of the model is the Terrebonne gage (RM 27.7).

Gains Data Set and Calibration

Gains above Prineville Reservoir: The monthly gains (reservoir inflows) for water years 1962 through 1999 were estimated from a balance around the reservoir, so that:

gains = S(f) - S(i) + Rel + evap [AF/mo]

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[1] Modsim is a general, multi-purpose, multi-reservoir water allocation and simulation tool originally developed by Dr. John Labadie at Colorado State University, and since 1994 developed cooperatively with the Bureau of Reclamation. Documentation and the model can be downloaded from http://modsim.engr.colostate.edu.

where S(f) and S(i) are final and initial end-of-month storage values, Rel is the total monthly release, and evap is the total monthly evaporation.

Gains above Ochoco Reservoir: Gains above Ochoco Reservoir were calculated using a balance around the reservoir, similar to the calculation for gains above Prineville Reservoir. Missing gains (when all the data necessary for a balance were not available) were developed by using gains from similar water supply years.

Post-dam Historic Regulated Flows for the Crooked River Near Terrebonne: Flows at Terrebonne were required to calibrate the model and to develop the gains to the Crooked River below the Crooked River Feed Canal and gains to the Ochoco Feed Canal.

Estimated and observed historic flows at Terrebonne were developed using the following approaches:

- Water Years (WY) 1968-1973 and WY 1994-2001: Observed flows
- WY 1962-1967 and WY 1974-1993: Monthly flows at Terrebonne were estimated using a linear correlation to the Crooked River below Opal Springs.

Gains below the Crooked River Feed Canal and Gains to the Ochoco Feed Canal: A calibration model was used to determine the gains below the Crooked River Feed Canal and the gains to the Ochoco Feed Canal so that observed and estimated flows at Terrebonne were perfectly met. The modeled gains represent the additional reach flow required to satisfy nearly all the diversion demands (based on estimated diversion rates for a dry year) while meeting historic reservoir target contents and the observed and estimated historic flows at Terrebonne.

Originally, gains were calculated by subtracting observed Terrebonne flows (WY 1968-1973 and WY 1994-2001) from the flows below Bowman Dam and the flows in Ochoco Creek, and then attempting to correlate these gains to the gains above Prineville Reservoir. The correlation was poor. Since only 10 years of observed Terrebonne flows were available, a better approach was to model the gains in this reach.

Calibration: Although diversion data are not available and downstream flow data at Terrebonne are sparse, a calibration model was constructed using the gains described above. Modeled reservoir end-of-month contents compared favorably to historic values. Flows below the Crooked River Feed Canal and Ochoco Creek were consistent with anecdotal information. Flows at Terrebonne, due to the nature of their construction, calibrate successfully with existing Terrebonne flow data.

Natural Flow Rights and Reservoir Accrual

Prineville Reservoir is allowed to accrue with a 1914 water right up to a seasonal capacity of 148,633 acre-feet. Ochoco Reservoir is allowed to accrue with a 1914 water right up to a seasonal capacity of 45,200 acre-feet.

Natural flow rights to the Crooked River Feed Canal, Rice Baldwin, Peoples, Central, Low Line, and Rye Grass Canals are modeled as senior to Prineville and Ochoco Reservoirs' accrual rights. North Unit Irrigation District (NUID) is allowed to pump Crooked River water as supplemental water for Deschutes lands with a 1955 water right and as water for Crooked River lands with a 1968 water right. The following table shows the modeled natural flow rights.

Modeled Natural Flow Rights (in cubic feet per second (cfs))

Crooked River Feed Canal	400 cfs (limited by 160 cfs canal capacity)
Rice Baldwin Canal	7 cfs
Peoples Canal	19 cfs
Central Canal	7 cfs
Low Line Canal	5.5 cfs
Rye Grass	8 cfs
NUID pumps	200 cfs (two rights, limited by historic pumping rates)

Diversion Requirements

Measured flow data which could be used to determine diversion rates for OID and other Ochoco Creek and Crooked River irrigators do not exist. Measured diversions at the Crooked River Feed Canal reflect the need to maintain head at Barnes Butte Pumping Plant, so these flows include spills to Ochoco Creek and subsequent diversion to Rye Grass Canal. In addition, water wasted to McKay and Lytle Creeks, which had been measured at the Crooked River Feed Canal diversion, is credited back to Ochoco Irrigation District's (OID) Prineville Reservoir storage account. For these reasons, measured flows at the Crooked River Feed Canal do not reflect actual irrigation and diversion requirements or reservoir duty. Therefore, the diversion requirements for irrigated lands were calculated by estimating the acres irrigated and assuming irrigation requirements, distribution efficiencies, and application efficiencies. The following section describes the process used to develop the diversion requirements.

Acres Irrigated

Total irrigated acres were determined from the primary, supplemental, and natural flow-served lands on the Project Proof Survey,[2] and verified by comparison to the allowable acres and duty in the contracts; comparison to the natural flow rights; comparison to earlier estimates in the *Draft Ochoco Irrigation District Water Management/Conservation Plan*[3] (Draft Water Conservation Plan); and conversations with OWRD (Bob Main, former Regional Manager and Kyle Gorman, Regional Manager) and OID (Hugh Moore, former Manager). OID was determined to irrigate 20,148 acres in an average year. Other irrigators, including other spaceholders in Prineville Reservoir and those served by natural flow rights, were determined to irrigate an additional 3,221 acres.

Once irrigated lands were identified and incorporated into the calibration model for the Crooked River Model, it was demonstrated that modeled flows at the Crooked River Feed Canal successfully simulated Crooked River Feed Canal observed flows; modeled flows at Barnes Butte Pumping Plant successfully simulated anecdotal pumping rates; and modeled spills from the Barnes Butte Pumping Plant in Ochoco Creek successfully simulated anecdotal flows.

Irrigation Requirement

An annual irrigation requirement (IR) of 1.945 acre-feet/acre for a crop mixture of primarily mint, alfalfa, hay, and grass pasture was used.[4,5] The irrigation requirement is the crop evapo-transpiration less the effective precipitation. The irrigation requirement is not the diversion requirement, but is just one component of the diversion requirement. A monthly distribution of the annual irrigation requirement per acre was applied as shown in the following table[6].

Monthly Irrigation Requirement (acre-feet/acre)

Oct	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*WY*
.035	0	0	0	0	0	.084	.276	.409	.602	.332	.205	1.945

[2] U.S. Bureau of Reclamation. 1980. Project Proof Survey Maps.

[3] H&R Engineering. 1999. *Draft Ochoco Irrigation District Water Management/Conservation Plan.* Prepared for OID. Cover letter dated March 30, 1999.

[4] Ibid.

[5] Ross, Elwin. 1998. Facsimile dated August 18, 1998. H&R Engineering, Redmond, Oregon.

[6] Ibid.

The diversion required to satisfy the irrigation requirement also includes deep percolation to groundwater, surface runoff, evaporation, and distribution losses. Modeled diversion requirements are based on data collected from the 1992-1997 irrigation seasons and summarized in the Draft Water Conservation Plan (H&R Engineering 1999). Although the analysis was performed using data for OID lands, the assumptions were assumed to apply project-wide.

The following table summarizes the delivery analysis from the Draft Water Conservation Plan.

Delivery Analysis from Draft Water Conservation Plan

Flows (Average from 1992-1997)		Comments
Diversion (from records)	83,742 AF	
Spill	27,960 AF	Spill occurs at Barnes Butte Pumping Plant and is not considered 'diverted' water.
Adjusted Diversion (diversion - spill)	55,782 AF	
Delivery (from records)	43,000 AF	
Distribution Losses (adjusted diversion - delivery)	12,782 AF	
Distribution Efficiency	77 percent	Distribution efficiency is (1.0 - distribution losses / adjusted diversion).
Crop Water Use, IR (based on 20,306 acres irrigated)	39,495 AF	The value of 20,148 used in the model is a more recent estimate, although the difference is insignificant.
On-farm Losses (delivery - IR)	3,505 AF	
On-farm Efficiency	92 percent	On-farm efficiency is (1.0 - on-farm losses / delivery)

Given the above efficiencies, for every 1.0 acre-feet of irrigation requirement, 1.41 acre-feet is required for diversion in an average water supply year:

$$1.0 /(.77 * .92) = 1.41.$$

Diversion requests are aggregated in the model based on points of delivery and application. The diversion request (DIV) for each block of aggregated diversions for an average water supply year is then:

$$DIV = 1.41 \cdot IR \cdot ACRES$$

where DIV is the monthly required diversion, IR is the monthly irrigation requirement in acre-feet/acre, and ACRES is the estimated acres of land irrigated. In the model, the diversion required is adjusted up or down based on water supply year type.

Estimated Distribution of Losses

	Surface Irrigation	**Sprinkler Irrigation**	**Sprinkler + Surface**
Acres->	2015	18135	**20150**
Percent of delivery that goes to:			
Deep Percolation	25.0	20.0	**20.5**
Runoff	25.0		**2.5**
Evaporation		15.0	**13.5**
(1-sum)	50.0	65.0	**63.5**

Calculation of Diversions and Returns Based on IR

Multiply diversion by ...	**x**	**y**	**to get……**	**to get……**
Diversion (calculated)	1.000		55782	141.3
Distribution Loss	0.229		12782	32.4
Delivery to Farm	0.771		43000	108.9
Used for IR (given)	0.771	0.918	39495	100.0
Deep Percolation	0.771	0.205	8815	22.3
Runoff	0.771	0.025	1075	2.7
Evaporation	0.771	0.135	5805	14.7

Estimated Distribution of Returns

% of DIV which returns in......				
	Current Month	***Next 2 Months***	***Never***	***Total***
	*x*y*	*X*y*	*x*y*	
Diversion				
Distribution Loss	0.229			
Delivery to Farm				
Used for IR				
Deep Percolation		0.158		
Runoff	0.019			
Evaporation			0.104	
Sum->	0.248	0.158	0.104	0.511
	0.487	0.310	0.204	

Return Flows and Spills

For the purposes of this study, "return flows" refer to that portion of water diverted from the Crooked River which returns to the river via surface and subsurface pathways. This includes some channel loss, surface runoff, infiltration and seepage from irrigated lands, drainage, and spill (with the exception of Barnes Butte Pumping Plant spill) which occur after the water has been diverted. Return flows are made available downstream as natural flow.

Crooked River Feed Canal diversions in excess of the capacity of the Barnes Butte Pumping Plant (spills) are modeled to return to the Crooked River immediately and are then made available downstream as natural flow.

Total return flows are assumed to be very nearly the diversion minus the irrigation requirement and evaporation losses. Modeled return flows are distributed over a three month period by the heuristic: 33 percent of the diversion returns in the first month after diversion, 16 percent in the second month after diversion, and 7 percent in the third month after diversion. These diversion returns were used in model calibration.

OID provided measured return flows for the 1994-1997 irrigation seasons. Assuming the measurements captured return flows from the Crooked River Feed, Ochoco Feed, and Rye Grass Canals and returns occurred over a three month period, these measured returns accounted for 22 percent of diversions (minus the spills at Barnes Butte Pumping Plant). OWRD (Kyle Gorman and Bob Main) estimated return flows to be about 35 percent. However, in calibrating to the few years of data available for the Terrebonne gage (1968-73 and 1994-1997), the best calibration was achieved when 56 percent of all diversions returned upstream of the gage, lagged over 3 months (33 percent in the first month after diversion, 16 percent in the second month, 7 percent in the third month). This value is consistent with the Draft Water Conservation Plan if the total diversion minus irrigation requirement and evaporation is assumed to return over a three month period. This is the "high end" of the return flow estimate.

Dry River contributes runoff from Central Oregon Irrigation District above the Terrebonne gage. This is not measured and was not estimated for the model. Flows entering the Crooked River from Dry River would be accounted as return flows from Crooked River diversions in the return flow calculations described above, introducing unknown error.

Minimum Instream Flows

The model requests a 75 cfs minimum instream flow below Prineville Reservoir throughout the year, with the exception that 35 cfs is requested in very dry water supply years. If water is not already flowing in the reach to meet downstream demands and if natural flow is not available to increase flows to 75 cfs, releases are made from Prineville Reservoir to meet the minimum streamflow target.

Downstream at the NUID's Crooked River pumps, the model requires a 10 cfs minimum streamflow to pass the pumps so that the Crooked River is not dried up.

Spaceholder's Contracts

Current contracted space and uncontracted space in Prineville Reservoir is modeled as follows:

OID contracted space	57,893 acre-feet
Other contracted space	10,389 acre-feet
Total contracted space	68,282 acre-feet
Uncontracted space	80,351 acre-feet
Total active storage	148,633 acre-feet

NUID Crooked River Pumping Requests

Modeled requests for Crooked River pumping by NUID uses historic measured values for 1977 through 1997. For years where historic data does not exist (1942-1976), modeled pumping rates are the average of the historic values. NUID relies on its natural flow right of 200 cfs (priority dates of 1955 and 1968), but is limited by a 150 cfs pumping capacity.

Channel Losses

Channel losses in the Crooked River between Bowman Dam and the Crooked River Feed Canal diversion were modeled as 8.5 percent. Channel losses in the Crooked River below the Crooked River Feed Canal diversion were modeled as zero. [7]

Rule Curves and Flood Space

Section 7 flood control rule curves for Prineville Reservoir are applied in the model. Rule curves dictate target end-of-month contents based on current reservoir contents and forecast inflow. In the model, forecast inflow is a "perfect" forecast, because the model knows the inflow which occurred following each historic month of record.

Recreation Targets

Prineville Reservoir September end-of-month storage contents of about 100,000 acre-feet was selected as the recreation target.[10] This volume maintains boat access at Prineville Reservoir State Park. The historic 1961-1997 average September contents for Prineville Reservoir are 92,116 acre-feet and maximum contents are 118,400 acre-feet.

Special Modeling Considerations

Crooked River Feed Canal Diversions

OID's preferred operation is to divert 160 cfs from the Crooked River into the Crooked River Feed Canal at all times to keep the pumps at Barnes Butte Pumping Plant running efficiently. OID uses a 400 cfs senior natural flow right and stored water to maintain this flow. The modeling goal is to divert 160 cfs when it is available in right and divert less when water is not available. This is accomplished by using a flow-through demand node which draws water from the Crooked River with two distinct rights. The first right is a very senior 400 cfs natural flow right. Once this water flows through to the head of the feed canal, it is distributed in the natural flow step to demands which are served with natural flow links with Unit Costs of -1.

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[7] OWRD. 1991. Memo from OWRD to Prineville Reservoir Users Re: Crooked River Losses. August 16, 1991.

[10] Moore, Hugh. 1997. Personal Communication. Former Manager, Ochoco Irrigation District.

If the natural flow right is not enough to meet the 160 cfs request, another link ("force 160cfs") draws water out of Prineville Reservoir with a Unit Cost of -90,000 during the storage step (the Stg Flow Only flag is set to 1, so the link only opens during the storage step). Although the water which flows through the "force 160cfs" link is not debited from a storage account *here*, once it flows through to the head of the feed canal, it is distributed through storage ownership links serving the demand nodes on the canal and then debited from the appropriate accounts.

<u>Return Flow Credits from the Crooked River Feed Canal</u>
Although the Crooked River Feed Canal requests 160 cfs to keep the pumps operating efficiently, the capacity of the pumps is only 140 cfs (and the requests for water in this portion of the system might be even less), so water spills into Ochoco Creek and eventually back to the Crooked River. OWRD and OID have agreed to credit this stored water back to OID's account. In the model, the water spills back to Ochoco Creek via the link "BarnesBPP spill." Although spilled, this water is still considered Prineville Reservoir storage water.

Several demand nodes on Ochoco Creek and the Rye Grass Canal receive Prineville Reservoir water only by utilizing this spill, but also have access to Ochoco Reservoir water. When a storage ownership link opens up during the storage step, it pulls water from the reservoirs according to the reservoir priorities. So it is possible for the Prineville ownership links which serve these demands to draw water from Ochoco Reservoir while debiting that water (in the accounting) from Prineville Reservoir. Therefore, the Prineville storage ownership links to the Ochoco Creek and Rye Grass Canal demand nodes are limited by the spill. This is accomplished by constructing the "P2spill" network which watches the spill. The net result is that the total of the flows through the Prineville storage ownership links serving the demand nodes on Ochoco Creek and the Rye Grass Canal can not exceed the spill from the pumping plant.

3. EXTENDED DESCHUTES BASIN SURFACE WATER DISTRIBUTION MODEL

The Upper and Middle Deschutes Basin Surface Water Distribution Model was extended from its original termination point below Bend so that Deschutes River flows as far downstream as Madras could be modeled. This was achieved by combining output from the Crooked River Surface Water Distribution Model described earlier and the observed flows from the Metolius River and other contributing tributaries to the Upper and Middle Deschutes Basin Surface Water Distribution Model.

Groundwater Gains

Diversions above the gage at the Deschutes River below Bend (14070500, Hydromet station code DEBO), contribute to the groundwater gains to the Deschutes River below Bend, the Crooked River below Terrebonne, and Lake Billy Chinook. However, groundwater gains to that region developed from observed data do not appropriately represent gains which would occur if modeled diversions above DEBO differ significantly from observed diversions. The Deschutes River basin BA studies required simulating current conditions (the "with Reclamation" scenario) as well as removing Reclamation operations (the "without Reclamation" scenario). Since diversions above DEBO differ from observed diversions in both scenarios, the model needed to respond by adjusting groundwater gains accordingly.

The best approach for determining groundwater returns due to diversions above DEBO would be to develop response functions based on the information compiled by the U.S. Geological Survey (USGS).[8] Budget and time constraints did not allow for this arrangement. Reclamation examined two potential approaches.

The first approach was developed by OWRD, with input from the USGS, to adjust groundwater gains to the Lake Billy Chinook region when modeled diversions differ from observed diversions. The OWRD method takes half of the difference between the modeled and observed diversions, applies a 5-year running average, and returns those averages as positive or negative groundwater gains to the Lake Billy Chinook region. The calculation of the difference in diversions and the change in groundwater gains is performed outside the model. This approach produces a very flat distribution.

The second approach models half of the flow diverted above DEBO to return as groundwater gains to locations above and below the Deschutes River Near Culver gage, to Opal Springs on the Crooked River, and to Lake Billy Chinook. This value is lagged to return to the river throughout the next 10 months in 10 percent increments. This method results in groundwater gains more closely reflecting anecdotal information about gains expected from irrigation diversions above DEBO. This "10 month flat lag" approach was used in the Extended Deschutes Model. However, this method may be conservative in estimating the positive effects of Reclamation activities on late summer flows.

Groundwater gains due to diversions above DEBO return to the river at several locations above Madras. Because model output was required at the Deschutes River Near Culver (RM 120.0), it was necessary to determine what percentage of those gains return above and what percentage below the Culver gage. To determine this percentage, a calibration run was performed, allowing the model to select the return location based on the need to perfectly achieve historic flows at Culver. In general, it appeared that about 84 percent of the groundwater gains due to diversions above DEBO return *above* the Culver gage. The remaining 16 percent was allowed to return below the Culver gage to the Crooked River and Lake Billy Chinook.

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[8] Gannett, Marshall, Kenneth E. Lite Jr., David S, Morgan, and Charles S. Collins. 2001. *Ground-Water Hydrology of the Upper Deschutes Basin, Oregon.* USGS, Water-Resources Investigations Report 00-4162.

Gannett, Marshall. 2001. Personal Communications. USGS.

In addition to the gains already developed for the Upper and Middle Deschutes Surface Water Distribution Model, gains and losses for the extended model were developed from the observed flows at:

The Deschutes River Near Culver (RM 120.0)
The Metolius River confluence (RM 111.3)
The Crooked River Below Opal Springs (RM 6.7)
The Deschutes River Near Madras (RM 100.1)

Contributions from the Crooked River

Inflows to Lake Billy Chinook from the Crooked River were determined by a run of the Crooked River model (described in Section 2, *Crooked River Surface Water Distribution Model*). The Crooked River model extends only to the Crooked River at Terrebonne (RM 27.7). Below Terrebonne, significant groundwater gains from the Deschutes River basin enter the Crooked River at Opal Springs.

However, it is not necessary to model flows between Terrebonne and the Crooked River below Opal Springs (RM 6.7, near where the Crooked River enters Lake Billy Chinook), as long as the change in the contributions from the Crooked River to Lake Billy Chinook can be determined. Consider the water budget equations for historic and modeled scenarios:

$$opal_{HIST} = terre_{HIST} + GW_{HIST} + other$$
$$opal_{MODEL} = terre_{MODEL} + GW_{MODEL} + other$$

where terre represents Crooked River flows at Terrebonne, opal represents Crooked River flows below Opal Springs, GW represents the groundwater gains to the Crooked River due to diversions above DEBO, and other represents all other groundwater and surface water gains and losses. The subscripts $_{HIST}$ and $_{MODEL}$ refer to historic observed or modeled flows. other is assumed not to change from scenario to scenario.

Combining and rearranging:

$$opal_{MODEL} = opal_{HIST} + Terre_{MODEL} - Terre_{HIST} + GW_{HIST} - GW_{MODEL}$$

The model handles differences between groundwater gains due to irrigation ($GW_{HIST} - GW_{MODEL}$) as part of the 16 percent of gains which return below Culver as described earlier in the "Groundwater Gains" section. The remaining values to complete the contributions from the Crooked River, $opal_{MODEL}$, are historic and modeled flows at Terrebonne. Modeled Terrebonne flows are determined by the Crooked River Surface Water Distribution Model described in section 2.

Pelton-Round Butte Operations

In the model, Pelton-Round Butte was operated by targets which reflect historic average elevations. Pelton-Round Butte operations attempt to release the minimum of either (1) the required minimum flow at Madras or (2) reservoir inflow. The July through February required minimum flow at Madras is 3000 cubic feet per second (cfs); the March through June required minimum flow is 3500 cfs.

Calibration

The Extended Deschutes Model was calibrated to available historic (observed) flows, diversions, and reservoir contents. Calibration results indicate that the model successfully represents water supply and system operations.