Upper and Middle Deschutes Basin Surface Water Distribution Model

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In Cooperation with
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Surface Water
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Background and Purpose:

The Oregon Water Resources Department (OWRD) and the U.S. Bureau of Reclamation (BOR) are partners in the management of water in the Deschutes basin, along with irrigation districts and private landowners in the region. Several reservoirs, including Wickiup and Prineville (Figure 1), are owned by the Bureau of Reclamation and operated by the irrigation districts and OWRD, primarily for irrigation and flood control within the basin. Stream flows in the Deschutes basin are severely depleted during the winter months in some reaches of the Upper Deschutes (above Bend) and in the Middle Deschutes (Bend to Lake Billy Chinook) during the summer months. For example, the median ratio of summer to winter flows from 1961 through 1999 below Bend (Figure 2) are roughly 30/600 cubic feet per second (cfs) and 1500/30 cfs below Wickiup reservoir (Figure 3). Increasing flows in these reaches during low flow periods would benefit both the aesthetics and ecology of the river. However, higher stream flows in these depleted reaches could negatively impact current irrigation withdrawals in the basin.

A surface water distribution model for the Deschutes basin that optimizes the allocation of water for both irrigation and stream flows was developed in the basin to simulate the effects of increased flows in specific depleted reaches in the Upper and Middle Deschutes on current demands. The model permits simulations of different management strategies or "what-if" scenarios to best meet downstream demands based on hydrologic conditions in the basin. This report discusses the model development and a specific application on the effects of higher minimum flows below Wickiup Reservoir on current demands.

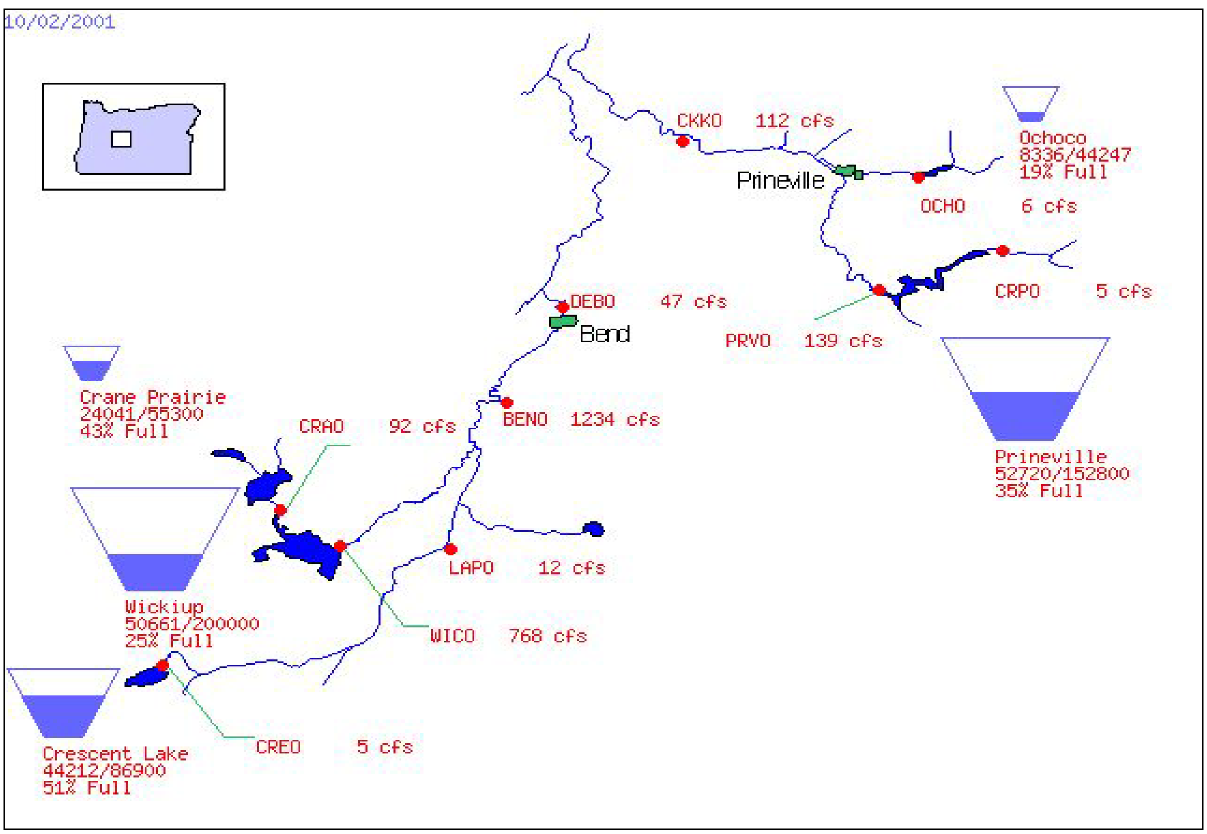
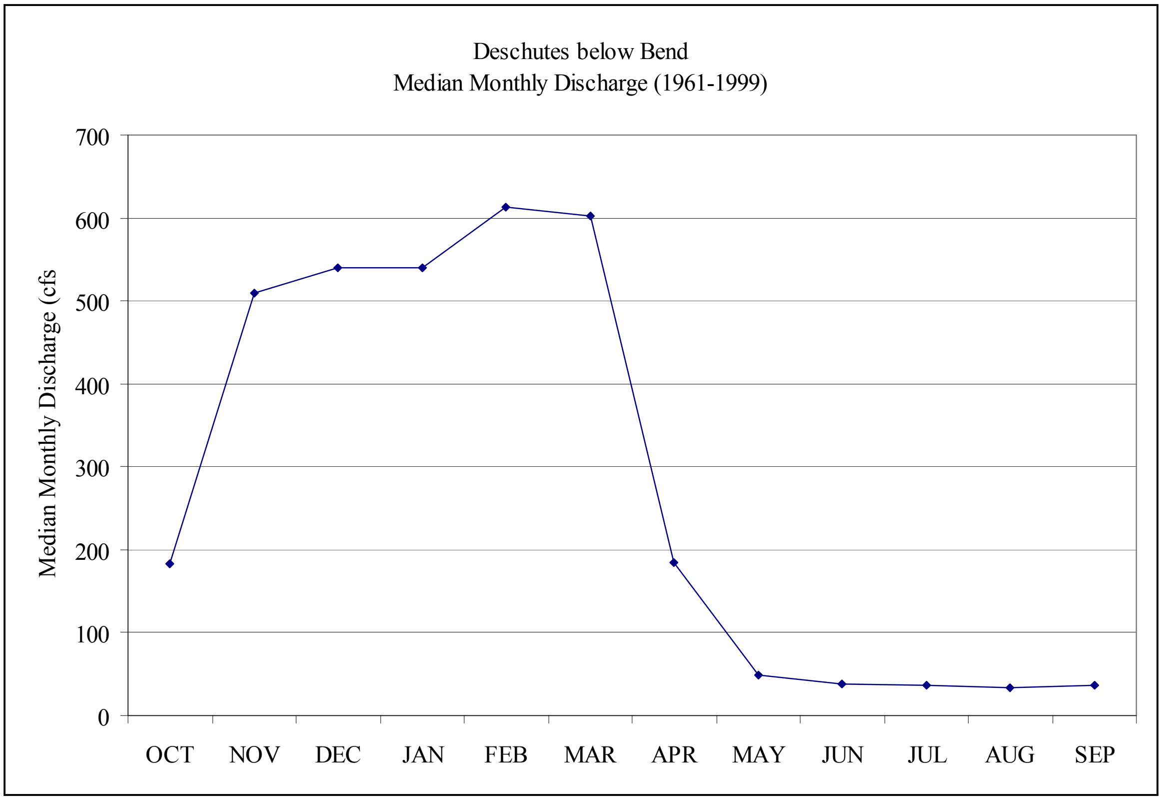


Figure 1: Upper and Middle Deschutes Basin Reservoirs



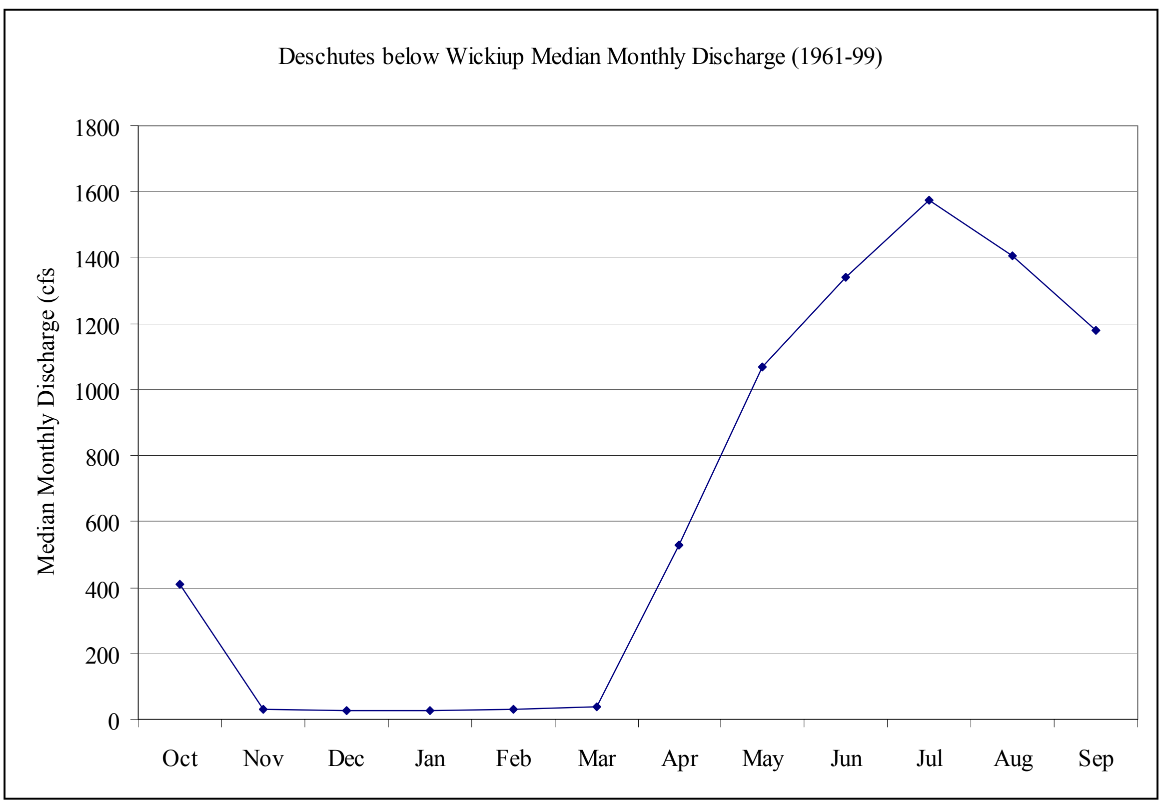


Figure 2 and 3: Median Monthly Flows Below Bend (Top) and Below Wickiup Reservoir (Bottom)

A diagram of the water distribution system for the Deschutes basin above Trout creek is shown in Figure 4. The distribution model was developed for all irrigated areas supplied water from the Deschutes River and its tributaries above Lake Billy Chinook, except for the Crooked River. A separate project covers the Crooked River system.

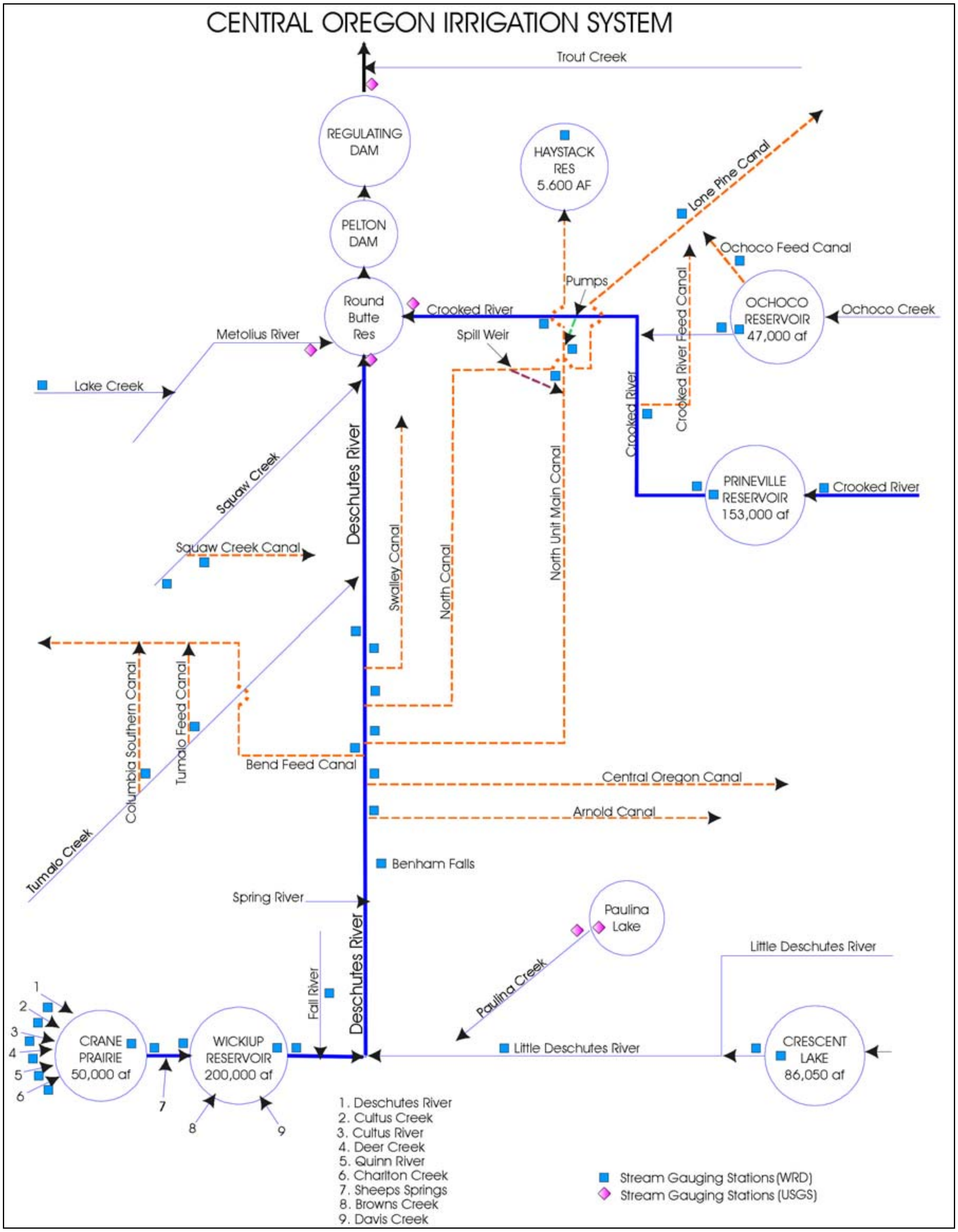


Figure 4: Central Oregon Irrigation System.

Approach:

The surface water distribution model for the Upper and Middle Deschutes basin was developed using MODSIM (Labadie 1994, Frevert et. al., 1994) a general, multi-purpose, multi-reservoir, water allocation simulation model. The model simulates how different water users interact in the basin based on water rights, historical or current use, reservoir/network constraints, and historical flow conditions. There were three basic types of simulations (typical for modeling studies) used in this study: 1) calibration simulation, 2) base-case simulation, and 3) alternative management simulation. For each simulation, the model automatically routes water on a *monthly* time step to demands (i.e., instream, storage, or consumptive) in order of their priority and subject to streamflow gains and losses, and reservoir/network operations and constraints.

In the calibration phase of the study, historic hydrologic conditions were used with *historic* demands and operations (reservoir operations, water rights, typical targets flows in depleted reaches, accounting procedures, etc.) to ensure the model accurately simulated water distribution and storage in the basin. After the model was calibrated, a base-case scenario was run. This base-case phase represented water distribution, given historic hydrologic conditions and *current* operations and demands. Against the base-case simulation, the alternate management simulation was compared. This comparison isolates the effect of the management scenario on water distribution from the effects of changes in historic demands or operations on water distribution. For example, several irrigation districts experienced water shortages during the dry years of the early 1990s. In the alternate management simulation, these shortages may also be present. If the output of the alternate management scenario is examined on its own, then the cause of the shortages may be incorrectly attributed to the change in operations, as opposed to the real cause, which was dry hydrologic conditions. By looking at both the base-case simulation and alternative simulation, the effect of the change in operation is isolated. All three types of simulations are covered in depth in the Results section.

The basic model inputs are: 1) water right priority dates, quantities and inter-district agreements, 2) current and historic demands, 3) historic natural streamflow (i.e., gains and losses) and, 4) reservoir parameters (i.e., area/capacity curves, operational curves, storage claims, evaporation etc.). Each of these inputs is discussed in detail below.

Model Inputs:

Water Rights—

The water rights used for the model were identified through OWRD Watermaster office in Bend, OR (Tables 1 and 2). These water rights were used to constrain the maximum diversion rate, minimum target flows for stream reaches, and set priorities for water rights in the basin. Some water rights have mid-monthly rate changes (Table 1), so an average for each month was used in the model (the model runs on a monthly time step).

The current minimum target flows for the depleted reaches are a mixture of water rights, inter-district agreements, and instream leases. There are *instream* water rights for some of the depleted reaches, but these are of such junior priority as to not have any effect on instream flows. The stream reaches of interest are for Crescent Creek below Crescent

Lake, the Deschutes River below Crane Prairie Reservoir, below Wickiup Reservoir, and below Bend, and Tumalo Creek below the Tumalo Feed Canal. Target minimum flows in Crescent Creek below Crescent Lake and the Deschutes River below Bend are based on the irrigation districts verbal agreement to maintain flows of 5 and 35 cfs, respectively. Target minimum flows for the Deschutes below Crane Prairie and for Tumalo Creek below the Tumalo Feed Canal (TFC) are based on irrigation district verbal agreements or instream leases for 30 and 2.5 cfs, respectively. Target flows below Wickiup Reservoir are set at a minimum of 20 cfs for fisheries under the Wickiup Reservoir storage right. These low flows occur during the fall/winter for the reaches below the storage facilities and in the summer for the Deschutes River below Bend, and Tumalo Creek below TFC.

Table 1: Water Rights for Deschutes River Diversions above Bend

	Period------------->>>>	1	2	3	3	3	3	3	4	5
District & Date	*Description*	*April 1-30*	*May 1-14*	*May1 5-31*	*June*	*July*	*Aug*	*Sept 1-14*	*Sept 15-30*	*Oct 1-31*
Lone Pine 1900	Max Rate (cfs)	25	31	38	38	38	38	38	31	25
	Volume/Period (ac-ft)	1458	916	1215	2279	2355	2355	1140	916	1506
	Total for Month (ac-ft)	**1458**	**2132**		**2279**	**2355**	**2355**	**2056**		**1506**
Swalley 1899	Max Rate (cfs)	55	73	121	121	121	121	121	73	55
	Volume/Period (ac-ft)	3255	2163	3827	7176	7415	7415	3588	2163	3363
	Total for Month (ac-ft)	**3255**	**5990**		**7176**	**7415**	**7415**	**5751**		**3363**
Arnold 1905	Max Rate (cfs)	87	113	136	136	136	136	136	113	87
	Volume/Period (ac-ft)	5147	3362	4316	8093	8362	8362	4046	3362	5319
	Total for Month (ac-ft)	**5147**	**7678**		**8093**	**8362**	**8362**	**7408**		**5319**
North Unit 1913	Max Rate (cfs)	1101	1101	1101	1101	1101	1101	1101	1101	1101
	Volume/Period (ac-ft)	65514	32757	34941	65514	67698	67698	32757	32757	67698
	Total for Month (ac-ft)	**65514**	**67698**		**65514**	**67698**	**67698**	**65514**		**67698**
COID 1900	Max Rate (cfs)	564	752	989	989	989	989	989	752	564
	Volume/Period (ac-ft)	33560	22374	31386	58850	60811	60811	29425	22374	34679
	Total for Month (ac-ft)	**33560**	**53760**		**58850**	**60811**	**60811**	**51798**		**34679**
COID 1907	Max Rate (cfs)	0	0	401	401	401	401	401	0	0
	Volume/Period (ac-ft)	0	0	12726	23861	24657	24657	11931	0	0
	Total for Month (ac-ft)	**0**	**12726**		**23861**	**24657**	**24657**	**11931**		**0**
Walker 1897	Max Rate (cfs)	9	9	14	19	19	16	10	10	10
	Volume/Period (ac-ft)	564	282	428	1129	1167	973	283	283	584
	Total for Month (ac-ft)	**564**	**710**		**1129**	**1167**	**973**	**565**		**584**
Walker 1900	Max Rate (cfs)	1	1	1	2	2	2	1	1	1
	Volume/Period (ac-ft)	60	30	44	104	108	92	30	30	61
	Total for Month (ac-ft)	**60**	**74**		**104**	**108**	**92**	**60**		**61**
Walker 1902	Max Rate (cfs)	8	8	12	16	16	13	8	8	8
	Volume/Period (ac-ft)	476	238	381	952	984	820	238	238	492
	Total for Month (ac-ft)	**476**	**619**		**952**	**984**	**820**	**476**		**492**

Table 2: Water Rights for Tumalo Creek Diversions

District/Priority	Rate (cfs)	Monthly Total (ac-ft)											
TID		Oct (-15th)	Nov	Dec	Jan	Feb	Mar	Apr (15th-)	May	Jun	Jul	Aug	Sep
8/1900	5.45	168						162	335	324	335	335	324
9/1900	42	1291						1250	2582	2499	2582	2582	2499
4/28/1905	4.3	132						128	264	256	264	264	256
5/1907	0.37	11						11	23	22	23	23	22
6/1907	13.8	424						411	849	821	849	849	821
1913	128.5	3951						3823	7901	7646	7901	7901	7646
City of Bend	Rate (cfs)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
unrestricted	6	369	357	369	369	333	369	357	369	357	369	369	357
8/1900	2	123	119	123	123	111	123	119	123	119	123	123	119
9/1900	7.43	457	442	457	457	413	457	442	457	442	457	457	442
4/28/1905	0.2	12	12	12	12	11	12	12	12	12	12	12	12
6/1907	1.52	93	90	93	93	84	93	90	93	90	93	93	90
1913	3.9	240	232	240	240	217	240	232	240	232	240	240	232

Historic and Current Demands—

Historic demands were used in the calibration simulation to verify that the logic of the water distribution system resembles real life management of the resource. *Current* demands are used in the base-case and alternative simulations to quantify how water distribution might change under different management scenarios that represent viable options. Current irrigation demands may or may not be similar to historic demands, depending on changes that have occurred in the operations, efficiency, or irrigated acreage in the districts, in addition to any historic shortages that may have occurred.

In the Upper and Middle Deschutes (i.e., Tumalo and Squaw Creeks), the majority of diversions occur via large canals. These canals all have gaged historical records over the period of interest (1960-1999). Therefore, the historic demands as well as historic undepleted flows, gains, and losses in the basin can be calculated directly from gaged data using a simple mass balance approach. The exception is Walker canal, and several small diversions on Squaw Creek (excluding Squaw Creek canal). For Walker canal, historic use was determined from miscellaneous, instantaneous measurements on the canal in the 1970s and continuous record taken from 1924-1929. These measurements were used to estimate the typical monthly diversion rate for Walker. This estimate is thought to be a good representation of the historical use (per comm. Kyle Gorman, Bob Main). The smaller diversions for Squaw Creek were not estimated or included in the analysis. However, Squaw Creek canal diversions were included in the model. This exclusion of the smaller diversions represents a status-quo approach with regard to simulated distributions for these diversions in the Squaw Creek drainage. That is, the historic diversions also represent current use in the management simulations. If alternate management scenarios in the Squaw Creek drainage are of interests, a separate more detailed model of that basin could be developed.

Current demand for the irrigation districts were estimated by averaging the historical monthly diversions for each year that was thought to represent current operations. Any year with identified water shortages was not included in the estimate because diversions in these years under represent actual demand for that year, and thus, bias the average downward. The years in which shortages occurred were determined by examining graphs of total annual diversions (Figure 5), and confirmed with the Watermaster and Regional Manager.

Trends in historic diversions (after shortage years were removed) were also identified to establish a timeframe that was indicative of present day operations. If no trends were identified, then the entire record (minus any years with shortages) was used to calculate the average current demand. However, if a trend was detected in the historical record, then a sub-time frame was identified that represents current demand, in which no trend was apparent. The identified timeframe was estimated using a double-mass analysis along with a statistical test described later.

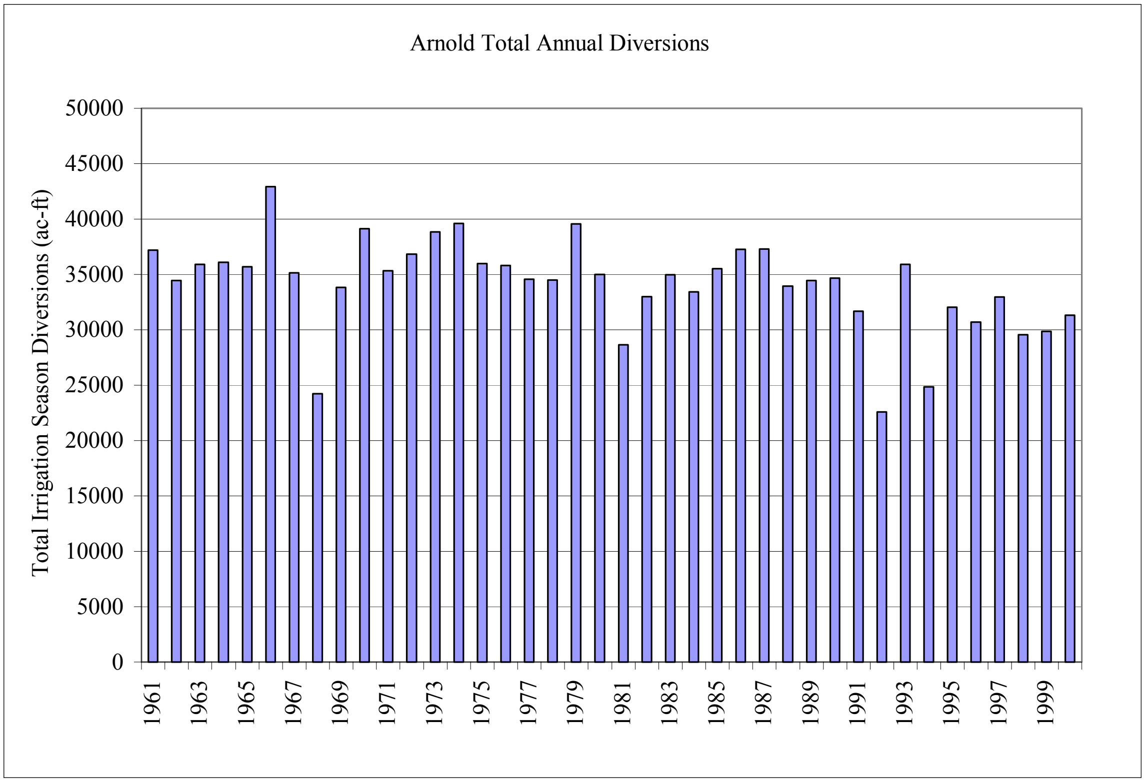


Figure 5: Total Annual Diversions for Arnold Canal. Water shortages present in 1968, 1992, and 1994.

The process for determining the trends in diversions is best shown in an example for the Central Oregon Canal (CENO). First, the total annual historic diversion is calculated for each year and plotted versus time. All years in which shortages occurred are removed. For the CENO canal there were no shortages present for the period of interest, so the entire record of interest was used (60-99). Next a regression line is fitted to the annual diversions (with time as the independent variable). The slope of the regression line in Figure 6 indicates that a decreasing trend over time is present for annual diversions in the CENO canal. However, if the trend is non-significant (i.e., occurs by chance) or due to climatic factors (i.e., increased precipitation or decrease temperature), then any trend in annual diversions can be ignored, and the entire record use to calculate the average monthly demand. Basically the tests determine if the trends are due to changes in irrigation acreage or efficiencies, or due to chance or non-controllable climatic reasons.

Figure 6 indicates an increase in precipitation at Bend during the growing season accompanies the decrease in demands. Kendall's Tau test for trends was performed on both variables (precipitation and diversions) to determine their significance. For CENO diversions, it was determined that the decrease in diversions was significant, while the increase in precipitation over the irrigation season was not. This indicates that a decrease in diversions over time is present, is not due to increased precipitation, and most probably is due to increased efficiency or a decrease in irrigated acreage. Furthermore, it indicates that to use the entire record to calculate the current monthly demand would be in error, since the presence of a decreasing trend indicates that diversions in the 60s and 70s were higher than diversions in later years.

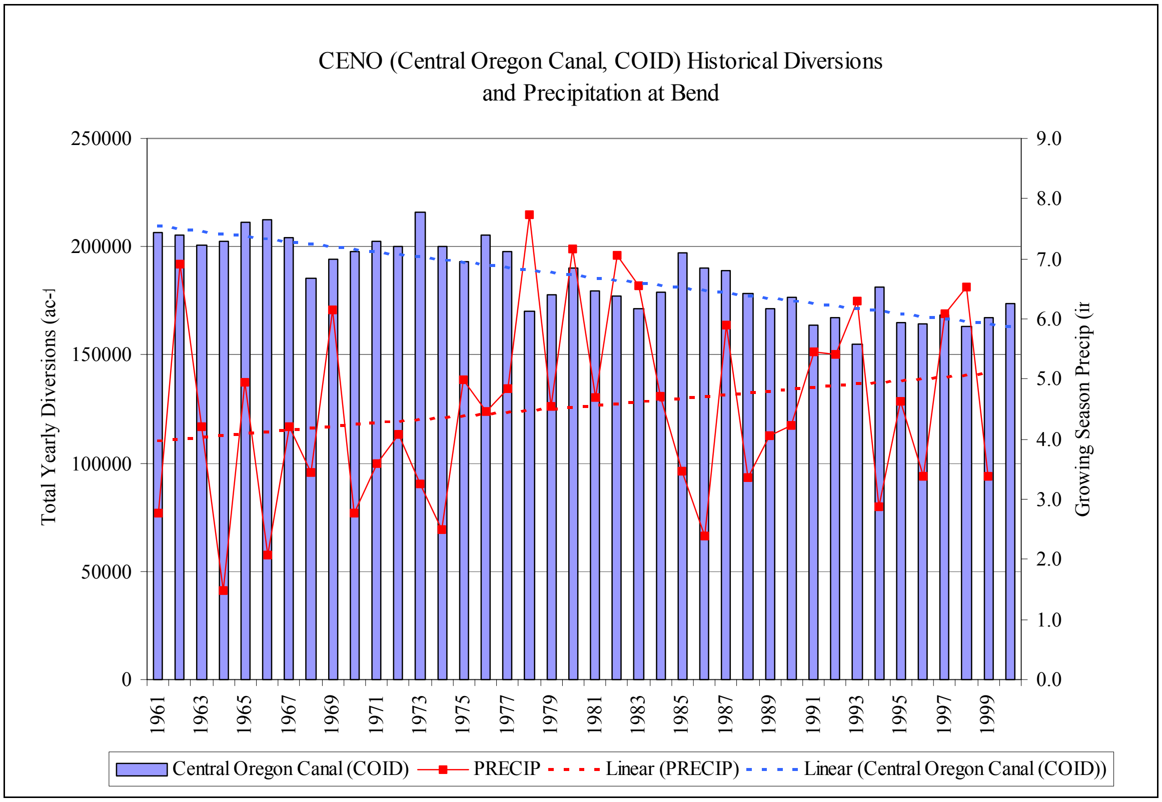


Figure 6: Total Annual Diversions and Trend for CENO Canal with Growing Season Precipitation at Bend.

A double-mass analysis was used to identify a year in which the annual diversions could be broken into two groups; the first indicative of the higher diversions occurring earlier in the record, and the later being indicative of current diversions. Figure 7 shows the double-mass analysis for CENO canal versus annual precipitation in Bend. A break in slope indicates that a change in diversions may have occurred, beginning in water year 1981.

Next, a Mann-Whitney test was performed to determine if there were significant differences in the average annual diversions before and after 1981. The test indicated that there was a significant difference between average annual diversions before and after 1981. Based on these tests, the average of monthly diversions for CENO canal between 1981 to 1999 was used to represent the current demand for the canal. This process was repeated for each canal, except for the North Unit Irrigation District (NUID). Due to the fact that significant portions of the canal have been lined, demands for NUID were calculated separately. The details of this calculation are covered in a report entitled "Estimate of Historic Demand for NUID Deschutes and Crooked River Lands" (Appendix C). The results for all canals are shown in Table 3.

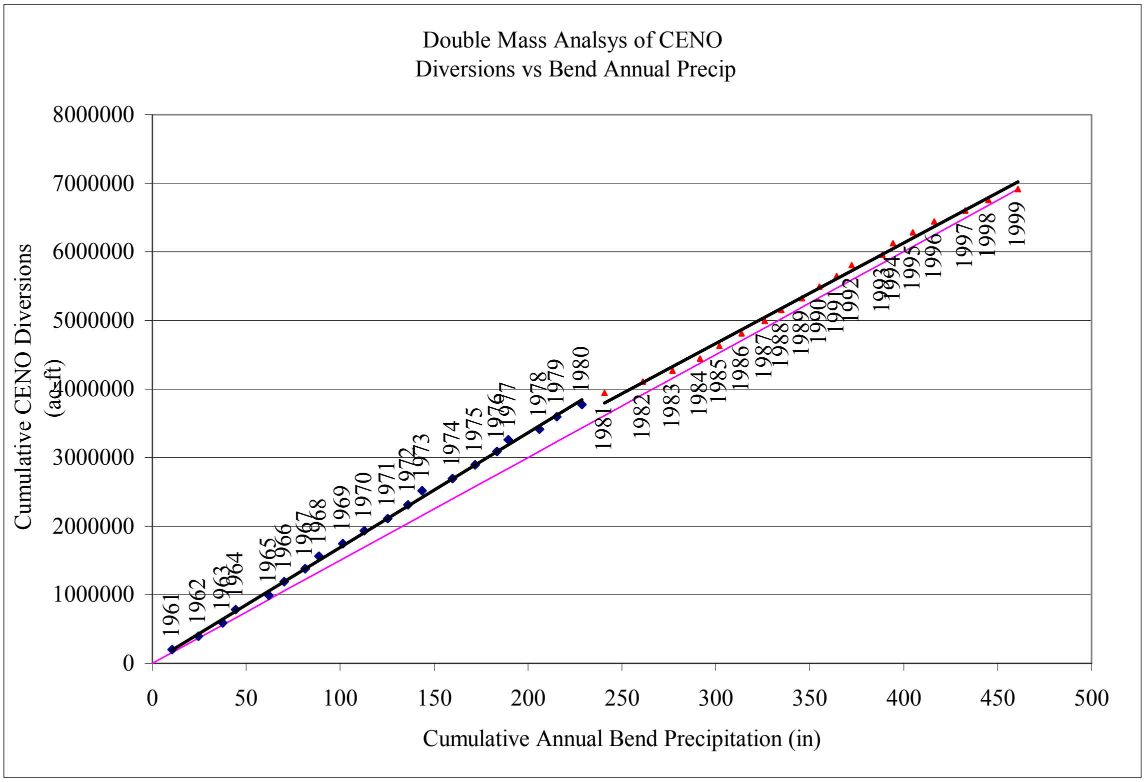


Figure 7: Example of double mass analysis for CENO canal.

Table 3: Period of record used to calculate mean monthly demand (acre-feet per month).

District/Canal	Record Used for Averages	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
CENO	81-00	8901	2132	1691	1664	1485	1657	11983	26860	28523	31458	31653	25942	173949
NCAO	81-00	8694	1728	1353	1441	1379	1405	10933	24573	26600	28846	29394	24457	160804
TID	61-68, 70-74, 76-79, 83-90, 96-97	3018	1650	708	742	1133	1827	4330	11344	13470	13259	12337	9138	72957
LONE PINE	81-00 (w/o 92)	550	21	5	3	0	0	677	1895	2075	2449	2328	1733	11736
ARNO	90-91, 93, 95-00	1779	361	134	108	278	272	1665	5656	5769	6246	6099	5002	33368
SWCO	61-00	3315	409	375	349	368	363	2887	5756	6740	6718	7130	5510	39922
NMCO	61-00*	15157	0	0	0	0	0	16909	32097	36905	39379	29210	23903	193559
WALKER	68-76**	455	0	1	0	0	152	449	1465	2042	2278	2032	1302	10177
City of Bend	74-88***	540	414	267	317	273	300	487	1070	1035	1071	1070	1035	7880
Squaw Crk	61-00 w/o 77,92,94	1982	766	434	292	448	886	2462	5872	8018	7614	5353	3397	37525
*	Record was adjusted to account for reduced seepage losses from canal lining.													
**	Estimated from miscellaneous measurements and historical record 1924-1929.													
***	Used maximum monthly mean diversion rate for each month during period of record as typical current demand,													
	except for May-Sept used max demand (17.4cfs)													

Streamflow—

Historical streamflow, gains, and losses were determined using a mass balance approach and available gaged records on the Deschutes, its tributaries, and diversions. Gains and losses were aggregated to regional areas based on location of these gages. Figure 4 shows the relative location of these gages. The principle areas consisted of: 1) Crane Prairie, Wickiup and Crescent Lake Reservoirs, 2) the Deschutes River from Wickiup to Benham Falls and from Benham Falls to Bend, 3) the Little Deschutes River between Crescent Creek and the mouth, and 4) Tumalo and Squaw Creeks.

Gains and losses to Reservoirs and Lakes:

Gains to the reservoirs for the Deschutes system (Figure 4) were based on mass balance analysis (equation 1).

gains = increase in storage + outflows + evaporation + seepage losses (eqn 1)

Note that a decrease in storage is represented in the above equation with a negative sign in front of the first term. All outflows from the reservoirs and lakes of interest are measured. Evaporation was estimated from temperature records at Wickiup using Hargreaves equation and correlated to available pan evaporation data at Wickiup Dam. Temperature records at Wickiup were adjusted to Crescent Lake and Crane Prairie locations based on the PRISM monthly average minimum and maximum temperature data set. For Crescent Lake and Wickiup Reservoir seepage losses are thought to be negligible and were taken as zero in the above equation (this is also equivalent to determining net gains to these reservoirs). For Wickiup reservoir, inflows to Wickiup from Crane Prairie releases were also separated from overall gains defined in Equation 1. This is because the simulated outflows from Crane Prairie may differ from the historical record (depending on the scenario) and should be separated from the other non-regulated gains to Wickiup reservoir. Finally, for Crane Prairie reservoir, all surface water gains were measured so that seepage losses could be determined by rearranging the terms in equation one and solving for seepage losses. A regression equation was then used to relate Crane Prairie elevations to seepage losses. Therefore, if the simulated elevations differed from historic elevations, a new seepage rate could be calculated and subtracted from simulated Crane Prairie contents.

Gains and Losses in the Deschutes River:

Gains in the Deschutes River between Wickiup reservoir and Benham Falls were calculated using gage data at the following locations: 1) below Wickiup Reservoir, 2) at Benham Falls, and 3) at the Little Deschutes near Lapine. Gains were taken as discharge at Benham Falls minus discharge below Wickiup reservoir minus the Little Deschutes near Lapine. These gains by definition include inflows to the Deschutes from Spring and Fall River plus any direct groundwater gains and losses in the reach. According to the USGS study on groundwater hydrology in the basin (Marshall et. al. 2001), the stream reach between Benham Falls and Wickiup Reservoir is a *gaining* reach. However, storage releases from Wickiup and Crane Prairie reservoirs are charged a 12.5% channel *loss* between the reservoirs and Benham Falls due to an inter-district agreement. This loss was also included in the accounting for the distribution model so that storage releases could be charged a loss to the appropriate irrigation district's storage account.

The next reach, between Benham Falls and Bend is a losing reach. By relating the total flow at Bend (i.e., adding all diversions above Bend to the flow below Bend) to the total flow at Benham Falls, an equation was developed to relate losses in this reach to discharge at Benham Falls. The relationship shown in Figure 8 was incorporated into the distribution model, to account for losses in the simulated scenarios.

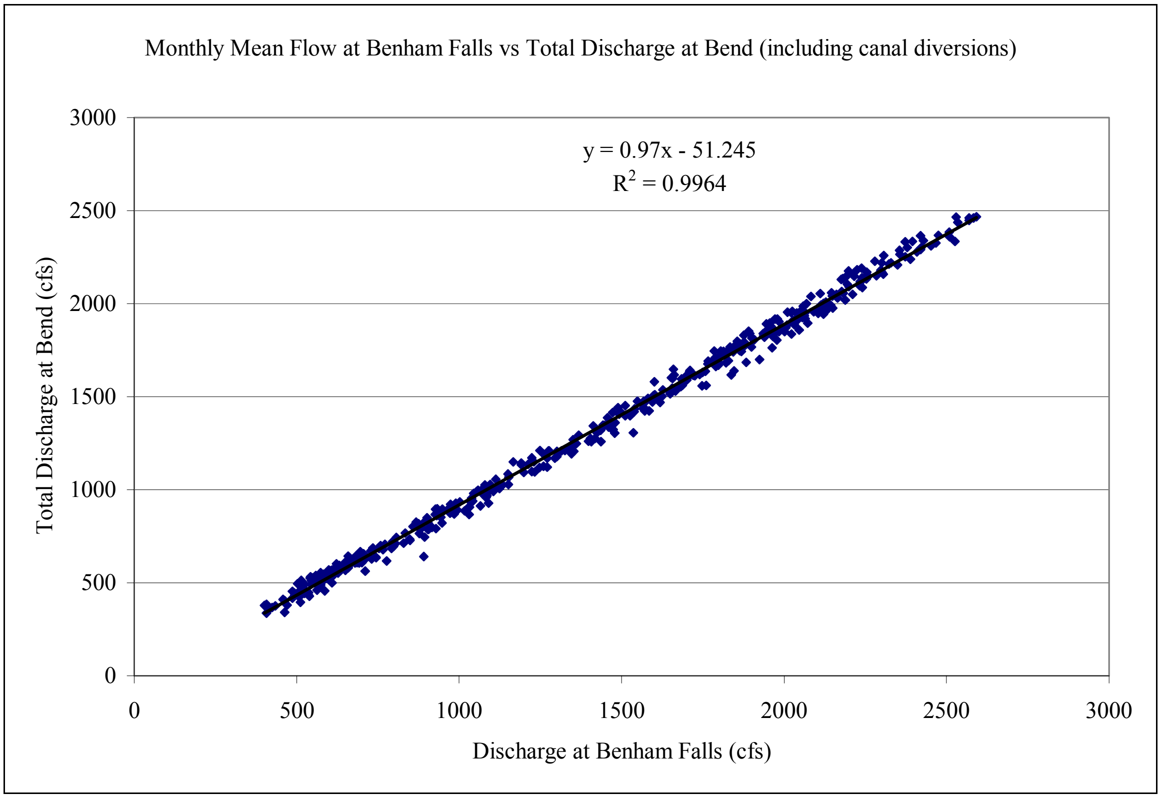


Figure 8: Relationship showing losses between Benham Falls and Bend amount to 3% of the flow at Benham plus an additional 51 cfs.

Gains in the Little Deschutes:

Gains in the Little Deschutes were calculated by taking the gage data for the Little Deschutes near Lapine, subtracting releases from Crescent Creek, and adding diversions from Walker canal. According to an inter-district agreement, storage releases from Crescent Lake are charged an 18 percent loss between the lake and the mouth of the Little Deschutes, even though this is also a gaining reach. This accounting loss was incorporated into the model so that any simulated releases had the appropriate loss charge to the storage account in Crescent Lake.

Tumalo and Squaw Creek Natural Flow:
Tumalo Creek natural flows were determined by adding diversions from the City of Bend and for the Columbia Southern canal back into the gage record. The gage on Tumalo Creek was discontinued in 1987, so a regression equation established with Squaw Creek was used to generate the record from 1987 to 1999. The relation is shown in Figure 9. The natural flow for Squaw Creek was taken from gage #14075000, which is above the Squaw Creek canal and other smaller diversions.

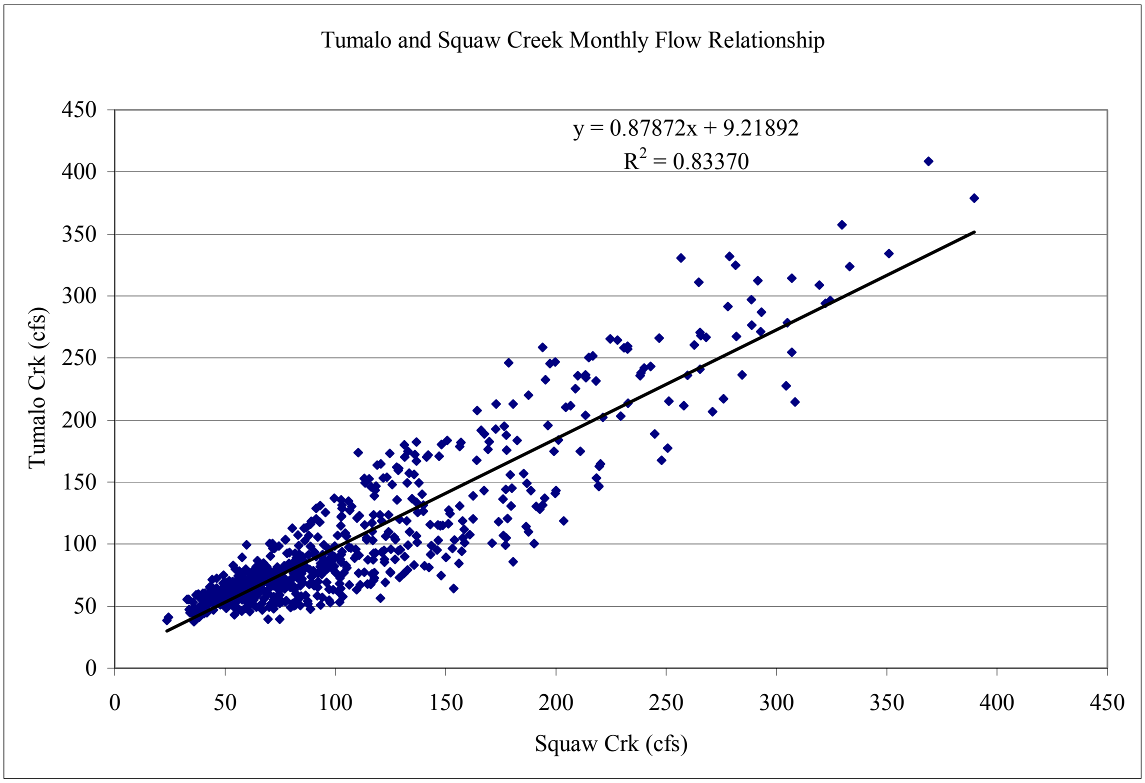


Figure 9: Relationship between discharge in Tumalo Creek and Squaw Creek.

Reservoir Parameters:

MODSIM uses reservoir parameters to constrain operations of the reservoirs to imitate real operations. Most of these parameters reflect actual physical constraints. Other parameters represent agreements between agencies or operational parameters that have been designed over the years to make best use of the reservoir. The parameters consist of: 1) maximum and minimum volume, 2) area, elevation, capacity relationships, 3) evaporation rates, 4) maximum channel or spill capacity, 5) spill capacity and elevation relation, 5) ramping constraints, and 6) target storage contents based on water year types (wet, average, dry). The last of these parameters is used along with "balance tables" to calibrate the simulated reservoir contents to historic levels. Even though the reservoirs on the upper Deschutes are primarily used to store water for irrigation, some flood control benefits are realized. Target storage contents for the reservoirs change based on water year type. The year type is determined for each month by taking the previous month reservoir contents, adding the current month inflows and then dividing this sum by the maximum contents. The resulting number is termed the hydrologic state and is used to set the target levels for each month's contents.

In addition to the physical parameters, there are general accounting guidelines for splitting inflows to Crane Prairie and Wickiup reservoirs. Inflows to Crane Prairie can be passed down to Wickiup, but since Wickiup is downstream of Crane Prairie, the reverse is not true. Initially inflows to Crane Prairie and Wickiup are split so that 1/7 of the total inflows are stored in Crane Prairie and 6/7 are stored in Wickiup, until Wickiup contents reach 180,000 acre-feet and Crane Prairie contents reach 30,000 acre-feet (per comm. Kyle Gorman, Bob Main). After Wickiup reaches 180,000 ac-ft, Crane Prairie downstream releases are reduced, subject to the minimum stream flow agreement, until Crane Prairie contents increase by an additional 15,000 acre-feet. At this point, the majority of inflows into Crane Prairie can again by passed downstream until Wickiup reaches maximum capacity. Finally, Crane Prairie is filled to capacity. During this fill process, forecasts for inflows to the reservoirs are used to adjust spills and maximize flood control benefit. The inflows are credited to the irrigation storage accounts as follows:

1) First 30,000 ac-ft stored in Crane Prairie: A) 10,500 ac-ft credited to Lone Pine ID, B) next 10,500 credited to Arnold, C) next 9,000 ac-ft credited to COI.

2) First 180,000 ac-ft stored in Wickiup: All credited to NUID.

3) Next 15,000 ac-ft stored in Crane Prairie: A) 3,000 ac-ft credited to Arnold, B) 12,000 ac-ft credited to COI.

4) Final 20,000 ac-ft stored in Wickiup: All credited to NUID.

5) Next 5,000 ac-ft stored in Crane Prairie: All credited to COI.

6) Final 5,000 ac-ft stored in Crane Prairie: All credited to river account (i.e., Deschutes summer flows below Bend).

The storage rights for both Wickiup and Crane Prairie reservoirs have a priority date of 1913 and consists of 200,000 acre-feet for NUID, 10,500 acre-feet for Lone Pine, 13,500 acre-feet for Arnold, and 26,000 acre-feet for COID. Storage rights for Crescent Lake are 35,000 acre-feet for TID with a priority date of 1911, and 51,050 acre-feet for TID with a priority date of 1961.

Types of Simulations:

In typical modeling projects, the initial simulations are performed to calibrate the model. In this phase, modeled outputs are compared to historical data to determine if the model logic accurately depicts historic operations. In the case of the upper Deschutes distribution model, the calibration phase used the historical hydrologic inputs and the *historical* demands, in conjunction with the network and reservoir constraints (e.g., water rights, channel capacities, etc.). The outputs used to see if the model was calibrated were primarily the reservoir levels, but also include the simulated diversions and stream flows. These simulated outputs were compared to the historic data. These comparisons are presented in the "Results" section of the report.

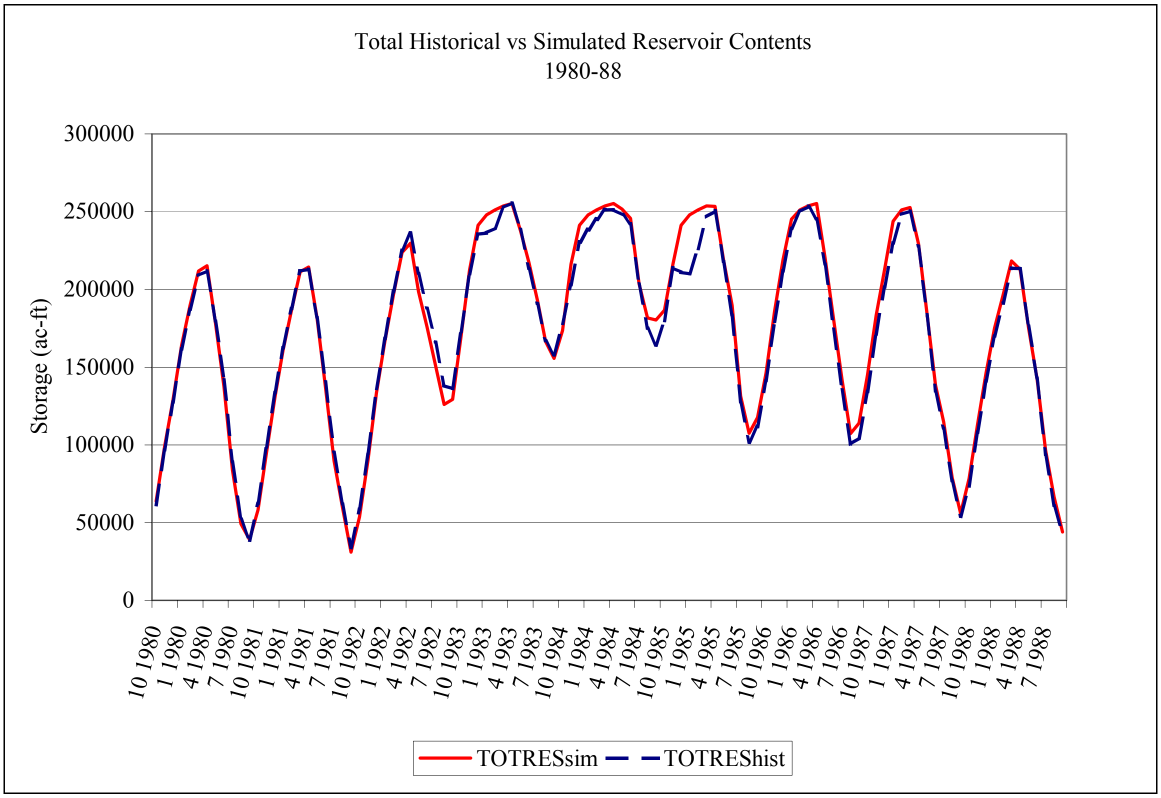
Once the model was calibrated, the next phase was to generate output for the base-case operations. This simulation basically represents the operation of the system under *current conditions* with the *historic hydrologic conditions*. As previously suggested, the deliveries and storage of water have changed over time as new management strategies were implemented, supply forecasts were developed, canals were lined or piped, and additional measurement devices were installed to better manage the resource. Thus, *historical* operations do not necessarily represent *current* operations. The base-case uses the same historic hydrologic inputs as the calibration phase, but imposes on the system new demands that represent current conditions, current operations with regards to target minimum flows at certain locales, and reservoir operations. The output from this simulation represents reservoir levels, flows, and deliveries that would have occurred had the present condition of the distribution system been in place with the historical hydrologic inputs. For example, the simulated deliveries for irrigation under the base-case scenario in 1969 represents how much water would have been delivered to the irrigation districts with the hydrologic conditions in 1969, but with the present demands, reservoir operations, and stream flow requirements.

After the base-case has been established, the next step in a modeling project is to run alternate management scenarios. In these model runs, different "what-if?" proposals are simulated to see the alternative management effects on demands, levels, and flows in the system. These effects are demonstrated by comparing the alternate scenario with the base-case scenario. In this way, the effects of the different resource management strategies are isolated from effects of changes in historic demands or operations. The alternative scenario example used in this report was to increase minimum target flows below Wickiup Reservoir from 20 cfs to 50 cfs.

Results:

Calibration Phase—

The results shown in Figures 10 through 13 demonstrate that simulated operations of the calibrated system mimic historic operations, as reflected by instream flows and reservoir levels. Figure 10 shows the combined contents of Wickiup and Crane Prairie versus the historic contents. The contents of the two reservoirs were combined because they act as a single storage facility in many respects, even though individual storage accounts within the reservoirs are tracked separately. For example, water is sometimes released from Wickiup to meet release obligations from Crane Prairie because of logistics. Travel time for Wickiup releases to the point of diversion are less than that from Crane Prairie. Water can later be released from Crane Prairie to backfill Wickiup, or stored water in Crane Prairie can be credited to the Wickiup space holder (i.e., NUID). In real life, these operations are done on a day-to-day or weekly basis, with accounting back calculated on a monthly time frame. The distribution model allows for the above-described flexibility and also debits the storage accounts according to water rights, storage availability, and



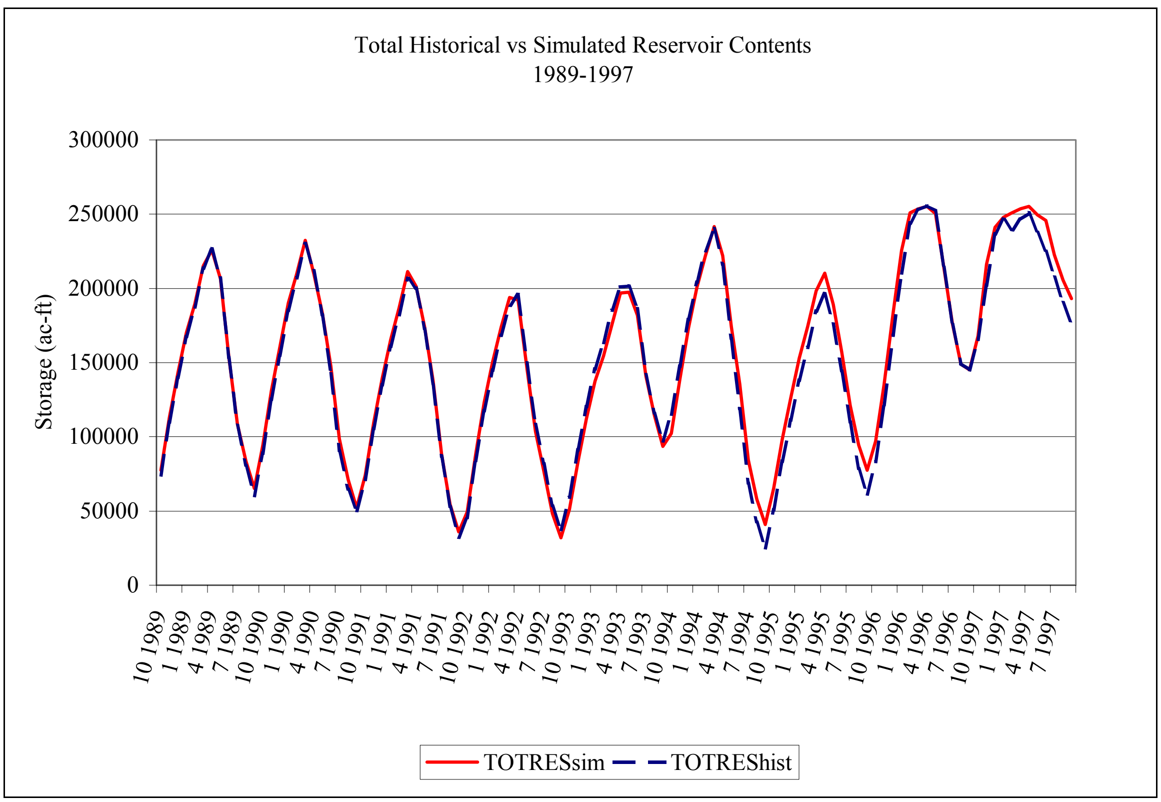


Figure 10a and 10b: Calibrated (TOTRESsim) and Historic (TOTREShist) End of Month Contents for Crane Prairie and Wickiup Reservoirs (WY 1980-1997).

usage. Water stored in the non-irrigation season is credited as previously explained.

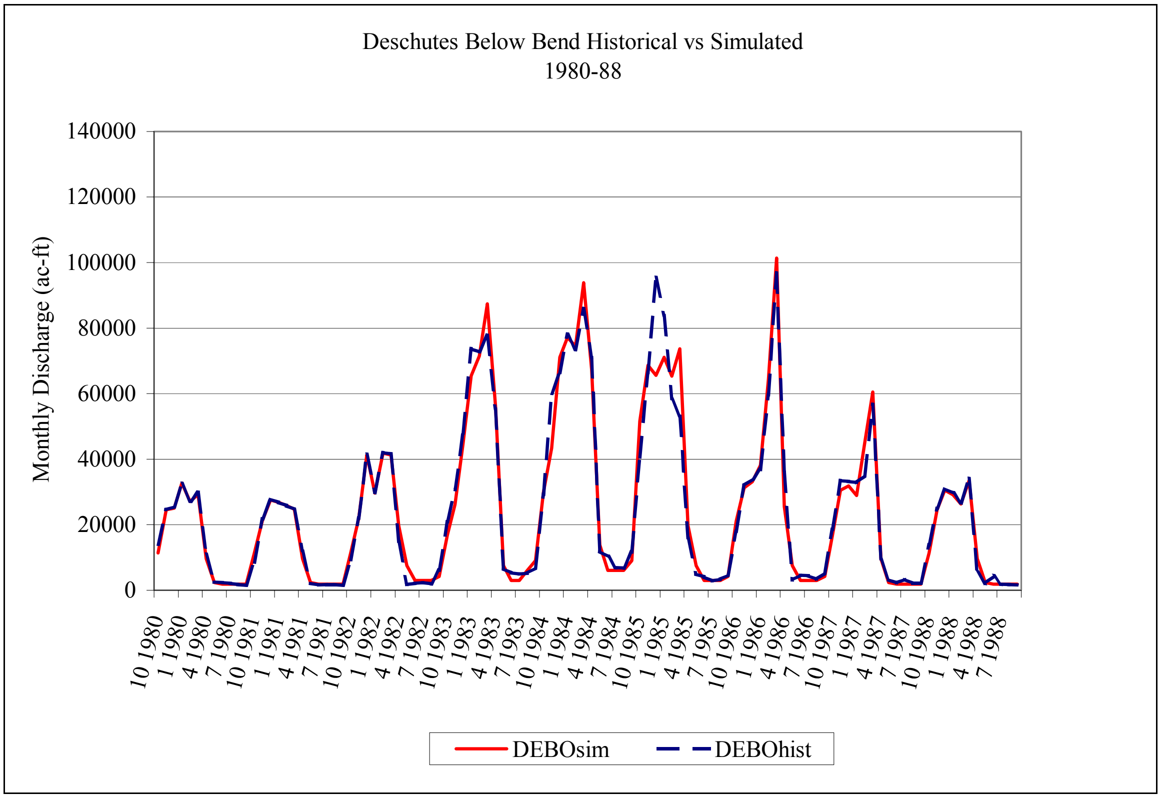
The model was also calibrated to replicate the historic individual contents of Crane Prairie and Wickiup, although this was of secondary importance to the total contents and stream flows. The individual contents were calibrated so that historic seepage and evaporation losses, and the corresponding charges to the storage account are accurately simulated. The results for the individual reservoirs are given in Appendix A.

Figure 11 compares the simulated versus historic monthly discharge below Bend and demonstrates that the simulated flows closely match the historic record. There are some deviations in winter peak flows for water year 1985, which are also shown as differences in the simulated and historic total Crane Prairie and Wickiup reservoir contents for 1985 (Figure 10a). The reason for this difference is that the model sees no benefit for bypassing reservoir inflows downstream, as long as the reservoir contents are below the flood control limit specified in the model, as was the case. Therefore, the model stored the water, which resulted in lower simulated winter flows below Bend, than what historically occurred.

Some difficulty was encountered in simulating flows below Bend in October and April. This was due to the timing of when irrigation districts started and stopped deliveries. The distribution model runs on a monthly time step. However, typically the irrigation districts come on line in mid-April and shut-off in mid-October. Flows below Bend prior to the onset of irrigation (April 15th) maybe upwards of 700 cfs, and 100 cfs after the canals are opened. In this example, the April monthly mean flow below Bend would have been 400 cfs. However, the *minimum* target flow below Bend in April even during a wet year is only 100 cfs. The model will not send more water downstream of Bend than what is specified by the target minimum flow (or any unused gains), and routes the remaining natural flows to the irrigation demands (also specified on a monthly time step). So a difference sometimes existed between the simulated and historic flows below Bend. To account for this mid-month change in flows and demands, instream demand below Bend for the beginning and end of the irrigation season was increased in the model. The increased demand was determined by looking at historical monthly average flows in October and April and relating these flows to water year type (i.e., wet, average, dry). The water year type was based on hydrologic state for that month (described earlier).

Crescents Lake simulated contents are compared to historic contents in Figure 12. The Crescent Lake system operates independently from Crane Prairie and Wickiup reservoirs for the most part. Tumalo Irrigation District (TID) is the sole storage holder in Crescent Lake. Storage releases from Crescent are dependent on available flows in Tumalo Creek as well as available natural flow in the Deschutes River. Comparison of the simulated and historic Crescent Lake levels demonstrates that TID's demand from Tumalo Creek, the Deschutes River, and Crescent Lake are being simulated correctly as is the available water from these three sources.

Figure 13, show the simulated and observed flows for Tumalo Creek below the Tumalo Feed canal. As in the Crescent Lake comparison, this demonstrates that the interaction of



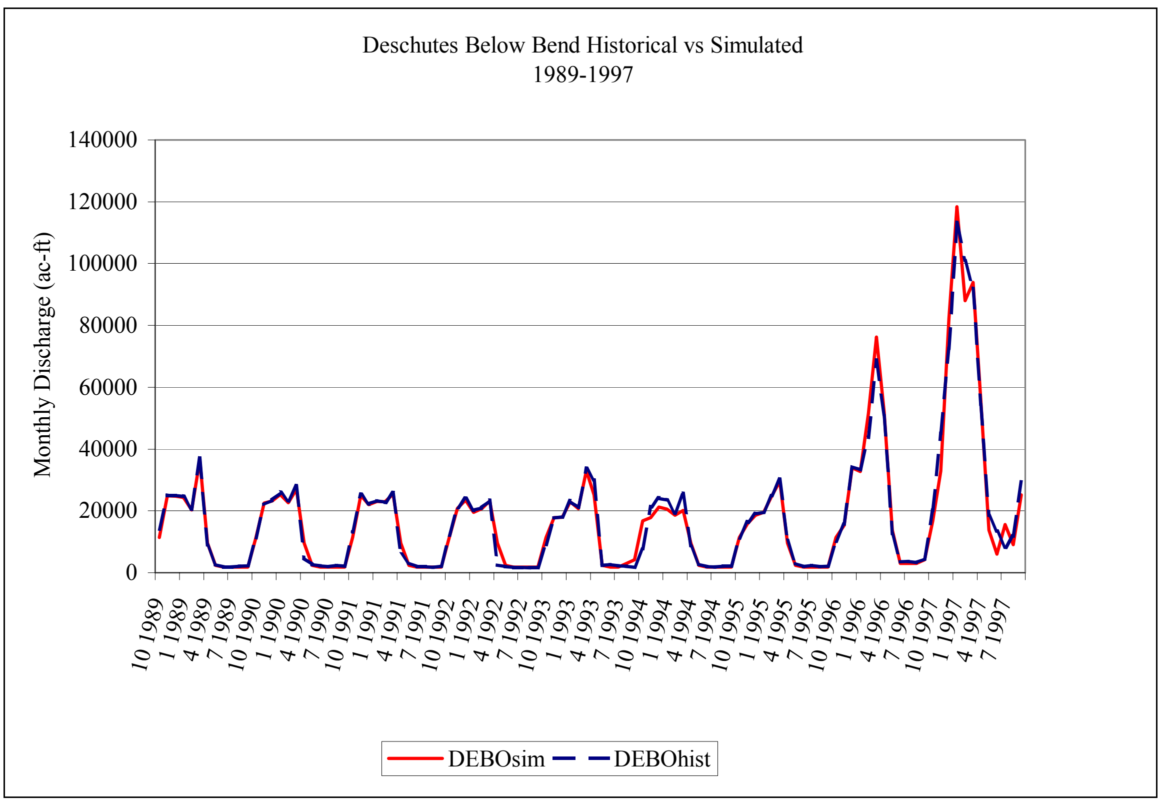
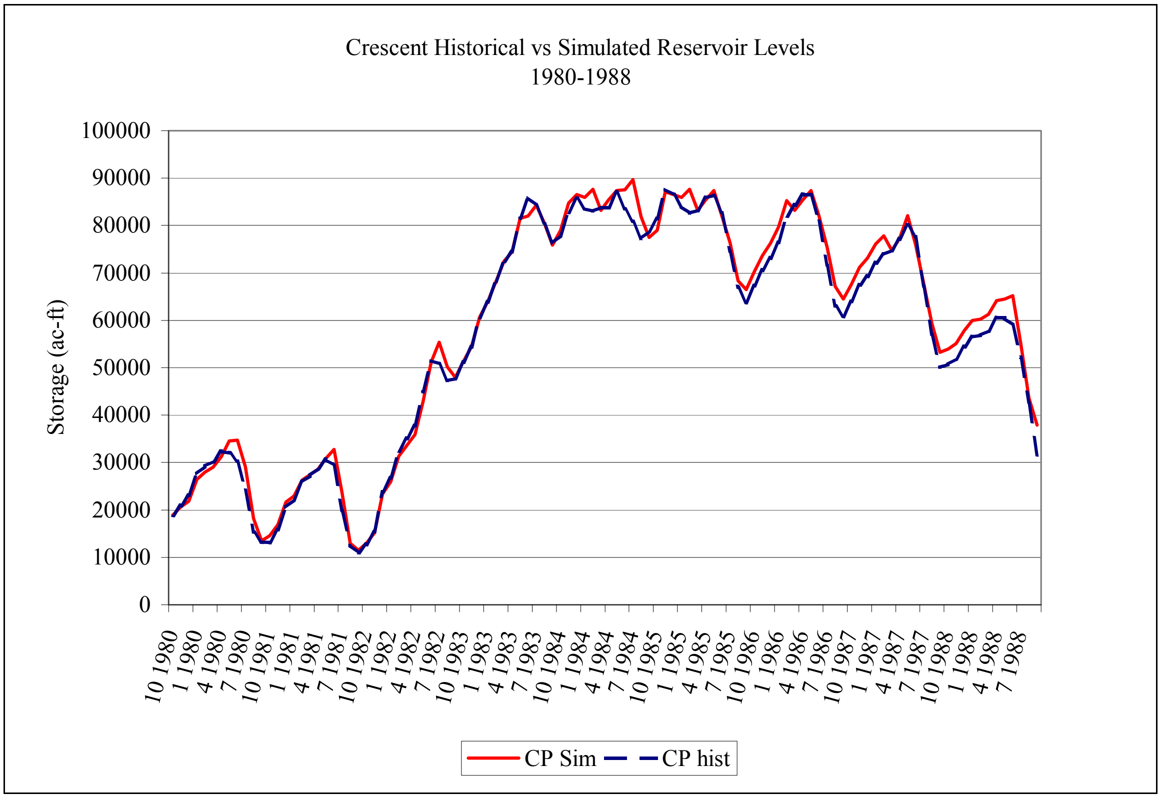


Figure 11a and 11b: Calibrated (DEBOsim) and Historic (DEBOhist) Flows below Bend (WY 1980-1997).



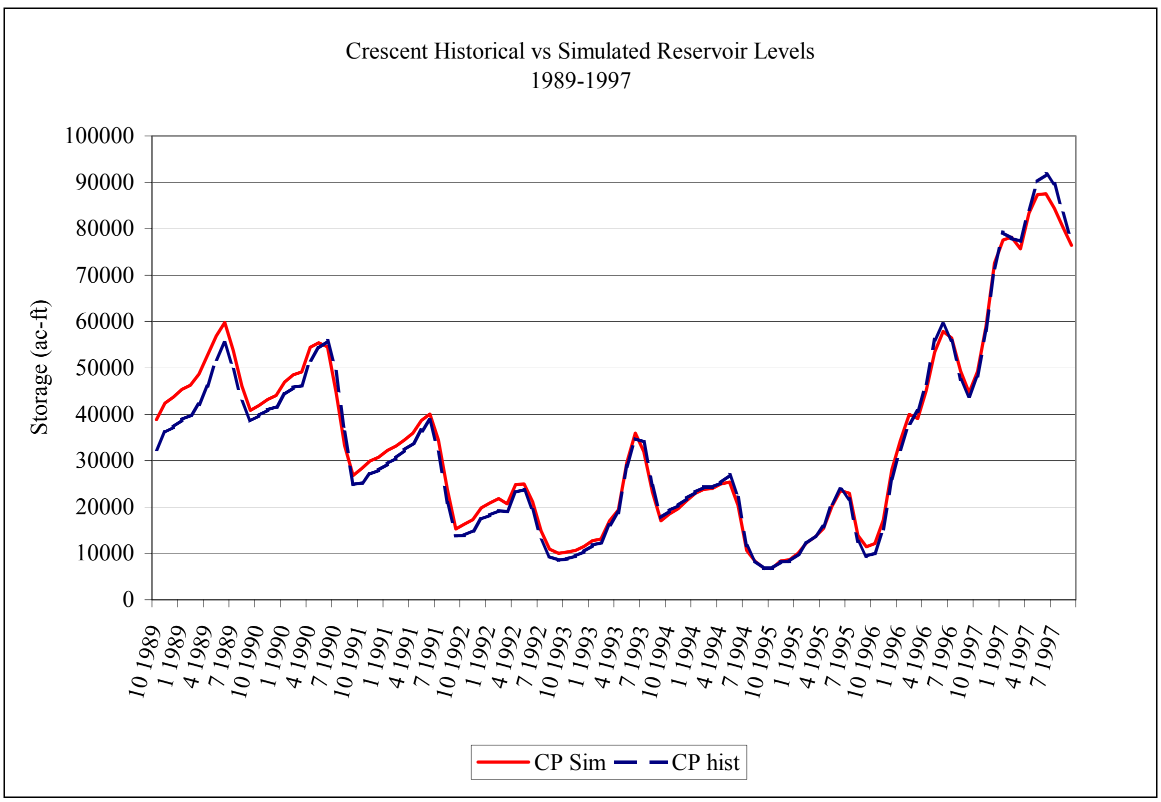
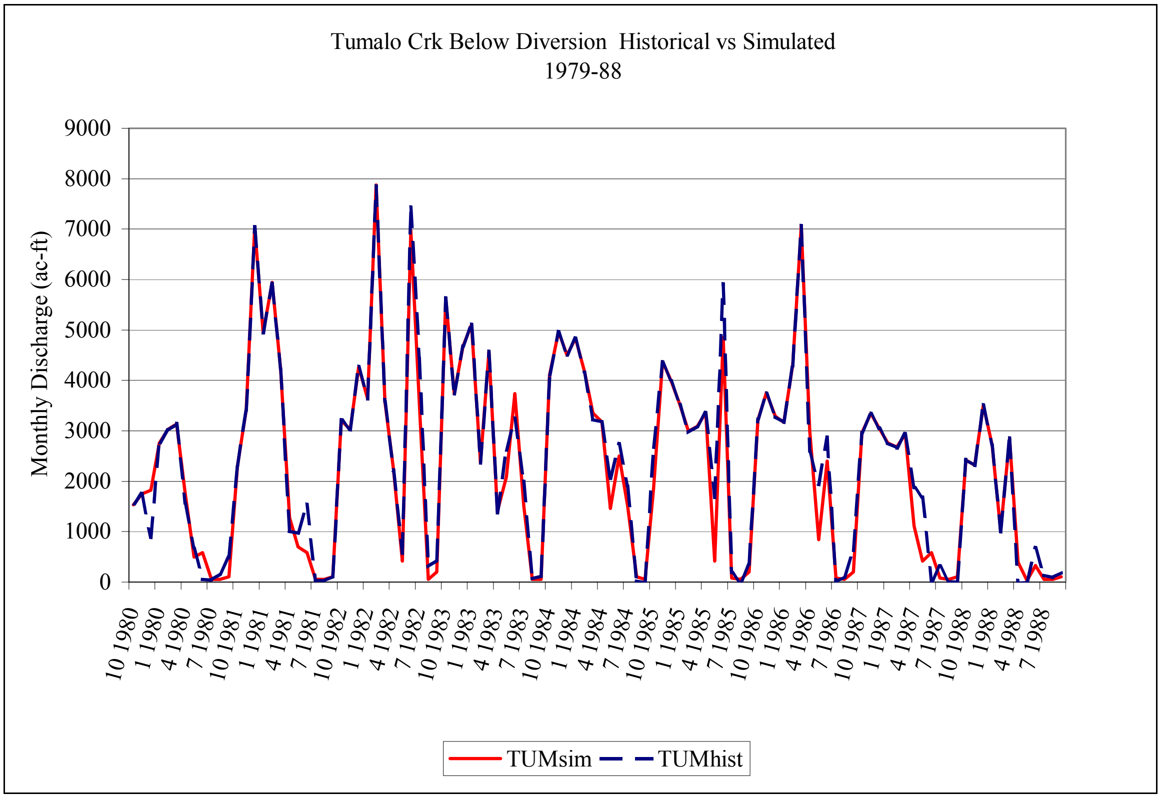


Figure 12a and 12b: Calibrated (CPSim) and Historic (Cphist) Monthly Contents for Crescent Lake Reservoir (WY 1980-1997).



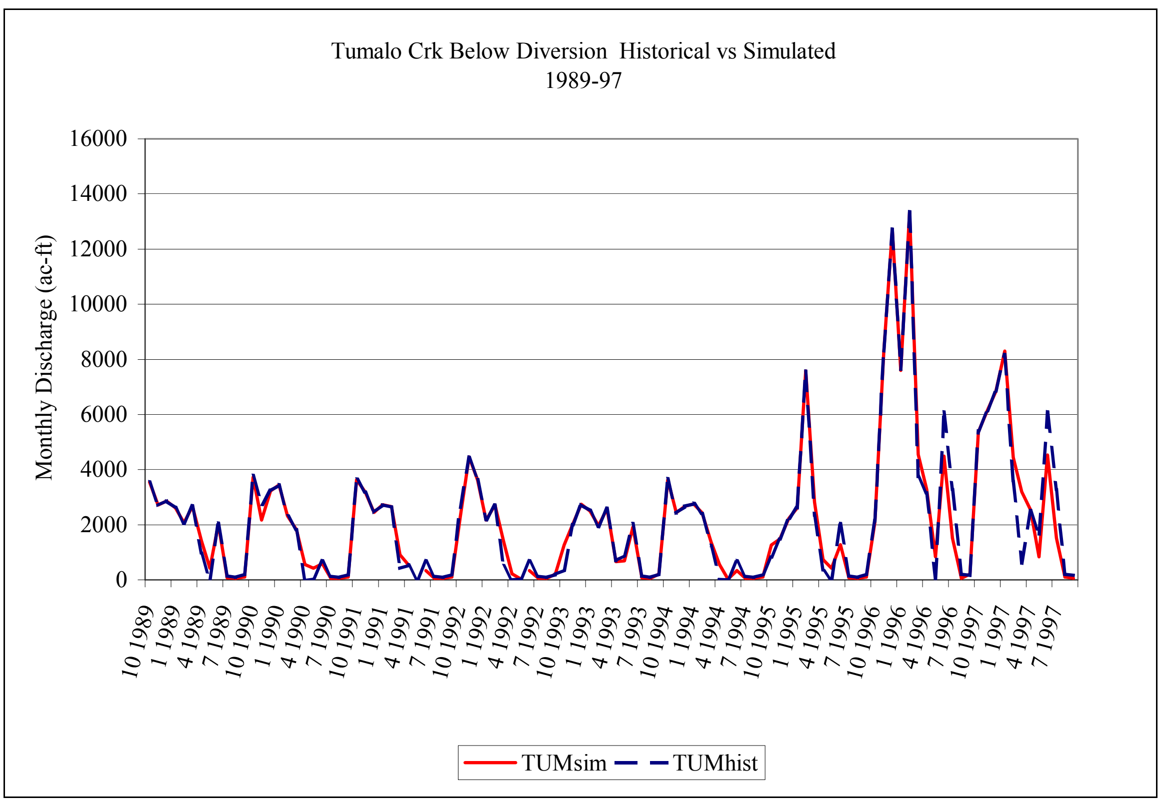


Figure 13a and 13b: Tumalo Creek Calibrated and Historic Flows below Tumalo Feed Canal (WY 1980-1997).

available live flows and TID demand from Tumalo Creek, the Deschutes River and stored water in Crescent Lake is being simulated correctly.

Overall, Figures 10 through 13 demonstrate that the model is accurately simulating the physical routing and storage of water in the system, as well as the paper accounting of the stored and delivered water.

Base Case Simulation Phase—

For the base-case simulation, the current typical demands (Table 3) were used for the irrigation districts, instead of the historic diversions. In addition, the stream flow requirements were set to a minimum 30 cfs below Crane Prairie, 20 cfs below Wickiup, and 5 cfs below Crescent Lake. Target minimum flows for Tumalo Creek, below the Tumalo feed and for the Deschutes, below Bend, are shown in Tables 4 and 5.

Table 4: Tumalo Target Stream Flows below Tumalo Feed Canal (CFS)

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Dry	20	0	0	0	0	8.9	3.6	2.5	2.5	2.5	2.5	2.5
Avg.	30	0	0	0	0	23	9.3	3	3	3	3	3
Wet	30	0	0	0	0	31	20	6	6	6	6	6

Table 5: Deschutes Target Stream Flows below Bend (CFS)

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Dry	190	0	0	0	0	0	160	35	35	35	35	35
Avg.	280	0	0	0	0	0	200	70	50	50	50	50
Wet	500	0	0	0	0	0	300	140	100	100	100	100

Note that in the winter months (November through February for Tumalo Creek and November through March for Deschutes below Bend) the target stream flows are set to zero. This is because stream flows in the winter months are much higher than any minimum requirement, so they are unnecessary. Target levels at the beginning and end of the irrigation season reflect the variability in the start and end times of diversions for Tumalo Creek and the Deschutes below Bend (discussed previously). These numbers were estimated during the calibration model runs. Likewise, the stream flows designated for the spring and summer represent the current target levels for those months. For example, the stream flow requirement for Tumalo Creek during the summer is 2.5 cfs. However, the actual stream flow may be higher due to: 1) additional instream leasing of water rights, 2) greater availability of water during wet years that exceeds out-of-stream demand, and 3) mid-month turn-on and shut off times at the beginning and end of the irrigation season. The same is true for the Deschutes below Bend. The spring and summer values represent historical flows in these reaches that are thought to represent current practices, based on water supply.

Monthly target storage levels for the reservoirs are shown in Tables 6 and 7. Again, these values were determined by looking at typical contents in the historical record, which were adjusted in the calibration phase. Target storage contents are treated as a maximum content value for the month and may be viewed as an upper operational limit or flood control value between late fall and early spring.

Table 6: Target Storage Contents for Wickiup Reservoir (ac-ft)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Dry	146100	164000	185000	195000	198500	200000	200000	190495	183000	126900	90000	80000
Avg.	146100	164000	185000	195000	198500	200000	200000	200000	183000	165000	135000	100000
Wet	146100	164000	180000	192500	195000	198500	200000	200000	183000	170000	160000	140000

Table 7: Target Storage Contents for Crane Prairie Reservoir (ac-ft)

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Dry	42000	48000	50560	52650	52545	53570	55300	55300	55300	50000	48000	44510
Avg.	42000	48000	49650	51650	52545	53570	55300	55300	55300	51000	49000	45510
Wet	42000	44000	48650	50650	51545	51570	53570	55300	55300	52000	50000	46510

Although neither reservoir was built for flood control, there is some benefit under current operations for this purpose. This benefit is reflected in the model as well. Notice that the December wet year target contents for Wickiup Reservoir are less than for dry years. In a wet year, the forecasted spring runoff is higher than for dry years. Thus, some storage space is kept vacant and filled later in the year. The target levels for June through September along with the model's "balance tables" represent the relative priorities for storage releases from the two reservoirs. These numbers were estimated based on the historic record and then adjusted during the calibration phase. As previously mentioned, the storage account credits and debits are somewhat flexible. Storage accounts are credited based on the logic stated in section "Reservoir and Lake Parameters". Accounts are debited based on diversion amount and water right, regardless if the physical water is released from Wickiup or Crane Prairie. The target levels are used to ensure that the simulated relative levels between the reservoirs are reasonable, compared to the historic record (Appendix A). This translates to simulated debits to the storage accounts from seepage and evaporation losses that are representative of historical values.

Results for the base-case simulation are presented in terms of exceedance values of annual diversions for the irrigation districts (Figure 14 and 15) and exceedance values of monthly mean flows for the depleted reach locations (Figure 16, 17, 18, and 19). Exceedance values are the percentage of time that a certain flow or diversion is exceeded. Figures 14 and 15 show the annual amount of water each irrigation district could expect to receive given the hydrologic conditions from 1929 through 1999, with current demands. For NUID, this translates to full deliveries 80 percent of the years in the study. For the two COI canals, deliveries are close to full, 90 percent of the time. For TID and Arnold canals, full deliveries occurred approximately 70 percent of the time. Swalley canal always receives full deliveries, while Lone Pine receives full deliveries 80 percent of the time. The City of Bend's demands are almost always met. There is a slight reduction at the 40 percent exceedance value. However, as depicted by the nearly horizontal line in Figure 15, the shortage is extremely small, and would be met by municipal wells.

Figures 16 and 17 show the monthly exceedance values (also called flow duration curves) for the Deschutes River, below Crane Prairie reservoir, below Wickiup reservoir, and below Bend. Figure 16 demonstrates the range of flows experienced at these locations, while the scale is reduced in Figure 17 to focus on the lower exceedance values. Likewise, Figure 18 demonstrates the range of exceedance flows for Tumalo and Squaw Creeks, below the major diversion canals on those creeks, and for Crescent Creek below Crescent Lake. Figure 19 concentrates on the lower exceedance discharge values for these locations.

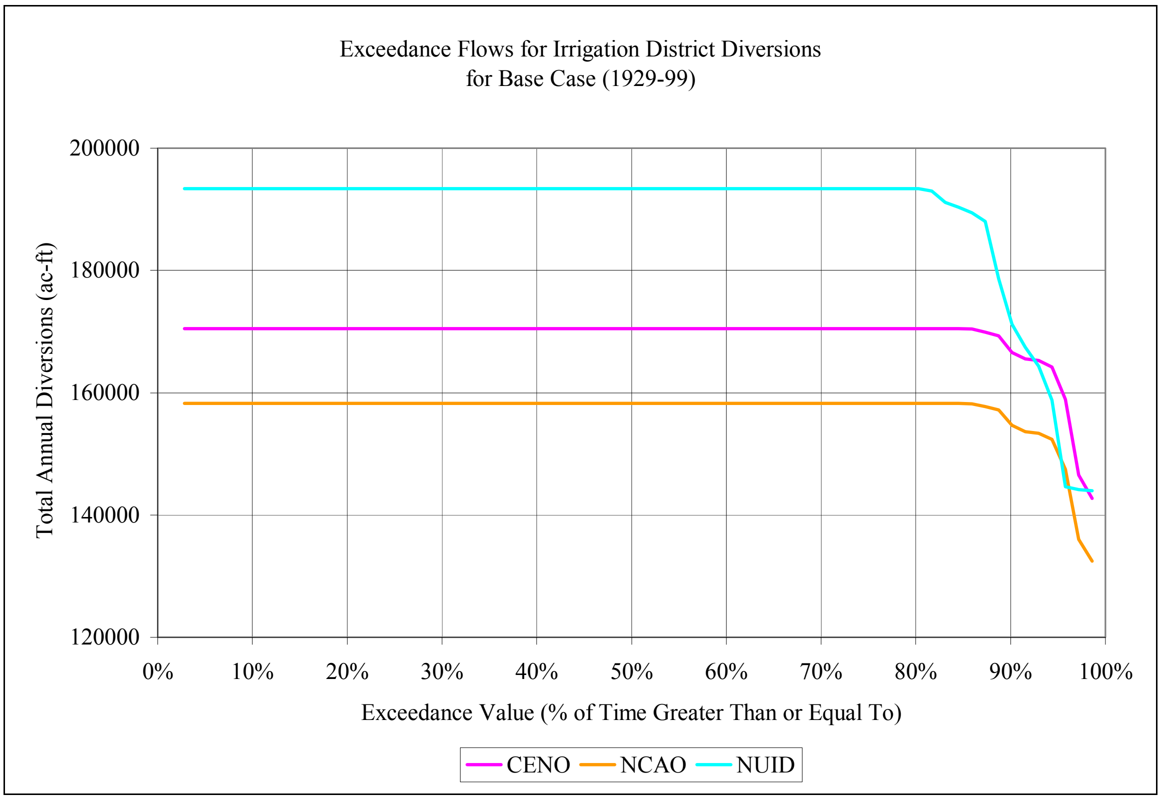


Figure 14: Exceedance Flows for North Unit Irrigation District and Central Oregon Irrigation District's two canals.

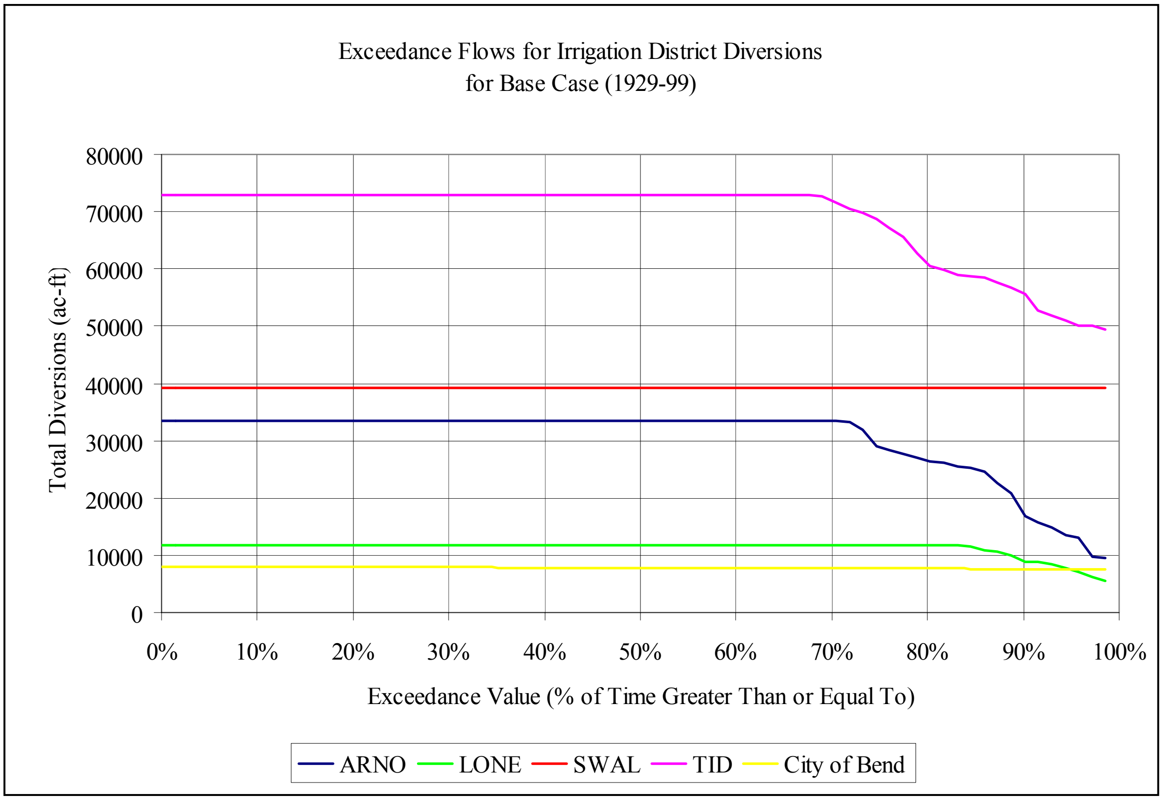


Figure 15: Exceedance Flows for the City of Bend, and Arnold, Swalley, Lone Pine, and Tumalo Irrigation Districts.

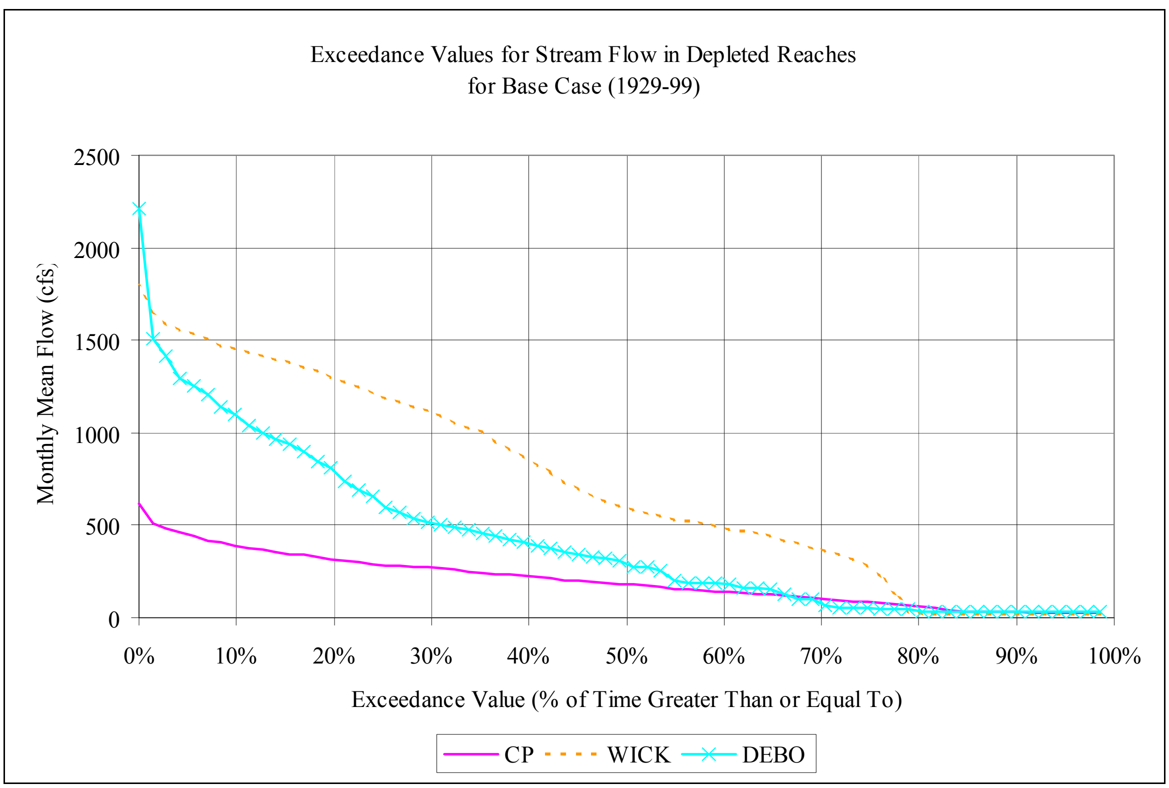


Figure 16: Exceedance Values for Deschutes River Discharge below Bend, and below Crane Prairie and Wickiup Reservoirs.

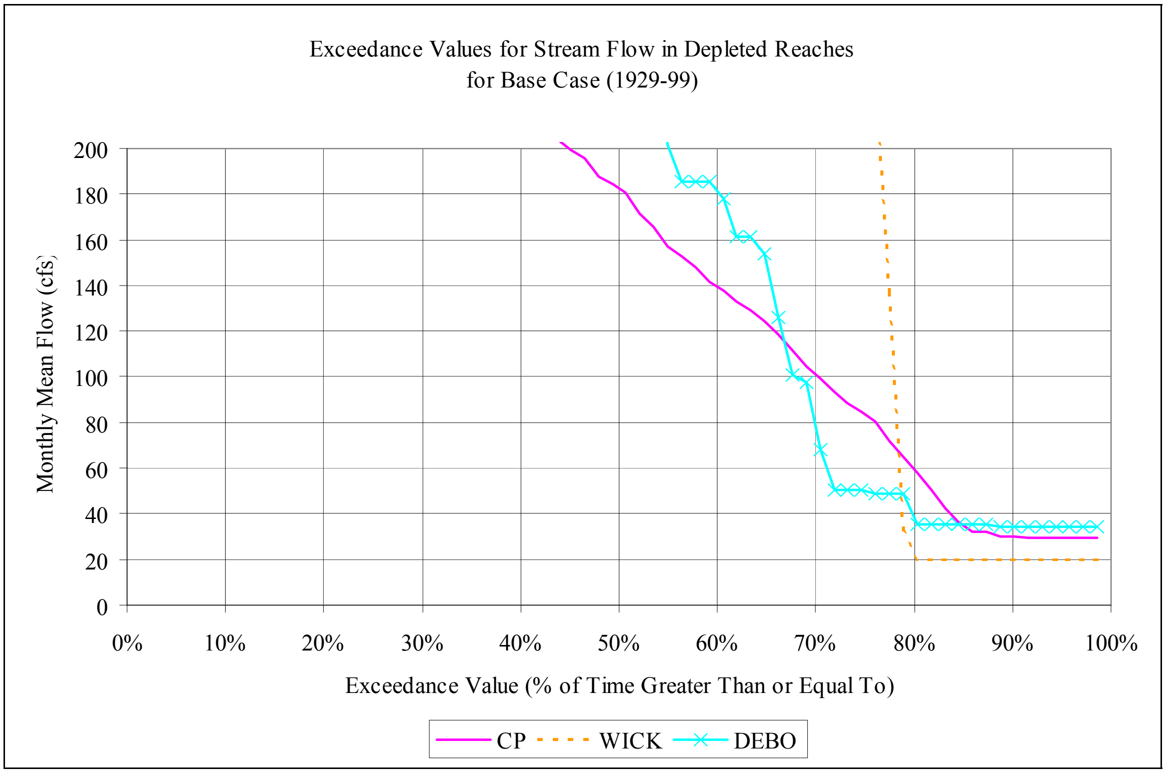


Figure 17: Lower Exceedance Values for Deschutes River Discharge below Bend, and below Crane Prairie and Wickiup Reservoirs

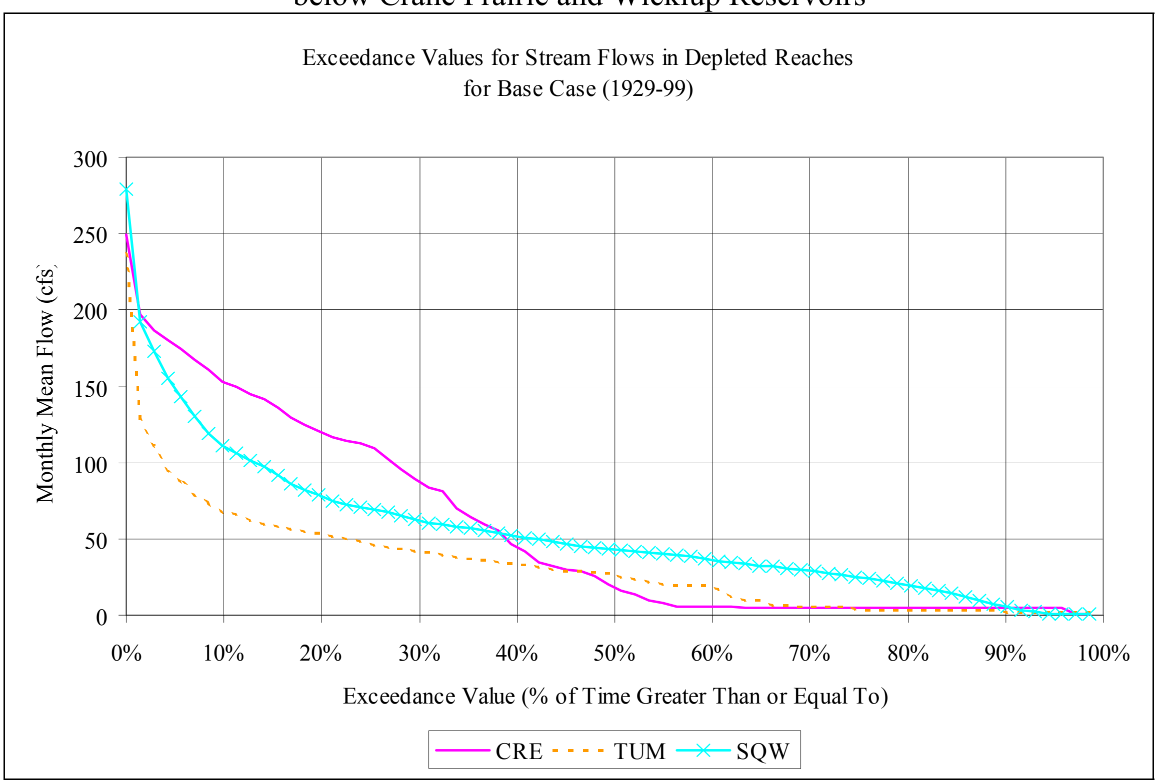


Figure 18: Exceedance Flows for Tumalo and Squaw Creek below canal diversions and for Crescent Creek below Crescent Lake.

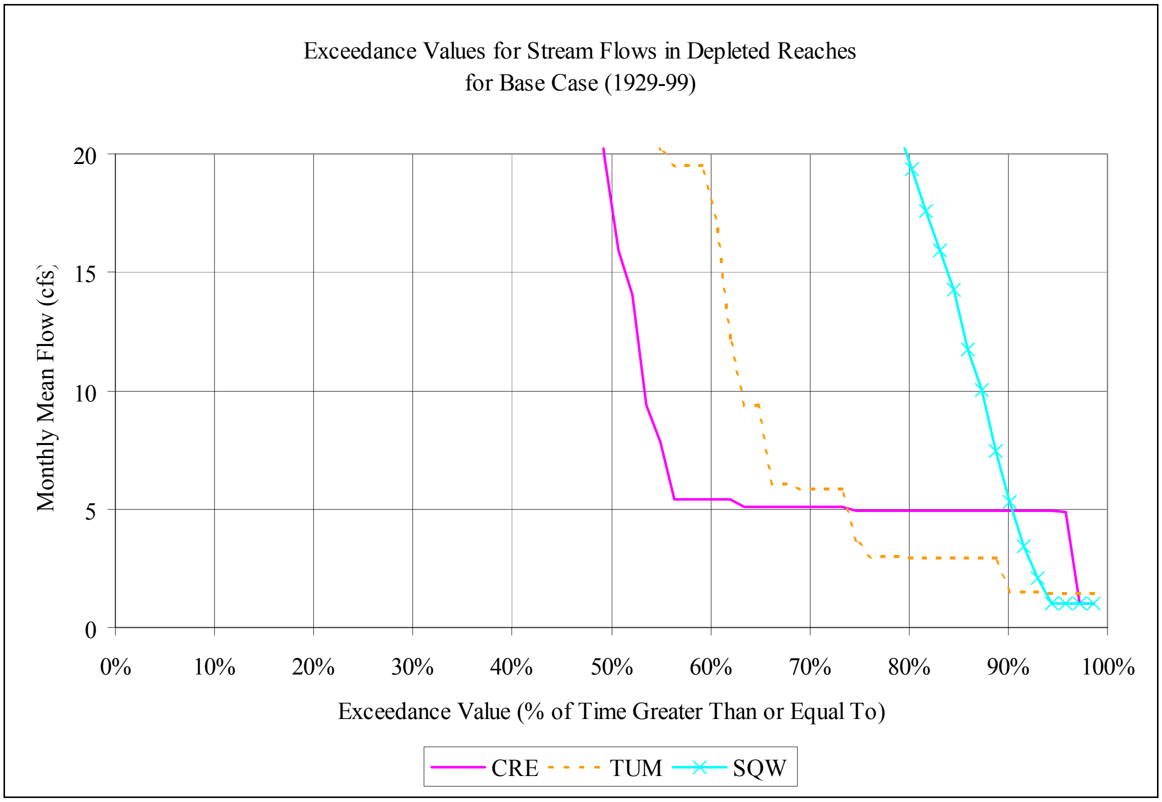


Figure 19: Lower Exceedance Flows for Tumalo and Squaw Creek below main diversion canals and for Crescent Creek below Crescent Lake.

Alternative Management Simulation -

For the alternative management simulation, flows below Wickiup reservoir were increased from a minimum of 20 cfs to 50 cfs. All other model inputs were identical to the base-case simulation. Results are again presented in terms of exceedance values. Each graph compares results from the base-case to the alternative management simulations. Results for Squaw Creek were not included since, unlike Tumalo Creek, diversions from that drainage are independent of operations in the Deschutes.

Figure 20 shows the results for the larger irrigation districts, NUID and COI. Increasing the target minimum flows below Wickiup has little effect on COI diversions. This result is to be expected, since COI has a senior, large, natural flow right and relies less on stored water than all of the other irrigation districts (except Swalley). The increase in target minimum flows below Wickiup would only affect storage accrual in Crane Prairie and Wickiup reservoirs. NUID, on the other hand, has a junior natural flow right and relies heavily on storage in Wickiup reservoir. Therefore, the decrease in winter storage impacts NUID more than COI. However, 80 percent of the time there is no effect on NUID deliveries. The other portion of time, the effect would be a reduction in deliveries *from* the base-case scenario from approximately 3,500 to 10,000 ac-ft. These simulated shortages occur during successive dry years of the early 1930s and 1940s, as well as the early 1990s (Appendix B). Supplemental water for the Crooked River pumps might be used to offset some of these shortages. In all other years, there would be no effect on deliveries for NUID.

For the smaller irrigation districts, the resulting effect was much less or non-existent. Figure 21 shows the results for Lone Pine and Arnold Irrigation Districts, as well as the City of Bend. There is no effect on the City of Bend diversions, since the city's water supply is from Tumalo Creek. The results for Lone Pine and Arnold are similar to those for NUID, but to a lesser extent. Approximately 80 percent of the time, there is no effect on deliveries. Decreases in water delivery for the other time periods are slight (less than 1500 ac-ft), compared to the base case. This decrease is due to a slight reduction is stored water in Crane Prairie reservoir. Arnold and Lone Pine both hold storage accounts in Crane Prairie and, therefore, are impacted by the decrease in storage. There is no effect on deliveries to Swalley and TID between the two scenarios (Figure 22). Swalley Irrigation district has the most senior natural flow right on the Deschutes and no storage rights, while TID diversions depend on flows in Tumalo Creek and storage in Crescent Lake. Neither source of water would be affected by higher winter flows below Wickiup. The results for each individual year are given in Appendix B.

The effects on stream flow below Wickiup and Crane Prairie reservoirs, and below Bend are depicted in Figure 23. The graph shows that there was little effect on flows below Bend. Flows below Crane Prairie increased slightly between the 55% and 80% exceedance levels, and flows below Wickiup increased from 20cfs to 50cfs at all exceedance levels above 79%.

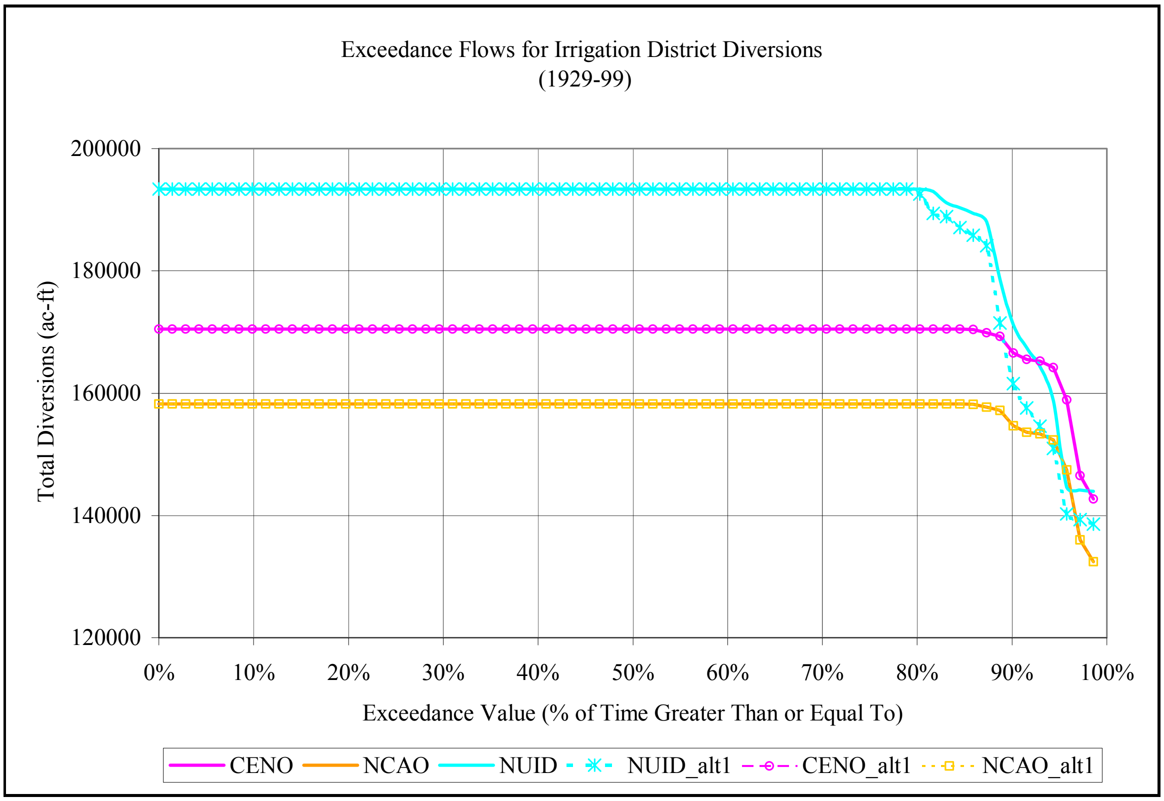


Figure 20: Comparison of deliveries to COI and NUID. Base Case = Solid Line (20cfs target flow below Wickiup), Alternate = Dashed (50cfs target flow)

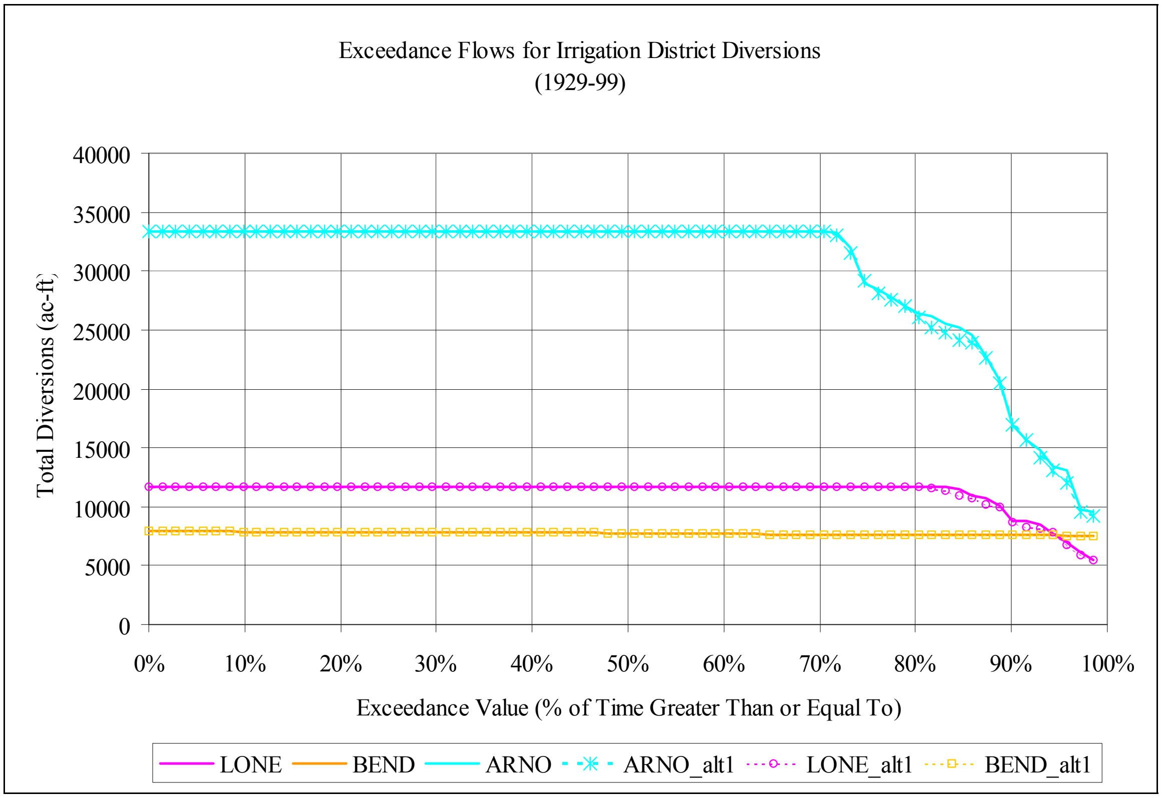


Figure 21: Comparison of deliveries to Lone Pine, Arnold and City of Bend. Base Case = Solid Line (20cfs target below Wickiup), Alternate = Dashed (50 cfs target)

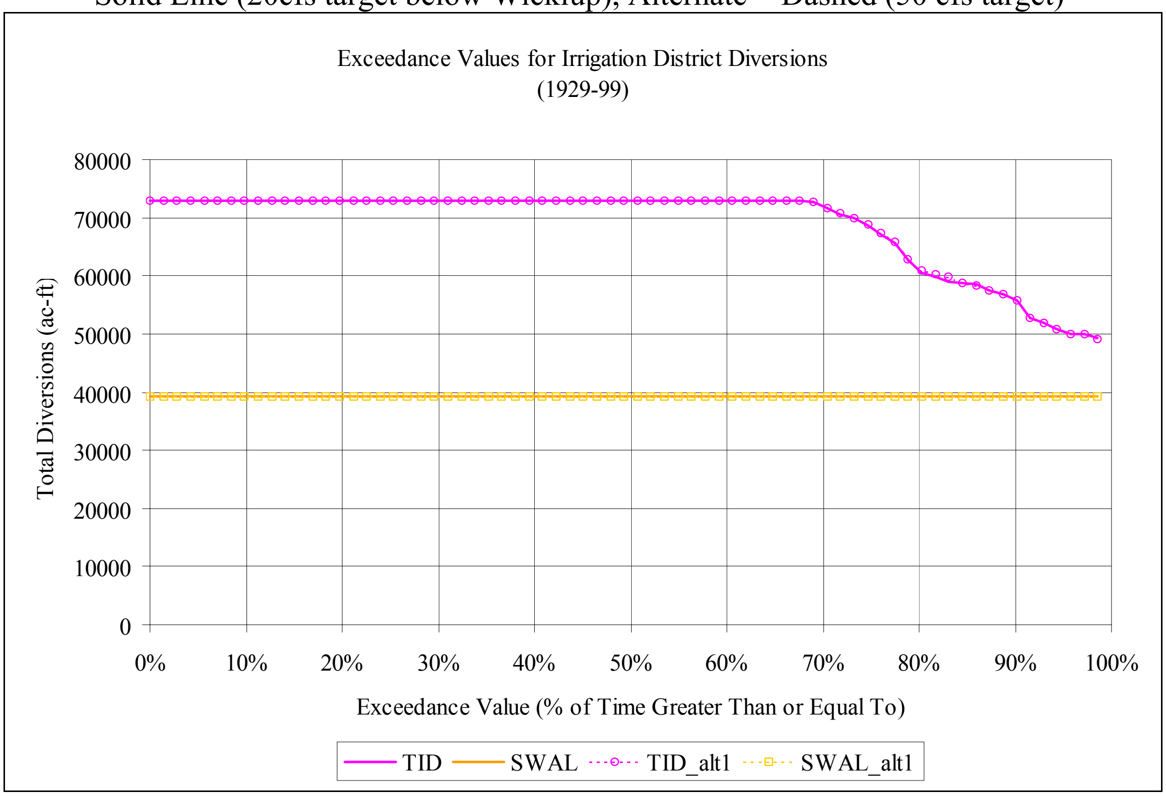


Figure 22: Comparison of deliveries to Swalley and TID. Base Case = Solid Line (20cfs target below Wickiup), Alternate = Symbol (50 cfs target)

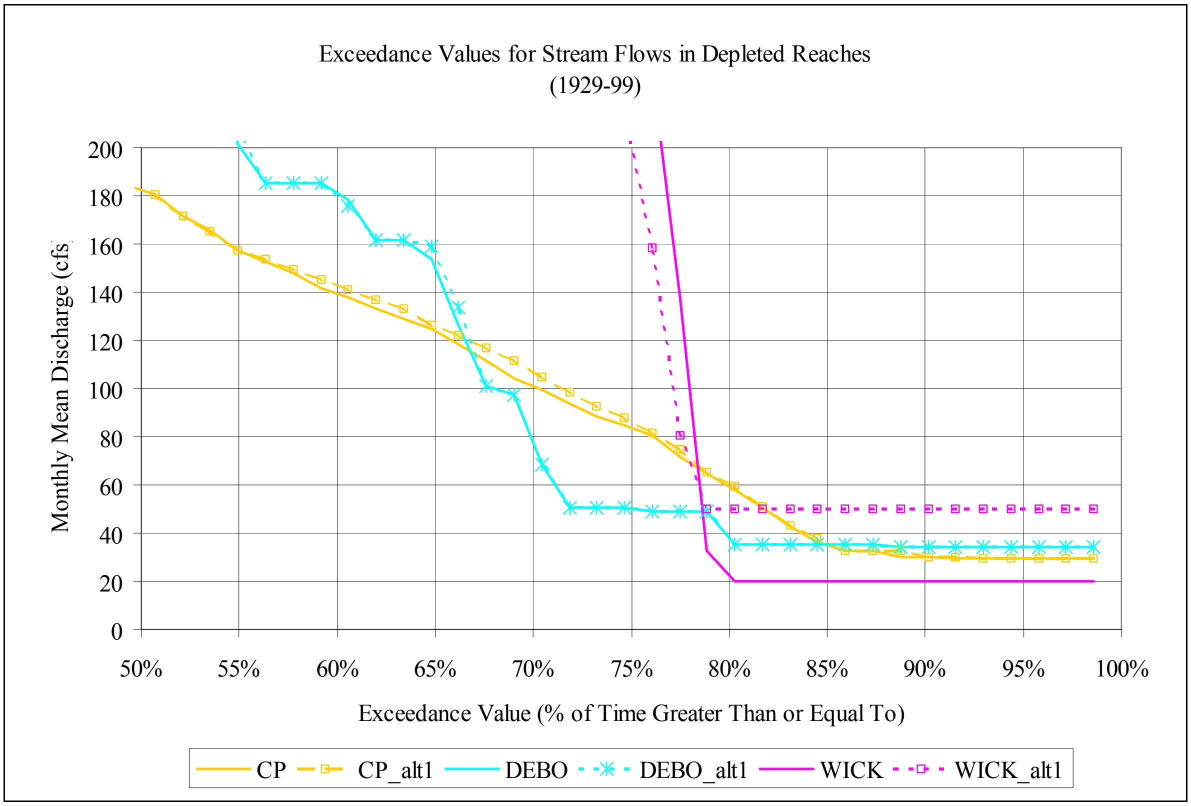


Figure 23: Comparison of stream flow for Deschutes River below Crane Prairie, Wickiup, and Bend. Base Case = Solid Line (20cfs target below Wickiup), Alternate = Symbol (50 cfs target)

Conclusion:

A distribution model was developed for the water storage and distribution system of the upper Deschutes basin. Using the historic gaged record and demand, the calibrated model was found to realistically simulate the historic operations and accounting of the system on a monthly time step.

For most irrigation districts, it was found that demand has decreased over time. The result is that historic diversions overstate current demands. Using statistical analysis, a time frame for each irrigation district that was representative of current demands was found. The distribution model was then used along with the newly calculated current demands and historic hydrologic conditions (1929-1999) to estimate water supply with the delivery and reservoir system in its current state. It was found that full deliveries could be expected in 80% of the years for NUID, 89% for COI, 72 % for Arnold, 69% for TID, 100% for Swalley, and 85% for Lone Pine. These values represent expected future deliveries with the current operations and delivery system.

An alternative management scenario was evaluated to demonstrate the use of the model as a general management tool. The effect of increasing winter target minimum flows below Wickiup Reservoir from 20 cfs to 50 cfs on current demands was found using the distribution model with historic hydrology. The effect was a slight reduction to irrigation deliveries over the base levels for several districts during successive multiple dry years (e.g., 1930s and early 1990s). The reductions in deliveries affected the 80% exceedance levels for NUID, Lone Pine and Arnold. NUID would be affected the most with an approximate reduction over base-case deliveries from 3,000 to 10,000 ac-ft. Lone Pine and Arnold would also be affected to a lesser extent with a maximum 1,500 ac-ft reduction. The reduction was a result of decreased storage in Wickiup and Crane Prairie reservoirs that resulted from the higher minimum winter flows below Wickiup. During most years, these higher flows did not affect the maximum storage in either reservoir, due to adequate inflows. However in successive dry years the increased requirements did decrease storage in the two reservoirs, at the beginning of the irrigation season.

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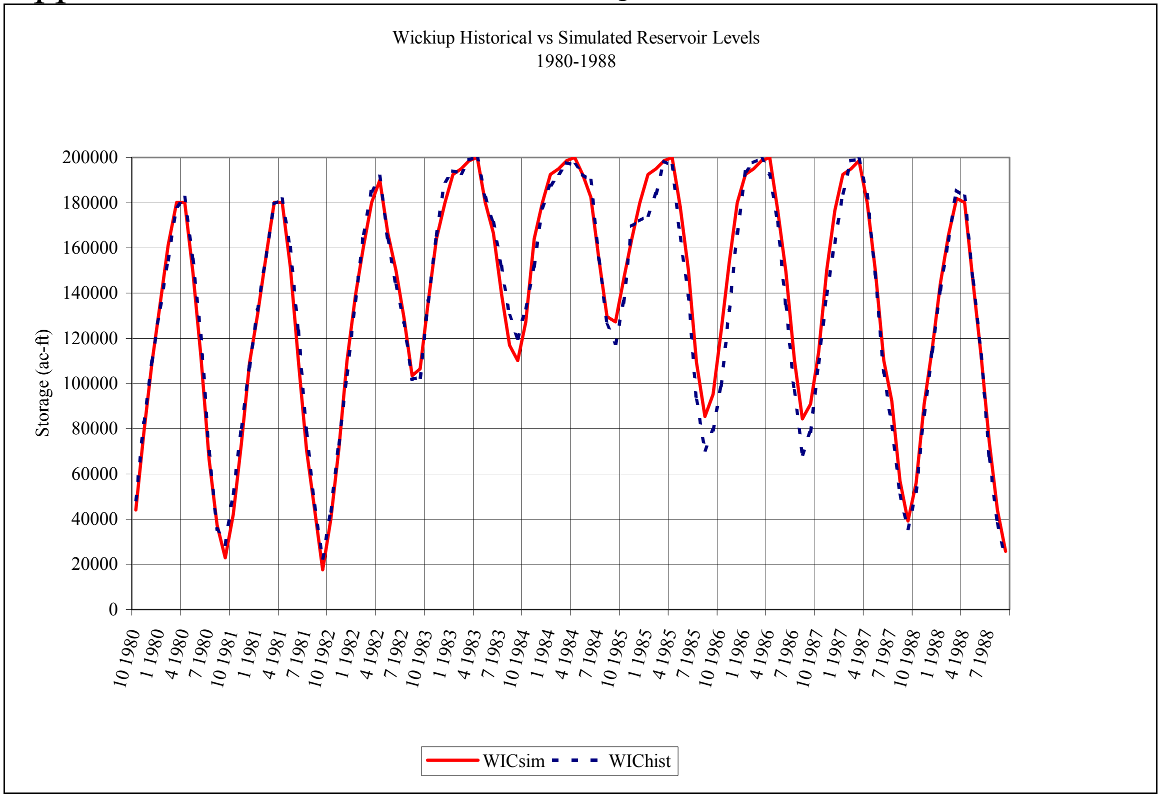
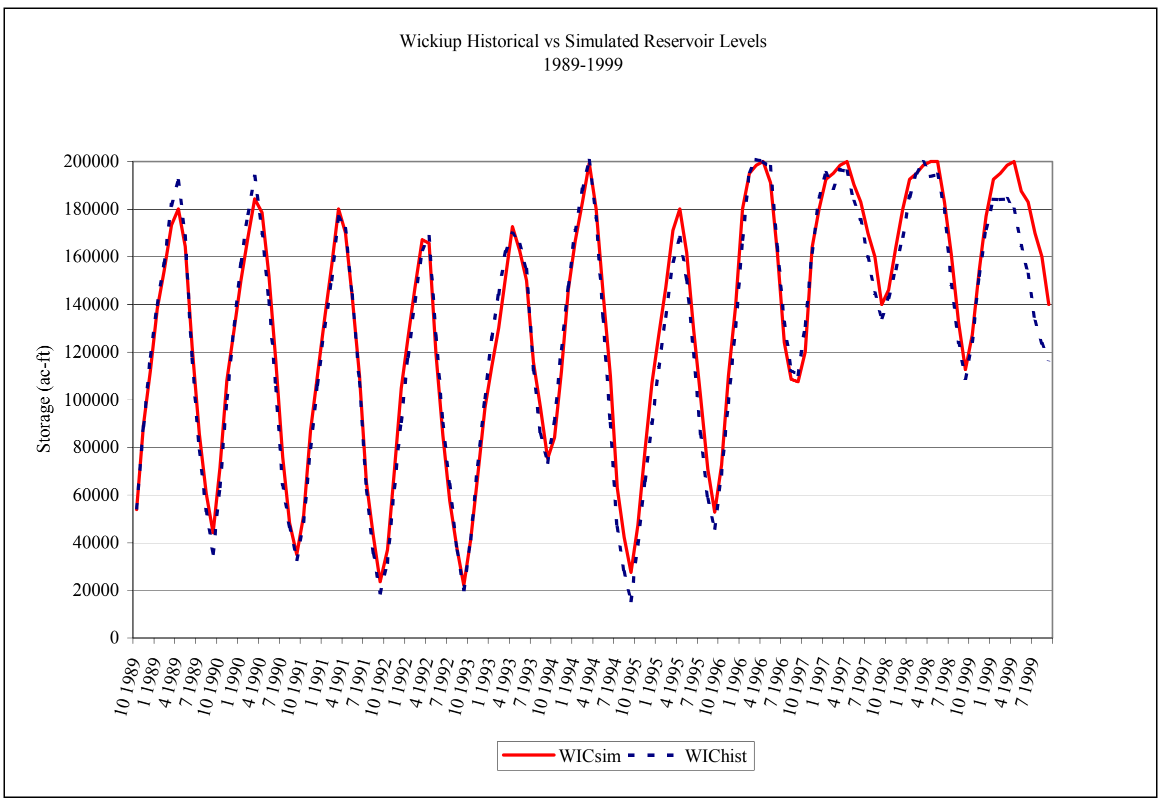
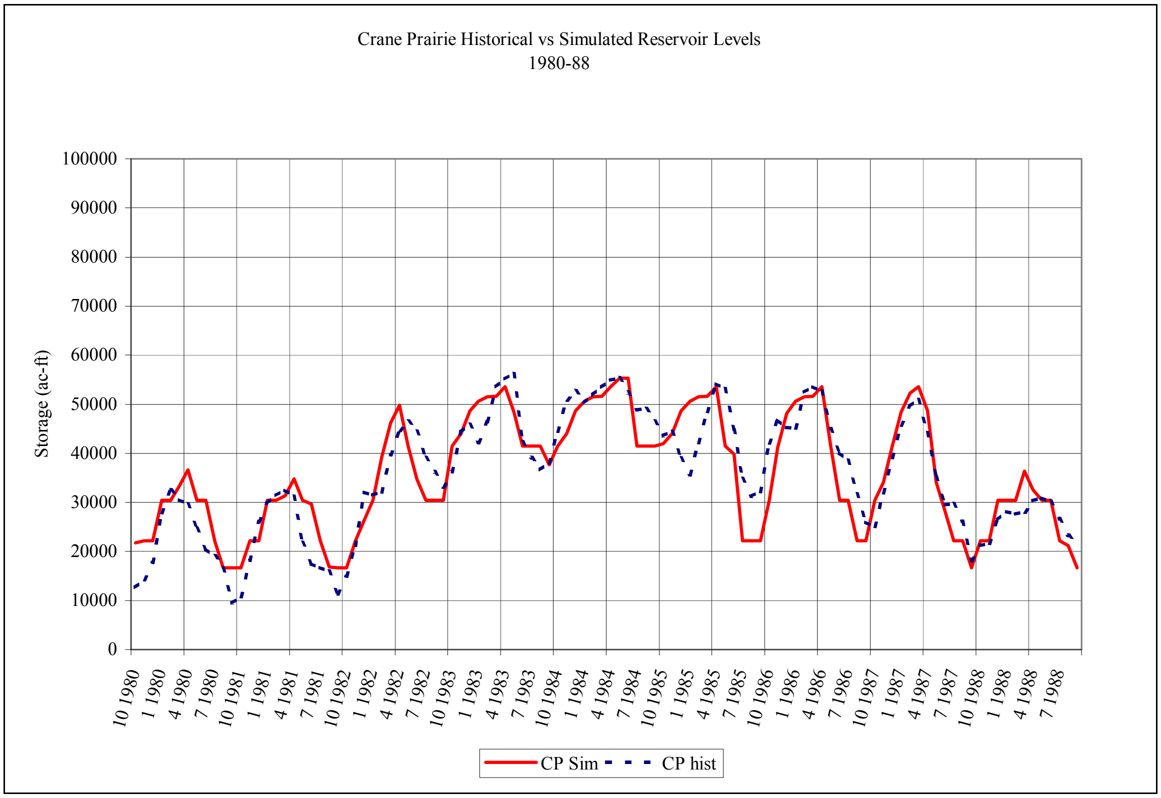
Appendix A: Calibration results for Wickup and Crane Prairie Reservoirs






Crane Prairie Historical vs Simulated Reservoir Levels
1980-88
Storage (ac-ft)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
10 1980
1 1980
4 1980
7 1980
10 1981
1 1981
4 1981
7 1981
10 1982
1 1982
4 1982
7 1982
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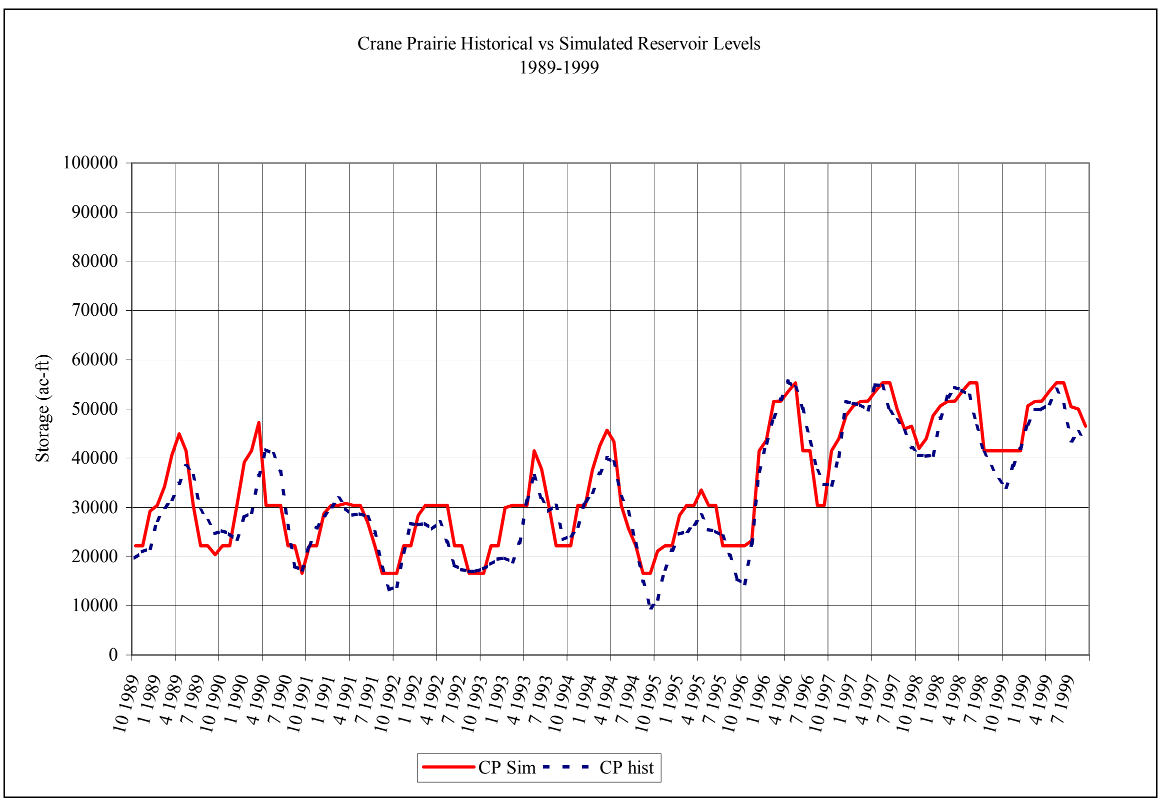
4 1988
7 1988
CP Sim
CP hist


Crane Prairie Historical vs Simulated Reservoir Levels
1989-1999
Storage (ac-ft)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
10 1989
1 1989
4 1989
7 1989
10 1990
1 1990
4 1990
7 1990
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10 1997
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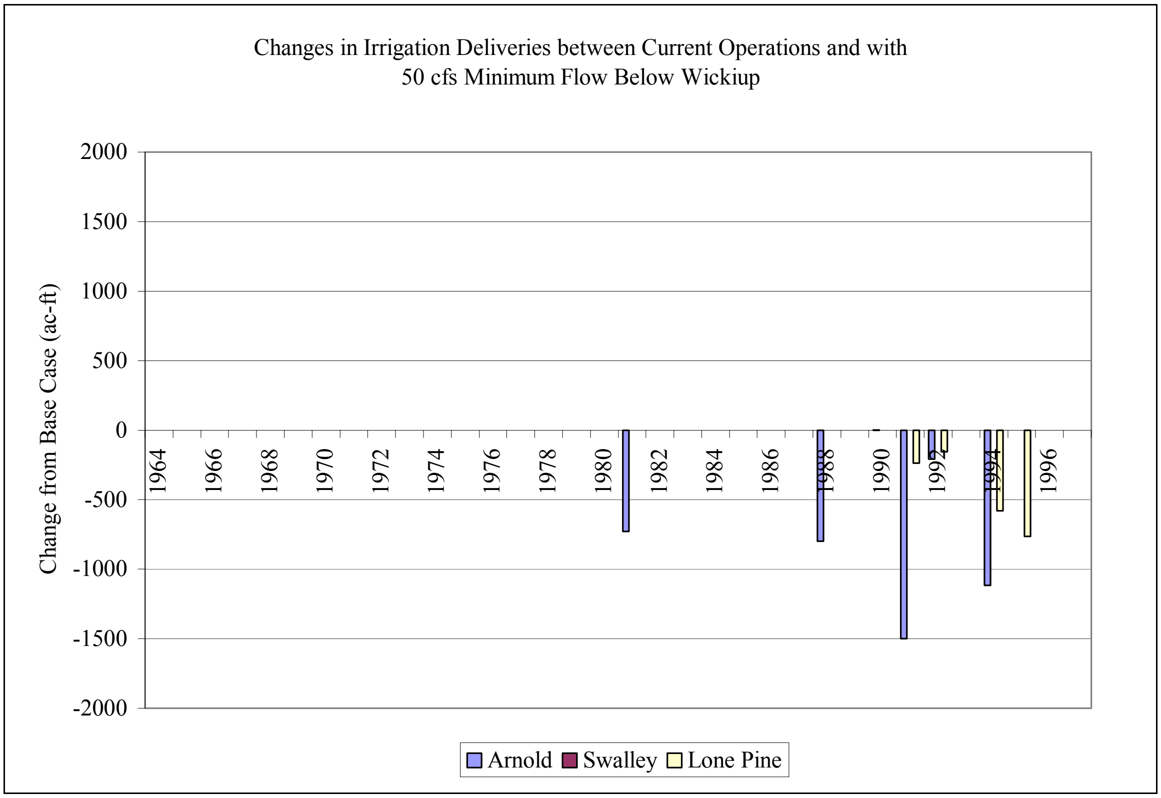
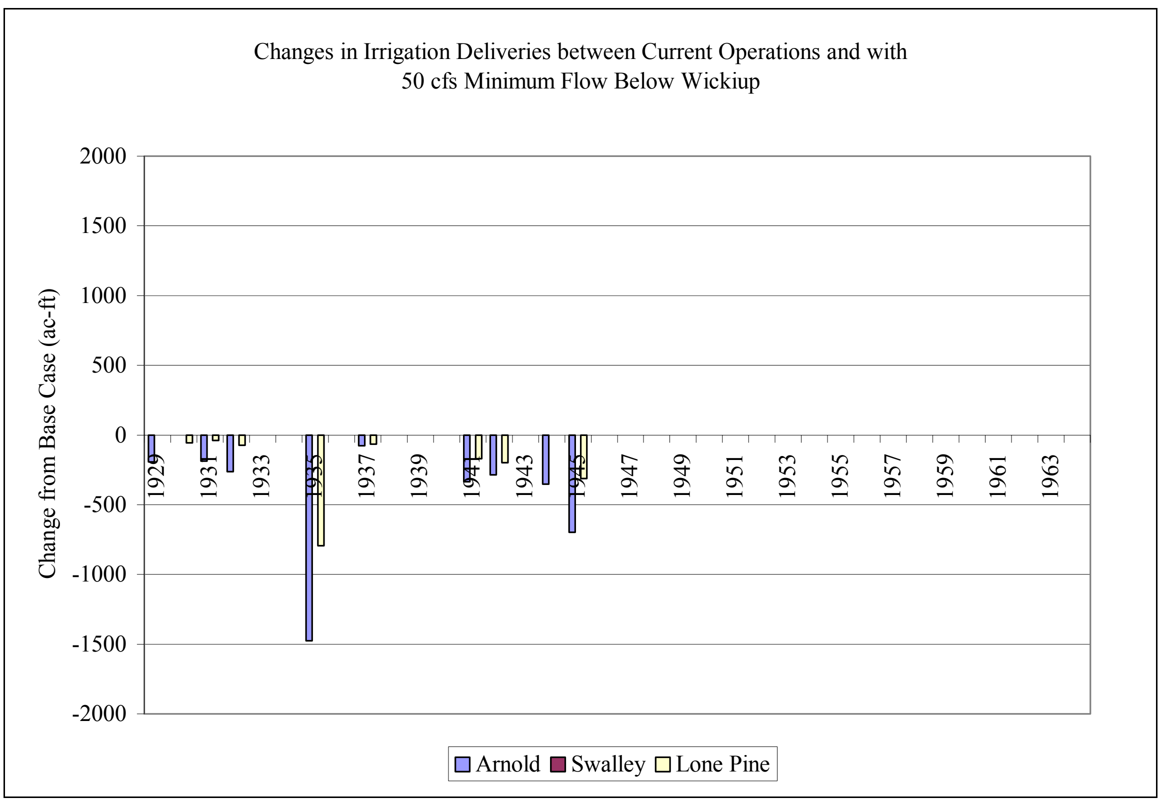
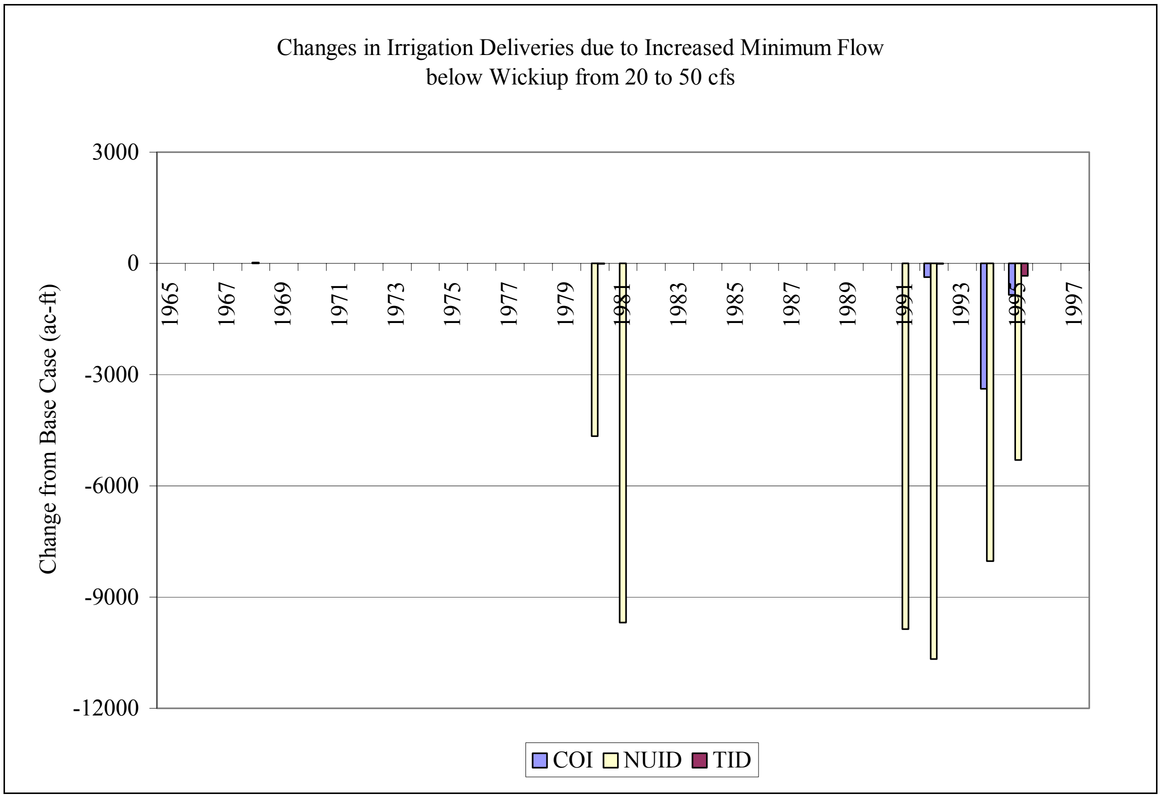
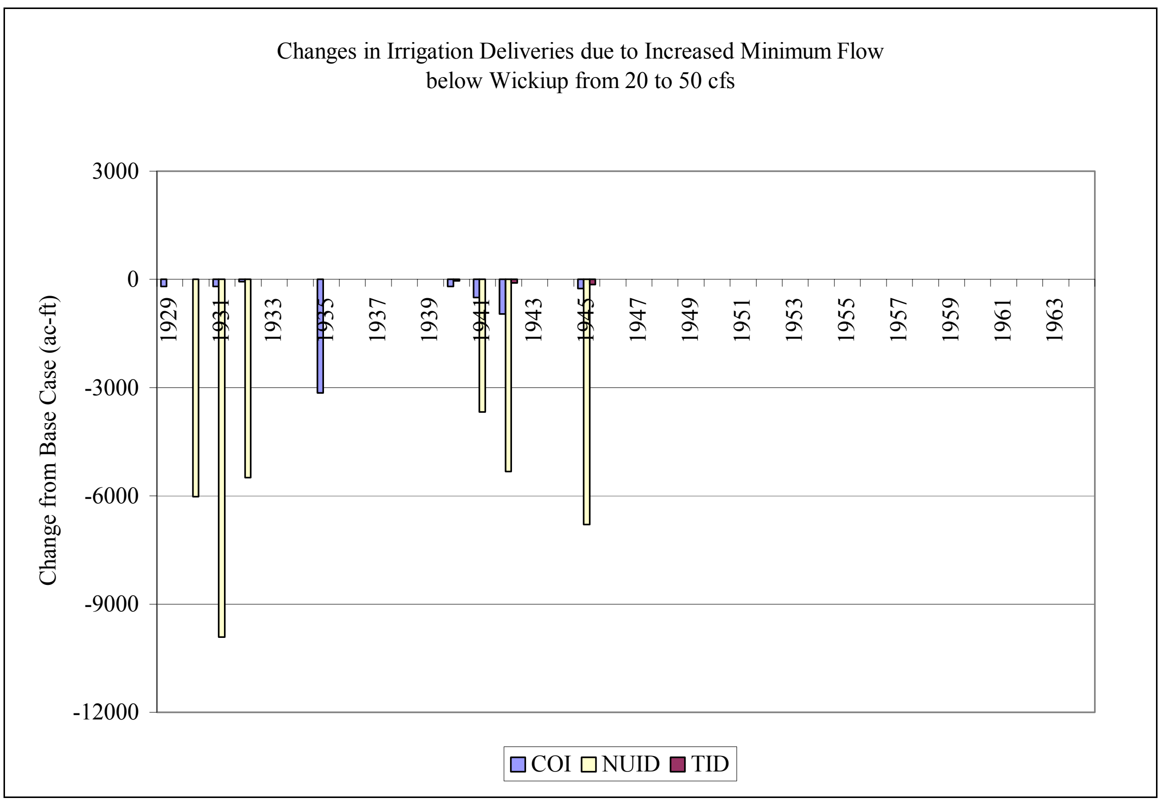
Appendix B: Results between Base-Case & Alternate Management for Irrigation.






Changes in Irrigation Deliveries due to Increased Minimum Flow
below Wickiup from 20 to 50 cfs
Change from Base Case (ac-ft)
3000
0
-3000
-6000
-9000
-12000
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
COI
NUID
TID


Changes in Irrigation Deliveries due to Increased Minimum Flow
below Wickiup from 20 to 50 cfs
Change from Base Case (ac-ft)
3000
0
-3000
-6000
-9000
-12000
1929
1931
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
COI
NUID
TID

Appendix C:

Estimate of Historic Demand for NUID Deschutes and Crooked River Lands

<u>Background</u>:

The North Unit Irrigation District (NUID) diverts water from the Deschutes River, near Bend to supply water to approximately 50,000 acres of project lands in the vicinity of Madras. A water right from Crooked River supplies water to an additional 8800 acres of the project. There is also a supplemental water right from the Crooked River for the 50,000 acres (primary right is from the Deschutes River). Crooked River diversions join Deschutes water in the NUID canal near a flume, which crosses the Crooked River at about mile 24.5. Until recently, the supply of water to the entire 58,800 acres of project lands was from the Deschutes system, with diversions from the Crooked River occurring during dry years. In 1996, an agreement between OWRD and NUID instituted a formula based on total deliveries to the project to ensure that the 8800 acres of Crooked River lands were supplied with water from the Crooked River. However, the historical separate demand for Deschutes and Crooked River lands is unclear. Lining of sections of the NUID canal has further changed demand from the Deschutes River from the historical record.

This paper presents an explanation of how the historic demands from the Deschutes and Crooked River were segregated and modified to reflect the current operation and conditions of the diversion system. In particular, the seepage losses effect on water pumped from the Crooked River and the lining of sections of the NUID canal have been accounted for to generate a new "historic" demand based on current conditions.

<u>Approach</u>:

The generation of the "new" historic demand for Crooked and Deschutes River water involved several steps. First, the total historic diversions, annual project consumptive use (including on-farm losses), and historic canal losses were determined. Next, the new demand was calculated by accounting for the decrease in canal losses associated with lining of the sections on the main canal and separation of the required diversions for Deschutes and Crooked River land.

<u>Historic Demand, Associated Losses, and Annual Consumptive Use</u>

Historical records are available back to the mid-1940s for diversions through the NUID canal. There are also records available for the Crooked River pumps (brought online in 1968). In addition, a spill weir was constructed in 1989 to bypass excess flows in COI's North canal to the NUID canal. Therefore, the total historic diversions for NUID lands are simply:

TD (total diversion @ div pts)= NUID Diversions + CR Pumps + COI Spill Weir (1)

Obviously, supply from the CR pumps and COI spill weir was zero prior to their construction.

Next, the total loss for the system was determined. According to actual deliveries (1984-1995) to the project lands reported in the NUID Water Management/Conservation Plan, *percent* losses (predominately canal leakage) between the diversion points to the project varied from 42.3% to 58.7%, and decreased (as percent of diversions) with increasing diversions. The following relationship was developed based on this data:

$$\% \text{ TL (total loss)} = -1.61 \times 10^{-6} \times \text{TD} + .8166 \qquad R^2 = 0.76 \qquad (2)$$

Using this relationship the percent total loss of diversions (and therefore total loss) for the remaining years was determined (1960-1983 & 1996-2000). The average percent total loss for the period of record was 46%.

Since sections of the canal reach between the Deschutes diversion point and the flume over the Crooked River (Canal Reach 1) have been lined, the pre and post losses need to be determined. In addition, losses in this reach need to be separated from other losses in the system because it *affects Deschutes waters* only. Records from gauge (#14257500) operated by NUID near the end of the reach were available from 1988 through 1999. Monthly losses in the reach are determined by simply subtracting the flows near the end of the reach from flows at the diversion point (#14069000). The losses increase with diversions (prior to canal lining, 1997) and have a fair predictive relationship given by:

$$\text{LossCR1 (Loss Canal Reach 1)} = 6.46752 \times \text{diversion}^{0.45892}, \; R^2 = 0.69 \qquad (3)$$

Using this relationship, the losses in Reach 1 attributable only to Deschutes diversions was determined for the historical period. The average calculated loss was 44,027 ac-ft, or 22% of the water diverted by the NUID canal from the Deschutes. This loss is somewhat higher than the 33,480 ac-ft reported in the USBRs Upper Deschutes River Basin Water Conservation Study. Differences between the two may be attributable to higher wetted perimeters during irrigation than used in the USBR ponding study, increased losses associated with water velocities encountered during irrigation season, or uncertainty in the estimate.

The canal losses from the rest of the canal reaches and laterals were calculated as the total loss in the system minus the loss in reach 1.

$$\text{LossOCR (loss in all other canal reach's)} = \text{TL} - \text{Loss CR1} \qquad (4)$$

To determine the percent of flow lost in the other canal reaches and laterals, the losses are divided by the flow into the remaining canal system (i.e., the flow at the end of Reach 1).

$$\% \text{ LossOCR} = \frac{\text{Loss OCR}}{(\text{NUID Div} - \text{LossCR1} + \text{CR pumps} + \text{COI Spill Weir})} \qquad (5)$$

The actual historic demand for the Crooked River lands and Deschutes River lands was calculated as follows. First, the actual consumptive use for the entire project was determined by dividing the estimated deliveries (described earlier) by the irrigated acres reported by NUID in each year.

$$ACU = (TD - TL)/\text{Irrigated acres} \qquad (6)$$

Prior to 1972, the record for irrigated acres was not available. Therefore, a multiple linear regression was used to predict ACU between 1961 and 1972, using maximum Wickiup Reservoir contents, precipitation over the irrigation season, and June through August mean air temperature at Madras.

"New" Historic Diversions Associated with lining of canals for Deschutes and Crooked R lands.

To determine the actual *needed* diversions for the Crooked River and Deschutes lands, the ACU was multiplied by the *entire* acreage and divided by one minus the annual % loss for the canal losses.

$$\text{Crooked River Diversion}_{new} = \frac{ACU \times 8800 \text{ acres}}{(1 - \%\text{ loss OCR})} \qquad (7)$$

Likewise, the Deschutes River demand can be written as:

$$\text{Deschutes River Diversion}_{historic} = \frac{ACU \times 50000 \text{ acres}}{(1 - \%\text{ loss OCR}) \times (1 - \%\text{ lossCR1})} \qquad (8)$$

The average annual diversion demand for Crooked River lands is roughly 30,000 ac-ft to deliver 20,000 ac-ft (i.e., 32% seepage loss). The average annual diversions needed for Deschutes River lands is roughly 217,000 ac-ft to deliver 114,000 ac-ft (i.e., 48% seepage loss). Recall from Equation 3, that the percent losses in canal Reach 1 (% lossCR1) is dependent on the diversions from the Deschutes. Thus, the historic Deschutes River demand shown in Equation 8 was determined through an iteration process.

As previously mentioned, since portions of NUID canal have been lined, the seepage loss and therefore, demand from the Deschutes River should have decreased. The Crooked River demands would not be affected since the pumps are located after the lined reach of the NUID canal. There are only two years of partial record available to determine losses for the reach in question (Reach 1). From this short record, it appears that losses are no longer dependent on diversions and averaged about 69 cubic feet per second (cfs) over the period of record. Therefore, a constant loss of 69 cfs was used as the post lining loss in this reach (although a longer record is needed to confirm this analysis).

To determine the "new" Deschutes River diversion associated with the canal lining, the diversion, as determined by Equation 8, needs to be modified to account for the change in losses in Reach 1. This process consists of taking the demand as (determined by

Equation 8) subtracting out the losses associated with the pre-lined canal, and adding back the constant 69 cfs loss over the irrigation season.

$$\text{Deschutes R Diversion}_{new} = \text{Deschutes R Diversion}_{historic} - \text{LossCR1}_{unlined} + \text{LossCR1}_{lined}$$

The new annual average demand is calculated as 193,000 ac-ft (41 %seepage loss) to deliver 114,000 ac-ft to the Deschutes lands.

Summary:

The annual diversions from the Crooked and Deschutes River to *fully* irrigate NUID lands were determined using record of historical deliveries, diversions, irrigated lands, and seepage losses. Over the period of interest (1961-2000), the average annual diversion required for lands with water rights from Crooked and Deschutes River were found to be 30,000 ac-ft and 215,000 ac-ft, respectively. This result assumes that the historical idle lands would have similar consumptive use requirements as the historically irrigated lands. In addition, the consumptive use requirements for the Deschutes and Crooked River lands have similar crop needs as the historical deliveries to the entire project.

The actual required on farm deliveries were calculated as 20,000 ac-ft and 114,000 ac-ft for the lands irrigated from the Crooked and Deschutes Rivers, respectively. This corresponds to average annual system losses of 33% for the Crooked River diversions and 47% for the Deschutes River diversions.

Lining of sections of the first 24.5 miles of the NUID canal has no effect on losses from the Crooked River, but reduces losses from the Deschutes River to 41%. This reduction in losses means that the new average annual demand from the Deschutes River is 193,000 ac-ft. Demand from the Crooked River would remain the same at 30,000 ac-ft.