ANGOSTURA UNIT
CONTRACT NEGOTIATION AND WATER MANAGEMENT
HYDROLOGY APPENDIX
SURFACE WATER QUANTITY

Draft Environmental Statement

Bureau of Reclamation
Dakotas Area Office
Bismarck, North Dakota

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Appendix A-1

Appendix A-2

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Surface Water Quantity

1. Historic Conditions
Angostura Dam is located on the Cheyenne River seven miles southeast of Hot Springs, SD in the area known as the Jackson Narrows. Homer M. Derr, former South Dakota State Engineer, named the project Angostura which is Spanish for "Narrows". It was suggested by the narrow gorge at the reservoir site resembling a land mark he had seen while building a dam in Columbia, South America. The Angostura Unit was first aythorized in 1939, then re-authorized by the Flood Control Act of 1944. Construction of the dam began in 1946 and it was completed in 1949. Delivery of water bagan in 1953, full service in 1956. The Angostura Unit consist of Angostura Dam, Angostura Reservoir; main canal and irrigation distribution system, and public lands surrounding the reservoir.

a. Angostura Dam and Reservoir physical features

Pool Capacities:
1. Dead = 8,598 acre-feet
2. Inactive = 39,727 acre-feet
3. Active conservation = 82,443 acre-feet
4. Surcharge = 56,360 acre-feet

Total pool capacity:
1. Top of dead = 8,598 acre-feet
2. Top of inactive = 48,325 acre-feet
3. Top of active conservation = 130,768 acre-feet
4. Top of surcharge (maximum water surface) = 187,128 acre-feet

Area:
1. Top of dead = 1,065 acres
2. Top of inactive = 2,449 acres
3. Top of active conservation = 4,612 acres
4. Top of surcharge (maximum water surface) = 5,564 acres

Elevation :
1. Top of dead (river outlet invert) = 3139.75 feet
2. Top of spillway crest (bottom of spillway gates) = 3157.2 feet
3. Top of inactive (canal outlet) = 3163.0 feet
4. Top of active conservation (top of spillway gates) 3187.2 feet
5. Top of surcharge (maximum water surface) = 3198.1 feet
6. Top of dam = 3199.0 feet

Discharge Capacities:
1. Spillway discharge capacity of 247,000 cfs at the top of surcharge at water elevation 3198.1.
2. Maximum river outlet release rate = 590 cfs at elevation 3198.1.
3. Angostura canal discharge capacity = Minimum of 290 cfs at elevation 3169.4.
   Maximum of 720 cfs at elevation 3187.2.

The Reservoir Capacity Allocations and drawing, approved May 5, 1982, are shown in Appendix D. The reservoir was resurveyed in May 1979 using range method. Ranges were profiled by standard surveying techniques and an echo sounder.

b. Reservoir Operations
The Reservoir is operated primarily to service 12,218 irrigated acres in the Unit and to maintain as much storage as possible in the active conservation pool, providing maximum carryover storage for irrigation.

Normally, no releases are made from the dam to the river except when runoff is expected to fill the Reservoir above the top of the conservation pool at elevation 3187.2. When this occurs, the automated controls on the spillway gates should progressively open the spillway gates as the Reservoir fills from elevation 3186.9 up to 3197.88. At elevation 3197.88, the gates should be fully open. At no time should water be allowed to flow over the top of the spillway gates. No minimum downstream releases are made—the seepage past the radial gates, flows from the Fall River, and irrigation return flows satisfy all downstream water rights.

There is no forecasting of peak spring inflows into the Reservoir or the volume of spring runoff because of the extreme variability of precipitation patterns in the upstream drainage basin.

c. Irrigation District - The District, headquartered at Oral, South Dakota, assumed responsibility for operation and maintenance of the Unit, under terms of contract, on January 1, 1968. Reclamation operated the Unit during the development period prior to 1968. The Reservoir provides water to the District for irrigation of 12,218 acres of land along both sides of the Cheyenne River. Temporary water service agreements for irrigating an additional 184.8 acres have been signed with the Hot Springs Airport (139.8 acres), and two private landowners (45 acres). The 184.8 acres lie within District boundaries, but are not part of the original 12,218 acres authorized to receive water for irrigation. Irrigation of the 184.8 acres is allowed only when the Reservoir pool elevations are above 3184.2 feet (Pers. Comm. Kay Benson, January 1996). The District lands are located on alluvium terraces and upland soils from the Reservoir downstream for approximately 24 miles within Custer and Fall River Counties, South Dakota.

d. District Canal, Laterals, and Drains - Irrigation water for the District lands is directly diverted from the Reservoir and delivered through a 30-mile-long main canal with a capacity of 290 cfs. A typical cross section of the canal has a bottom width of 14 feet with 2:1 side slopes and normal water depth of 5.2 to 5.5 feet. The canal extends from Angostura Dam along the south edge of the Unit serving about 78 percent of the irrigated lands, then crosses under the Cheyenne River through a 9,800-foot inverted siphon to serve the remaining 22 percent of irrigated lands. Average annual Reservoir releases to the Unit lands are about 40,000 acre-feet of water, providing an average onsite farm delivery of 2.7 acre-feet per acre (refer to Table 10). Thirty-nine miles of laterals and 21 miles of open and closed drains serve individual farms. A pictorial overview of the Angostura Irrigation District Main Canal System and irrigation practices is shown in the main report of the Angostura EIS.

e. Irrigation Return Flows - Irrigation return flows drain to the Cheyenne River throughout the length of the project and are not reused for irrigation. Lands in the Unit are located relatively close to the Cheyenne River and are quite permeable, having a substrata layer of shale which dips toward the river assisting in the percolation of return flow (Reclamation, DPR, 1950). The 1950 DPR estimated 25 percent of the water lost in deep percolation and by seepage in canals and laterals is not recoverable; the other 75 percent is recovered as return flow. Farm waste was estimated as 38 percent and canal loss was estimated as 35 percent. The net return flow is expressed in terms of percent of diversion requirement as follows:

Farm Waste = (Div. Req. X 65%) x 38%	= 25% of Div. Req.
Canal Loss	= 35% of Div. Req.
Total Loss	= 60% of Div. Req.
Net Return Flow (75% of total loss)	= 45% of Div. Req.

The estimated monthly return flows for the years 1951 through 2000 were tabulated in the 1950 DPR.

A Cheyenne River water budget analysis was completed in 1999 in cooperation with Reclamation and the USGS in Rapid City. The results of the analysis estimated the District irrigation consumptive use is 46% of canal release and the District return flow is 54% of canal release (Appendix J).

f. Cheyenne River Streamflow Characteristics

The Cheyenne River, fed by spring snowmelt and direct storm runoff, is the major inflow to the Reservoir. The Reservoir contains the only dependable source of surface water in the area. The annual average runoff of 101,400 acre-feet for USGS gauging station Cheyenne River near Hot Springs for period of record 1915-20 and 1943-72 and 5,220 acre-feet for Horsehead Creek at Oelrichs, 1984-97. This accounts for about 107,000 acre-feet and 8,897 of the 9,100 sq. mi. (98%) drainage area above the reservoir. This is a good indication of the inflow to the reservoir, but the period of record are not the same, so care should be taken when using these records. See USGS report "Streamflow Characteristics for the Black Hills of South Dakota through Water Year 1993" Water Resources Investigation Report 97-4288 (WRIR 97-4288) for USGS gaging stations that show streamflow characteristics in the Cheyenne River above and below the reservoir.

Under normal conditions, 60 to 80 percent of the runoff occurs during late spring and summer. With the exception of a few spring-fed streams close to the perimeter of the basin, all channels are dry most of the time.

1. Cheyenne River above Angostura Reservoir

Much of the information in this section comes from the *Angostura Resource Appraisal Study Report* (U.S. Bureau of Reclamation, 1996).

The Cheyenne River Basin upstream of Angostura Reservoir comprises an area of about 9,100 sq. mi. in the high plains of east Wyoming, southwestern South Dakota, and northwestern Nebraska (figure 3.1 in the EIS). The basin is relatively flat and gently rolling with local steep-walled tributary stream valleys. Most of the streambeds are narrow with vertical banks and relatively low flows. Flash floods frequently overtop the banks. The Cheyenne River channel itself ranges from 50 feet wide in the upper reaches to 300 feet wide in the lower; the flood plain ranges from a few hundred feet to a mile or more wide. The Black Hills area has a maximum relief of about 2,000 feet with eroded sandstone and shale formations. This area is entirely different from the remainder of the basin and contributes very little silt to the reservoir (Reclamation, 1953).

The Cheyenne River rises in the high plains of Wyoming, near the center of Campbell County in the Thunder Basin National Grasslands. Tributaries from Niobrara, Converse, Weston, and Campbell Counties in Wyoming; Fall River and Custer Counties in South Dakota; and Sioux County in Nebraska contribute to the river. About 50 miles from the Wyoming-South Dakota border, two of the larger tributaries—Antelope Creek and Dry Creek—join to form the Cheyenne River (see figure 3.1 in the EIS). The river from this point meanders around the southern end of the Black Hills, entering South Dakota about 14 miles northwest of the town of Edgemont. It then passes through what is called Jackson Narrows about seven miles southeast of Hot Springs, where Angostura Reservoir is located. Although the river receives some flows from the southern Black Hills, most of the flows are from the plains.

Many tributaries enter the Cheyenne River from both the north and the south, most with long reaches of dry channels prone to high water losses from periodic storms. Larger tributaries from the north are Beaver Creek, the principal tributary of which--Stockade Beaver Creek--drains the southern slopes of the Black Hills, Lodgepole Creek, and Black Thunder Creek. The two main tributaries from the south are Lance Creek and Hat Creek (see figure 3.1 in the EIS). Both rise along the flank of Pine Ridge, a prominent north-facing escarpment that forms the southern drainage divide of the basin. Hat Creek, fed by springs along Pine Ridge, is perennial in the upper reaches. Nearly all perennial flows are diverted for irrigation, leaving the lower reaches dry except for direct runoff from storms or spring snowmelt.

The Cheyenne River above the perennial Cascade Springs is occasionally dry except when flow occurs from rain or melting snow.

2. Cheyenne River below Angostura Reservoir

The Cheyenne River below Angostura Reservoir comprises a drainage area of about 14,800 sq. mi. (Total Cheyenne River drainage area of 23, 900 sq. mi. minus drainage area above Angostura Reservoir of 9,100 sq. mi.). The area between Angostura Dam and Red Shirt comprise a drainage area of about 1,000 sq. mi. and has been regulated by Angostura Reservoir since October 1949. Red Shirt, located on the Pine Ridge Indian Reservation, is about 50 miles downstream of Angostura Dam. Angostura Reservoir releases and a number of tributaries from the Black Hills contribute flow to the Cheyenne River in this reach. The major tributaries in this 50 mile reach are Fall River, Beaver Creek, Cottonwood Creek, and French Creek. Angostura Unit also contributes return flow from about 10,000 irrigated acres along the Cheyenne River. Iron Draw located below Beaver Creek is one of the tributaries that contribute return flow to the Cheyenne River.

The Cheyenne River drainage area below Red Shirt comprise an area of about 14,000 sq. mi. with tributaries contributing runoff from the Black Hills and the plains of western South Dakota. Rapid Creek and Belle Fourche River have been regulated by Reclamation Reservoirs. Rapid Creek flow has been regulated by Pactola Reservoir since June 1963 and Belle Fourche River flow has been regulated by Keyhole Reservoir since October 1952 and Belle Fourche Reservoir since May 1910. Flow also affected by diversion of about 70,000 acres and return flow from irrigated areas.

g. USGS Streamflow Gaging Stations

Flows have been measured by the USGS (U.S. Geological Survey) at two gauging stations on the Cheyenne River and three tributaries above Angostura Reservoir and 8 gauging stations on the mainstem of the Cheyenne River below Angostura Dam (Table 1). Reclamation's Hydrological-Meteorologic database (Hydromet) (Reclamation, 1997) inflow/Outflow and adjusted inflow for Angostura Reservoir are also included in Table 1. See Figure 3.1 in the EIS for location of these stations.

1. Cheyenne River flow above Angostura Reservoir

The gauge at Edgemont, South Dakota measures flow from 7,143 sq. mi. of the basin, about 78% of the drainage area of 9,100 sq. mi above Angostura Reservoir and about 30% of the whole Cheyenne River drainage basin. Average flow from this part of the basin for Water Years 1929-1932 and 1947-1997 was 81.4 cfs (cubic-feet/second) and 58,990 AF (acre-feet) per year. The median flow is 10 cfs. The lowest daily mean and annual seven day minimum flow was zero, which occurs at times in most years. An instantaneous peak flow of 28,000 cfs occurred on May 20, 1978. Many small stock or irrigation reservoirs above the Edgemont gauge store about 45,000 AF of water (USGS, 1998).

Hat Creek gauge, 13 miles southeast of Edgemont, measures flow from a drainage area of 1,044 sq. mi. above Angostura Reservoir, with an average flow 16.9 cfs and 12,230 AF/year based on recorded flows in 1906 and 1951-97. The median flow is 0.4 cfs. The lowest daily mean and annual seven day minimum flow was zero, which occurs for many days in each year. An instantaneous peak flow of 13,300 cfs occurred on June 16, 1967. Lander Ditch diverts water from Hat Creek about ½ mile above this gauge to irrigate hayland. Diversions for the ditch have been measured at various times by the USGS (USGS, 1998).

The Cascade Springs gauge near Hot Springs measures flow from a 0.47 sq. mi. drainage area above Angostura Reservoir. Cascade Springs--the source of Cascade Creek--is one of the largest single springs found in the Black Hills. Based on records from 1977-1995 (Discontinued), average flow from this part of the basin was 19.5 cfs and 14,150 AF/year. The median flow is 19 cfs. The lowest daily mean occurred July 22, 1993 at 13 cfs and annual seven day minimum flow of 14 cfs occurring July 16, 1993. An instantaneous peak flow of 49 cfs occurred July 4, 1977 (USGS, 1996).

The Cheyenne River gauge near Hot Springs, measuring flow from a drainage area of 8,710 sq. mi. above Angostura Reservoir, found average flow of 139.9 cfs and 101,400 AF/year based on records of 1915-1920 and 1943-1972 (Discontinued). An instantaneous peak flow of 114,000 cfs occurred May 20, 1920 (USGS, 1973).

Horsehead Creek gauge at Oelrichs measures flow from a drainage area of 187 sq. mi. above Angostura Reservoir. Average flow was 7.21 cfs and 5,220 AF/year based on records from 1984-1997. The median flow is 0.0 cfs. The lowest daily mean and annual seven day minimum flow was zero, which occurs for many days in each year. An instantaneous peak flow of 8,270 cfs occurred May 11, 1991. Diversions upstream from this gauge are used to irrigate 624 acres (USGS, 1998).

Table 1: USGS Gauging Stations Data for the EIS

Gauge	Station ID	Period of Record	Drainag e Area (sq. mi.)	Annual Average (cfs)	Media n (cfs)	Highest Annual Average		Lowest Annual Average		Annual Average Runoff (AF)	Instan-taneous Peak Flow (cfs)
						(cfs)	(year)	(cfs)	(year)		
Cheyenne River At Edgemont	06395000	1929-32 & 1947-97	7,143	81.4	10	434	1962	12.0	1988	58,990	28,000
Hat Creek Near Edgemont	06400000	1906 & 1951-97	1,044	16.9	0.4	112	1967	0.16	1989	12,230	13,300
Cascade Springs Near Hot Springs	06400497	1977 -1995 Discontinued	0.47	19.5	19	21.4	1984	16.3	1993	14,150	49
Cheyenne River near Hot Springs	06400500	1915-20 & 1943-1972	8,710	139.9	--	453	1962	30.9	1961	101,400	114,000
Horsehead Creek At Oelrichs	06400875	1984-1997	187	7.21	0.0	29.3	1986	0.0	1990	5,220	8,270
Angostura Reservoir Computed Inflow	Hydromet Data	1953-1997	9,100	114.0	--	553	1962	19.2	1961	82,500	N/A
Angostura Reservoir Adjusted Inflow	Adjusted	1953-1997	9,100	123.6	--	565	1962	26.2	1961	89,500	N/A
Cheyenne River below Angostura	Hydromet Data	1953-1997	9,100	60.0	--	404	1962	0.0	----	43,400	N/A
Cheyenne River below Angostura	06401500	1951-1978	9,100	67.1	1.4	404	1962	0.83	1961	48630	30,300
Fall River at Hot Springs	06402000	1970-1997	137	21.9	22	25.5	1997	20.9	1981	15,880	13,100
Beaver Creek near Buffalo Gap	06402500	1939-1997	130	7.19	--	12.5	1995	3.78	1961	5,210	11,700
Cheyenne River near Buffalo Gap	06402600	1969-1980 Discontinued	9,800	107.4	--	263	1971	56.5	1976	77,900	25,000
French Creek above Fairburn	06403300	1983-1997	105	10.4	3.7	34.7	1995	1.01	1989	7,510	1,060
Cheyenne River near Wasta	06423500	1964-97	12,800	340	123	1,143	1997	81.0	1989	246,200	26,900
Cheyenne River near Plainview	06438500	1951-81 & 1995-1997	21,640	722	260	2,417	1997	97.2	1961	522,900	69,700
Cheyenne River near Cherry Creek	06439300	1961-1994 Discon tinued	23,900	802	261	1,748	1978	100	1961	581,000	55,900

Sources: USGS *Water-Data Reports* SD-72-1, SD-80-1, SD-94-1, SD-97-1;
HYDROMET Data (Reclamation, 1997)

2. Cheyenne River Flow below Angostura Reservoir

The gauge below Angostura Dam measures flow from a drainage area of 9,100 sq. mi. Average flow following completion of the dam was 67.1 cfs and 48,630 AF/year based on records from 1951-1978. The median flow is 1.4 cfs. The lowest daily mean was 0.0 cfs and annual seven day minimum flow of 0.2 cfs occurring in April 1951. An instantaneous peak flow of 30,300 cfs occurred May 20, 1978 (USGS, 1998). Hydromet data for 1953-1997 average flow is 60.0 cfs and 43,400 AF/year below Angostura Dam.

The Fall River gauge at Hot Springs 6.0 miles upstream from the mouth, a tributary of the Cheyenne River about 5 miles below Angostura Dam, measures flow from an area of 137 sq. mi. Average flow, based on records from regulated period of 1970-1997, was 21.9 cfs and 15,880 AF/year. The median flow is 22 cfs. The lowest daily mean of 14 cfs occurred for some days in 1982, 1983, and 1985 and annual seven day minimum flow of 15 cfs occurred in September 23, 1983. An instantaneous peak flow of 13,100 cfs occurred September 4, 1938 and 1,170 cfs since 1970. Flow regulated by Coldbrook Reservoir since September 1952 and Cottonwood Springs Lake since June 1969 (USGS, 1998).

The Beaver Creek gauge near Buffalo Gap 4.5 miles upstream of the mouth, a tributary of the Cheyenne River about 25 miles below Angostura Dam, measures flow from an area of 130 sq. mi. Average flow, based on records from 1939-1997, was 7.19 cfs and 5,210 AF/year. The median flow was 63 cfs with the lowest daily mean of 0.7 cfs occurring July 20, 1980. An instantaneous peak flow of 11,700 cfs occurred September 4, 1938. Much of the flow is diverted above station during irrigation season (USGS, 1998).

The Cheyenne River gauge near Buffalo Gap 34 miles downstream from the dam and 12 miles east of the city of Buffalo Gap, South Dakota measures flow from an area of 9,800 sq. mi. Average flow, based on records from 1969-1980 (Discontinued), was 107.4 cfs and 77,900 AF/year. Median flow of 63 cfs and lowest daily mean of 0.7 cfs occurred July 20, 1980. An instantaneous peak flow of 25,000 cfs occurred May 21, 1978 (USGS, 1981).

The French Creek gauge above Fairburn measures flow from an area of 105 sq. mi. Average flow, based on records from 1983-1997, was 10.4 cfs and 7,510 AF/year. The median flow is 3.7 cfs. The lowest daily mean and annual seven day minimum flow was 0.02 and 0.03 cfs respectively occurring in February 1989. An instantaneous peak flow of 1,060 cfs occurred May 8, 1995. Flow regulated by Stockade Reservoir 12 miles upstream (USGS 1998). This gage is located upstream of a loss zone, so flow characteristics at the confluence with Cheyenne River much are different.

The Cheyenne River gauge near Wasta 108 miles downstream from the dam and 3.0 miles east of the city of Wasta, South Dakota measures flow from a drainage area of 12,800 sq. mi. Based on records from regulated period of 1964-1997 (regulated by Angostura Dam since October 1949 and by upstream dams on Rapid Creek since August of 1956), average flow at this point was 340 cfs and 246,200 AF/year (records are available for period of record 1934-1997). The median flow is 123 cfs. The lowest daily mean of 3.0 cfs occurred December 23, 1990 and annual seven day minimum flow of 4.0 cfs occurring in January 1991. An instantaneous peak flow of 26,900 cfs occurred on May 25, 1957. Prior to October 1963 an instantaneous peak of 46,300 cfs occurred May 6, 1932 (USGS, 1998).

The Cheyenne River gauge near Plainview 167 miles downstream from the dam measures flow from a drainage area of 21,640 sq. mi. The following based on records from 1951-1981 and 1995-1997. Average flow was 722 cfs and 522,900 AF/year and median flow was 260 cfs. The lowest daily mean of

0.0 cfs occurred December 14 and 19 through 21, 1961 and annual seven day minimum flow of 1.0 cfs occurring in January 1962. An instantaneous peak of 69,700 cfs on May 28, 1996 (USGS, 1998).

The Cheyenne River gauge near Cherry Creek, 197 miles downstream from the dam and 0.5 miles east of the village of Cherry Creek, South Dakota, measures flow from a drainage area of 23,900 sq. mi. Average flow, based on records from 1961-1994 (Discontinued), was 802 cfs and 581,000 AF/year and median flow was 261 cfs. The lowest daily mean of 0.0 cfs occurred January 6 through February 2, 1962 and annual seven day minimum flow of 0.0 cfs occurring in January 1962. An instantaneous peak of 55,900 cfs on May 22, 1982 (USGS, 1995). Cheyenne River near Eagle Butte have a flow record of 1934-1967 has a drainage area of 24,500 sq. mi., about 600 sq. mi. more than Cherry Creek gage.

h. Historic Reservoir Net Monthly inflow - A 45 year period of record for calendar years 1953 through 1997 were available for the net monthly inflow and were retrieved from Reclamation's Hydrological-Meteorological databases (Appendix B, Hydromet data). The reservoir's computed net inflow for this period of record averages 82,520 acre-feet. The Reservoir operations ranged from a minimum content of 55,454 acre-feet on September 11, 1989 with a minimum elevation of 3162.90 on September 28, 1960. The maximum content of 169,020 acre-feet on June 18, 1962 with a maximum elevation of 3189.37 on May 20, 1978 (Hydromet data). The estimated historic net monthly inflow into the reservoir was computed by using historic end-of-month content, diversion records to Angostura Irrigation District, and outflow to the Cheyenne River from the reservoir (Appendix F, Hydromet Data), and the 1949, 1966, and 1981 elevation/area/capacity tables (Appendix E). The net evaporation and precipitation on the reservoir were not included. Negative net inflows could be a result of bank storage effects, evaporation, and/or measurement data errors. The negative flows are retained to maintain a balance with the recorded data.

i. Historic Reservoir Adjusted (Gross) Inflow - The estimated adjusted inflow was estimated by using the HYDROMET net historic inflow and including the reservoir evaporation and precipitation by using the estimated net lake evaporation rate in Table 4 The inflow was corrected for July 1958 and adjusted for the October 1966 and September 1981 area-capacity tables. The inflows were calibrated by the Angostura Reservoir Annual Operation Plan (AGRAOP) computer model (Appendix A) by comparing the historic EOM content. The estimated adjusted inflow for the years 1953-1997 averages 89,500 acre-feet. Taking out the negative net inflows equals about 102,000 acre-feet - retained to maintain a balance with recorded data - could have resulted from bank storage effects, evaporation, and/or measurement data inaccuracy. A maximum of 409,000 acre-feet (562.7 cfs) occurred in 1962 and a minimum of 19,000 acre-feet (26.1 cfs) in 1961. An annual median inflow (50 percent chance of occurring) shows 92.1 cfs (66,900 AF/Year), which is about 75 % the annual average. See Table 2 for kaf statistical values and Table 3 for cfs statistical values and Appendix C for monthly values.

Reservoir Adjusted inflow in Table 2 presents estimated Reservoir monthly frequency inflow (kaf) adjusted for evaporation and precipitation effects for the years 1953 through 1997. The table shows frequency of occurrence for reasonable minimum (10 percentile), most probable (50 percentile), and reasonable maximum (90 percentile). The percentile [10, 25, 50 (median), 75, and 90] of the 45 inflow values for each month during the years 1953-1997 had values that were less than or equal to those shown. An example would be for the month of January 1,600 acre-feet would occur less than or equal to 50 percent of the time (22.5 months), and reasonable minimum of 1,200 acre-feet would occur less than or equal to 10 percent of the time (4.5 months). The arithmetic mean is the sum of the monthly totals divided by the total years (45 years). See Appendix C for the 1953-1997 monthly reservoir adjusted inflow used by the model. Figure 1 displays the minimum, reasonable minimum, most probable, reasonable maximum, and maximum reservoir inflow in a graphical representation.

Table 3 shows the historic 1953-1997 monthly and annual inflow statistics that include the mean, minimum, maximum and the 10, 50 (median), and 90 percentile frequency of occurrence for the 45 year period of record. Figure 2 shows a graph of the historic reservoir mean monthly inflow. Angostura Reservoir adjusted annual, monthly, and accumulated inflow are shown in a graphic representation in Figures 1, 2 and 3 of Appendix C. This shows the variability of the inflows with low inflow periods of about every 15 years (1961, 77, and 90). The Reservoir operations ranged from minimum elevation of 3163.01 in September of 1960 to maximum elevation of 3187.71 in May of 1962 (Appendix F).

j. Definite Plan Report Anticipated Reservoir Inflow - The Definite Plan Report (DPR) (1950) states the anticipated annual average inflow is 126,600 acre-feet. There are a total of 2,492 surface water storage
rights above the reservoir for a total of 33,336 acre-feet. See Table 9 in water rights section for a listing of the water rights that are senior and junior to the reservoir. The adjusted historic inflow plus the storage water rights totals 122,836 acre-feet, which is within 3% of the DPR average inflow of 126,600 acre-feet. This difference is probably due to the evaporation that occur on each storage facility above the reservoir. The difference between the DPR anticipated average inflow and the adjusted average annual inflow during 1953-1997 is primarily due to the large number of stock ponds that were constructed in the basin during the late 1940's and early 1950's. Refer to Stock Dams reports in reference section (USGS Circular 223, 1953 and Survey Water-Supply Paper 1531A, 1961).

k. Reconnaissance Report Estimated Reservoir Inflow - The reconnaissance report on Supplemental Water Supply for Angostura Unit (Reclamation, September 1962) reports average annual inflows during the 33-year period ending in 1961 were estimated to be 108,500 acre-feet.

Table 2: Estimated Reservoir monthly frequency inflow for years 1953-1997 (Kaf)

Month	Minimum	10 Percentile Reasonable Minimum	25 percentile	50 Percentile Most Probable	75 Percentile	90 Percentile Reasonable Maximum	Maximum	Arithmetic mean
Jan	1.0	1.2	1.4	1.6	2.0	2.7	8.9	2.0
Feb	0.9	1.5	1.8	2.5	5.7	8.4	38.7	4.6
Mar	1.8	3.2	5.7	7.9	15.1	25.7	49.2	12.0
Apr	0.7	1.6	2.4	5.2	8.1	16.1	50.4	7.4
May	0.0	1.4	2.4	6.3	18.9	63.7	155.9	20.1
Jun	0.0	0.6	2.4	7.6	26.2	52.0	168.5	21.5
Jul	0.0	0.7	1.8	3.4	8.2	19.2	84.2	9.7
Aug	0.0	0.5	1.0	2.4	7.3	14.2	27.7	5.2
Sep	0.0	0.0	0.5	1.1	1.7	6.0	16.4	2.0
Oct	0.0	0.4	1.1	1.4	2.2	3.0	13.4	1.6
Nov	0.3	1.0	1.3	1.6	2.2	2.8	3.2	1.7
Dec	0.6	1.0	1.4	1.6	1.9	2.4	4.2	1.7
Annual	19.0	27.5	41.9	66.9	108.3	180.6	408.9	89.5

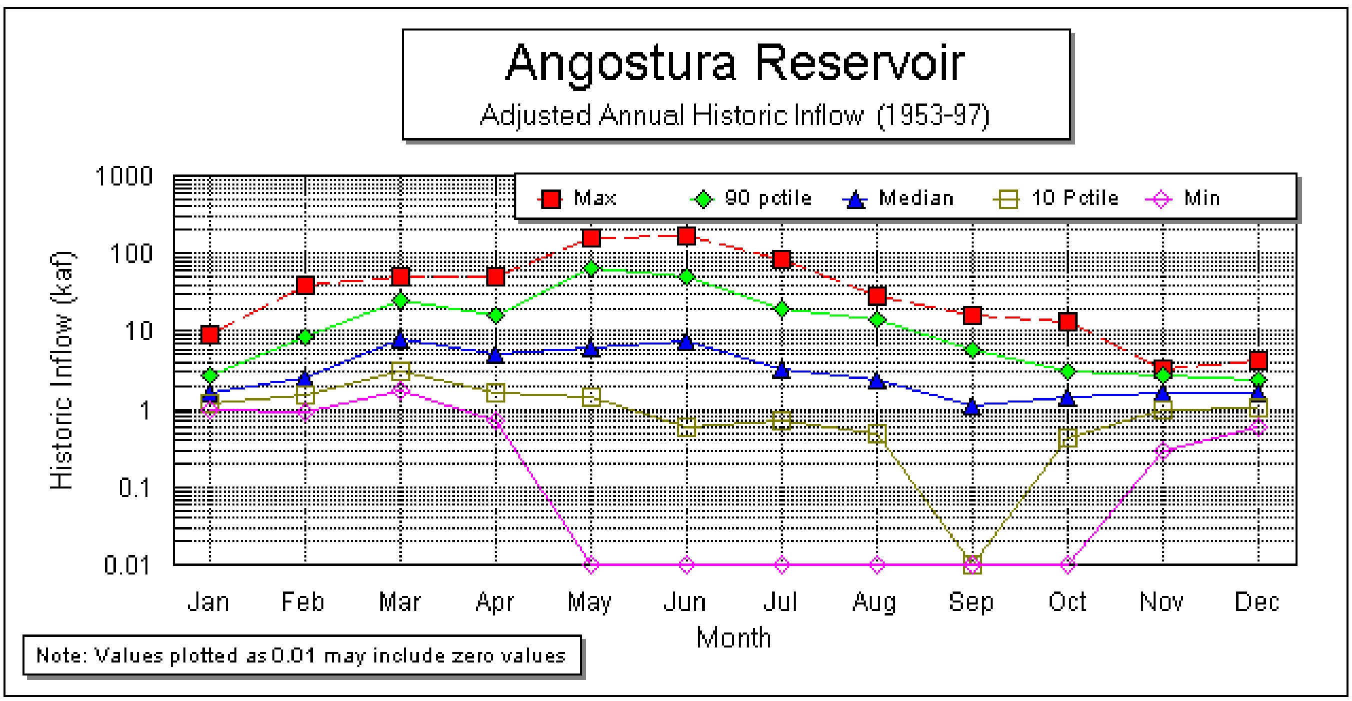


Figure 1: Angostura Reservoir Adjusted Monthly Historic Statistical Inflow (kaf)

Table 3: Angostura Reservoir Historic Reservoir Monthly Statistical Inflow (1953-1997 in cfs)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	31.7	83.1	195.8	125.0	326.4	360.7	157.6	83.9	34.3	26.1	29.3	27.4	123.5
Min.	15.8	16.2	29.3	11.8	0.0	0.0	0.0	0.0	0.0	0.0	5.0	9.8	26.1
10 percentile	18.9	27.0	51.7	27.6	23.4	10.1	12.0	8.1	0.0	7.2	16.5	16.9	38.0
Median	26.2	45.0	128.5	87.4	102.5	127.7	55.3	39.0	18.5	22.8	26.9	26.0	92.1
90 percentile	44.0	151.3	417.3	270.9	1035.7	874.2	312.6	230.6	100.2	49.4	46.4	38.4	252.1
Max.	145.4	696.8	800.2	847.0	2535.5	2831.7	1369.4	450.5	275.6	217.9	53.8	68.3	562.7

Source: HYDROMET database adjusted for evaporation and precipitation by the AGRAOP model.

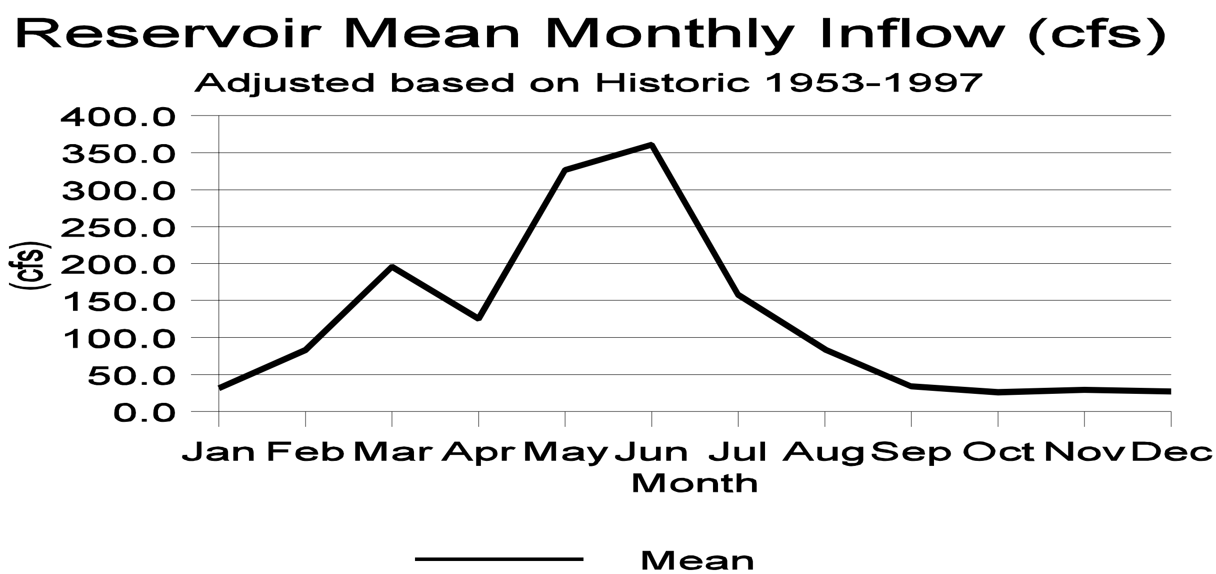


Figure 2: Angostura Reservoir Adjusted Mean Monthly Inflow (cfs)

l. Estimated Reservoir Net Evaporation Rate - The monthly evaporation rate was computed using monthly pan evaporation from Angostura Reservoir May through October for years 1949 to 1970; Rapid City, SD April and November for years 1953 to 1970 (NOAA Technical Report NWS 34); and Oral SD, May through September for years 1971 through 1993. This data was weighted to get the average pan evaporation for period of 1949 through 1993. Monthly net evaporation is estimated by multiplying the average pan evaporation by a factor of 0.70 to convert to free water surface evaporation. The 1949 to 1993 Angostura Dam weather station average monthly precipitation on the reservoir surface water itself was subtracted from the estimated monthly free water surface evaporation to calculate the monthly net lake evaporation rate. The reservoir was assumed to be iced over for the December through March period. Table 4 shows the average monthly evaporation rate in feet which are applied to the monthly water surface area to calculate evaporation loss. These rates were used to compute historic natural inflows and the reservoir operations using the AGRAOP model. The average evaporation was 7,454 acre-feet with a maximum monthly rate of 1,841 acre-feet occurring in July of 1962 and a minimum of 408 acre-feet occurring in April of 1961. The total annual maximum of 8,659 acre-feet occurred in 1955 and minimum of 5,233 acre-feet occurring in 1961. See Appendix K for the AGRAOP model generated values.

Table 4: Angostura Reservoir Net Evaporation Rate (Feet)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0.00	0.00	0.00	0.140	0.168	0.229	0.380	0.385	0.248	0.194	0.090	0.00	1.834

m. Calibration of the AGRAOP model: The estimated adjusted inflows to the reservoir were used as natural inflows to verify or calibrate the operation of the reservoir using the Angostura Reservoir model (AGRAOP). The AGRAOP model operates the Angostura Reservoir in a monthly time step to meet the system demands from the runoff and stored water and, if possible, the given end-month target elevations for the model. The model was calibrated by analysis of historic operation of the reservoir using the estimated reservoir monthly natural inflows (Appendix C). The natural inflows are defined as inflows that would exist in the absence of any upstream water developments such as reservoirs, diversions, and return flows. However, in this study stock ponds that were constructed in the upper Cheyenne River basin during the late 1940's and early 1950's and irrigation in the upper Hat Creek drainage would continue depleting the streamflow and will continue the same effect to the reservoir historic inflow for the 1953-1997 period of record.

The following model inputs were used in this calibration analysis (see Appendix A for details):

Reservoir Adjusted inflow was estimated as discussed previously. The average annual adjusted inflow for the 1953-97 year period was 89,500 acre-feet. See Appendix C.

Historic end-of-month content for the reservoir was obtained from Hydromet data (See Appendix F). The initial EOM content was for December 1952 at 118,700 acre-feet. The average EOM content was 112,060 acre-feet with a maximum of 162,165 acre-feet occurring in May of 1962 and a minimum of 56,903 acre-feet occurring in August of 1989. The highest annual average storage occurred in 1963 of 147,608 acre-feet with a lowest annual average occurring in 1989 of 67,913 acre-feet. See Appendix K for the EOM content generated by the AGRAOP model.

End-of-month Target Elevation is a look ahead feature that allows the model to look to the next target elevation that will enable the model to release water to the river forcing the reservoir to spill excess water in anticipation of high flows to keep the pool at or below top of conservation and top of spillway gates. There were times when the elevation was higher than the top of spillway gates at elevation 3187.2. To operate the model as historic conditions elevation of 3195.0 was used as the target elevation and maximum elevation. The historic average EOM elevation was 3179.81 feet with a maximum of 3187.71

feet occurring in May of 1962 and a minimum of 3163.01 feet occurring in September of 1960. The highest annual average elevation of 3185.63 occurred in 1979 and a lowest annual average of 3164.86 occurred in 1961. See Appendix K for the AGRAOP model generated values.

Seepage from the reservoir is not significant. Leakage past the radial gates is normally about 3.5 cfs or about 200 acre-feet per month. Seepage is not used in calibrating the model as this is accounted for in the change of content or river discharge.

Diversion records for the Angostura Irrigation District were obtained from Hydromet data (See Appendix F). The average canal discharge was 38,600 acre-feet (1953-97) with a maximum of 18,400 acre-feet occurring in August of 1959 and a minimum of zero acre-feet occurring in some months. The highest annual total of 59,100 acre-feet occurred in 1958 and lowest annual total of 12,100 acre-feet occurred in 1961 which reflects a record minimum inflow to the Reservoir of 19,000 acre-feet for the year of 1961. Temporary water service contracts for irrigating another 184.8 acres when the reservoir is above elevation 3184.2 feet have been signed with the Hot Springs Airport (139.8 acres) and two private landowners (45 acres). These lands are within the district boundaries, but are not part of the original authorization for irrigation.

River Outflow from the reservoir were obtained from Hydromet data (See Appendix F). The average river discharge was 43,400 acre-feet with a maximum of 168,100 acre-feet occurring in June of 1962 and a minimum of zero acre-feet occurring in many months. The highest annual total of 294,500 acre-feet occurred in 1962 and lowest annual total of zero acre-feet occurring in 1976 and 1977.

Reservoir elevation-area-capacity table for 1949, 1966, and 1981 and the previous *end-of-month content* were used to compute the end-of-month surface area. The reservoir elevation-area-capacity table for 1949, 1966, and 1981 are shown in Appendix E. These tables were used in the analysis of historic reservoir inflows based on historic reservoir operation data. The original 1949 table was used for the period January 1953 through September 1966; the 1966 table was used for the period October 1966 through August 1981; and the 1981 table was used for the period September 1981 through December 1997. Angostura Reservoir was resurveyed in May 1979 using range method. Ranges were profiled by standard surveying techniques and an echo sounder. The September 1981 Area-Capacity table was generated by Reclamation in the Denver Technical Service Center D-8570 and presently used for Reservoir Capacity Allocations. See Appendix D for the 1981 Reservoir Capacity Allocations form and drawing and Appendix E for the 1981 elevation-area-capacity curve. The average EOM surface area was 3,992 acres with a maximum of 4,879 acres occurring in May of 1962 and a minimum of 2,644 acres occurring in August of 1989. The highest annual average surface area occurring in 1966 and lowest annual average occurring in 1961. See Appendix F for the AGRAOP model surface area values.

The model was used to compare current and future water uses against Reservoir adjusted inflows.

n. Angostura Reservoir Storage

Storage to Angostura Reservoir began October 3, 1949 and the dam was completed December 1949. Area-capacity tables for the reservoir have included the original 1949, the sediment resurvey of 1966 and 1981 (Appendix E). The 1981 area-capacity table (presently used) shows an active conservation capacity of 82,443 AF between elevations 3163.0 feet and 3187.2 feet (top of spillway gates) with a total capacity of 130,768 AF. Inactive storage is 39,700 AF between elevations 3139.75 feet (invert of lowest river outlet) and 3163.0 feet. Dead storage below elevation 3139.75 feet is 8,598 AF. Surcharge capacity is 56,360 AF between elevations 3187.2 feet and 3198.1 feet (maximum water surface).

Historic end-of-month content for the reservoir was obtained from HYDROMET water year database and converted to a calendar year database. The average 1953-1997 EOM content was 112,100 acre-feet at Elevation 3179.83 feet with the highest annual average storage of 147,600 AF occurring in 1963 with a lowest annual average of 67,900 AF occurring in 1989. A maximum monthly EOM content of 162,200 AF at elevation 3187.61 feet occurred in May of 1962. A minimum EOM content of 56,900 AF occurred in August of 1989 with a monthly minimum EOM elevation of 3162.92 feet occurring in September 1960 (Table 5 and 6). Figure 3 and 4 show a graph of the monthly EOM content and Elevation statistics. The reason for the difference of the months of the minimum content and elevation is due to the use of different area-capacity tables.

Table 5: Historic Reservoir Monthly EOM Content (1953-1997 in kaf)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	105.9	109.4	117.4	121.7	126.6	126.1	117.4	107.3	102.4	102.4	103.5	104.6	112.1
Min.	65.7	67.8	70.6	72.1	77.5	73.5	65.9	56.9	60.4	61.2	62.8	64.3	67.9
10 percentile	74.0	80.9	87.9	89.1	100.2	95.8	82.5	71.9	70.0	70.6	71.5	72.7	85.4
Median	102.6	109.0	120.3	129.6	130.0	129.5	117.8	106.9	99.6	100.7	102.6	101.5	113.0
90 percentile	132.2	137.1	138.4	142.1	157.9	158.9	147.7	142.0	135.1	129.6	129.9	129.9	134.5
Max.	148.1	153.2	160.0	160.3	162.2	160.2	160.2	155.7	160.0	155.5	150.7	149.6	147.6

Source: HYDROMET database.

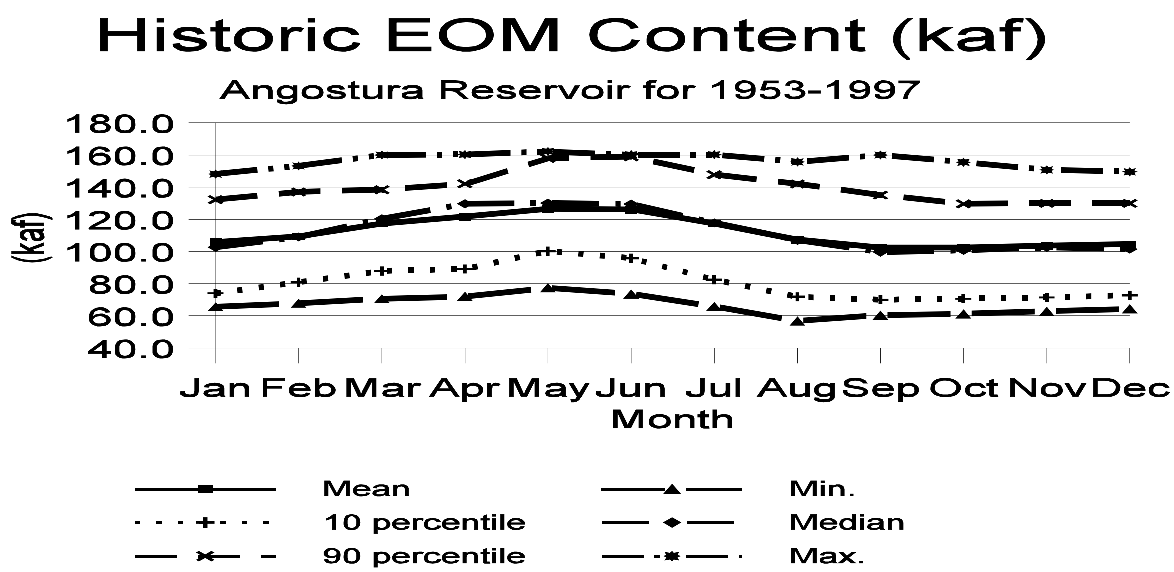


Figure 3: Reservoir EOM Content (kaf)

Table 6: Historic Reservoir Monthly EOM Elevation (1953-1997 in feet)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	78.28	79.17	81.20	82.21	83.43	83.31	81.16	78.57	77.34	77.47	77.76	78.08	79.83
Min.	64.42	64.88	65.50	65.75	66.09	66.26	64.68	63.63	62.92	63.11	63.43	63.93	64.78
10 percentile	70.09	70.68	72.72	73.47	77.01	77.05	74.11	70.20	68.46	68.70	69.12	69.60	73.86
Median	79.30	79.79	82.51	84.23	86.01	86.06	83.78	79.93	78.28	78.45	78.85	79.36	81.63
90 percentile	85.38	86.70	87.03	87.09	87.17	87.19	86.74	85.52	84.03	84.41	84.74	84.99	84.34
Max.	85.84	86.97	87.16	87.22	87.61	87.30	87.24	86.34	87.17	86.22	85.38	85.34	85.69

Source: HYDROMET database**.**

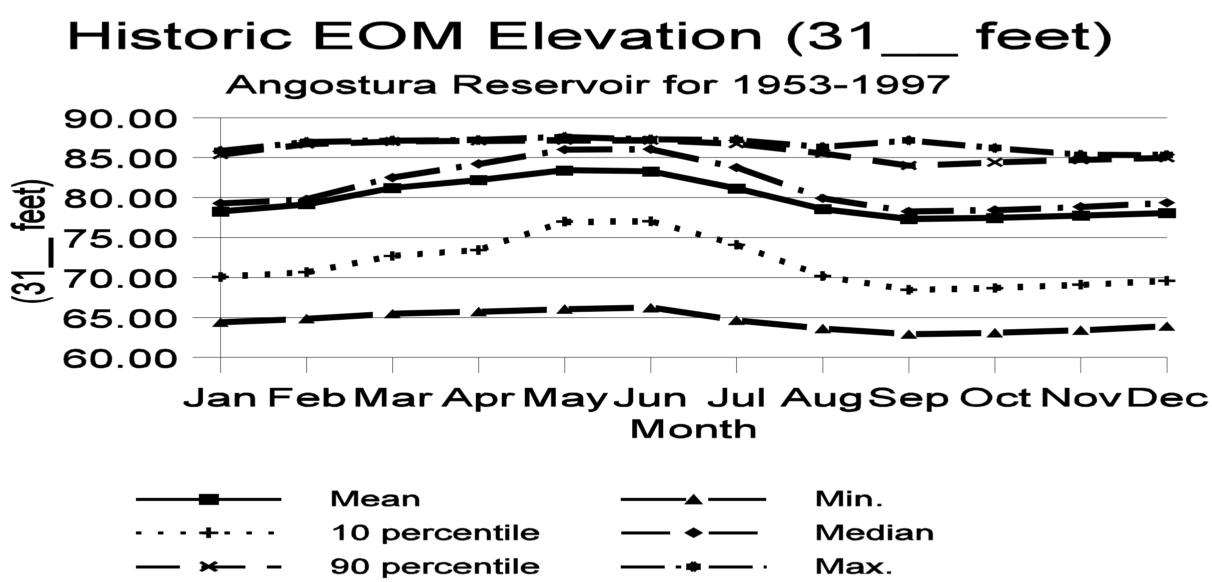


Figure 4: Reservoir EOM Elevation (31__ feet)

o. Angostura Reservoir canal releases to the District

Canal release records for the Angostura Irrigation District were obtained from Hydromet water year database and converted to a calendar year database. The district started irrigating in 1955 with Hydromet records for the 1955-1997 period showing an annual average canal discharge of 55.2 cfs (40,400 AF/Year) and an average irrigated lands totaling 10,500 acres. An annual median canal flow (50 percent chance of occurring) shows 55.6 cfs (40,700 AF/Year), which is about the same as the annual average. A maximum monthly discharge of 299.2 cfs (18,400 AF) occurring in August of 1959 and a minimum of zero AF occurring during some months in the irrigation season. The highest annual total of 81.0 cfs (59,100 AF) occurred in 1958 and lowest annual total of 16.4 cfs (12,100 AF) occurred in 1961 which reflects a record minimum inflow to the Reservoir of 26.2 cfs (19,000 AF) for the year of 1961 (Table 7). Figure 5 shows a graph of the historic monthly canal release, which indicates that the largest reservoir discharge occurs in July and August. Temporary water service contracts for irrigating another 184.8 acres when the reservoir is above elevation 3184.2 feet have been signed with the Hot Springs Airport (139.8 acres) and two private landowners (45 acres). These lands are within the district boundaries, but are not part of the original authorization for irrigation.

Table 7: Historic Reservoir Monthly Canal Release (1955-1997 in cfs)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	0.0	0.0	0.0	4.5	53.6	74.5	208.0	213.4	97.9	10.0	0.0	0.0	55.2
Min.	0.0	0.0	0.0	0.0	0.0	3.4	112.2	68.3	0.0	0.0	0.0	0.0	16.4
10 percentile	0.0	0.0	0.0	0.0	2.0	21.8	134.0	156.1	52.4	0.0	0.0	0.0	43.0
Median	0.0	0.0	0.0	0.0	53.7	62.2	221.2	222.8	97.5	0.0	0.0	0.0	55.6
90 percentile	0.0	0.0	0.0	15.1	93.7	135.5	262.2	267.4	139.2	33.5	0.0	0.0	66.1
Max.	0.0	0.0	0.0	45.4	117.1	218.5	287.9	299.2	191.6	65.1	1.7	0.0	81.0

Source: HYDROMET database

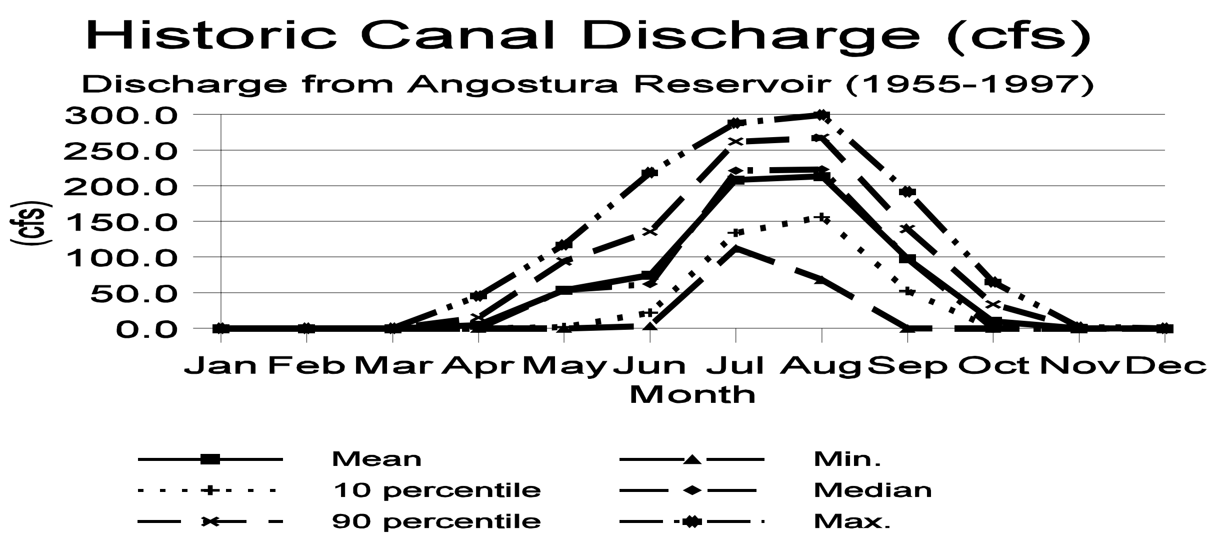


Figure 5: Reservoir Historic Canal Release (cfs)

p. Angostura Reservoir downstream releases to the Cheyenne River

Seepage from the reservoir is not significant. Leakage past the radial gates is normally about 3.5 cfs or about 200 AF/month.

River release from the reservoir was obtained from Hydromet water year database and converted to a calendar year database. Releases to the Cheyenne River below the dam occur when the capacity of the reservoir reaches elevation 3187.2 feet (top of spillway gates). The average river discharge was 59.9 cfs (43,400 AF/year) with the highest annual total of 406.7 cfs (294,500 AF) occurring in 1962 and lowest annual total of zero acre-feet occurring in 1976 and 1977. An annual median river flow (50 percent chance of occurring) shows 29.4 cfs (20,600 AF/Year), which is about half the annual average (Table 8). Figure 6 shows a graph with historic Angostura river discharge statistics. USGS records show a highest daily mean of 20,600 cfs was observed June 18, 1962 with an instantaneous peak flow of 30,300 cfs on May 20, 1978.

Table 8: Historic Reservoir Monthly River Release (1953-1997 in cfs)

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	10.2	20.3	66.0	38.7	183.7	280.3	75.3	18.9	6.1	4.8	6.6	7.9	59.9
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 percentile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Median	0.0	0.0	0.0	1.7	8.1	13.4	1.6	0.0	0.0	0.0	0.0	0.0	29.5
90 percentile	47.5	76.0	160.4	123.0	527.9	803.6	192.6	52.3	8.4	12.7	23.9	37.1	177.4
Max.	117.1	212.5	673.3	369.7	2384.2	2825.0	1229.5	198.4	95.8	58.5	89.1	84.6	406.7

Source: HYDROMET database.

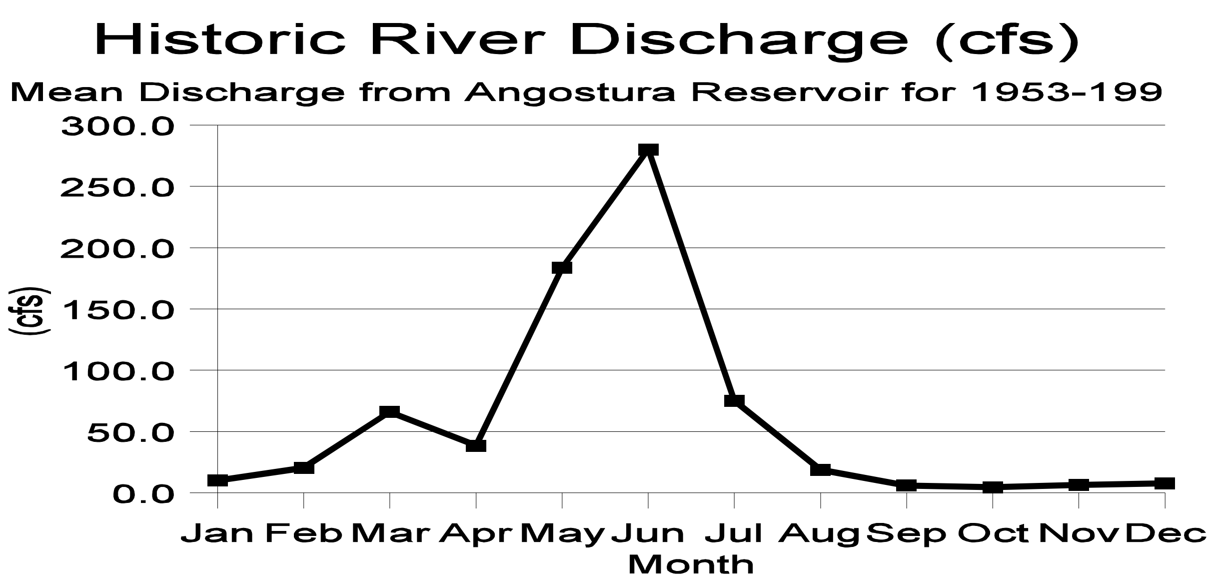


Figure.6: Reservoir Historic Mean River Discharge (cfs)

q. Water Rights above Angostura Reservoir: The Black Hills was open to settlement in 1876. The Supreme Court ruled no water right priority prior to February 28, 1877. Table 9 summarizes existing senior and junior water rights for the tri-state area above the Reservoir. These existing water rights for South Dakota, Wyoming, and Nebraska as of August 1995, May 1996, and August 1995 respectively, are senior or junior to the Angostura project water rights of April 11, 1941.

The project water right, U.S. Withdrawal License No. US5792 dated April 11, 1941 (also amended March 18, 1946, and November 26, 1976), is held by Reclamation. This withdrawal reserves 138,761 acre-feet of stored water for irrigation of 12,342 irrigable acres. The 138,761 acre-feet includes carryover allowance and inactive storage. South Dakota water law allows application of up to 3 acre-feet per irrigable acre for the Angostura Irrigation Project. Additional Reservoir diversions are allowed for water losses in the project distribution system (SDDENR).The District first entered into a water service and repayment contract with the United States in 1951. By an amendatory contract, the operation and maintenance responsibility for the dam, Reservoir, and conveyance works was transferred from the United States to the District effective January 1, 1968.

Stock dams under 25 acre-feet can be constructed in South Dakota by simply filing a location notice with the County and a copy to the Water Management Board before construction. There is no advance permitting process to control development. Stock dams are not listed with the State of Nebraska if the dam has a capacity less than 15 acre-feet and a height of less than 25 feet. Wyoming requires permits on all stock dams.

On August 13, 1948, representatives from Wyoming and South Dakota signed the Cheyenne River Compact; however, it was not approved by the U.S. Congress. A revised compact was approved by South Dakota in 1951 but was not approved by Wyoming. At this time, there is no compact allocating flows in the Cheyenne River between Nebraska, Wyoming, and South Dakota.

Wyoming has proposed construction of several reservoirs for recreation, fish, and wildlife purposes on Beaver Creek and Stockade Beaver Creek near Newcastle, Wyoming, and Indian Creek 20 miles north of Lusk, Wyoming. Due to the present economic infeasibility of these projects, there is no anticipated development in the near future (Green, 1995). Water rights described in Table 9 are computer-generated totals that represent the water rights of record in the Wyoming State Engineer’s Office as filed on the computer (the computer entries have not been proofed for accuracy). The following adjudicated (finalized) totals were used for this survey—reservoirs, ditch/pipeline facilities, and enlarged ditch/pipeline facilities. Many times the permitted amount was not entirely adjudicated and unadjudicated permits exist. Stock reservoirs no longer require adjudication, so the entire permitted database was used for stock reservoirs with less than 20 acre-foot capacities (not all of the stock ponds permitted have been constructed). Some stock reservoirs may be filled with sediment and/or no longer used. Inspection of facilities by State Engineer’s staff occurs only through the adjudication process or when changes to an adjudicated right are requested through petition, unless regulation of water is called for. The office records may, or may not, reflect the actual situation on the ground. Failure to exercise a water right for 5 years, when water is available, may constitute grounds for forfeiture by Wyoming statutes (Wyoming State Engineer’s Office).

Table 9: Surface water rights above Angostura Reservoir

Senior to Angostura April 11, 1941	South Dakota[1]	Wyoming[2]	Nebraska[3]	Total
Flow right permits	80	388	53	521
Rate (cfs)	175	336	63	574
Acre-feet per day	347	N/A	124	471
Acres	10,324	23,527	6,106	39,957
Storage permits[4]	0.00	156	24	180
Storage (AF)[4]	0.00	13,765	3,210	16,975
Junior to Angostura April 11, 1941	**South Dakota[1]**	**Wyoming[2]**	**Nebraska[3]**	**Total**
Flow right permits	59	437	34	530
Rate (cfs)	156	303	34	493
Acre-feet per day	310	N/A	67	377
Acres	10,741	21,210	4,222	36,173
Storage permits[4]	5	2,258	49	2,312
Storage (AF)[4]	361	13,557	2,443	16,361

[1] Data from South Dakota Department of Environment and Natural Resources (SDDENR), August 1995.
[2] Data from Wyoming State Engineer's Office, May 1996. Water rights described in this table are computer-generated totals that represent the water rights of record in our office as filed on the computer (the computer entries have not been proofed for accuracy).
[3] Data from Nebraska Department of Water Resources, August 1995.
[4] These amounts include reservoirs and stock dams. The permitting process for stock dams are explained in section f, Water Rights.

r. Water Rights below Angostura Reservoir: There are no requirements for any minimum flow releases to the Cheyenne River below the Reservoir. Releases from the Reservoir have not been required—seepage past the radial gates, flows from the Fall River, and irrigation return flows have satisfied all downstream water rights. There are no proposed instream fishery developments since all land bordering the river is private with limited public access.

There are three downstream appropriators with senior water rights to Angostura Reservoir (April 11, 1941). One water right, located above Wasta, South Dakota, has a total of 2.39 cfs (4.7 acre-feet per day) for 167 irrigated acres. Two water rights below Wasta have a total of 8.85 cfs (17.6 acre-feet per acre) for 620 irrigated acres (SDDENR). Downstream accretions are normally sufficient to accommodate these water right needs.

There are 27 junior rights below the Reservoir requiring 68.73 cfs (136 acre-feet per day). This provides irrigation for 5,911 acres. One junior right is entitled to 2.5 acre-feet of storage.

s. Drawdowns: Reservoir elevations can have direct effects on recreation, fish, wildlife habitat, land management, and cultural resources. The Reservoir normally does not fall below the top of the inactive pool, elevation 3163.0. Drawdowns can adversely affect boat ramps by limiting their inherent purpose. At Reservoir elevations of 3170.0 feet and 3171.0 feet, the north and south boat ramps are exposed, respectively.

Fluctuating elevations during the spring adversely impact the Reservoir fishery by limiting spawning success. Spawning success would be enhanced if Reservoir elevations remain constant during April and May. Archeological and paleontological resources are affected by the rate of rise or drawdown in the Reservoir. These effects would be minimized if the Reservoir remained below the flood pool elevation of 3187.2 feet.

Fluctuating elevations also affect recreation interests. High elevations diminish the beach areas available on the reservoir. Low elevations expose rocks and leave some boat ramps unusable.

t. Flooding: There is no designated flood control space in the Reservoir. However, the conservation capacity may at times provide some flood control benefits, and when the Reservoir enters the surcharge pool, the operation of the automated spillway gates may also provide some incidental flood control. Recent Safety of Dams investigations for Angostura Dam identified a hydrologic deficiency. These investigations indicated that the Probable Maximum Flood would overtop Angostura Dam, potentially causing dam failure. An Early Warning System (EWS) was developed and implemented in 1992 to address this deficiency. The EWS uses the damtender as a principal detection point and the HYDROMET data as a backup detection method to determine when certain Reservoir levels are exceeded and if the rate of inflow would jeopardize the structure. The Reservoir has exceeded elevation 3187.2 (top of spillway gates) 21 out of the last 43 years during the months of March through August. The maximum historic Reservoir content was 152,228 acre-feet occurring on May 5, 1978, at elevation 3189.89. Minimum content observed since normal operating level reached 45,350 acre-feet on September 28, 1960, at elevation 3162.9. Flood control is accomplished using the conservation pool until it is full and then using the flood surcharge pool to reduce peak flows downstream. The maximum flood control release was 23,525 cfs on May 20, 1978, with a peak inflow of 24,901 cfs on May 28, 1978. (Reclamation, 1978).

2. Consumptive Water Demands

a. Angostura Irrigation District: Reservoir releases to the District have averaged about 40,000 acre-feet/year from 1958 to 1997. For the period from 1988 to 1997, Reservoir releases averaged about 34,400 acre-feet/ year—5,600 acre-feet less than average. District records from 1988 to 1997 show an average farm delivery of 2.65 acre-feet/acre. See Table 10 for Districts records for water years 1958-1997.

The canal and lateral distribution system, maintained by the District, has achieved a delivered to farms average of 76.5-percent efficiency in water deliveries to on-farm irrigation systems (based on District records from 1988-1997). Highly permeable reaches of the main canal and lateral system have been lined with concrete, asphalt, and bentonite with most of the bentonite reaches relined with asphalt. The District keeps good delivery records and measures and accounts for their water all through the system.

Table 10 shows 1958 through 1997 District records and gives some idea of the on-farm efficiencies taking place at Angostura District. To estimate on farm efficiency, net irrigation consumptive use (amount of water required by the crop for peak production estimated by the Blaney-Criddle Method) is divided by the amount of water delivered to the farms. The on-farm efficiency averaged 55 percent and is the amount of water required by the crop versus the total volume applied. It does not take into account the timing of the irrigation to meet crop needs or how much water was needed to fill the root zone in relation to how much water is applied. Dry years and wet years show an effect on the on-farm irrigation efficiencies in that more water is or is not available in the Reservoir. The effective precipitation varies and has a direct influence on the irrigation efficiencies.

The on-farm irrigation efficiencies shown in the last column in table 10 are very rough efficiencies but do show that the water is being used in a fairly efficient manner when you consider that less than 10 percent of the acres are sprinkler irrigated. In the 1988-1997 period the years of 1993, 1990, and 1989 show how a wet year (1993), a low reservoir year (1990), and a very dry year as well as low Reservoir (1989) can effect efficiencies. The effective precipitation that occurred in 1993 created a situation for low efficiencies because farmers on the District irrigate primarily by gravity methods, and to apply water in amounts less than required to fill the crop's root zone or to leave a deficit in the root zone for rainfall is very difficult. The year of 1989, and to a degree 1990, show 2 years when crop water requirements were not met because of lack of rainfall and an inadequate supply of water available in the Reservoir. Irrigators had to choose which crops to irrigate with the limited water supply, and some of the crop needs were not met. When the years 1989, 1990, and 1993 in Table 10 are dropped from the computed average, the on-farm irrigation efficiency is 49 percent. This number is very rough but if it used for computing the release requirements in Table 12, the values would go up over 20 percent and the numbers would be 49,600 acre-feet and 41,300 acre-feet for 12,000 acres and 10,000 acres, respectively. This would show that the Reservoir release of 34,400 acre-feet is not meeting all the crop water use requirements based on 49 percent irrigation efficiency. Therefore water conservation efforts and increased irrigation efficiencies will be required as water supplies decrease in the Reservoir.

The Reservoir provides water to the District for 12,218 irrigable acres of land along both sides of the Cheyenne River. During the years 1958 through 1997, an average of 10,458 acres was irrigated. This is an indication of lack of rainfall and not having an adequate supply of water available in the Reservoir. Irrigators had to choose which crops to irrigate with the limited water supply, and some crop needs were not met.

Table 10: Angostura Unit Irrigation District Statistics

Year	Reservoir release to Main Canal (acre-feet)	Delivered to farms (acre-feet)	Delivered to farms (percent)	Irrigated Acres (acres)	Delivered to farms (AF/acre)	Reservoir Release to Farms (AF/acre)	Effective Precipitation (AF)	Net Irrigation Consumptive Use (inches)	(AF)	On Farm Efficiency (Percent)
1958	58,334	32,134	55.1	11,258	2.85	5.18	5,657	20.08	18,838	59
1959	56,041	35,653	63.6	11,382	3.13	4.92	6,886	21.41	20,307	57
1960	33,495	16,098	48.1	11,371	1.42	2.95	3,250	25.38	24,050	***
1961	12,188	5,081	41.7	8,821	0.58	1.38	4,337	22.10	16,245	***
1962	35,508	21,943	61.8	9,687	2.27	3.67	7,943	16.45	13,279	61
1963	37,127	23,946	64.5	10,425	2.30	3.56	9,626	17.82	15,481	65
1964	45,862	31,925	69.6	11,777	2.71	3.89	5,849	21.73	21,326	67
1965	28,153	21,714	77.1	10,310	2.11	2.73	8,257	15.66	13,455	62
1966	42,030	32,347	77.0	9,590	3.37	4.38	5,818	20.43	16,327	50
1967	37,331	27,641	74.0	10,129	2.73	3.69	5,706	17.35	14,645	53
1968	37,270	24,370	65.4	9,961	2.45	3.74	7,545	15.08	12,518	51
1969	45,569	29,573	64.9	9,765	3.03	4.67	5,892	20.87	16,983	57
1970	45,434	31,652	69.7	10,116	3.13	4.49	5,682	22.42	18,900	60
1971	40,996	26,016	63.5	9,900	2.63	4.14	5,313	18.40	15,180	58
1972	42,286	28,331	67.0	9,415	3.01	4.49	6,363	16.31	12,797	45
1973	44,255	32,582	73.6	10,155	3.21	4.36	4,841	17.49	14,801	45
1974	47,621	37,244	78.2	11,010	3.38	4.33	4,046	19.87	18,231	49
1975	42,403	34,357	81.0	11,186	3.07	3.79	4,968	19.38	18,065	53
1976	38,263	29,800	77.9	11,194	2.66	3.42	7,248	17.85	16,651	56
1977	40,148	27,555	68.6	11,353	2.43	3.54	9,546	17.63	16,679	61
1978	47,153	36,159	76.7	11,355	3.18	4.15	7,163	18.47	17,477	48
1979	42,879	32,494	75.8	11,333	2.87	3.78	7,414	17.64	16,660	51
1980	48,333	36,856	76.3	11,373	3.24	4.25	6,151	21.08	19,979	54
1981	52,163	30,983	59.4	11,462	2.70	4.55	7,202	19.06	18,205	59
1982	36,006	27,483	76.3	11,193	2.46	3.22	8,796	14.75	13,758	50
1983	40,217	32,085	79.8	11,444	2.80	3.51	6,132	19.16	18,272	57
1984	40,785	32,496	79.7	11,482	2.83	3.55	6,612	18.66	17,855	55
1985	48,441	33,348	68.8	10,932	3.05	4.43	4,947	21.06	19,186	58
1986	33,452	28,898	86.4	10,072	2.87	3.32	5,934	18.30	15,360	53
1987	39,502	30,754	77.9	9,259	3.32	4.27	4,452	20.96	16,172	53
Mean	41,308	29,051	70.0	10,624	2.73	3.88	6,319	19.10	16,923	55

Note: 1960 and 1961 on farm efficiency has no computed value as there were water shortage for a full supply to the crop.

Table 10 continued: Angostura Unit Irrigation District Statistics

Year	Reservoir release to Main Canal (acre-feet)	Delivered to farms (acre-feet)	Delivered to farms (percent)	Irrigated Acres (acres)	Delivered to farms (AF/acre)	Reservoir Release to Farms (AF/acre)	Effective Precipitation (AF)	Net Irrigation Consumptive Use (inches)	Net Irrigation Consumptive Use (AF)	On Farm Efficiency (Percent)
1988	44,099	32,085	72.8	9,347	3.43	4.72	5787	19.68	15,329	48
1989	24,084	16,175	67.2	8,894	1.82	2.71	3,861	20.95	15,527	96
1990	26,084	18,945	72.6	8,376	2.26	3.11	4,781	19.89	13,883	73
1991	30,855	25,939	84.1	9,116	2.85	3.38	6,981	16.86	12,808	49
1992	35,983	25,831	71.8	10,024	2.58	3.59	7,234	13.88	11,594	45
1993	33,665	27,267	81.0	10,234	2.66	3.29	9,799	10.60	9,040	33
1994	43,572	35,235	80.9	10,685	3.30	4.08	3,936	21.62	19,251	55
1995	37,412	29,519	78.9	11,007	2.68	3.40	7,164	15.30	14,034	48
1996	40,331	32,996	81.8	10,739	3.07	3.76	6,712	16.32	14,605	44
1997	28,287	20,980	74.2	11,199	1.87	2.53	9,687	13.28	12,394	59
Mean 1958-97	39,590	28,412	71.6	10,458	2.71	3.78	6,345	18.74	16,332	55
Mean 1988-97	34,437	26,497	76.5	9,962	2.65	3.46	6,594	16.84	13,847	55

DEFINITION OF COLUMNS

- Year - District yearly recorded data.
- Reservoir release to main canal (acre-feet) - Amount of water in acre feet released from Angostura Reservoir to the main canal. The average reservoir release from 1958 through 1997 was 39,590 acre-feet with the maximum of 56,041 acre-feet in 1959. Data from the district.
- Delivered to farms (acre-feet) - Amount of water in acre feet delivered to the farm units from main canal and laterals. Data from the district.
- Delivered to farm (percent efficiency) - The amount of water that was required to deliver to the farm versus the reservoir release. Delivered to farms column in acre-feet divided by the reservoir release.
- Irrigated Acres (acres) - Harvested cropland and pasture acreage. Data from the district.
- Delivered to Farms (acre-feet per acre): Delivered to farms divided by irrigated acres.
- Reservoir release to farms (acre-feet per acre): Reservoir releases divided by irrigated acres.
- Effective precipitation (acre-feet): Amount of effective precipitation assumed to be used by the crop in feet (estimated by Modified Blaney-Criddle) multiplied by irrigated acreage.
- Net irrigation consumptive use (inches): Amount of irrigation water in inches required by the crop to meet its needs for peak production. This number does not take into account irrigation efficiency or deep percolation needs. It is simply crop consumptive use minus effective precipitation. Estimated by Blaney-Criddle Method.
- Irrigation consumptive use (acre-feet): Amount of irrigation water required by the crop. Net irrigated consumptive use in feet multiplied by irrigated acres.
- On-Farm efficiency: The amount of water that was required by the crop versus the total volume applied. Net irrigation consumptive use column in acre-feet divided by the delivered to farms column in acre-feet.

b. Districts Water Demand for various crops

The District irrigated 10,234 acres in 1993 with the following crops and acreage percentage: alfalfa and pasture-hay 58 percent, corn 38 percent, wheat or small grains 3 percent, and beans 1 percent. Table 11 illustrates water demands for the various crops produced within the District boundaries based on the period of 1953-1997. Crop consumptive use, effective precipitation, and net irrigation consumptive use is estimated by the Modified Blaney-Criddle Method. See Appendix L for the Modified Blaney-Criddle Method monthly data.

Table 11 : Water demand for various crops

Crop	Crop consumptive use	Effective precipitation	Net irrigation consumptive use
Wheat	11.84 inches	5.07 inches	6.77 inches
Corn	19.95	5.81	14.13
Beans	17.58	4.87	12.71
Pasture	33.15	9.00	24.16
Alfalfa	30.50	8.29	22.20
Weighted	26.01	7.28	18.74

DEFINITION OF COLUMNS

- Crop: Crops grown on Angostura Project. In 1993 Alfalfa 50 percent of total irrigated acres, Pasture 8 percent, Corn (grain and silage) 38 percent, Beans 1 percent, Wheat and Oats 3 percent. Crop percentage from Angostura District.
- Crop Consumptive Use ((Crop Irrigation requirement (CIR))- The amount of water used by the crop in a given period. These numbers show from planting to harvest or end of season. Estimated by Modified Blaney-Criddle Method.
- Effective Precipitation: Amount of precipitation in inches used by the crop. This number was computed by the Modified Blaney-Criddle Method using 1953-1997 weather data.
- Net Irrigation Consumptive Use: Amount of irrigation water in inches required by the crop to meet its needs for peak production. This number does not take into account irrigation efficiency or deep percolation needs. It is simply crop consumptive use minus effective precipitation. Estimated by Modified Blaney-Criddle Method .

c. Consumptive Irrigation Requirements

Reservoir releases are based on water demand, which corresponds directly to climatic conditions (i.e., drier climatic conditions result in greater water demand and releases). Table 12 reflects monthly district irrigation water demand (releases from the Reservoir) based on the Modified Blaney-Criddle Method using average climatic conditions for the period of 1953-1997, and interpolated 1993 crop production and acreage (See Appendix L). The average weighted monthly net consumptive use (Crop Irrigation Requirements) for all crops is 18.74 inches (1.56 feet). Table 12 estimates irrigation of 12,000 acres (about full supply) and 10,000 acres (reduced supply based on 1988-1997 average) and shows a release requirement of 41,843 and 34,247 acre-feet per year, respectively, from the Reservoir. These release requirement estimates are based on the assumption that the delivered to farms system efficiency is 76 percent and the farmers of the District are irrigating with an on-farm efficiency of 60 percent. The system efficiency of 76.5 percent for the last 10 years of 1988-1987 and on-farm efficiency estimated by the Modified Blaney-Criddle Method of about 55 percent (See Table 10). The actual on-farm irrigation efficiency for the District is not known and needs to be taken into account when comparing the actual Reservoir releases from 1988-1997 and the release requirements shown in Table 12. See Appendix L for the Modified Blaney-Criddle Method output for the consumptive use data.

d. Improved Efficiency Water Savings

Table 12 "Average Monthly Crop Irrigation Requirements (CIR)" presents an average annual net irrigation consumptive use demand for years 1953 through 1997 of 18.74 inches with a full supply acreage of 12,218 acres.

1. Assume that an Improved Efficiency would increase system efficiency by 5% (Belle Fourche's R&B increased system efficiency by 10 % but not as good a system as Angostura). Therefore system efficiency goes from 76% to 81%. Block of water saved by pipe and lining is 18.74 inches multiplied by 12,218 Acres divided by 12 inches divided by .76 (this is 25,106 acre feet) minus 18.74 inches multiplied by 12,218 Acres divided by 12 inches divided by .81 (this is 23,217 acre feet)

WATER SAVED FROM INCREASED SYSTEM EFFICIENCY EQUALS ABOUT 1,900 ACRE-FEET

2. Assume by sprinkler irrigation, surge valves, and educational efforts on farm efficiency goes from 60% to 70%. (25,106 AF divided by .60 minus 25,106 divided by .70)

THEREFORE THE WATER SAVED FROM ON FARM EFFICIENCY INCREASE IS ABOUT 6,000 ACRE- FEET.

3. The water saved by doing both initiatives (system efficiency from 76% to 81% and on farm from 60% to 70%) is; 18.74 inches multiplied by 12,218 acres divided by 12 , divided by .76 divided by .60 (this is 41,843 acre-feet) minus 18.74 inches multiplied by 12,218 acres divided by 12, divided by .81 divided by .70 (this is 33,652 acre-feet).

WATER SAVED BY BOTH INITIATIVES EQUALS ABOUT 8,200 ACRE- FEET.

See Appendix V for water savings calculations and assumptions.

Table 12: Average Monthly Crop Irrigation Requirements (CIR)
(Note: Based on assumption of 12,000 and 10,000 acres irrigated and crop percentages of 1993)

Months	Average Crop Irrigation Requirements (CIR)		District Monthly Demand at full supply for 12,218 acres		District Monthly Demand at reduced supply for 10,000 acres	
	(inches)	(feet)	Present Conditions (AF)	Improved Efficiency (AF)	Present Conditions (AF)	Improved Efficiency (AF)
April	0.29	0.024	648	521	530	426
May	1.47	0.123	3,282	2,640	2,686	2,160
June	3.46	0.288	7,726	6,213	6,323	5,085
July	6.17	0.514	13,777	11,080	11,276	9,068
August	5.51	0.459	12,303	9,894	10,069	8,098
September	1.83	0.153	4,086	3,286	3,344	2,690
Total	18.74	1.562	41,843	33,652	34,247	27,543
AF/acre			3.42	2.75	3.42	2.75

DEFINITION OF COLUMNS

- Month: Irrigation season April 15 through September 30.
- Average Crop Irrigation Requirements (CIR): Monthly and annual average CIR (net irrigation consumptive use) for years 1953-1997 at 18.74 inches (1.56 feet). This is based on the Modified Blaney-Criddle Method average monthly weighted consumptive use for all crops (See Appendix L). This number does not take into account irrigation efficiency or deep percolation needs. It is simply crop consumptive use minus effective precipitation. This is based on weather data for years 1953 through 1997 and is an interpolated value using the cropping pattern based on 1993 crops and acreage percentage as follows: corn at 38 percent, beans at 1 percent, wheat or small grains at 3 percent, alfalfa at 50 percent, and pasture-hay at 8 percent. The District records show that the 1993 cropping pattern represent the present use and would probably be a good representation of the future conditions. The weather data (temperature and precipitation) would account for the annual difference in consumptive irrigation requirements.
- District Monthly Demand at full supply for 12,218 acres (Acre-Feet): Amount of water required to be released from Angostura Reservoir for District irrigation requirements is determined by multiplying the CIR (feet) by 12,218 acres irrigated dividing by 0.76 (system efficiency), and by 0.60 (assumed on-farm irrigation efficiency). For peak production of the crop the demand is estimated to be 41,843 acre-feet to meet the Districts full supply for 12,218 acres. This compares to the Districts 1958-1997 average reservoir release to the main canal of 39,590 acre-feet (Table 10). Improved Efficiency would increase system efficiency to 0.81 and on-farm to 0.70.
- District Monthly Demand at reduced supply for 10,000 acres (Acre-Feet): Amount of water required to be released from Angostura Reservoir for District irrigation requirements is determined by multiplying the CIR (feet) by 10,000 acres irrigated dividing by 0.76 (system efficiency), and by 0.60 (assumed on-farm irrigation efficiency). For peak production of the crop the demand is estimated to be 34,247 acre-feet for reduced supply of 10,000 acres. This compares to the Districts 10 year period of 1988-1997 average release to main canal of 34,437 acre-feet for about 10,000 acres (Table 10). Improved Efficiency would increase system efficiency to 0.81 and on-farm to 0.70.

e. Water Conservation

1. Irrigation delivery and on-farm irrigation: Initiated in 1994, the District and Reclamation have been developing a water conservation plan. Because the District's delivery system is relatively efficient (approximately 76 percent), conservation efforts are being focused at on-farm irrigation usage. The District maintains detailed records, within a 10-percent accuracy, of all water delivered through their system. The accuracy of delivery records is instrumental in identifying future water conservation measures. Some of the objectives developed by the District for the development of their water conservation plan include:

4. Work with NRCS and the Extension Service to provide educational information to farmers (e.g., newsletter). The information would include crop needs, and an understanding of soil, plant, and water relationships.

5. Promote or provide workshops on irrigation scheduling, soil probing, length of run requirements, and other irrigation practices.

6. Show, through education, that scheduling and developing improved water efficiencies can result in economic benefits which outweigh the increased cost of developing and maintaining a more efficient system.

7. Develop water conservation tools, such as a water operation model and water accounting spreadsheet.

The District recognizes the importance of water conservation and is working to improve both delivery and on-farm irrigation efficiency. Economic benefits must be realized in conjunction with water savings for water conservation efforts to be achieved.

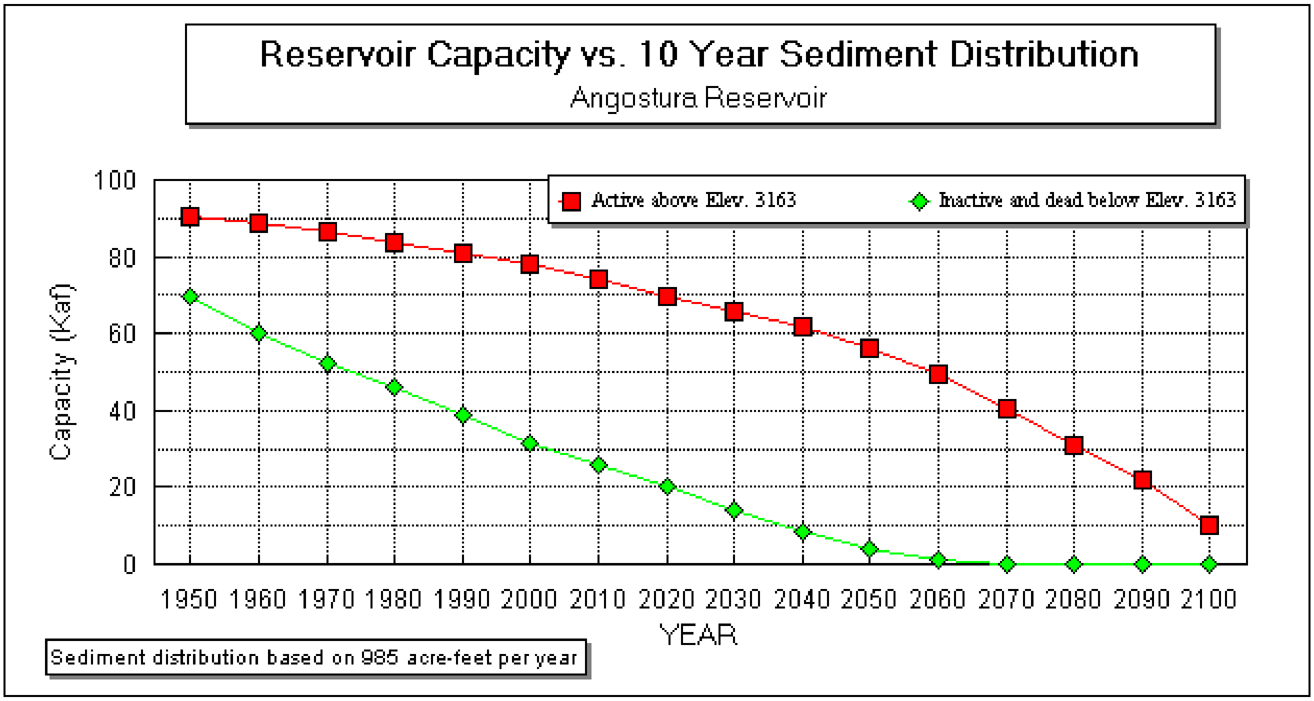
3. Sedimentation: Sedimentation of the Reservoir is a concern because of the on going loss of capacity in the Reservoir. The original surface area of the Reservoir in 1949 was 4,841 acres, and the capacity was 159,919 acre-feet at normal water surface elevation of 3187.2 feet (Top of active conservation). See Appendix E. The sedimentation rate of 1,700 acre-feet per year with an estimated useful Reservoir life of 50 years. The reservoir accumulated sediment would be about 85,000 acre-feet (1,700 acre-feet multiplied by 50 years) leaving a total Reservoir capacity of about 75,000 acre-feet in the year 2000 based on the original estimates.

Reclamation sedimentation surveys were completed in 1965 and in 1979. The 1979 survey shows the Reservoir with a surface area of 4,612 acres; a capacity of 130,768 acre-feet at elevation 3187.2 (top of active conservation); an active capacity of 82,443 acre-feet (between elevation 3163.0 and 3187.2) and dead and inactive storage of 48,325 acre-feet. The Reservoir has no designated exclusive flood control space, although surcharge capacity of 56,360 acre-feet, in conjunction with conservation storage, may be used to realize some flood control benefits. A total sediment accumulation of 29,151 acre-feet (1949 original capacity minus 1979 capacity), indicates an average annual sedimentation rate of 985 acre-feet; and a loss of about 18 percent from the original capacity (Reclamation, 1983). The September 1981 elevation-area-capacity table and curve, based on the 1979 sediment survey, are shown in Appendix E.

Appendix E shows the 1949, October 1966, September 1981 (Reclamation, 1983), and estimated 1997, 2042, and 2087 area capacities. The September 1981 area capacity is presently being used. A Reclamation program named DISSED was used to distribute sediment in the reservoir (Appendix I). This program estimated the 1997, 2042, and 2087 area capacities based on the 1979 sediment survey, which estimated accumulation of sediment at 985 acre-feet per year. A total volume of sediment accumulation in the Reservoir for the 93 year period 1949 to 2042 is estimated at 91,605 acre-feet; for the 138 year period 1949 to 2087 is estimated at 135,930 acre-feet, indicating a capacity loss of about 57 and 85 percent respectively. The Reservoir total capacity at elevation 3187.2 in the year 2042 would be 68,314 acre-feet (1949 capacity of 159,919 acre-feet minus 2042 sediment of 91,605 acre-feet) with active capacity of about 61,000 acre-feet (2042 capacity of 68,314 acre-feet minus inactive of 7,257 acre-feet). The Reservoir total capacity at elevation 3187.2 in the year 2087 would be 23,989 acre-feet all of it being in the active conservation pool with dead and inactive pool completely full of sediment. Figure 7 shows reservoir capacity versus a 10 year sediment distribution for years 1950 through 2100. The active conservation pool would be about 50,000 acre-feet with the inactive and dead pool being full of sediment by about the year 2060, which is about another 60 year effective life of the reservoir.

The fully effective life of any reservoir is the period of time during which sufficient reservoir capacity is available to provide all the benefits for which the reservoir is constructed. Benefits continue to accrue after the effective life, but at a continually reducing rate due to encroachment on reservoir area and capacity by sediment deposition. Reclamation customarily constructs only sufficient capacity in its reservoirs so that a tolerable irrigation shortage exists in the driest years. A shortage of 50 percent in any one isolated year is not unreasonable. The effective life of Angostura should be based on having a shortage of at least 33 percent in the maximum year.

Figure 7: Reservoir Capacity versus 10 year Sediment Distribution for years 1950-2100 (kaf)



a. Bottom Sediment Quality

Table 13 show a summary of comparison of median and range of trace-elements concentrations in the less than 62-micrometer fraction of the bottom sediment in the study area (See part 2- Water Quality: Attachment C for all samples). These samples were collected by the USGS in 1988, Ogalala Sioux Tribe in 1996, and USBR in 1997. The trace-elements were divided into six reaches in the study area; above the reservoir; in the reservoir; below the reservoir above Red Shirt; Cheyenne River at Red Shirt; Cheyenne River at Rapid Creek; and Cheyenne River at Cherry Creek. The concentrations of Arsenic, Boron, Copper, Lead, Mercury, Molybdeum, and Zinc generally increase from above the reservoir downstream to the Cheyenne River at Cherry Creek. Cadmium and Uranium are about the same from upstream to downstream, while Chromium, Selenium, and Vanadium show a decrease. All median concentrations fall within the Western Soils baseline range except for Arsenic at Cheyenne River at Cherry Creek; Lead at Cheyenne River at Rapid Creek and Cheyenne River at Cherry Creek; Molybdeum in the reservoir and Cheyenne River at Rapid Creek.

Table 13 : Comparison of trace-elements concentrations in the less than 62-micrometer fraction of the bottom sediment in the study area, (USGS, 1988; OST, 1996; USBR, 1997) and geochemical baseline for soils from the western United States
(Total concentrations in micrograms per gram. < is less than; -- is no data)

Element	Above Reservoir		In the Reservoir		Below Reservoir Above Red Shirt		Cheyenne River At Red Shirt		Cheyenne River At Rapid Creek		Cheyenne River At Cherry Creek		Western Soils [1]	
	Median	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Geometric Mean**	**Baseline Range [2]**
Arsenic	8.1	7.6- 11.0	7.2	5.1-16.4	10.8	6.2-21.7	6.5	4.9-7.0	15.9	15.9	104.3	104.3	5.5	1.2- 22
Boron	5.5	5.5	19.5	2.1- 27	5.5	1.2- 23	12.0	1.4-56.5	12.0	12.0	7.0	7.0	23	5.8- 91
Cadmium	<2.0	<2.0	1.45	1.3- 2.0	0.7	0.3- 2.0	1.9	0.6-2.0	0.5	0.5	1.9	1.9	--	--
Chromium	22.5	20- 64	25	21- 85	17.0	2.0- 72	15.9	10-35	14.0	14.0	12.0	12.0	41	8.5- 200
Copper	8.5	7.0- 23.0	26	20- 29	19.0	4.0- 28	16.0	12-24	24.0	24.0	19.0	19.0	21	4.9- 90
Lead	12.0	12- 55	35.5	19- 62	62.8	18- 167	21.0	17-25	116.2	116.2	137.5	137.5	17	5.2- 55
Mercury	<0.02	.02- .04	<0.10	.04-.10	<0.10	.02- .10	0.07	.02-.10	<.10	<.10	<.10	<.10	0.46	.0085-0.25
Molybdeum	<2.0	<2.0	6.6	2.0- 7.5	3.0	1.9- 6.9	3.4	2.0-14.7	4.7	4.7	3.9	3.9	0.85	0.18- 4.0
Selenium	0.95	0.6- 1.0	1.0	0.4- 1.9	0.9	0.3 -14	0.20	0.1-0.6	0.5	0.5	0.8	0.8	0.23	0.039- 1.4
Uranium	2.0	1.9- 2.0	2.1	2.1	2.1	1.9- 5.3	2.1	2.1	--	--	--	--	2.5	1.2- 5.3
Vanadium	38.5	31-110	44.5	25-140	30.0	11-200	31.6	19-67	24.0	24.0	21.0	21.0	70	18- 270
Zinc	49	39-96	96	59-110	71	24-317	54	40-58	91.0	91.0	63.0	63.0	55	17- 180

Source: Water quality samples from USGS 1988, OST 1996, and USBR 1997. See Appendix __ for all water quality samples.
[1]Modified from Shacklette and Boerngen, 1984.
[2]Range in which 95 percent of sample concentrations are expected to occur.

4. Angostura Unit Water Supply Analysis

Angostura Reservoir is the only reliable water supply source to the district and Cheyenne River below the reservoir. Return flows from irrigated lands in the district also contribute flows to the Cheyenne River in the area below the reservoir and Red Shirt. The historic inflow data adjusted for evaporation and precipitation from the period of 1953 through 1997 was used to develop runoff above the reservoir. Alternatives were analyzed by the Angostura Reservoir Annual Operation Plan (AGRAOP), which uses the River Operations Modeling System (ROMS). This model uses the inflow to show probable demands on the reservoir from the district for period of study 1998-2042 and analyzed reservoir end of month (EOM) content, EOM elevation, canal discharge and Cheyenne River discharge.

The four alternatives being analyzed in the EIS are as follows. Table 14 show the basic model criteria for each alternative. In abbreviated form, they are:

* The ***No Action Alternative.*** This alternative would entail no change in the water service contract with the Angostura District beyond those required by law, and no changes in water management at the reservoir.

* The ***Re-establishment of Natural Flows Below the Dam Alternative.*** As the title implies, this alternative would re-establish natural flows as much as possible in the Cheyenne River downstream of the dam.

* The ***Improved Efficiencies Alternative.*** This alternative would implement measures to save irrigation water and create a committee to advise on how the saved water would be used.

* The ***Reservoir Recreation and Fisheries Alternative.*** This alternative would give priority to recreational use and fisheries at the reservoir.

Table 14 - Angostura EIS Alternatives

AGRAOP Scenario Nnumbers	Alternatives AGRAOP Scenario number designated by irrigated acres and minimum reservoir elevation							
Period of Study 1998-2042	No Action		Re-establish of Natural Flows		Improved Efficiency		Reservoir Recreation	
	Irrigation Acres	Elevation Feet	Irrigation Acres	Elevation Feet	Irrigation Acres	Elevation Feet	Irrigation Acres	Elevation Feet
Natural			None	3157.2				
1	12,218	3163						
2	10,000	3163						
5							12,218	3170
6							10,000	3170
13					12,218	3163		
14					10,000	3163		
15					12,218	3170		
16					10,000	3170		
17					12,218	3175		
18					10,000	3175		
19					12,218	3184		
20					10,000	3184		

NOTE: - Scenario defined as model run completed for an Alternative
- District full supply at 12,218 acres.
- District reduce supply at 10,000 acres.
- Elevation 3163 feet at top of inactive and at District canal outlet.
- Elevation 3170 feet at minimum elevation of north boat ramp.
- Elevation 3175 feet at minimum elevation allows use of all eight boat ramps.
- Elevation 3184 feet allow a foot decrease in June, July, and August for recreation use and fish spawning.
- Scenario number 1 and 2 minimum reservoir elevation at 3163 feet, with target elevations December-October 3187.2 feet and November 3184 feet.
- Scenario number 5, 6, and 13 through 20 minimum reservoir elevation represent as above with target elevation December-May 3187.2 feet, June 3186 feet, July 3185 feet, and August-November 3184 feet.
- Scenario number 13 through 20 represent reservoir demand reduced about 8,200 acre-feet due to Improved Efficiency for canal and on-farm improvements.

a. Common Parameters for the AGRAOP model

The Angostura Reservoir model (AGRAOP) is used for the Angostura Contract Renegotiation Draft EIS alternatives. The AGRAOP model, created by Alan Mackichan of our Reclamation Billings Office, operates the Angostura Reservoir to meet the system demands from runoff and stored water and, if possible, the given end-month target elevations for the model. The model uses the 45 year historic 1953 through 1997 monthly inflow period of record. The future period of study begins in January 1998 and ends in December 2042 (to match 45 year historic data). This assumes that the historic monthly inflows will stay the same and the drought periods of 1961, 1977, and 1989 will occur in the future. If the demands are not met in the drought periods the model will compute a shortage. This is an indication of inadequate flows to meet the demands. In a month where the reservoir runs out of water, demand will be served in the following order. 1) evaporation and seepage loss, 2) District canal demands 3) instream flow requirement and Oglala Soiux Tribe delivery, and 4) wetland delivery. Area-capacity tables were developed for years of 1997 and 2042 (December) based on Reclamation's DISSED Program (Appendix I). The 1949 original area capacity was applied to Reclamation's DISSED Program to predict future sediment deposition in the reservoir. This program was developed to distribute sediment in large reservoirs by the Empirical Area Reduction method and follows the procedures outlined in the Reservoir Sedimentation Guideline (1982) and detailed in the Revision of the procedure to Compute Sediment Distribution in Large Reservoir (1962). The AGRAOP model has the capability of using these area-capacity tables to reflect the reduced capacity due to sediment accumulation of about 985 acre-feet per year.

The model will operate the reservoir at minimum reservoir active conservation storage at elevation of 3163 feet, which is at minimum canal operating level with target elevations December-October 3187.2 feet and November 3184 feet for the No Action Alternative Scenario number 1 and 2. A Reservoir Recreation Alternative with reservoir elevation of 3170 feet with conservation measures being taken to minimize drawdowns when pool drops below 3173 feet (scoping meetings comments from State of South Dakota Game, Fish, and Parks) with target elevation December through May at 3187.2 feet, June 3186 feet, July 3185 feet, and August-November 3184 feet for Scenario number 5 and 6. Improved Efficiency scenarios would save about 8,200 acre-feet due to canal efficiency and on farm improvements (See improved efficiency water saving section). The Improved Efficiency Scenario number 13 through 20 were selected to show a system efficiency increase from 76% to 81% and on farm efficiency from 60% to 70%. The Improved Efficiency target elevations are the same as Scenario number 5 and 6 with reservoir minimum elevation at 3163 feet (minimum canal operating level), 3170 feet (allow two out of eight boat ramps to be used), 3175 feet (allow all eight boat ramps used), and 3184 feet (recreation use and fish spawning).

Example of the AGRAOP model run using Reservoir Recreation Alternative Scenario number 5 (see table 15) showing the following model input data items. Table 16 show the model output which has a District irrigation demand of 12,218 acres and recreation minimum elevation of 3170 for future year 2006 (historic 1961 low flow year) and has shortages for the District. The model was revised to include the Ogalala Sioux Tribe irrigation, but the Tribe decided not to be included, so Tribal requirement and demand is zero.

Table 15, Model Input for Reservoir Recreation Alternative Scenario number 5:

- Initial Content (kaf) - (AGRRES) Angostura Reservoir minimum elevation of 3170 feet, maximum elevation at top of conservation of 3187.2 feet, Angostura Reservoir initial content based on December 1997 end of month content at 112,639 acre-feet, which is from the revised 1997 area-capacity table.
- End-Month Target Elev. (ft) - (AGRTGT) The target elevation for December through May at 3187.2 feet, June 3186 feet, July 3185 feet, and August-November 3184 feet.
- Evaporation Factors (feet) - (AGREVP) The reservoir evaporation rate is computed using Oral and Angostura weighted mean pan evaporation multiplied by .70 minus Angostura mean precipitation for the period 1948-1993. Table 4 show average monthly evaporation rate in feet and are input to the model and are applied to the monthly water surface area to calculate evaporation loss.
- Monthly inflow (kaf) - (AGRINF) The water supply to Angostura Reservoir and the project will be historic hydromet computed inflow to the reservoir adjusted for evaporation for the 45 year historic period of 1953-1997. The year 1953 is the first full calendar year of hydromet data.
- Monthly Seepage (kaf) - (AGRSPG) Angostura Dam monthly seepage of 200 acre-feet per month with an annual total of 2,400 acre-feet (gates leak about 3.3 cfs).
- Instrean flow req (kaf) - (AGRIFR) There are no instream flow requirements as needs are presently met below Angostura Dam by seepage past the radial gates, Fall River inflows to the Cheyenne River, and irrigation return flows.
- Canal Demand (kaf) - (CNLREQ) Canal requirements based on net irrigation consumptive use estimated by the Modified Blaney-Criddle Method based on weather data for years 1953 through 1997 and cropping pattern based on 1993 crops with acreage percentage as follows: corn at 38 percent, beans at 1 percent, wheat or small grains at 3 percent, alfalfa at 50 percent, and pasture-hay at 8 percent. The District records show that the 1993 cropping pattern represent the present use and would probably be a good representation of the future conditions. The weather data (temperature and precipitation) would account for the annual difference in consumptive irrigation requirements. Angostura Irrigation District acres irrigated at present full supply of 12,218 acres and reduced supply of 10,000 acres based on average of 1958-1997 (Table 10). The Angostura Irrigation District system efficiency based on Districts 10 year average of 1988 through 1997 delivered to farms of 76 percent (Table 10) and assumed on-farm efficiency of 60 percent. The irrigation demand is estimated by using the Crop Irrigation Requirement (CIR) of 1.56 feet (18.74 inches) estimated by the Modified Blaney-Criddle Method multiplied by the acres irrigated divided by the system efficiency (table 12). See Appendix M for monthly canal requirements in cfs units.
- Wetlands Demand (kaf) - (WETREQ) No wetland deliveries.
- Station Gain (cfs) - (OSTSGC) Ogalala Sioux Tribe station gain is the Red Shirt Table conveyance loss based on river losses in delivering irrigation water to Red Shirt, about 40 miles downstream of Angostura Reservoir. No water was delivered to Red Shirt under this Alternative.
- Tribal Demand (kaf) - (OSTREQ) Ogalala Siuox Tribe requirements for irrigation water. No water delivered under this Alternative.

Table 15: Angostura Reservoir Monthly Operations AGRAOP Input File

Reservoir Recreation Alternative, AGRAOP model input data for year 2006 (Historic=1961)

```
! AGRAOP V1.42      Probability: Fut
! Saved: Tue Jan 06 08:34:06 1998
!
! Initial Problem Parameters
!      Month  Year  #Yrs Probability Forecast
HEADER   1,    1998,   45, PROB:Fut  TITLE: "FN=Scen5-1998-2042,CIR for 12218 acres,Min.Elev.@3170.0"
!
! Angostura Reservoir - min, max elevation (ft), initial content (kaf)
AGRRES 3170.0, 3187.2, 112.6,
!
! End-Month Target Elev (ft)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct    Nov     Dec
AGRTGT 3187.20,3187.20,3187.20,3187.20,3187.20,3186.00,3185.00,3184.00,3184.00,3184.00,3184.00,3187.20,
!
! Evaporation Factors
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
AGREVF   0.000,  0.000,  0.000,  0.140,  0.168,  0.229,  0.380,  0.385,  0.248,  0.194,  0.090,  0.000,
!
! Monthly Inflow (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
AGRINF  1.4   1.3   1.8   1.1   1.5   1.4   4.1   2.4   0.5   1.3   1.2   1.0
!
! Monthly Seepage (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
AGRSPG    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,    0.2,
!
! Instream Flow Req (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
AGRIFR    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,
!
! Canal Demand (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
CNLREQ    0.0,    0.0,    0.0,    0.4,    2.9,   12.4,   12.6,   17.4,    3.6,    0.0,    0.0,    0.0,
!
! Wetlands Demand (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
WETREQ    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,
!
! Station Gain (cfs)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
OSTSGC      0,      0,      0,      0,      0,      0,      0,      0,      0,      0,      0,      0,
!
! Tribal Demand (kaf)
!        Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec
OSTREQ    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,    0.0,
```

Table 16, Model output for Reservoir Recreation Alternative Scenario number 5:

Angostura Reservoir

- Monthly Inflow (kaf and cfs) - Same as Table 15.
- Evaporation (kaf) - Evaporation loss from the reservoir. The model calculates the evaporation loss by using the average monthly evaporation rate in feet (Table 4) and applied to the monthly water surface area.
- Seepage (kaf) - Same asTable 15.
- River Release (kaf and cfs) - Computed monthly river release from Angostura Reservoir. These values do not include seepage.
- Canal delivery (kaf) - Computed monthly canal delivery based on canal requirements minus canal shortages.
- Canal Release (cfs) - Computed monthly canal release based on canal requirements minus canal shortages.
- Wetlands Deliv (kaf and cfs) - No wetland deliveries or MR&I releases.
- End-Month Targets (ft) - The model will try to keep the elevation of 3187.2 feet, if possible, during December through May and at 3186 feet in June, 3185 feet in July, 3184 feet in August through November for recreation and fisheries. This is a look ahead feature to the next target elevation that will enable the model to release water to the river forcing the reservoir to spill excess water in anticipation of high flows to keep the pool at or below target elevations or top of conservation (top of the spillway gates).
- End-Month Elevation (ft) - This is the end of month elevation based on estimated 1997 and 2042 area capacity tables. The model estimates the elevation by interpolating between the area-capacity tables.
- End-Month content (kaf) - This is the end of month content based on estimated 1997 and 2042 area capacity tables. The reservoir capacity is reduced by accumulation of about 985 acre-feet of sediment each year. The model estimates the elevation by interpolating between the area-capacity tables.
- Net change content (kaf) - The change in content from previous end of month content.
- Instrean flow req (kaf) (input item) - Same as Table 15.
- Tribal req at res (kaf) - Tribal requirements at the OST Reservation plus loss on the river below dam. Not used for this Alternative.
- River flow (kaf and cfs)- Computed flow in the Cheyenne River below the dam. This is computed as the sum of river releases from dam plus seepage losses.
- Spill (kaf) - This is releases to keep reservoir elevation below target elevation.

Ogalala Sioux Tribe

- Station gain (kaf) - Same as Table 15.
- Flow at diversion (kaf) - This is total flow at Red Shirt diversion. This is computed as river flow minus river losses.
- Tribal demand (kaf) - Same as Table 15.
- Tribal delivery (kaf) - Tribal total water delivery.
- Tribal shortage (kaf) - Tribal shortage computed as demand minus delivery.
- Basin outflow (kaf and cfs) - This is river flow below the Tribal diversion. This does not include any runoff from the drainage basin below the dam. This is flow that the model estimated that may be there from the reservoir.

Demand and Delivery

- Canal demand (kaf) - Same as Table 15.
- Canal delivery (kaf) - District total water delivery.
- Canal shortage (kaf) - District shortage computed as demand minus delivery.
- Wetlands Demand, Deliv, and shortage not used.

Table 16: Angostura Reservoir Monthly Operations AGRAOP Output File

Reservoir Recreation Alternative, AGRAOP model output data for year 2006 (Historic=1961)

AGRAOP V1.42 Run: 05-Apr-1999 14:30
FN=Scen5-1998-2042,CIR for 12218 acres,Min.Elev.@3170.0

ANGOSTURA RESERVOIR MONTHLY OPERATIONS

Angostura Reservoir   Initial Content   46.1 kaf   Operating Limits: Max 104.7 kaf, 3187.20 ft.
Min 43.9 kaf, 3170.00 ft.

	2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Monthly Inflow	kaf	1.4	1.3	1.8	1.1	1.5	1.4	4.1	2.4	0.5	1.3	1.2	1.0	19.0
Monthly Inflow	cfs	23	23	29	18	24	24	67	39	8	21	20	16	
Evaporation	kaf	0.0	0.0	0.0	0.4	0.5	0.6	1.0	1.0	0.6	0.5	0.2	0.0	4.8
Seepage	kaf	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.4
River Release	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River Release	cfs	0	0	0	0	0	0	0	0	0	0	0	0	
Canal Delivery	kaf	0.0	0.0	0.0	0.4	2.9	5.0	2.9	1.3	0.0	0.0	0.0	0.0	12.5
Canal Release	cfs	0	0	0	7	47	84	47	21	0	0	0	0	
Wetlands Deliv	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands Deliv	cfs	0	0	0	0	0	0	0	0	0	0	0	0	
End-Month Targets	ft	3187.20	3187.20	3187.20	3187.20	3187.20	3186.00	3185.00	3184.00	3184.00	3184.00	3184.00	3187.20	
End-Month Elevation	ft	3171.26	3171.71	3172.34	3172.39	3171.63	3169.96	3169.99	3169.97	3169.88	3170.14	3170.47	3170.80	
End-Month Content	kaf	47.3	48.4	50.0	50.1	48.0	43.6	43.6	43.5	43.2	43.8	44.6	45.4	
Net Change Content	kaf	1.2	1.1	1.6	0.1	-2.1	-4.4	0.0	-0.1	-0.3	0.6	0.8	0.8	-0.7
Instream Flow Req	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tribal Req @ Res	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
River Flow	kaf	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.4
River Flow	cfs	3	4	3	3	3	3	3	3	3	3	3	3	
Spill	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Ogalala Sioux Tribe	2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Station Gain	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flow @ Diversion	kaf	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.4
Tribal Demand	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tribal Delivery	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tribal Shortage	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basin Outflow	kaf	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.4
Basin Outflow	cfs	3	4	3	3	3	3	3	3	3	3	3	3	

Demand and Delivery	2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Canal Demand	kaf	0.0	0.0	0.0	0.4	2.9	12.4	12.6	17.4	3.6	0.0	0.0	0.0	49.3
Canal Delivery	kaf	0.0	0.0	0.0	0.4	2.9	5.0	2.9	1.3	0.0	0.0	0.0	0.0	12.5
Canal Shortage	kaf	0.0	0.0	0.0	0.0	0.0	7.4	9.7	16.1	3.6	0.0	0.0	0.0	36.8
Wetlands Demand	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands Deliv	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetlands Shortage	kaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

b. AGRAOP Model Analysis

This analysis showed that the average annual EOM content was reduced from historic conditions (112,100 acre-feet) to future years 1998-2042 by about 28% to 43% (81,100 to 63,800 acre-feet - 13,300 for Re-establishment) depending on the alternative due to sediment deposition in the reservoir. The average annual EOM elevation increased from about 0% to 6% (3179.8 to 3184.9 feet - 3158.4 feet for Re-establishment) over the study period. River release is increased from historic conditions (59.9 cfs) by about 1% to 48% (60.2 to 88.8 cfs - 120.7 cfs for Re-establishment) depending on the alternative. Average canal release is reduced from historic conditions by about 0% to 55% (55.1 to 25 cfs - no canal release for Re-establishment) depending on the alternative. Highest annual irrigation shortages for future years 1998-2042 is about 0% to 75% (0 to 37,000 acre-feet) depending on the alternative. See Attachments H through P for more details. Table 17 show the analysis of the AGRAOP model results for EOM content, EOM elevation, river release, canal release, and the highest annual shortage for each alternative.

Table 17: Angostura Unit Water Supply Analysis

Alternative	Average Irrigation (acres)	Minimum Reservoir Elevation (feet)	EOM Content (kaf)	EOM Elevation (feet)	River Release (cfs)	Canal Release (cfs)	District Highest Annual Shortage (cfs)
Historic	10,460	3163	112.1	3179.8	59.9	55.2	39.4
No Action	12,218	3163	65.9	3180.3	60.2	55.1	32.0
No Action	10,000	3163	71.7	3182.1	68.4	46.4	6.0
Re-establishment	0.0	3157.2	13.3	3158.9	120.7	0.0	N/A
Improved Efficiency	12,218	3163	72.0	3182.2	68.9	45.7	5.0
Improved Efficiency	12,218	3170	68.9	3181.5	70.6	44.7	25.0
Improved Efficiency	12,218	3175	70.1	3181.9	71.5	43.6	28.0
Improved Efficiency	12,218	3184	81.0	3184.8	86.1	27.8	31.0
Improved Efficiency	10,000	3163	76.7	3183.6	76.3	37.7	0.0
Improved Efficiency	10,000	3170	72.8	3182.6	77.3	38.0	3.0
Improved Efficiency	10,000	3175	73.4	3182.9	78.0	36.8	17.0
Improved Efficiency	10,000	3184	81.1	3184.9	88.8	25.0	24.0
Reservoir Recreation	12,218	3170	63.8	3180.0	62.3	53.5	37.0
Reservoir Recreation	10,000	3170	68.6	3181.4	70.0	45.3	27.0

5. REFERENCES CITED

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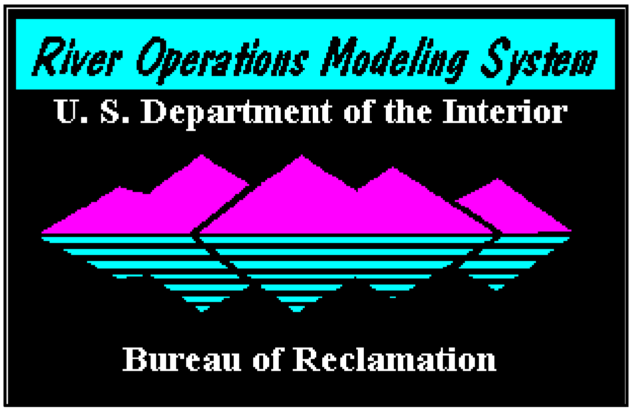
River Operations Modeling System

Help File and User Guide



AGRAOP

Angostura Reservoir

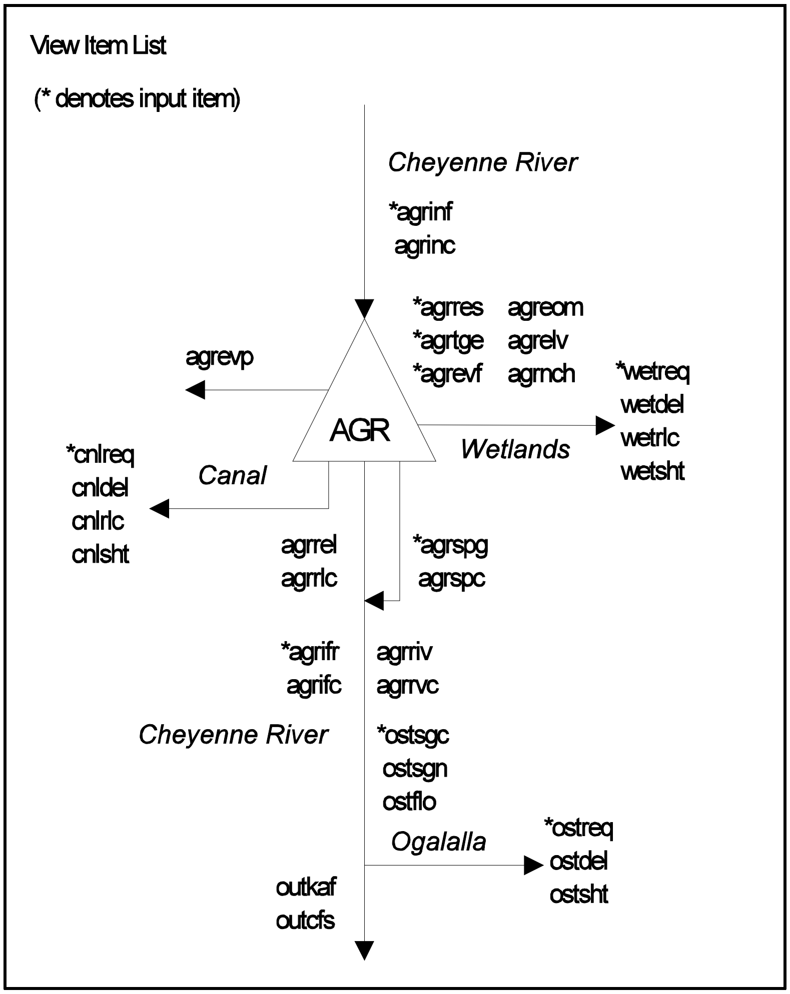
Version 1.41, 17-Dec-1997

AGRAOP Help Contents

The following Help Topics are available:

For Help on Help, Press F1

System Diagram



Algorithm

AGRAOP operates the model by attempting to meet the system demands from runoff and stored water and, if possible, the given end-month target elevations for the model.

AGRAOP uses target elevations rather than target contents because Angostura Reservoir is accumulating silt at a significant rate. While the elevation of the dam crest and the outlet works remain constant, the content at each elevation is constantly declining. See Data Tables for further discussion of how the model deals with this issue.

The hydrology algorithm uses an implied priority scheme which is, from lowest to highest,:

(1) Target elevations. This is considered to be operational convenience, and is useful in forcing the reservoir to spill excess water in anticipation of high inflows.

(2) Diversion demands and instream flow requirements. These are considered to be contractual obligations, and are more important than meeting the targets.

(3) Reservoir constraints. A reservoir cannot release water it doesn't have, and it cannot retain water above the dam crest. These are absolute constraints which may not be violated under any circumstances.

AGRAOP does not require target elevations in any particular month, as long as the targets are spaced no more than 12 months apart.

The time interval between targets is called a "Lookahead Period", and is the basis for the hydrology computations. The computational goal in each lookahead period is to look at where the reservoir starts and where it should end, sum the inflows and demands, and schedule the river releases so that (if the total outflow is more than the total demand) the river flows will be as uniform as possible during the period while honoring any min/max constraints. If the inflow is insufficient to meet the demands and the target, the target is ignored and the demands are met until the the reservoir runs out of water (defined as the minimum operating elevation).

In a month where the reservoir runs out of water, demands will be served in the order:

(1) evaporation and seepage losses
(2) canal demand
(3) instream flow requirement and Ogalala Sioux Tribe delivery
(4) wetlands delivery.

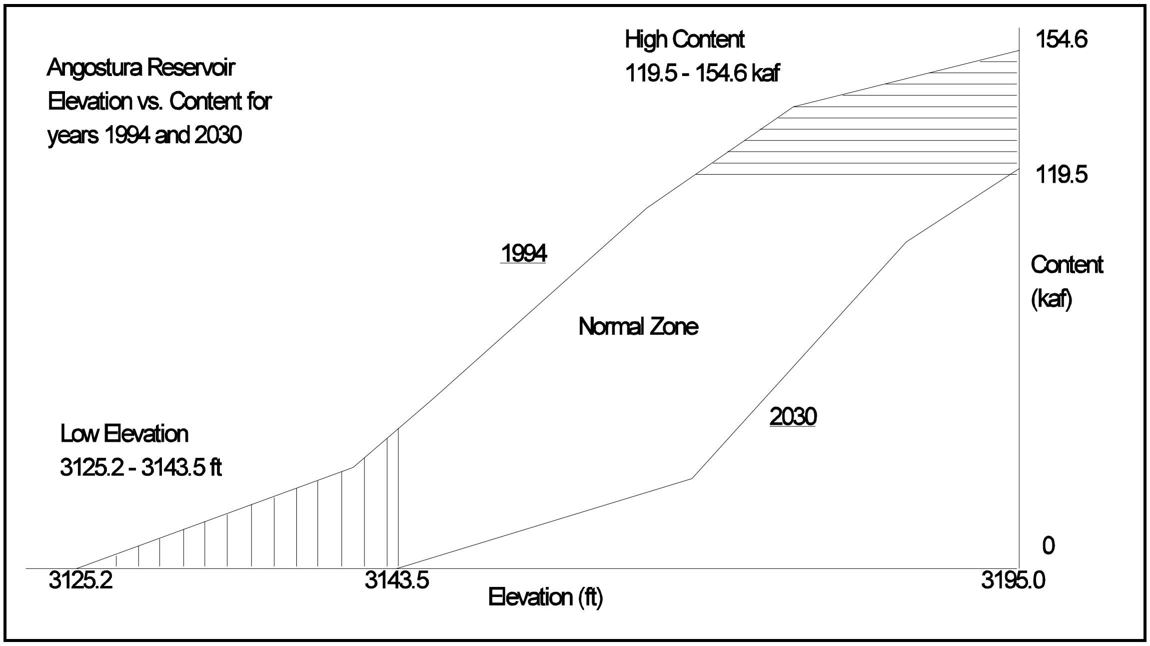
The minimum river flow below the dam is determined as the larger of (a) the IFR requirement, or (b) sufficient release to meet the Ogalala demands downstream. However, if the Ogalala demand is zero the release is determined solely by the IFR demand and the model makes no attempt to make up any station losses below the dam.

Data Tables

Angostura Reservoir is accumulating silt at a significant rate, so the usual time-independent tables for Area/Content/Elevation computation are not valid for this model. Instead, AGRAOP uses a pair of linear interpolation tables to perform time-dependent lookup computations. One of the tables is valid for the year 1994, the other is the projected table for the year 2030.

Note: The model will produce valid results only between January of the first table year and December of the last table year. However, the years (and the specific values that follow in the discussion below) are entirely contained in the table agr.tbl which lives in the same directory as the program executable agraop.exe. The methodolgy described below is written into the program code, but the table is an ASCII text file which can be changed or replaced by the user;.

The adjacent figure illustrates the relationship between elevation and content; there is a similar relationship between elevation and area.



Normal Zone

For elevations between 3143.5 (the anticipated silt level for 2030) and 3195.0 (the end of the table), the technique for computing the content from the elevation is to (1) interpolate a January 1994 content on the 1994 table, (2) interpolate a December 2030 content on the 2030 table, and (3) interpolate between the two values to get the content for the month in question.

For contents from 0 to 119.5 kaf (the maximum content for 2030), the procedure is to interpolate a January 1994 elevation, a December 2030 elevation, and then interpolate between the two values to get the elevation for the month in question.

Low Elevation Zone

For elevations between 3125.2 and 3143.5, the technique for computing content is to (1) interpolate by month along the 0 content line to determine the minimum elevation for the month in question, (2) interpolate along the 3143.5 elevation to get a content for the month in question at that elevation, and (3) interpolate between the two (elevation, content) pairs to find the content at the given elevation.

High Content Zone

For contents above 119.5 kaf, the technique for computing elevation is to (1) interpolate by month along the elevation 3195.0 line to determine the maximum content for the month in question, (2) interpolate along the 119.5 kaf line to determine the elevation for the month in question at that content, and (3) interpolate between the two (elevation, content) pairs to find the elevation at the given content.

The computations for Elevation - Area are analogous to the Elevation - Content computations; simply replace the word "content" with "area".

Data Items

This section contains the details of the data items used by the model.

Input Data

List of data items as they must appear in the input file.

Data Overview

Road map of the data items.

Data List

Complete data definitions, in the order they appear in the Overview.

Input Data

These are the input items for the AGRAOP model, ordered as they must appear in the input file.

HEADER	Standard header record
AGRRES	Angostura Reservoir constraints
AGRTGT	Target elevations (ft)
AGREVF	Evaporation factors (ft)
AGRINF	Monthly inflow (kaf)
AGRSPG	Monthly seepage (kaf)
AGRIFR	Instream flow requirement below dam (kaf)
CNLREQ	Irrigation canal requirement (kaf)
WETREQ	Wetlands diversion reuirement (kaf)
OSTSGC	Station gain below Angostura (cfs)
OSTREQ	Ogalala Sioux Tribe demand (kaf)

Data Overview

This list shows the data items used by the model, in order as they appear in the next section.

agrres	Angostura Reservoir constraints
agrtge	Target elevations (ft)
agrevf	Evaporation factors (ft)
agrevp	Evaporation loss (kaf)
agreom	End-month content (kaf)
agrelv	End-month elevation (ft)
agrnch	Net change in content (kaf)
agrinf	Monthly inflow (kaf)
agrinc	Monthly inflow (cfs)
agrspg	Monthly seepage (kaf)
agrspc	Monthly seepage (cfs)
agrifr	Instream flow requirement below dam (kaf)
agrifc	Instream flow requirement below dam (cfs)
agrrel	Dam release (kaf) - Excluding seepage
agrrlc	Dam release (cfs) - Excluding seepage
agrriv	River flow below dam (kaf)
agrrvc	River flow below dam (cfs)
cnlreq	Irrigation canal requirement (kaf)
cnldel	Irrigation canal delivery (kaf)
cnlrlc	Irrigation canal delivery (cfs)
cnlsht	Irrigation canal shortage (kaf)
wetreq	Wetlands diversion reuirement (kaf)
wetdel	Wetlands diversion delivery (kaf)
wetrlc	Wetlands diversion delivery (cfs)
wetsht	Wetlands shortage (kaf)
ostsgc	Station gain below Angostura (cfs)
ostsgn	Station gain below Angostura (kaf)
ostflo	River flow at Ogalala diversion (kaf)
ostreq	Ogalala demand (kaf)
ostdel	Ogalala delivery (kaf)
ostsht	Ogalala shortage (kaf)
outkaf	Basin outflow (kaf)
outcfs	Basin outflow (cfs)

Data List

The following paragraphs provide detailed definitions of the data items used by the AGRAOP model. They are presented in the same order as in the previous topic Data Overview.

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agrres

Defines the minimum operating elevation, maximum operating elevation, and the initial content of Angostura Reservoir, in kaf.

Minimum operating elevation is the level below which the reservoir will not release water. This value is constant for the entire period of study.

Maximum operating elevation is the level above which the reservoir will not retain water. This value is constant for the entire period of study.

Initial content is the content at the beginning of the first month of the study.

Note: These constraints differ from the usual content-based constraints because of the siltation problem at Angostura. See **Algorithm** and **Data Tables** for further discussion.

---

agrtge

Defines the desired elevation of Angostura Reservoir at the end of the specified months, in feet. A value of -1 means "don't care."

Targets are generally placed at points in time where the operation changes (eg, from drawdown to fill), but intermediate targets can be used as a method of refining the operations.

Targets must be spaced at intervals of no more than 12 months.

See also **Algorithm** and **Data Tables** for discussion of the time dependence of the content/elevation relationship.

---

agreom

Computed Angostura content at the end of each month, in kaf.

---

agrevf

Monthly evaporation factors (ie, feet of evaporation per month). When multiplied by the surface area of the average content for the month, the result is evaporation in acre-feet which the model then multiplies by .001 to get **agrevp** in kaf. The surface area of the average content is computed using the content-area table **agr.tbl**.

---

agrevp

Angostura monthly evaporation in kaf. Computed as the surface area of the average content for the month times the evaporation factor **agrevf** and divided by 1000.

Note that for this model, the relationship between content and surface area is a function of time. See also **Algorithm** and **Data Tables**.

---

agrnch

Computed net change in content, in kaf. These values are computed as end-month content **agreom** less begin-month content.

---

agrelv

Computed elevation of Angostura Reservoir at the end of each month, in feet. These values are computed from the end-month contents **agreom** by using the content-elevation table **agr.tbl**.

Note that for this model, the relationship between content and elevation is also a function of time. See also **Algorithm** and **Data Tables**.

agrrel

Computed monthly river release from Angostura Reservoir, in kaf. These values do **not** include seepage. The sum of this release and the seepage **agrspg** give the river flow **agrriv** below the dam, which should equal at least as much as the instream flow requirement **agrifr**.

agrrlc

Computed monthly river release from Angostura Reservoir, in cfs. These values do **not** include seepage. The values are computed by converting the **agrrel** values from kaf to cfs.

agrinf

Monthly inflow to Angostura Reservoir, in kaf. This is the only inflow to the reservoir.

agrinc

Monthly inflow to Angostura Reservoir, in cfs. These values are computed by converting the **agrinf** values from kaf to cfs.

agrspg

Monthly seepage from Angostura Reservoir in kaf. These values, plus the river release **agrrel**, equal the river flow **agrriv**.

agrspc

Monthly seepage from Angostura Reservoir, in cfs. These values are computed by converting the **agrspg** values from kaf to cfs.

agrifr

Minimum flow required in the Cheyenne River below Angostura Reservoir, in kaf. The sum of river releases **agrrel** and seepage losses **agrspg** should be at least as great as these requirements.

agrifc

Minimum flow requirement in the Cheyenne River below Angostura Reservoir, in cfs. These values are computed by converting the **agrifr** values from kaf to cfs.

agrriv

Computed flow in the Cheyenne River below the dam, in kaf. These values are computed as the sum of river releases from the dam **agrrel** plus seepage losses **agrspg**. Except in case of a water shortage, these values should be at least as great as the instream flow requirement **agrifr**.

agrrvc

Computed flow in the Cheyenne river below the dam, in cfs. These values are computed by converting the **agrriv** values from kaf to cfs.

cnlreq

Monthly canal diversion requirements, in kaf. The diversion is from the reservoir, and is not part of the dam release **agrrel**.

cnldel

Computed monthly canal delivery, in kaf. This will never exceed the requirements **cnlreq**, and will only be less if there is a shortage of water.

cnlrlc

Computed monthly canal release, in cfs. These values are computed by converting the **cnldel** values from kaf to cfs.

cnlsht

Canal shortage, in kaf. Computed as demand **cnlreq** less delivery **cnldel**.

wetreq

Wetland maintenance requirements, in kaf. The diversion is from the reservoir, and is not part of the river release from the dam **agrrel**.

wetdel

Computed wetland deliveries, in kaf. This will never exceed the requirements **wetreq**, and will only be less if there is a water shortage.

wetrlc

Computed wetland deliveries, in cfs. These values are computed by converting the **wetdel** values from kaf to cfs.

wetsht

Wetlands shortage, in kaf. Computed as **wetreq** less **wetdel**.

ostsgc

Station gain below Angostura, in cfs. Input item, may be negative to represent losses in the 40-mile reach to the Ogalala Sioux Tribe.

ostsgn

Station gain below Angostura, in kaf. Computed by converting **ostsgc** to kaf units.

ostflo

River flow above the Ogalala diversion, in kaf. Computed as the sum of river flow below Angostura **agrriv** and station gain below the reservoir **ostsgn**.

ostreq

Ogalala Sioux Tribe demand, in kaf.

ostdel

Ogalala Sioux Tribe delivery, in kaf. Computed as the smaller of **ostflo** or **ostreq**.

ostsht

Ogalala Sioux Tribe shortage, in kaf. Computed as demand **ostreq** less delivery **ostdel**.

outkaf

Basin outflow, in kaf. This is the river flow below the Ogalala diversion, computed as flow above the diversion **ostflo** less the diversion **ostdel**.

outcfs

Basin outflow, in cfs. Computed by converting **outkaf** to cfs units.

Calibration of Angostura Reservoir AGRAOP Model

The following is an example of the Angostura Reservoir Annual Operation Plan (AGRAOP) input file data using the River Operations Modeling System (ROMS). The model input file consist of historic data for the years 1953 through 1997 from the Hydromet information obtained from the Bureau of Reclamation (Reclamation) Regional Office, Billings, MT. See table 1 for the model output file for the year 1953.

- **Monthly Inflow (kaf) -** The Hydromet computed inflow data for July of 1958 was corrected (4.2 acre-feet difference). Computed inflows for October 1966 and September 1981 were adjusted for the 1966 and 1981 area-capacity tables. The Hydromet computed inflows were adjusted for net evaporation by a basic program called MODINF developed by the regional office in Billings, MT.
- **Evaporation Factors (Feet) -** The 1949 to 1970 Angostura Reservoir monthly pan evaporation was used for May through October (NOAA Technical Report NWS 34) and for April and November during 1953 to 1970 used estimated pan evaporation at Rapid City (NOAA Technical Report NWS 34). For the years 1971 through 1993, May through September, pan evaporation was used from Oral, SD, about eight miles east of the reservoir. This data was weighted to estimate the average pan evaporation for the period of 1949 through 1993. The monthly precipitation for the years 1948 through 1993 was from the weather station at Angostura Dam. Reservoir was assumed to be iced over for the months of December through March. Monthly net evaporation is calculated by the pan evaporation multiplied by a factor of 0.70 to estimate free water surface (FWS) lake evaporation minus precipitation.
- **Evaporation (kaf) -** Reservoir evaporation is estimated by net evaporation multiplied by the reservoir EOM area from the area-capacity table.
- **Seepage (kaf) -** For calibration purpose seepage was not included. Assume seepage is part of the river discharge.
- **River Release (kaf) -** Included in the instream flow requirement.
- **Canal Delivery (kaf) -** Included in the instream flow requirement.
- **Wetlands Delivery (kaf) -** For calibration purpose used for gate losses as these losses do not show up historically at the Cheyenne River below Angostura Dam gage.
- **End-Month Targets (Feet) -** For calibration purpose used maximum elevation of 3195.0 feet.
- **Instream Flow Requirements (kaf) -** For calibration purpose this includes Hydromet monthly total discharge from the Angostura Reservoir including river, canal and hydro power discharge.

Figure 1 shows the adjusted inflow used in the AGRAOP model.

Figure 2 shows the Angostura Reservoir end of month contents comparing the computed AGRAOP data versus the historic data for the years 1953 through 1997 using the 1949, October 1966, and the present September 1981 area-capacity tables. The comparisons are excellent which gives a very good confidence of the model.

Figure 3 shows the end of month difference vary about plus or minus 200 acre-feet between historic versus the AGRAOP model.

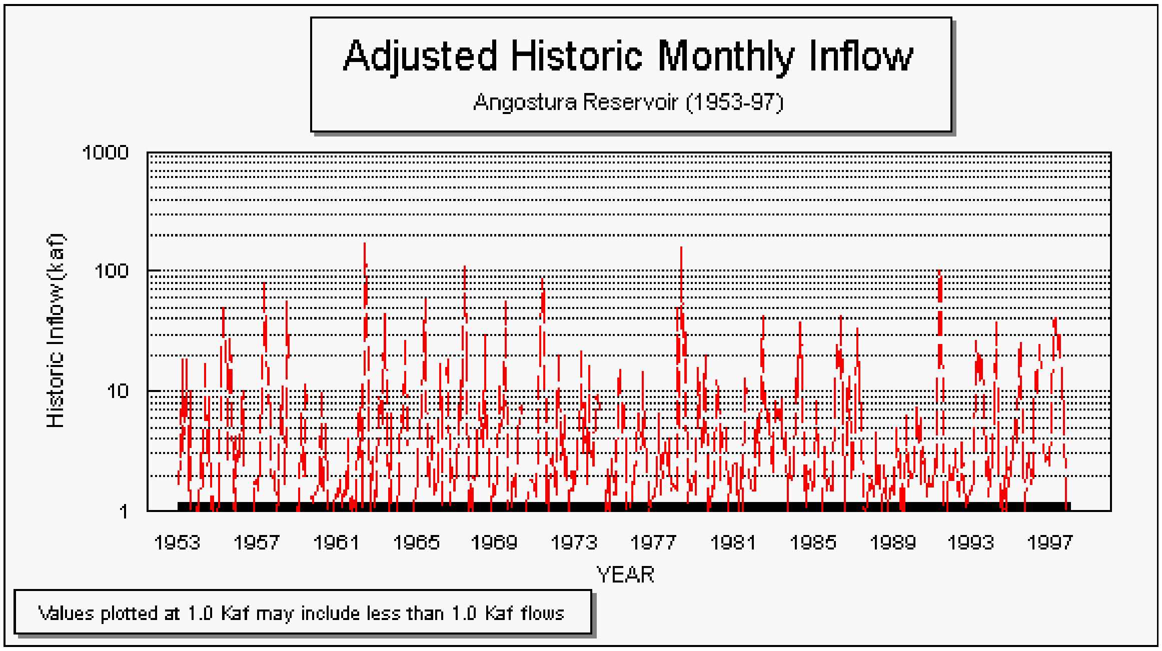


Figure 1

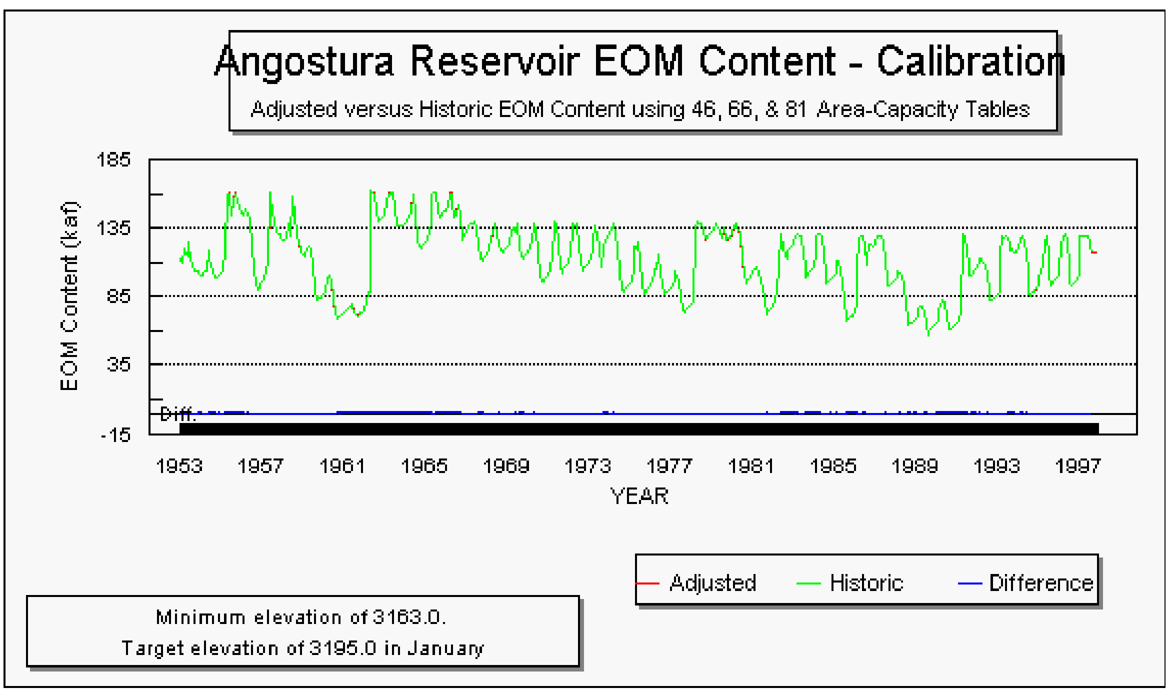
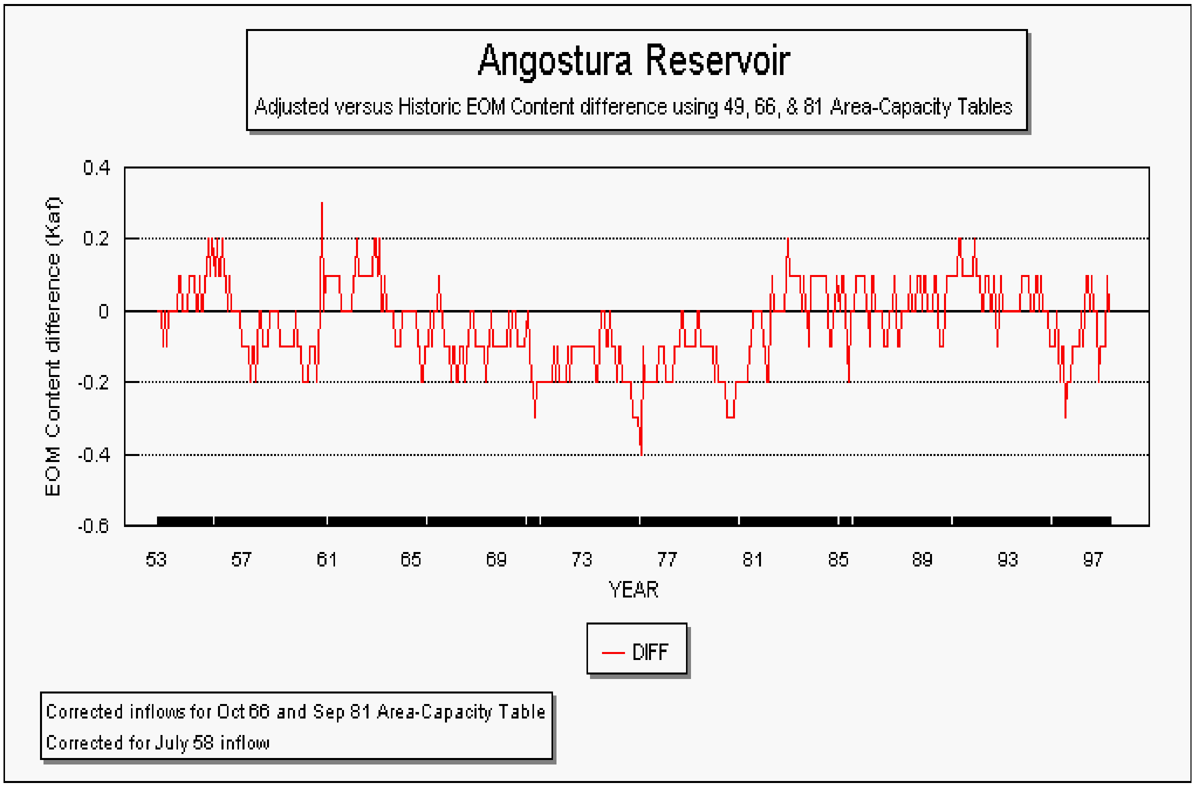


Figure 2

Figure 3



Angostura Reservoir
Adjusted versus Historic EOM Content difference using 49, 66, & 81 Area-Capacity Tables
0.4
0.2
0
-0.2
-0.4
-0.6
EOM Content difference (Kaf)
53
57
61
65
69
73
77
81
85
89
93
97
YEAR
DIFF
Corrected inflows for Oct 66 and Sep 81 Area-Capacity Table
Corrected for July 58 inflow