Angostura Irrigation District
Contract Renewals

South Dakota

Angostura Contract Renewals
Water Quality
Impact Assessment

March 27, 1999

Appendix T-1

Appendix T-2

Angostura Contract Renewals - Water Quality Impact Assessment

This impact assessment will focus on 2 aspects of the Angostura Unit. The first comparison will be based on the possible changes in eutrophication potential in Angostura . The second set of comparisons will be based on salt budgets, both in the reservoir and downstream. This will include TDS/EC effects or, more accurately, differences among the various alternatives. Other water quality measures, including trace elements, organics, and sediment, will be addressed qualitatively.

Methodology

The reservoir eutrophication effects will be evaluated based on the morphometric changes and their influence on a eutrophication index. The eutrophication potential will be based on an index of the areal phosphorus loading calculated as its ratio to Vollenweider's critical phosphorus loading (Rast and Lee, 1978):

$$L_c(P) = [P]_c \cdot q_s(1+\{\tau_\omega/q_s\}^{1/2}),$$

where: $[P]_c$ = critical spring phosphorus concentration (= 10 μg/L),

τ_ω = hydraulic residence time (= volume/inflow volume [year]),

q_s = hydraulic loading (= $\bar{z}$ / τ_ω [meters per year]),

$\bar{z}$ = mean depth (volume/area [meters]). The AGRAOP output files contain the reservoir volume, inflows, and outflows. The area, which is not included in the AGRAOP output, was computed using a 5th degree polynomial regression relationship developed from the area-capacity data based on the 1997 sediment adjustment. The regression relationship between water surface area and total reservoir water depth (actually, the height of the water surface above the streambed) is summarized in Figure 1. The depth was computed from the water surface elevation in the AGRAOP output by subtracting the sediment surface from the 1997 sediment study. As can be seen from Figure 1, the regression shows an excellent fit to the measured area. The error in the fitted data amounts to between 2 acres and 65 acres in the regression. The larger error (residual) is at elevation 3185, which is 7.2 feet below the maximum water surface elevation. The smaller residual occurs at the elevations near the reservoir bottom. The average residual over the range of data shown on Figure 1 is 19 acres. The acreages, volumes,

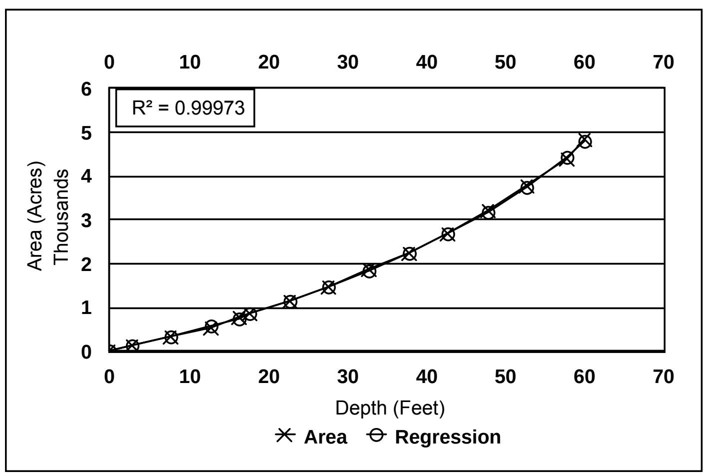

Figure 1: Regression of Angostura Reservoir surface area on water depth near the dam

and discharges were converted to metric equivalents for the calculation of the eutrophication indices. The eutrophication index is simply the ratio of the annual areal phosphorus load to the critical areal phosphorus load.

Another reservoir comparison is based on a running flow-weighted average TDS concentration in the reservoir. The number of entries in the running average is based on the hydraulic residence time (τ_{ω}) calculated in the previous analysis. The residence times range from 2 months to 11 months, as will be discussed later. The inflow volume and TDS are multiplied and summed over the number of months equivalent to the hydraulic residence time and divided by the total flow over the period. Monthly averages were also calculated for the period of the AGRAOP simulations from 1998 through 2042.

The downstream comparison will be based on a basin-wide salt budget analysis developed from regression analysis of the historic flow (Q), EC, and TDS data and the TDS data for the reservoir described above. The regression relationships for flow between gages on the mainstem of the Cheyenne River are shown in Table 1. The EC/Q and TDS/EC are presented elsewhere. Three of the four regressions in Table 1 are very good, *i.e.* $r^2 > 0.75$ (or 75%). The one poor regression relationship is the one between the flows at the Wasta and Buffalo Gap gage. This would indicate that side tributaries have a somewhat significant effect on the flow at the Wasta gage. Rapid Creek empties into the Cheyenne River between the two gages and provides significant flow to the river reach. The relationships will adjusted for the tributary flows and the salt loadings in evaluating the various alternatives based on the AGRAOP output.

Table 1. Summary of 1979-80 Regressions of flow between gages

Sites	b_1	b_0	r	p > r	r^2
Buffalo Gap on Dam Gage	0.9082	62.4920	0.993	<0.01	0.986
Wasta on Buffalo Gap	1.7932	32.1767	0.615	<0.01	0.379
Plainview on Wasta	1.7252	27.6510	0.903	<0.01	0.816
Cherry Creek on Plainview	1.0727	0.8416	0.987	<0.01	0.974

The key tributaries below Angostura Dam, the Fall River and Beaver Creek, were also included in the salt balance. These tributaries contribute the majority of the flow between the dam and the lower end of the AID when there is no release from the dam. This is an important consideration in the impact assessment. Return flows were not explicitly estimated, but are included in a gain-loss term calculated as the difference in flow between Angostura Dam and the lower end of the AID. This gain-loss term would include more than just return flows from the AID. It would also include tributary ground water and return flows from non-Project irrigation applications.

In evaluating both the regression for flow between the dam and Buffalo Gap, it seemed that there were differences in the ungaged gains that were related to flow. In many cases that flows were high, the gains were negative, *i.e.* they were losses. Because of this, a set of regressions were developed based on the estimated ungaged gains. These regressions are shown in Table 2 along with the original regression from Table 1. The original regression explained 98.6 percent of the variation in flow at the gage near Buffalo Gap. The revised regressions separately explain over 99 percent of the variation in the flow at the Buffalo Gap gage. The overall estimate developed from the pair of regressions should therefore explain over 99 percent of the total variation in flow. The revised regressions will be used in the impact assessment.

Table 2. Regressions of Flow at Buffalo Gap on Flow below Angostura Dam

	All Data	Gain < 20	Gain ≥ 20
b_1	0.9082	0.8856	1.0648
b_0	62.49	43.58	63.90
r^2	0.9856	0.9943	0.9908
r	0.9928	0.9971	0.9954
n	144	24	120

The success in deriving a much better relationship for the Buffalo Gap gage led to the attempt to improve the relationship for the Wasta gage. The addition of the discharge from the Rapid Creek gage near Farmingdale (Q_{rc}) to the flow of the Cheyenne River allowed the development of a multiple regression relationship between the Wasta gage (Q_W) and the Buffalo Gap gage (Q_{bg}). The multiple regression relationship explained about 85 percent of the variation in the flow at the Wasta gage. A comparison of the predicted (regressed) monthly flow against the measured monthly flow is shown on Figure 2. For the most part the predicted flows fall near the 45° "best fit" line. There is a grouping of four points that fall below the line in measured flows between 1000 and 1600 ft³/s that are the greatest underestimates (Figure 2). The newly derived regression has two effects on the Wasta flow calculation. The first is an obvious improvement in the estimate of the flow at Wasta. The second is that any change in flows at Buffalo Gap will show less of an effect at Wasta than would have been the case with the regression shown in Table 1. This revision provides a more realistic impact assessment than would be the case with the simple linear regression. This much improved regression relationship will be used in the impact assessment.

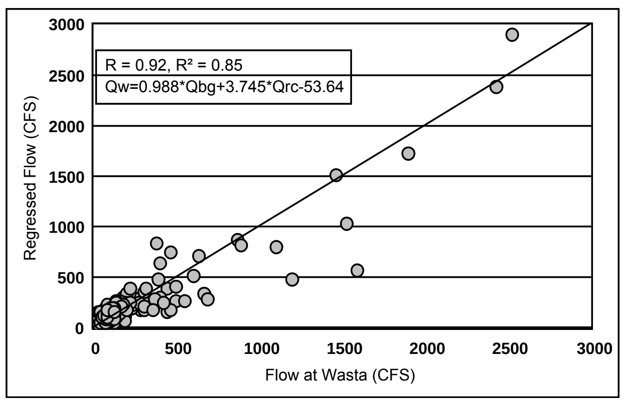

Figure 2: Comparison of measured and calculated flow at the Wasta gage for water years 1969 through 1980.

Eutrophication

The inflows are the same for all alternatives. The input data for the phosphorus budgets are taken from the USGS gage at Edgemont. The total phosphorus data for the Edgemont gage are confined to the early 1970's. The later phosphorus data are all for the dissolved fraction only. An attempt was made to extend the total phosphorus record by correlating within the overlapping period when there were data for both the dissolved fraction and the total concentration, but there is no statistically significant relationship. There is a statistically significant positive correlation between total phosphorus and flow. A positive correlation indicates that the phosphorus source is erosion and that much of the phosphorus is in particulate form. This may affect the applicability of the eutrophication index. If a significant part of the total phosphorus is not available for algal uptake, the eutrophication index will overestimate the eutrophication potential of the reservoir. However, the index is only being used to compare alternatives. In this case the alternative with the greatest difference from the No Action alternative will be assumed to have the greatest impact.

The input data to the critical phosphorus loading function are shown in Table 3. As is noted in Table 3, the inflow total phosphorus concentration is 0.08 mg/L. This is both the median and the geometric mean; the arithmetic mean is 0.24 mg/L. The arithmetic mean is obviously highly skewed. The arithmetic mean appears to be an overestimation rather than a good representation of the central tendency of the data set. For this reason it was not used.

Table 3. Eutrophication Index and Input Data for Each Alternative; Inflow Total Phosphorus Concentration Is 0.08 mg/L.

Alternative	$\bar{z}$ (meter)	T_ω (year)	q_s (m/year)	$[P]_c$ (µg/L)	$L_c(P)$ (g/m²/year)	P-load (g/m²/year)	Index
No Action 1	5.27	0.74	7.15	10.00	0.13	0.60	4.539
No Action 2	5.40	0.80	6.74	10.00	0.13	0.57	4.451
Natural Flow	2.28	0.15	15.39	10.00	0.21	1.30	6.093
Recreation	5.28	0.77	6.89	10.00	0.13	0.58	4.498
Improved Efficiency S14	5.50	0.86	6.40	10.00	0.12	0.54	4.379
Improved Efficiency S16	5.39	0.81	6.62	10.00	0.13	0.56	4.434
Improved Efficiency S18	5.40	0.82	6.57	10.00	0.13	0.55	4.425
Improved Efficiency S20	5.57	0.91	6.15	10.00	0.12	0.52	4.321

$\bar{z}$ (mean depth) = volume/area

The comparison of the alternatives (Table 3) indicates that the only alternative that shows a obvious difference from the No-Action alternative is the Natural Flow alternative. The main effect of the natural flow alternative is to reduce the reservoir size. This is reflected in the mean depth (Table 3), which is only about half that of the other alternatives. Because of this reduction in size, the retention time is reduced to 0.15 year or approximately 2 months. Because of the reduction in the area of the reservoir, the areal loadings increase; in other words, the same inflow phosphorus load is being applied to a much smaller surface area. All of the other alternatives are similar and each has a slightly lower index than the No Action 1 alternative.

All of the indices are well above 1, the value that indicates that the phosphorus load is equal to the critical phosphorus load. Reservoirs above the critical loading would be expected to be eutrophic. Angostura Reservoir is monitored by the DENR. They have consistently classified the reservoir as mesotrophic (Stueven and Stewart., 1996). Consequently the high eutrophication index does not necessarily mean that the reservoir is eutrophic or will be eutrophic if the index is greater for one or the other alternative. The index is simply being used as an indicator of effect in comparing alternatives.

<u>Total Dissolved Solids (TDS)</u>

Table 4 shows a comparison of the TDS in the inflow to and the outflow from Angostura Reservoir. Table 4 shows the monthly average TDS for the 45 years in the study period. The second part of the table shows summary statistics for the same set of data. Three measures of central tendency are presented in Table 4. The rationale for this is the above mentioned skew in the total phosphorus data, which indicated that the mean was not a good measure of central tendency.

There is also an indication that the distributions are somewhat different among the various alternatives. It can be mathematically demonstrated that the geometric mean will always be less than the arithmetic mean. The position of the median relative to the two means is dependent on the distribution of the data. For example, the median inflow TDS is greater than either of the two mean inflows values (Table 4). In this case, the lower limb of the distribution is somewhat truncated. The median of the natural flow TDS is also higher than either of the means, but the distribution is an elongated lower tail, the exact opposite of the inflow. The difference is that the lower tail of the natural flow distribution includes a number of outliers, so much so that the coefficient of skew for the TDS is negative, unlike that of any of the other alternatives. Because of the complex nature of the distributions of the projected TDS of the various alternatives, a comparison was made using the nonparametric Wilcoxon sign-ranks test (SYSTAT, 1997) to evaluate significance when comparing to the No Action alternative(s). The Wilcoxon test is analogous to the parametric paired *t*-test. The Wilcoxon test compares the rank values of the variables and counts the positive and negative differences (SYSTAT, 1997). The test statistic is the larger of the absolute value of the sum of the ranks associated with the positive and negative differences.

Table 4 shows that all of the alternatives have a lower reservoir TDS than the inflow to Angostura Reservoir. This is evident in the median and the overall means (Table 4B) and even in the monthly means (Table 4A). The Wilcoxon test statistic when comparing

Table 4. Summary Statistics - Comparison of TDS at Angostura Reservoir for All of the Alternatives

A. Monthly Mean TDS (mg/L) at Angostura Reservoir

Month	Inflow	No Action 1	No Action 2	Natural Flow	Recreation	Imp. Eff. Sc. 14	Imp. Eff. Sc. 16	Imp. Eff. Sc. 18	Imp. Eff. Sc. 20
January	2,526	1,724	1,722	2,189	1,722	1,724	1,718	1,716	1,707
February	2,175	1,707	1,694	2,147	1,708	1,697	1,693	1,693	1,691
March	1,764	1,629	1,615	1,941	1,641	1,637	1,624	1,625	1,642
April	2,019	1,675	1,671	1,859	1,685	1,688	1,677	1,678	1,674
May	1,854	1,665	1,659	1,765	1,668	1,676	1,664	1,669	1,681
June	1,830	1,774	1,738	1,705	1,760	1,723	1,744	1,745	1,740
July	2,068	1,909	1,870	1,697	1,866	1,812	1,835	1,826	1,780
August	2,300	1,971	1,937	1,787	1,916	1,871	1,891	1,865	1,771
September	2,807	1,893	1,867	1,891	1,859	1,834	1,843	1,830	1,754
October	2,646	1,779	1,785	2,002	1,775	1,776	1,780	1,773	1,744
November	2,597	1,733	1,753	2,068	1,724	1,758	1,734	1,730	1,732
December	2,578	1,719	1,714	2,143	1,716	1,718	1,707	1,705	1,710

B. TDS (mg/L) at Angostura Reservoir

	Inflow	No Action 1	No Action 2	Natural Flow	Recreation	Imp. Eff. Sc. 14	Imp. Eff. Sc. 16	Imp. Eff. Sc 18	Imp. Eff. Sc. 20
Mean	2,260	1,770	1,750	1,930	1,750	1,740	1,740	1,740	1,720
Median	2,340	1,718	1,704	1,968	1,714	1,704	1,713	1,713	1,710
Geometric Mean	2,210	1,710	1,710	1,890	1,710	1,700	1,700	1,700	1,680
No. of Obs.	540	531	530	538	531	530	530	530	529
Minimum	810	921	922	858	920	922	922	922	928
Maximum	4,470	3,621	3,634	2,790	3,153	3,327	3,264	2,839	2,542

NOTE: there were 18 months of no inflow to Angostura Reservoir in the 45 year period of record (1953-97) the reservoir TDS of each of the alternatives to the inflow range from a high of -12 (Natural Flow alternative - smallest difference) to a low of less than -16 (Improved Efficiency, scenarios 18 and 20 - greatest difference). The two-tailed probabilities of Wilcoxon test statistics of this magnitude occurring by chance alone are < 0.0005 for each of the Wilcoxon tests between the inflow and outflow TDS. The differences between the outflow TDS and the inflow are evident in both the minimum and maximum TDS. The minimum TDS in the outflow is higher than that of the inflow for each of the alternatives, while the maximum is smaller (Table 4). The reduction in the maximum TDS is greater than the increase in the minimum. This reduction in the range between the minimum and maximum TDS in the outflows is a reflection of the seasonal mixing of higher and lower TDS inflows within the reservoir. The mixing of the seasonally variable TDS of the inflows reduces the range of TDS in the outflows. The Wilcoxon test is not really necessary to see that the reservoir has reduced the overall TDS concentration of the river.

The difference in TDS among the various alternatives is not as evident (Table 4) as the difference in the inflow and outflow TDS. For this reason a statistical test is needed to evaluate differences. The results of a statistical comparison of the TDS of the reservoir outflows are shown in Table 5. The results indicate that all of the alternatives show a reservoir TDS that is significantly different from the TDS of the No Action alternatives. There is also a significant difference between the two No Action scenarios (Table 5). Specifically the No Action scenario with 10,000 acres of irrigation shows a significantly lower TDS than that with 12,000 acres of irrigation. In comparing the other alternatives to No Action, the Natural Flow alternative shows a significantly higher reservoir TDS than either. This is a reflection of the much smaller reservoir pool and a much lower degree of seasonal mixing. The Recreation alternative shows a significantly lower TDS than the larger No Action scenario, but a significantly higher TDS than the smaller No Action scenario. Each of the Improved Efficiency scenarios show a lower reservoir TDS than either of the No Action scenarios (tables 4 and 5).

Comparisons of TDS among the various alternatives at various sites in the Cheyenne Basin were also made. The results for the reservoir and the lower end of the AID, as represented by the former USGS gage near Buffalo Gap, are shown on Figure 2. A potentially misleading factor in the comparison relates to the projected flow at the former gage near Buffalo Gap. The regression of flow between the two gages is very good; however, implementation of an alternative has the potential to change the relationship between the two gages. As was noted above, the gain between the two gages consists in part of return flow from the AID. If the Project is changed, the return flows are likely to change. This would probably be a relatively minor change with any of the alternatives but the Natural Flow alternative. Since there are no deliveries for irrigation in the Natural Flow alternative, there are no return flows. In such a case the flow at the Buffalo Gap gage would be overestimated. For this reason a special study was undertaken to estimate the flows, including an estimate of the return flows from the

Table 5. Wilcoxon Test Results for the Comparison of Angostura Reservoir TDS among and between the No Action Alternatives and Each of the Other Alternatives				
Alternative	No Action 1		No Action 2	
	Wilcoxon Z	Two-sided Probability	Wilcoxon Z	Two-sided Probability
No Action 1	- - - - -	- - - - -	3.951	< 0.0005
Nat. Flow	10.139	< 0.0005	10.649	< 0.0005
Recreation	-5.000	< 0.0005	3.018	0.003
Imp. Eff. 14	-4.298	< 0.0005	-3.690	< 0.0005
Imp. Eff. 16	-4.565	< 0.0005	-6.434	< 0.0005
Imp. Eff. 18	-4.878	< 0.0005	-6.762	< 0.0005
Imp. Eff. 20	-4.923	< 0.0005	-4.571	< 0.0005

AID, for the Natural Flow alternative. Rather than using the regression relationship, the study results were used in the alternatives comparison shown in Table 5.

Figure 2 shows the comparison of the No Action, Natural Flow and Recreation alternatives in the plots at each gage on the upper half of the page and the four Improved Efficiency scenarios on the lower half of the page. The TDS for all alternatives at Angostura Dam is shown at the left of the page and the TDS for the Buffalo Gap gage is shown on the right. It was noted in the discussion of Table 3 that the Natural Flow alternative had a somewhat higher TDS than the other alternative. The data in Figure 2 show that the seasonal pattern of TDS is quite different from any of the other alternatives. The peak annual TDS is in the winter, while the peak for the other alternatives is in the late summer (late irrigation season). The difference is pretty much damped out by the time the water is at the Buffalo Gap gage. The flow and salt load are adjusted for the inflow of the Fall River and Beaver Creek between the two gages. There is a very low or no inflow to the reservoir during summer months. As a consequence there is a very low outflow with the Natural Flow alternative at that time. Under those circumstances, the tributaries are still controlling water quality at Buffalo Gap.

The seasonal TDS pattern at the gage near Buffalo Gap appears similar for each of the alternatives. Because of the loss of seasonal differences, the comparisons of the gages farther downstream is based on annual geometric mean TDS. These are shown in Table 6. In the lower reaches of the river, the alternative selected does not make

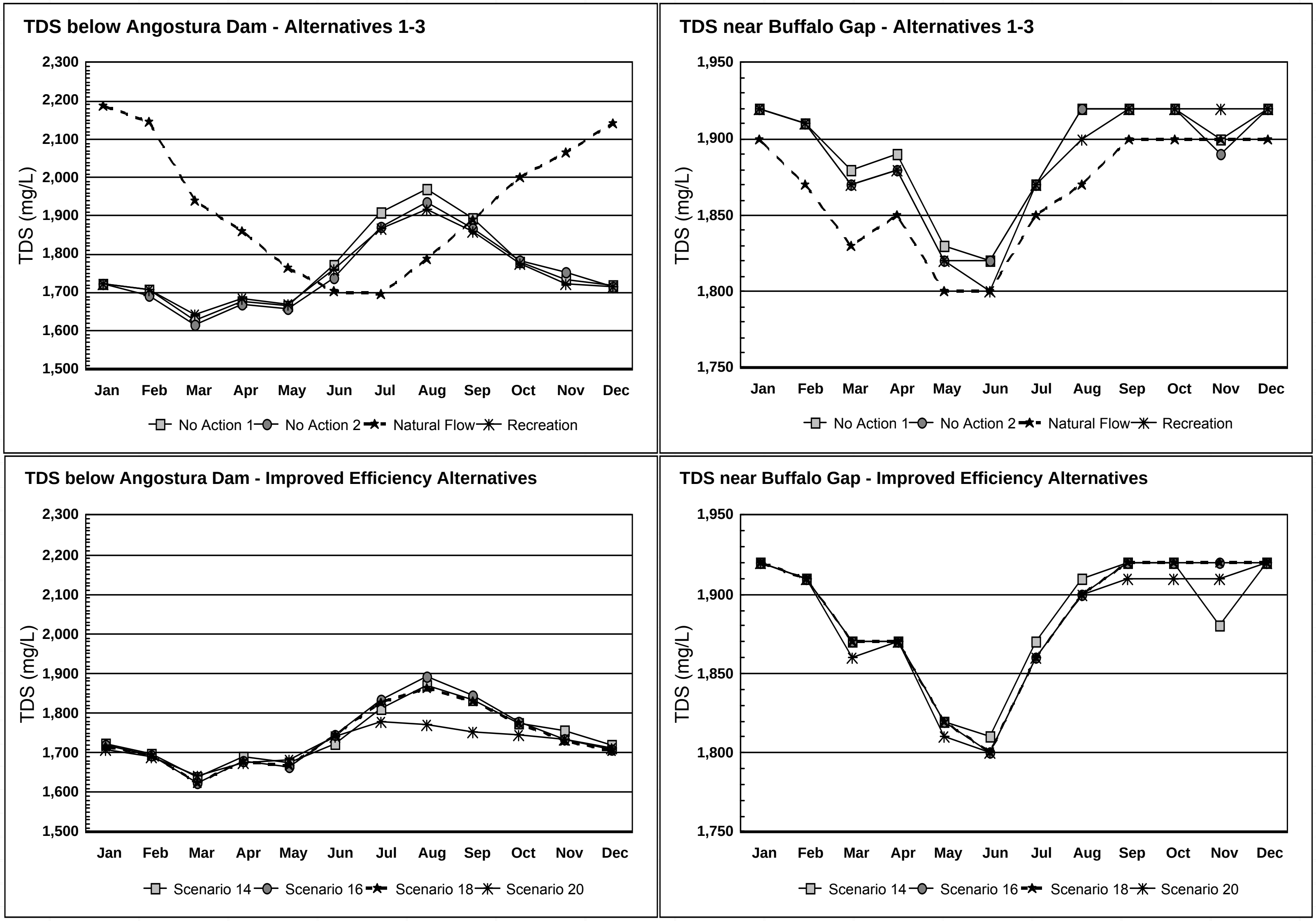

Figure 3: Mean Monthly TDS for each alternative in the Cheyenne River below Angostura Dam and at the former USGS gage near Buffalo Gap

Table 6. Angostura Contract Renewals Alternatives: Comparison of Geometric Mean Annual TDS [all in mg/L]

Alternative	Cheyenne River below Dam	Ungaged Gain/Loss	Cheyenne River near Buffalo Gap	Cheyenne River near Wasta	Cheyenne River near Plainview	Cheyenne River at Cherry Cr.
No Action 1	1,760	1,820	1,890	1,220	1,380	1,350
No Action 2	1,750	1,900	1,890	1,210	1,370	1,340
Natural Flow	1,930	1,810	1,860	1,160	1,320	1,280
Recreation	1,750	1,870	1,890	1,210	1,370	1,340
Imp. Eff. S14	1,740	1,920	1,880	1,200	1,360	1,330
Imp. Eff. S16	1,740	1,900	1,890	1,200	1,360	1,330
Imp. Eff. S18	1,740	1,910	1,890	1,200	1,360	1,330
Imp. Eff. S20	1,720	1,940	1,880	1,190	1,350	1,320
Inflow = 1990, Fall River = 980 mg/L, Beaver Creek = 1,880 mg/L						

much difference in the mean annual TDS. The Natural flow alternative shows a slightly lower TDS than the other alternatives and the recreation alternative shows a slightly higher TDS, but all are within 50 mg/L of each other in the lower basin.

Trace Elements

The effect of the various alternatives on trace element concentrations is a little more difficult to assess. It could be assumed that those trace elements that correlate with EC (and TDS) will be affected in a way similar to EC. Alternatively it could be assumed that those elements that correlate with flow will be affected in a manner that reflects the effect of flow on the concentration.

Tables 7 through 9 show Spearman correlations of flow and EC with major cations and anions and a selected set of trace elements for 6 gaging stations on the mainstem of the Cheyenne River. Spearman correlations are nonparametric correlations; in other words, the correlations are based on the ranks of the data when sorted by one of the data pairs calculated against the order of the data when sorted by the other of the pairs. The relationship that is being evaluated is more of a common trend than a predictive relationship; however, the influence of outliers is minimized. All of the data shown as less than any reporting limit were set to ½ the minimum reporting limit. In this way, all of the values below detection are relegated to ties in the ranking system. Based on this type of relationship the effects can only be evaluated qualitatively.

The gaging stations shown in the tables include 2 upstream from Angostura Reservoir (Table 7), the 2 nearest downstream gages (Table 8), and 2 other mainstem gages in the lower basin (Table 9). Obviously the upstream gages will not be affected by any of

Table 7. Spearman correlations - sites upstream from Angostura Reservoir

	Edgemont				Hot Springs			
	Flow		Conductivity at 25°C		Flow		Conductivity at 25°C	
	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency
D.O.	-0.008	40	0.034	34	0.400	4	-0.600	4
pH	0.157	57	-0.140	210	-0.405 **	43	0.382 *	43
Total Alk.	-0.469 *	20	0.697 ***	126	0.866	3	0.500	3
NO_2 & NO_3	0.359	12	-0.440	13	.	0	.	0
Calcium	-0.823 ***	27	0.857 ***	26	-0.714 ***	43	0.267	43
Magnesium	-0.848 ***	27	0.934 ***	26	-0.390 0	43	0.798 ***	43
Sodium	-0.645 **	20	0.886 ***	20	0.400	4	1.000 **	4
Potassium	-0.598 **	20	0.483 *	20	0.200	4	0.800	4
Chloride	-0.787 ***	28	0.883 ***	27	0.184	43	0.686 ***	43
Sulfate	-0.867 ***	28	0.927 ***	27	-0.705 ***	43	0.641 ***	43
Arsenic	.	6	.	6	-0.775	4	0.258	4
Boron	-0.257	6	0.600	6	-0.395	11	0.124	11
Cadmium	-0.439	6	0.676	6	-0.447	4	0	4
Chromium	0.258	4	-0.775	4	-0.949	4	-0.316	4
Copper	0.319	6	-0.203	6	0.447	4	0	4
Lead	-0.034	6	-0.135	6	.	4	.	4
Manganese	-1.000 **	4	1.000 **	4	.	0	.	0
Molybdenum	0.353	6	-0.265	6	-0.800	4	-0.800	4
Vanadium	-0.609	6	0.696	6	0.775	4	0.775	4
Zinc	-0.088	6	0.177	6	-0.316	4	0.632	4
Selenium	-0.738	4	0.211	4	0.258	4	0.775	4
Mercury		4	.	4		4	.	4

* - Prob. > r < 0.05 ** - Prob. > r < 0.01 *** - Prob. > r < 0.001 Otherwise, not statistically significant

Table 8. Spearman correlations - sites downstream from Angostura Reservoir

	Buffalo Gap				Wasta			
	Flow		Conductivity at 25°C		Flow		Conductivity at 25°C	
	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency
D.O.	.	0	.	0	0.364	11	0.055	23
pH	-0.085	76	0.231 0	122	0.093	18	0.010	39
Total Alk.	0.218	85	0.328 **	130	.	0	-0.857 0	7
NO_2 & NO_3	.	0	.	0	1.000	2	-1.000	2
Calcium	-0.072	85	0.525 ***	129	-0.591 *	14	0.924 ***	15
Magnesium	-0.311 **	84	0.685 ***	128	-0.737 **	14	0.927 ***	15
Sodium	-0.255 *	85	0.525 ***	130	-0.539	10	0.463	11
Potassium	-0.056	84	0.481 ***	128	-0.786 *	8	1.000	2
Chloride	-0.352 **	85	0.701 ***	129	-0.451	14	0.926 ***	14
Sulfate	-0.319 **	85	0.667 ***	130	-0.484	14	0.980 ***	20
Arsenic	.	0	.	0	-0.411	9	.	0
Boron	-0.254 *	85	0.352 **	128	0.500	3	-0.500	5
Cadmium	.	0	.	0	.	9	.	0
Chromium	.	0	.	0	.	9	.	0
Copper	.	0	.	0	0.411	9	.	0
Lead	.	0	.	0	0.548	9	.	0
Manganese	.	0	-0.182	17	-0.455	9	.	0
Molybdenum	.	0	.	0	.	0	.	0
Vanadium	.	0	.	0	.	0	.	0
Zinc	.	0	.	0	-0.411	9	.	0
Selenium	.	0	.	0	0.068	9	.	0
Mercury	.	0	.	0	0.247	8	.	0

* - Prob. > r < 0.05 ** - Prob. > r < 0.01 *** - Prob. > r < 0.001 Otherwise, not statistically significant

Table 9. Spearman correlations - sites on the Lower Cheyenne River

	Plainview				at Cherry Creek			
	Flow		Conductivity at 25°C		Flow		Conductivity at 25°C	
	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency	Spearman r	Pairwise Frequency
D.O.	-0.456	13	0.746 **	12	-0.430 ***	180	0.488 ***	159
pH	-0.286	14	0.070	166	0.063	217	0.078	221
Total Alk.	.	0	0.051	110	-0.573 ***	105	0.633 ***	107
NO_2 & NO_3	.	0	.	0	-0.097	119	0.171	121
Calcium	-0.714	6	.	0	-0.825 ***	181	0.798 ***	174
Magnesium	-0.986	6	.	0	-0.773 ***	181	0.785 ***	174
Sodium	-0.771	6	.	0	-0.704 ***	181	0.762 ***	174
Potassium	-0.657	6	.	0	-0.665 ***	181	0.476 ***	175
Chloride	-0.829	6	.	0	-0.837 ***	182	0.751 ***	175
Sulfate	-0.943 *	6	.	0	-0.788 ***	182	0.813 ***	175
Arsenic	-0.655	6	.	0	0.154	110	-0.137	101
Boron	.	0	.	0	-0.489	10	0.424	11
Cadmium	.	6	.	0	-0.179	108	0.191 *	100
Chromium	.	6	.	0	-0.101	84	0.043	76
Copper	-0.393	6	.	0	0.196 *	109	-0.288 **	100
Lead	.	6	.	0	0.184	85	-0.170	77
Manganese	-0.765	6	.	0	-0.694 ***	123	0.628 ***	114
Molybdenum	.	0	.	0	-0.405 **	49	0.382 **	49
Vanadium	.	0	.	0	-0.505 **	49	0.427 **	49
Zinc	-0.655	6	.	0	-0.053	112	0.007	102
Selenium	0.406	6	.	0	-0.252 *	96	0.285 **	89
Mercury	0.289	5	.	0	0.005	109	-0.050	100

* - Prob. > r < 0.05 ** - Prob. > r < 0.01 *** - Prob. > r < 0.001 Otherwise, not statistically significant

the alternatives, but the natural flow alternative would change the flow regime in the project area such that relationships that exist upstream from the reservoir would be carried downstream from the reservoir. It should be noted that no relationship is expected between pH and D.O. and either flow or EC; however, there are significant correlations between these disparate measures of water quality at several of the gages (tables 7, 8, and 9). These should represent either secondary relationships (real) or coincidences (not real). Based on the α-level used to evaluate the significance of the correlations and the number of correlations run, as many as one out of 20 of those with lower significance levels would be expected to be due to chance.

Upstream from the reservoir there are highly significant correlations between the major ions and both flow (inverse) and EC at Edgemont (Table 7). The inverse relationship to flow is a reflection of the influence of high flow dilution. The major ions would be primarily responsible for controlling EC and such a correlation is expected. The equivalent correlations at the Hot Springs gage are quite different. Only calcium and sulfate are significantly correlated with flow (Table 7). There is an extremely large disparity in the number of samples among the major ions. There are very few samples of sodium, potassium, and alkalinity; essentially too few to make correlations meaningful.

Tables 10 through 12 summarize the data used in the correlation analysis. The minimum flow at the Edgemont gage is 0 ft^3/s (Table 10). The river periodically dries up at the Edgemont gage, while the minimum flow at the Hot Springs gage is 13 ft^3/s. The Hot Springs gage is on a perennial reach of the river and the low flow quality is influenced by the tributary water in the intervening reach between the gages. Most of the inflow in the reach is from Cascade Springs, which is a ground water source and relatively independent of flow. There are also many more data points available at the Edgemont gage, than at the Hot Springs gage (tables 10 and 11). The better database could also influence the correlations at the more upstream of the 2 gages.

Table 12 summarizes the trace element data used in the correlations. The trace element data are extremely sparse at all of the gages except the farthest downstream at Cherry Creek. There are 10 or fewer measurements of the trace elements at the upstream gages and the two downstream gages near Buffalo Gap and Wasta. These latter two gages would be the most useful in evaluating the effects of the alternatives. There are no data whatsoever on any of the trace elements except boron at the gage near Buffalo Gap. At the Wasta gage, the vast majority of the measurements are below the reporting limit (Table 12). A complicating problem is that the reporting limits also vary. This makes the data even more difficult to work with and was the primary reason for setting all "<" values to a set minimum in the correlations. For example, if 9 out of 10 values are less than reporting limits and the data are set to ½ the limit, if the limits vary, ½ the greater reporting limit may be 4 or 5 times larger than a lower reporting limit.

Table 10. Summary of Flow, EC, D.O., pH, and Nitrite+Nitrate Data at 6 Mainstem gages on the Cheyenne River							
			61	95	300	400	630
Gage		Period of Record	Stream Flow, Inst-ft³/s	E.C. AT 25°C µmho/cm	D.O. mg/L	pH S.U.	NO_2 & NO_3 N-Total mg/L
Edgemont	Minimum	05/18/69	0	130	0.2	4.2	0.02
	Median	-----	17	4200	9.4	7.9	0.13
	Maximum	09/05/96	26,300	9200	13.1	8.9	0.64
	No. of Obs.	-----	203	411	40	216	13
Hot Springs	Minimum	10/20/49	13	716	7.2	7.2	-----
	Median	-----	197	2565	7.6	7.6	-----
	Maximum	08/22/88	5,400	4030	7.9	8.3	-----
	No. of Obs.	-----	137	41	3	42	0
Buffalo Gap	Minimum	09/26/68	16	1560	3.3	7.3	-----
	Median	-----	62	2300	3.3	8.0	-----
	Maximum	09/16/80	24,600	3650	3.3	8.7	-----
	No. of Obs.	-----	88	133	1	122	0
Wasta	Minimum	12/08/49	3	300	6.2	7.5	0.1
	Median	-----	138	1854	10.6	8.1	0.5
	Maximum	08/22/96	23,100	3500	14	9.5	1.1
	No. of Obs.	-----	239	208	23	41	3
Plainview	Minimum	10/19/68	28	610	7.6	6.8	0.2
	Median	-----	362.5	1960	10.2	8.1	0.2
	Maximum	09/03/96	66,600	4000	15.9	9.0	0.2
	No. of Obs.	-----	138	259	13	168	1
	No. < Det.	-----	-----	-----	-----	-----	-----
Cherry Creek	Minimum	06/14/72	6	610	0	7.2	0
	Median	-----	357	2170	9.1	8.2	0.51
	Maximum	08/28/95	21,600	3900	21.8	9.2	4.8
	No. of Obs.	-----	375	240	184	223	123

This does not mean the concentration in the first sample is any higher; it simply means that the minimum concentration that can be quantified is higher.

The effect of the alternatives essentially disappears at the Wasta gage. It would be difficult to evaluate the alternatives with a good data set with which to work. However, there are effectively no trace element data to correlate with EC data (Table 8), mainly because the trace element concentrations are constant. With so many trace element samples below a level of quantification, all were set to a minimum concentration and there is no variation remaining in the data and no correlation can be calculated.

The data for the farthest downstream gages are also included in tables 7 through 12 for completeness. The Plainview gage exhibits the same lack of data as those near

Table 11. Summary of Major Ion Data at 6 Mainstem gages on the Cheyenne River

Gage		915 Calcium Ca, diss mg/L	925 Magnesium Mg, diss mg/L	930 Sodium Na, diss mg/L	935 Potassium K, diss mg/L	940 Chloride Total mg/L	945 Sulfate SO_4-Total mg/L
Edgemont	Minimum	67	22	110	1.2	30	350
	Median	310	110	440	8.2	345	1650
	Maximum	820	250	1100	20.0	890	3300
	No. of Obs.	27	27	20	20	28	28
Hot Springs	Minimum	70	18	100	6.9	8	188
	Median	501	84.5	160	8	59	1485
	Maximum	588	122	320	9.1	495	1900
	No. of Obs.	42	42	3	3	42	42
Buffalo Gap	Minimum	123	35	130	1.6	1	620
	Median	240	74	200	15	113	980
	Maximum	370	120	300	22	160	1400
	No. of Obs.	130	129	131	129	130	131
Wasta	Minimum	25	1.8	60	5.8	5	153
	Median	135	36	141.5	11	41	610.5
	Maximum	268	80	262	17	114	1090
	No. of Obs.	23	23	20	10	23	30
Plainview	Minimum	91	26	78	7	9	360
	Median	190	82	211	10	37	880
	Maximum	294	122	267	17	89	1500
	No. of Obs.	7	7	7	7	7	7
Cherry Creek	Minimum	18	0.3	48	0.7	3	140
	Median	200	84	210	12	56.5	1100
	Maximum	390	150	1200	23	240	1900
	No. of Obs.	187	187	159	187	188	188

Table 12. Summary of Trace Element Data at 6 Mainstem gages on the Cheyenne River

Gage		1000 Arsenic As, diss µg/L	1020 Boron B, diss µg/L	1025 Cadmium Cd, diss µg/L	1030 Chromium Cr, diss µg/L	1040 Copper Cu, diss µg/L	1049 Lead Pb, diss µg/L
Edgemont	Minimum	< 0	210	< 0	< 0	< 1	< 0
	Median	0	280	1	1	10	1
	Maximum	1	440	9	1	75	10
	No. of Obs.	2	6	6	4	6	6
	No. < Det.	2	0	2	2	2	2
Hot Springs	Minimum	< 1	100	< 1	< 1	< 1	< 5
	Median	< 1	205	< 1	3	1	< 5
	Maximum	1	400	1	4	1	< 5
	No. of Obs.	3	10	3	3	3	3
	No. < Det.	2	0	2	1	1	3
Buffalo Gap	Minimum	----	< 20	----	----	----	----
	Median	----	300	----	----	----	----
	Maximum	----	1700	----	----	----	----
	No. of Obs.	0	129	0	0	0	0
	No. < Det.	0	1	0	0	0	0
Wasta	Minimum	< 1	200	< 0	< 5	< 1	< 0
	Median	< 6.5	270	< 3	< 10	< 50	< 18
	Maximum	50	470	10	< 10	50	50
	No. of Obs.	10	5	10	9	10	10
	No. < Det.	8	0	9	9	9	8
Plainview	Minimum	< 2	180	< 0	< 0	< 3	< 4
	Median	< 7	180	< 1	< 10	< 50	< 5
	Maximum	10	180	10	40	50	50
	No. of Obs.	7	1	7	7	7	7
	No. < Det.	5	0	6	6	5	6
Cherry Creek	Minimum	< 1	170	< 0	< 0	< 0	< 0
	Median	4	325	< 1	< 1	3	< 3
	Maximum	50	390	10	20	60	500
	No. of Obs.	114	12	112	87	113	88
	No. < Det.	8	0	91	57	16	55

Table 12. (Continued)

Gage		1056 Manganese Mn, diss µg/L	71890 Mercury Hg, diss µg/L	1060 Molybdenum Mo, diss µg/L	1145 Selenium Se, diss µg/L	1085 Vanadium V, diss µg/L	1090 Zinc Zn, diss µg/L
Edgemont	Minimum	52	< 0.0	2	< 0	2	< 10
	Median	270	0.1	4	3	4	20
	Maximum	670	0.1	9	20	15	420
	No. of Obs.	4	4	6	5	6	6
	No. < Det.	0	2	0	1	0	2
Hot Springs	Minimum	----	< 0.1	12	2	2	< 10
	Median	----	< 0.1	14	3	2	10
	Maximum	----	< 0.1	16	3	3	20
	No. of Obs.	0	3	3	3	3	3
	No. < Det.	0	3	0	0	0	1
Buffalo Gap	Minimum	0	----	----	----	----	----
	Median	60	----	----	----	----	----
	Maximum	240	----	----	----	----	----
	No. of Obs.	17	0	0	0	0	0
	No. < Det.	0	0	0	0	0	0
Wasta	Minimum	< 6	< 0.2	0	< 1	2	< 5
	Median	12.5	< 0.2	0	< 2	2	< 10
	Maximum	30	0.5	0	< 50	2	22
	No. of Obs.	10	8	1	9	1	10
	No. < Det.	4	7	0	7	0	8
Plainview	Minimum	< 0	< 0.2	4	< 2	0.8	< 3
	Median	13	< 0.2	4	5	0.8	< 10
	Maximum	90	0.3	4	20	0.8	20
	No. of Obs.	7	5	1	7	1	7
	No. < Det.	2	3	0	1	0	5
Cherry Creek	Minimum	< 0	< 0	< 1	< 1	< 1	< 0
	Median	20	< 0.1	6	3	< 4	10
	Maximum	460	3.3	30	50	22	100
	No. of Obs.	128	113	51	99	51	116
	No. < Det.	24	87	15	9	26	52

Buffalo Gap and Wasta. The Cherry Creek gage has a rather complete data set. There are significant correlations of trace elements, including those of copper, manganese, molybdenum, vanadium, and selenium, with both flow and EC. The copper correlation is the opposite of the usual relationship and is probably meaningless. The correlations could indicate the trend of any impact. For example, an increase in flow would cause a decrease in EC and indicate that there should be a decrease in manganese, molybdenum, vanadium, and selenium, each of which correlates inversely with flow and positively with EC. However, it was shown earlier that any change in EC at the gages at Wasta and downstream would be negligible and effects on trace elements would be expected to be similarly so.

It is sometimes possible to extrapolate relationships at one point on a stream to other points on a stream. There are insufficient trace element data at the 3 nearest upstream gages on the river to develop correlations with flow or EC. It may be possible to extrapolate the trace element relationships at Cherry Creek to the Plainview gage, but no farther upstream. The relationships in the lower basin are heavily influenced by the Belle Fourche River, which empties into the Cheyenne between the Wasta and Plainview gages. Consequently the capability to extrapolate upstream is limited.

Organic Contaminants

Data on organic contaminants are much more limited than those for trace elements. The vast majority of the samples have been below reporting limits for the organic analyses conducted. The majority of the organic analyses have been for various pesticides, including herbicides and insecticides. The low concentrations indicate that there is no measurable effect from current farming practices. The irrigation alternatives include 2 levels of development (scenarios). The first is the current level, and the second is a lesser level. If the current level is immeasurable, and lesser level may discharge a lower level of organic contaminants, but the difference would be immeasurable. This is also true of the natural flow alternative, which includes no irrigation whatsoever. Even though it is certain that the use of pesticides would drop on the lands if there were no crops raised, the baseline does not show a measurable discharge; therefore any reduction cannot be measured either. Based on this, it would seem that any difference would not be significant.

Sediment

TSS (total suspended solids) as was noted elsewhere includes particles of a variety of sizes. Only the very finest particles pass through Angostura Reservoir under normal conditions. When there are no releases to the river, the TSS is passed onto the Angostura Canal. As was noted in the description of existing conditions, the releases to the river consist of relatively sediment-free, clear water. The existing condition would be propagated into the foreseeable future under the No-Action alternative.

The alternatives that retain water in the reservoir the longest will retain the greatest percentage of the sediment, and conversely, those with the shorter residence time will bypass the greatest amount of sediment. Some of the hydrologic factors that most affect sediment retention are summarized in Table 13, which is based on monthly data from the 45-year AGRAOP output for each alternative. A comparison of these factors allows a qualitative assessment of sediment retention and discharge and consequently the turbidity of the releases. The number of spills is based on months with a release to the river that is greater than the 3 ft³/s of seepage that is usually below the dam. The size of the spill is estimated by summing all of the flows greater than 3 ft³/s and dividing by the number of spills. The E.O.M. is the average of the values in the AGRAOP output. The residence time is the average E.O.M. divided by the average spill size converted to acre-feet per month. This is in no way a real residence time, but is calculated for comparative purposes only. Based on these factors, the recreation alternative and the second and third improved efficiency alternative scenarios would release about the same amount of TSS as the No Action alternative. The remaining improved efficiency scenarios would decrease the average TSS in the reservoir release in comparison to the No Action alternative.

Table 13. Comparison of Primary Hydrologic Factors that Affect Sediment Retention by Alternative

Alternative	Total Spills [No./540 months]	Ave. Size of Spill [ft³/s]	Average E.O.M. [Ac.Ft.]	Res. Time [Months]
No Action 1	128	240	65,929	4.5
No Action 2	146	241	71,653	4.9
Natural Flow	488	130	13,219	1.6
Recreation	145	249	68,559	4.5
Improved Efficiency 1	165	240	76,765	5.2
Improved Efficiency 2	165	243	72,825	4.9
Improved Efficiency 3	165	245	73,465	4.9
Improved Efficiency 4	242	192	81,092	6.9

The natural flow alternative is a special case. At the beginning of the AGRAOP simulation, the Angostura Reervoir pool size is comparatively large, *i.e.* > 20,000 A.F. However, this is much smaller than the operating pool for the other alternatives. As time goes by, this reduced reservoir pool is filled with sediment, and there is essentially no storage remaining. Consequently the amount of sediment removed early in the 45-year simulation period will be noticeable, but toward the end of the simulation period, an equilibrium condition would be attained. In this case, part of the year, sediment will be deposited, and part of the year, it will be scoured. A new river channel will eventually form within the nearly level bed of the former reservoir. Under any of these conditions, the water will carry more sediment through the reservoir on an annual basis and be more turbid on the average than with any of the other alternatives.

All of the NIWQP and Reclamation contaminants data for the study area are for fine (<0.062 mm) bed sediments. These are the sediments that are representative of those most likely to be carried through the reservoir. Since there is no indication that there is any significant contamination in the existing sediments, the passing of additional sediments by any of the alternatives should have no effect on the distribution of sediment contaminants.

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