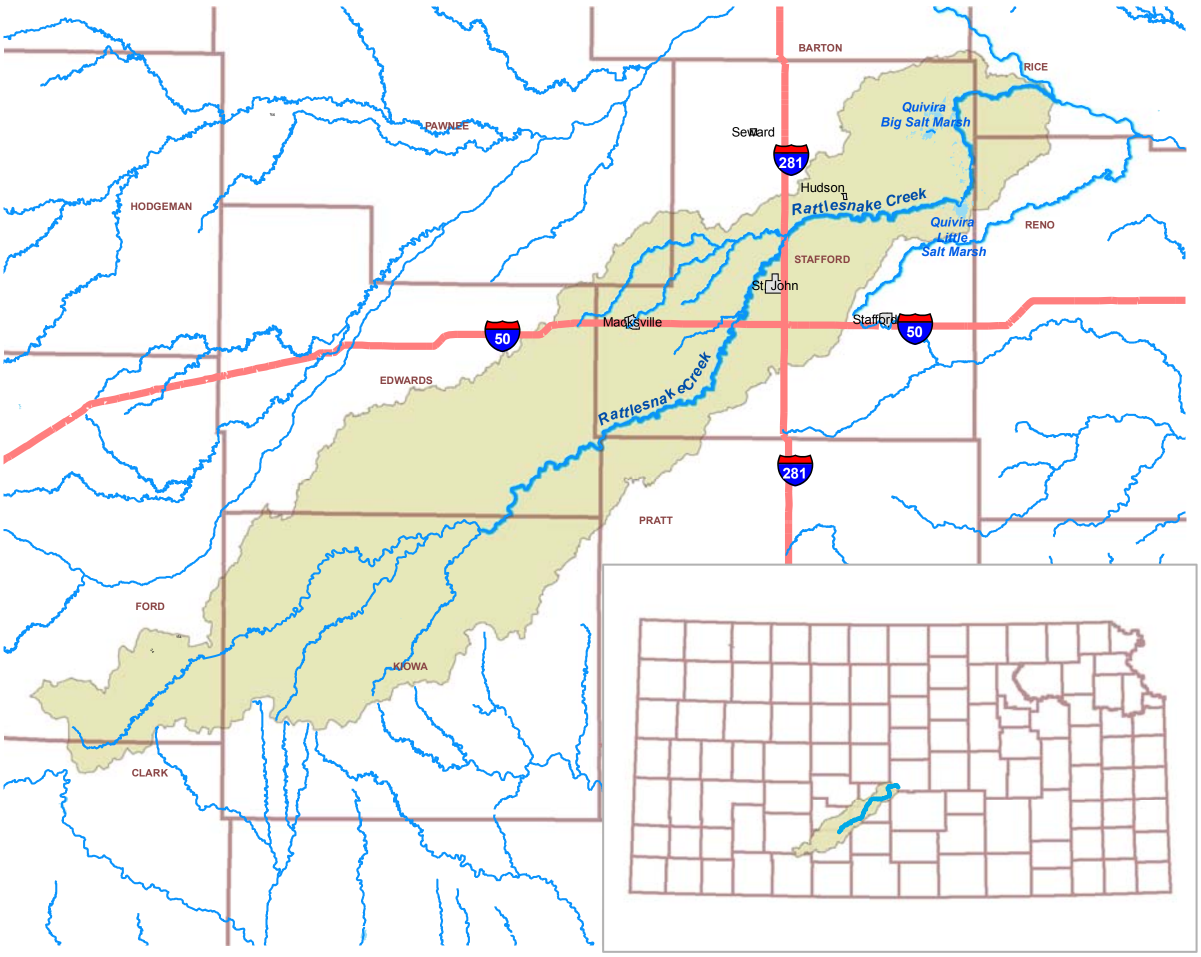
# Stream Flow Augmentation of Rattlesnake Creek




**Kansas Water Office**

January 31, 2006

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## Executive Summary

Stream flow augmentation was one of a number of the management strategies introduced in the June 29, 2000, Rattlesnake Creek Management Program Proposal by the Rattlesnake Creek/Quivira Partnership to address stream flow shortages due to fluctuating aquifer levels in the subbasin.

The Kansas Water Office estimates the frequency that an augmentation year would occur in the future is about 50 percent. The typical quantity of water needed for augmentation during a year that augmentation is necessary is about 1,460 acre-feet.

Should the augmentation strategy be implemented, the Kansas Water Office recommends the use of freshwater sources for augmentation, that water rights be purchased, rather than leased, for the supply of augmentation water and that the Big Bend Groundwater Management District No. 5 be responsible for the strategy's operation and maintenance.

Based upon the projected frequency and magnitude of augmentation in the future and the recommendations of it source, supply and operation, the Kansas Water Office estimates the total water right purchase cost for the augmentation strategy at $2.9 million, the total engineer and construction cost of the strategy at $2.2 million, the annual operation and maintenance cost of the strategy should average about $74,370 per year (with an augmentation year operation and maintain cost of $92,000 per year) and a 10 year total strategy cost of $5.9 million.

## Introduction

2005 Session HB2482 § 76 (d) directed the Kansas Water Officer to,

> complete a study on augmentation of the Rattlesnake creek basin and report the results of the study to the House of Representatives agriculture and natural resources budget committee on or before February 1, 2006.

This report is in response to that directive.

Groundwater augmentation of the natural base flow in Rattlesnake Creek was one of a number of the management strategies introduced in the June 29, 2000, Rattlesnake Creek Management Program Proposal (RCMP) by the Rattlesnake Creek/Quivira Partnership (Partnership) to address stream flow shortages due to fluctuating aquifer levels in the subbasin. In the program proposal, the Partnership acknowledged that these aquifer fluctuations,

> may result in stream flows that are inadequate for the appropriated surface water demand for periods of time during some years. (Page 3, RCMP)

Groundwater augmentation of stream flow was a specific management strategy included in the program to address this concern.

In the Rattlesnake Creek subbasin there are three main issues that will be addressed in this study of the augmentation proposal:

1) Water quality; assurance that the augmentation discharge meets existing water quality criteria,
2) Water quantity; the frequency with which augmentation may be required and magnitude or total volume of water which may be needed to satisfy surface water right requests, and
3) Cost of augmentation; estimate the costs associated with the recommended augmentation scenario.

## Rattlesnake Creek Management Program Augmentation Strategy

The following is reproduced from the June 29, 2000, Rattlesnake Creek Management Program Proposal (RCMP) by the Rattlesnake Creek/Quivira Partnership and outlines the augmentation assessment process established by that program.

> Augmentation will be utilized to meet Quivira's objective of having a water supply in the Fall when stream flows are inadequate for their appropriated surface water right. The partnership agrees that approximately 2,100 acre-feet is needed during August and September to meet the Refuge's needs. Augmentation would not be required in years of extreme drought.
>
> The Little Salt Marsh needs to be maintained at a [staff] gage height of 4.0 ft. in order to assure that water can be delivered to the other units the [U.S. Fish and Wildlife] Service wants to maintain. The Service would like to be able to fill and maintain Units 7, 10A, 10B, 10C, 11A, 11B, 14A, and 14B (surface area 306 acres, capacity 1,101 acre-feet). The Refuge would not operate to artificially create a situation where augmentation would be called for.
>
> An augmentation program will be developed using the following 4-step assessment process:
>
> 1. An augmentation year shall be designated when the average flow in January, at the Zenith gage, is less than 25 cfs.
>
> 2. A review will be made in July using the Palmer Drought Severity Index to determine if drought conditions exist. Augmentation will not be implemented when conditions in region 8 of Kansas depict an index value for a severe drought of -3.0 or worse.
>
> 3. Augmentation may begin on August 1, or when requested by the [Quivira National Wildlife Refuge] QNWR, if and when natural flows of 21 cfs are not being maintained and the staff [gage] water level at the Little Salt Marsh is below 4 feet. Augmentation will continue for up to 45 days if necessary. An average of 21 cfs for 45 days is needed to fill the pools and allow for evaporation. The rate of augmentation will be regulated to maintain the desired flow.

4. Augmentation will continue from September 15 through September 30 when natural flows of 7.05 cfs are not being maintained. 7.05 cfs is needed to offset evaporation in the refuge.

The quality of augmentation water supplied by wells will vary, but shall not exceed a maximum of 1,500 mg/l chloride, or as approved by KDHE standards. (Page 13, RSMP)

## Geologic/Water Quality Setting

To understand the water quality complexities associated with the augmentation of Rattlesnake Creek, the issue is framed by the geologic setting of the basin. The geologic setting helps to explain the source of the water quality issues in the basin and identifies the primary pollutant of concern, chloride.

The predominate source of chlorides found in the surface water of Rattlesnake Creek is from the Permian formation that underlies much of Stafford County. In fact, water obtained from Permian rocks in a large portion of Stafford County would be too highly mineralized for most ordinary uses. Cheyenne Sandstone is absent in much of eastern Stafford County where it was removed by erosion after the Cretaceous Period. Elsewhere, the Cheyenne overlies Permian rocks and it exists from a featheredge to more than 100 feet thick (shown as cross-section J - J' in **Figures 1** and **2**) in the area. Kiowa Shale is encountered by test holes and oil wells beneath younger deposits in most of the western half of Stafford County. Elsewhere, it was removed by post-Cretaceous erosion (**Figures 1** and **2**).

As one moves from upstream to downstream on Rattlesnake Creek the effects from the presence of Permian rocks and the absence of a Cheyenne sandstone and Kiowa shale cap is clearly evident. The base flow contribution in areas lacking a sandstone/shale cap over the Permian formation (generally in the lower quarter of the Rattlesnake Creek subbasin downstream of Highway 281 and north of Highway 50- see **Figure 3**) is notably higher in chloride concentration.

Kansas Department of Agriculture, Division of Water Resources (KDA/DWR) and Big Bend Groundwater Management District #5 (GMD5) collected concurrent chloride samples from various locations in Rattlesnake Creek in the 1990's. **Figure 4** shows, for the general season that augmentation would likely occur, the results of this sampling effort. For the reach of Rattlesnake Creek under consideration for augmentation, chloride concentrations are lowest upstream of Highway 281 and then increase toward the Zenith gage location. The largest incremental increase in chloride concentration is between Sites #1 and #5 (**see Figure 5** to locate these stream sites); the sites at Highway 281 and the next site downstream. This area would correspond to the transition where the Cheyenne sandstone/Kiowa shale cap occurs and is absent within the watershed.

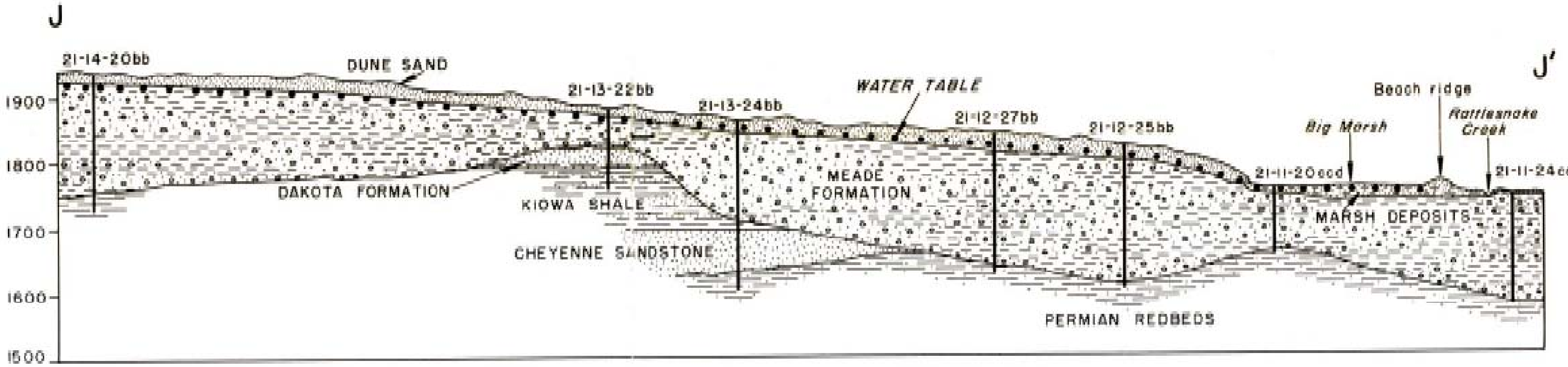



**Figure 1**: Geologic cross section of northern Stafford County (use Figure 2 as reference to locate the cross section).

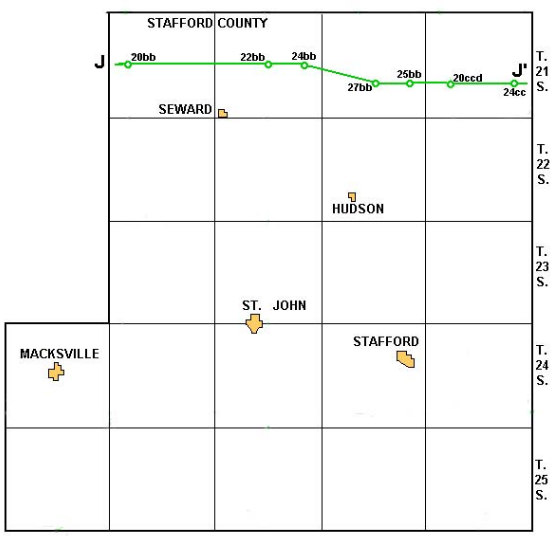



**Figure 2**: Location of cross section shown in Figure 1

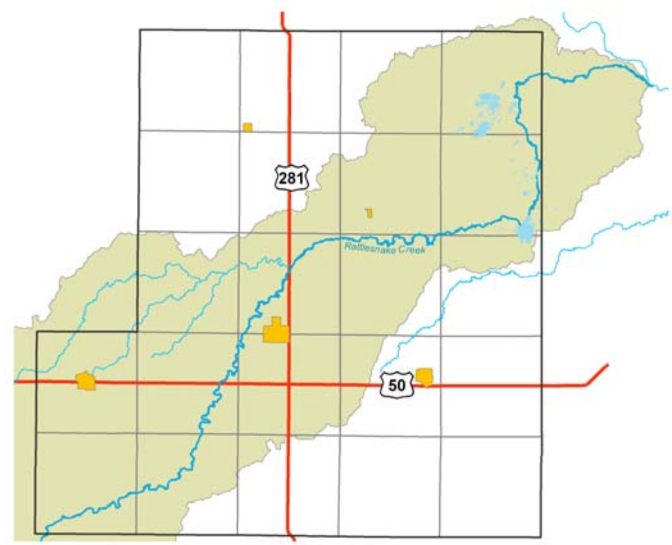



**Figure 3**: Map showing lower half of Rattlesnake Cr. subbasin

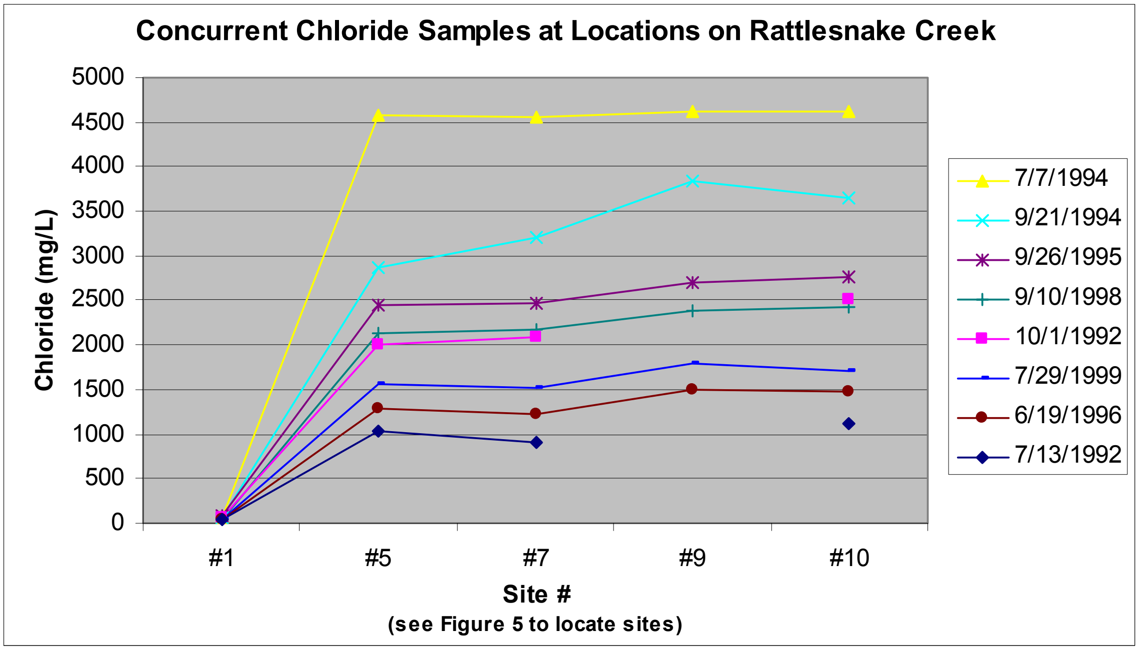



**Figure 4**: Chloride samples collected from Rattlesnake Creek in the 1990s

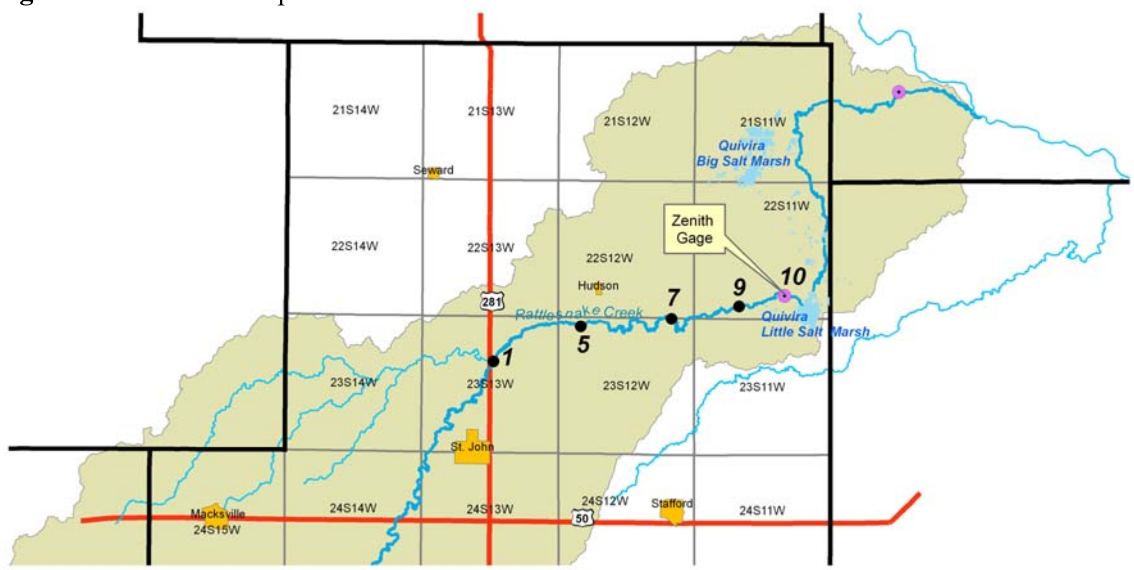



**Figure 5**: Chloride sample and flow measurement locations on Rattlesnake Creek

## Augmentation: Water Quality Considerations

As previously noted, a predominately natural mineral intrusion area exists generally downstream of Highway 281 in the Rattlesnake Creek subbasin. The primary natural pollutant of concern for the watershed is chloride.

A chloride Total Maximum Daily Load (TMDL) has been established for Rattlesnake Creek. This TMDL establishes a Phase II background concentration of chloride in Rattlesnake Creek above the Little Salt Marsh and downstream of the Wild Horse Creek confluence at 1,400 mg/L (the confluence of Wild Horse and Rattlesnake Creek is also where Highway 281 crosses Rattlesnake Creek on **Figure 5**). Kansas Surface Water

Quality Standards subsequently established the same chloride concentration for that reach of Rattlesnake Creek.

The November 5, 2004, Kansas Surface Water Register designates Quivira Big Salt Marsh and Little Salt Marsh as an outstanding national resource waters. The Antidegradation Policy for the State of Kansas provides Tier 3 protection (the highest level of water quality and designated use protection) for outstanding national resource waters.

Within the context of Rattlesnake Creek augmentation, Kansas Department of Health and Environment (KDHE) has suggested an augmentation discharge method that addresses both the TMDL and antidegradation water quality issues. This method establishes a natural chloride concentration across all flows that would be encountered when augmentation would be needed and uses this relationship to set a maximum chloride concentration, thereby limiting the chloride concentration of augmentation water, based upon the stream flow at the Zenith gage.

Using this same concept, the Kansas Water Office (KWO) analyzed a separate data set of flow and chloride concentration in Rattlesnake Creek to determine if a similar result could be produced. The KWO analyzed hourly flow (less than 21 cfs) and estimated chloride concentrations during July 15 through September 30 (the most likely augmentation period) for 1999-2003 at the USGS Zenith continuous water quality gage site. The median chloride concentration was calculated for small incremental flow ranges and plotted across the entire 0-21 cfs flow range (**Figure 6**). A linear regression was fit to the resulting data to establish a relationship between chloride concentration and flow for Rattlesnake Creek near Zenith. Although the KWO used different data to establish discharge/chloride concentration relationship than did KDHE in their analysis, the results were essentially the same (compare KWO and KDHE regression lines in **Figure 6**).

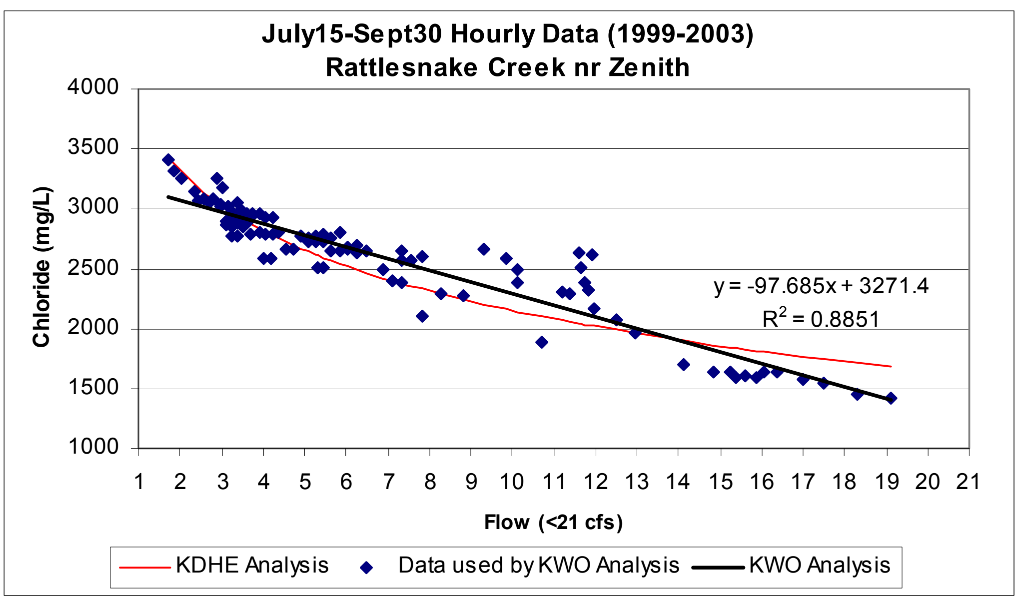



**Figure 6**: Relationship of flows less than 21 cfs during anticipated augmentation season and median chloride concentrations.

Using this inverse relationship between flow and natural background chloride concentrations, the following procedure could be applied when augmentation is required:

1. Note the flow at the Zenith gage
2. Calculate estimated chloride concentration for that flow using regression equation
3. Calculate target flow (augmentation + existing stream flow) chloride concentration
4. Calculate augmentation chloride concentration
5. Monitor chloride concentration of augmentation wells to confirm they are mixing to the correct augmentation chloride concentration
6. Use conductivity sensor at Zenith gage site as assurance that the target flow's chloride concentration is being achieved.

If all augmentation water is from areas outside the mineral intrusion area in Rattlesnake Creek subbasin, the only monitoring necessary would be at the Zenith gage site. This is because augmentation water from this fresh water source would actually dilute the chloride concentration in the natural flows so that the target flow would always be less than the relationship established between natural flows and chloride concentrations resulting in an overall improvement in the chloride concentration trend in the stream.

## USFWS Water Right at Quivira and Potential Impact on other Water Rights as outlined in Rattlesnake Creek Management Program Proposal

As of September 19, 2005, there were about 1,450 active water rights in the Rattlesnake Creek basin. Seventy-seven of those water rights were senior to the United States Fish and Wildlife Service (USFWS) water right for Quivira National Wildlife Refuge (Quivira) and 1,372 water rights were junior. Total appropriations in the watershed were about 268,200 acre-feet. In terms of the total quantity of water appropriated (excluding the USFWS water right for Quivira), about 6% is senior and 94% is junior to Quivira.

**Figure 7** shows the points of diversion associated with the water rights in the area defined as the 'stream corridor' in the Rattlesnake Creek Management Program Proposal (RCMP). The management program goal affecting these water rights is a streamflow target of 25 cfs in January as a 10 year (rolling) average.

> If, after the 12-year [implementation] time line, the goals have not been achieved, then sufficient reductions in water rights would be imposed to achieve the goals. (Page 16, RCMP)

The water use reductions in the stream corridor area are not specified in the RCMP, in part because those voluntary reductions that took place during the 12-year implementation period would need to be taken into account prior to establishment of reductions. However, relative reductions in water use based upon water right groups have been established within the management strategy.

**Water Right Group A** (Shown as blue dots in **Figure 7**): These are water rights senior to the USFWS water right at Quivira and would receive no reduction.

**Water Right Group B** (Shown as green dots in **Figure 7**): These are the senior half of the water rights junior to the USFWS water right at Quivira right and senior to Minimum Desirable Streamflow (MDS). This group would receive a reduction but the quantity of that reduction is expressed in the management program in terms of the reductions associated with Water Right Groups C and D.

**Water Right Group C** (Shown as yellow dots in **Figure 7**): These are the junior half of the water rights junior to the USFWS water right at Quivira right and senior to MDS. This group would receive a reduction that is 2.5 times greater than that of Group B.

**Water Right Group D** (Shown as red dots in **Figure 7**): These are the water rights junior to MDS. This group would receive a reduction that is 5 times greater than that of Group B.

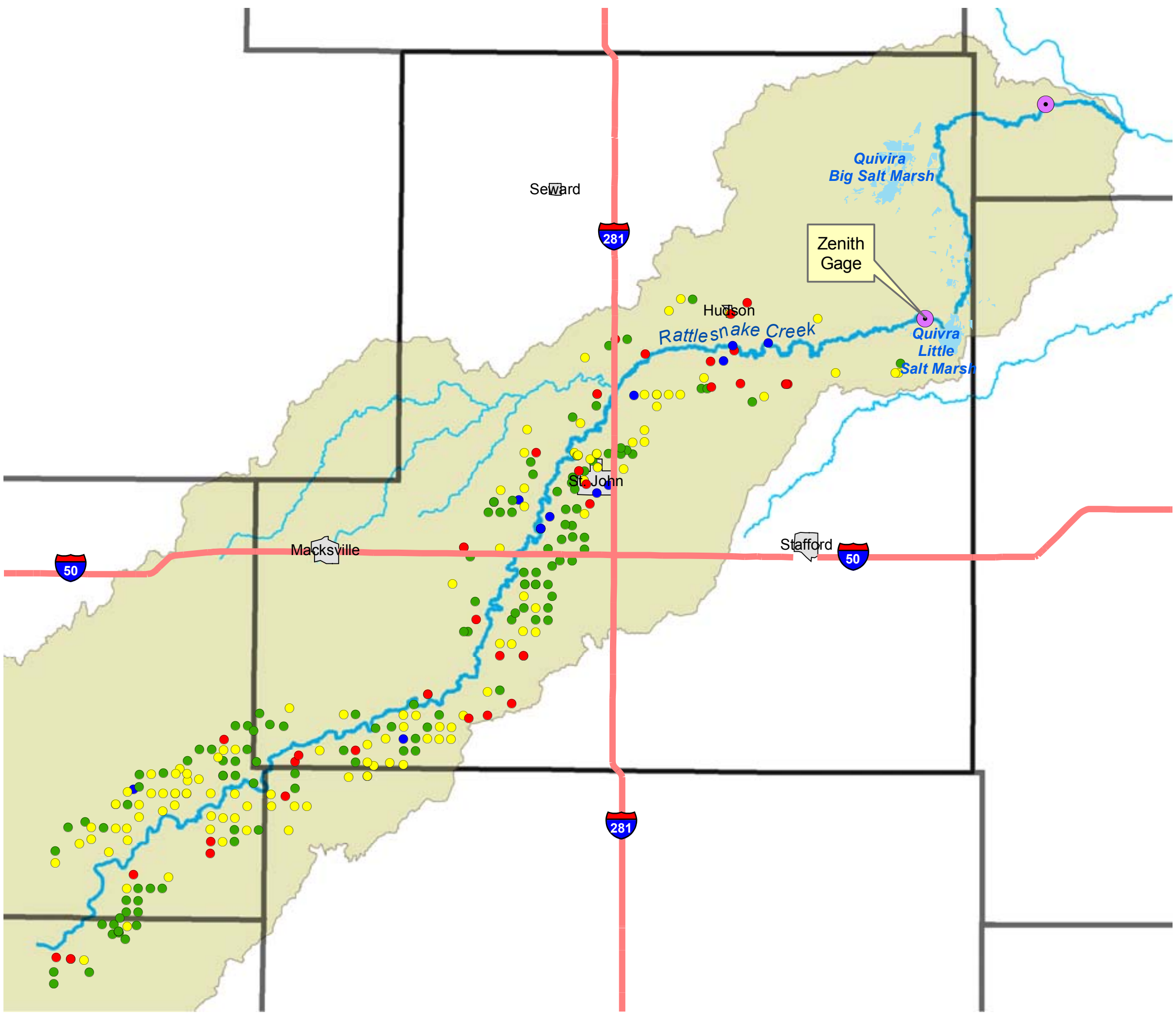


**Figure 7**: Color-coded water right groups for those points of diversion located in the stream corridor as defined by the Rattlesnake Creek Management Program.

## Augmentation: Water Quantity Considerations

### *Water Shortage: Historic Analysis of Frequency and Quantity of Augmentation*

The guidelines established in the Rattlesnake Creek Management Program for augmentation (see Page 2) were applied to the 31 years of flow data for the United States Geological Survey (USGS) gage on Rattlesnake Creek near Zenith to ascertain when the augmentation plan would have been applied historically. This review showed that an augmentation year, which is a year when the average January stream flow was less than 25 cfs, would have been designated in 14 years of the 31-year record. The year 1991 would have been designated as an augmentation year based on its average January flow, however augmentation would not have occurred because of the drought contingency on the augmentation strategy (see item #2 on Page 2). The year 1987 would also have been designated as an augmentation year, but no augmentation would have occurred because the minimum flows were met during the augmentation period (see items #3 and #4 on Page 2 of this report). Therefore, historically, augmentation would have actually occurred in 12 of the 31 years of record or an augmentation program frequency of 39%. This translates into about 4 years of augmentation in each ten year period.

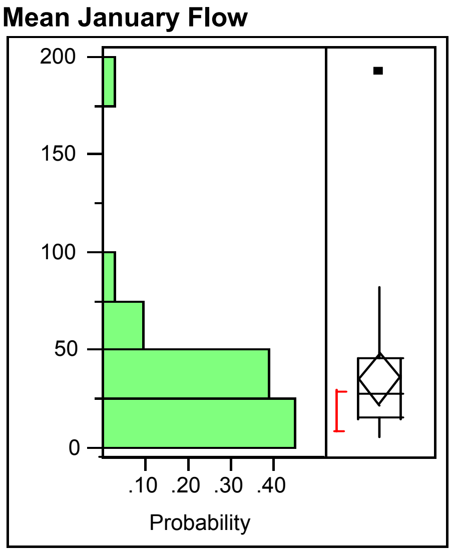
Using the guidelines established in the Rattlesnake Creek Management Plan for augmentation and applying the historical flows for those years in which augmentation would have occurred, the average quantity of water that would have been needed historically to augment Rattlesnake Creek would have been 1,146 acre-feet.

### *Establishing Confidence in the Frequency of Augmentation Estimate:*

In the previous analysis of the 31-year historical record available in the Rattlesnake Creek subbasin, we have found that 14 years would have been designated as augmentation years. However, the problem with concluding our analysis at this point is that, with a finite number of samples, past performance is no guarantee of future returns. With statistics we can build a certain amount of confidence into future expectations by utilizing the information provided in our sampling of the historical data.

We begin with a distribution analysis of mean January flow (1974-2004) on Rattlesnake Creek near Zenith for the 31 years on record (**Figure 8**). Notice in the figure that the data do not appear to be normally distributed.

The data were transformed (a natural log transformation is often appropriate for flow data) and the distribution analysis performed again (**Figure 9**). The distribution of data in **Figure 9** appears to be more normally distributed after the transformation. The Shapiro-Wilk test confirms (Prob<W = 0.7787) that the flow data are now normally distributed.



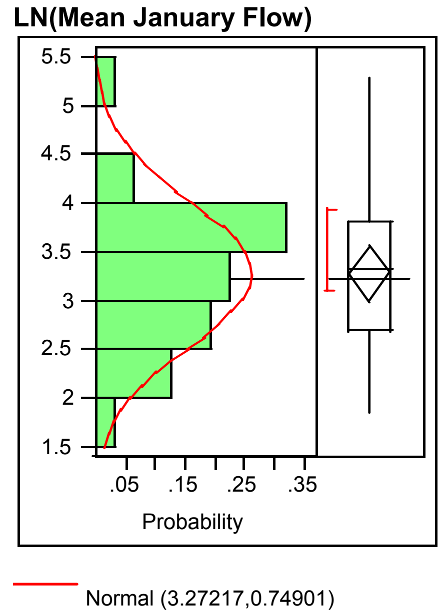

**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 192.00 |
| 99.5% | | 192.00 |
| 97.5% | | 192.00 |
| 90.0% | | 67.28 |
| 75.0% | quartile | 45.00 |
| 50.0% | median | 27.70 |
| 25.0% | quartile | 14.70 |
| 10.0% | | 8.69 |
| 2.5% | | 6.48 |
| 0.5% | | 6.48 |
| 0.0% | minimum | 6.48 |

**Moments**

| | |
|---|---|
| Mean | 35.260323 |
| Std Dev | 34.336852 |
| Std Err Mean | 6.1670806 |
| upper 95% Mean | 47.855181 |
| lower 95% Mean | 22.665464 |
| N | 31 |

**Figure 8**: Mean January Flow 1974-2004




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 5.2575 |
| 99.5% | | 5.2575 |
| 97.5% | | 5.2575 |
| 90.0% | | 4.2019 |
| 75.0% | quartile | 3.8067 |
| 50.0% | median | 3.3214 |
| 25.0% | quartile | 2.6878 |
| 10.0% | | 2.1619 |
| 2.5% | | 1.8687 |
| 0.5% | | 1.8687 |
| 0.0% | minimum | 1.8687 |

**Moments**

| | |
|---|---|
| Mean | 3.2721669 |
| Std Dev | 0.7490082 |
| Std Err Mean | 0.1345258 |
| upper 95% Mean | 3.5469053 |
| lower 95% Mean | 2.9974285 |
| N | 31 |

**Fitted Normal: Goodness-of-Fit Test**

Shapiro-Wilk W Test

| W | Prob<W |
|---|---|
| 0.978808 | 0.7787 |

**Figure 9**: LN(Mean Jan. Flow) 1974-2004

At this point we have a sample of data (31 years of mean January flow) that are normally distributed. The distribution analysis in **Figure 8** has provided, among other things, a sample mean and a sample standard deviation as an estimate of the population (true) mean and population (true) standard deviation. Because we can never know with 100% certainty what the true mean and standard deviation are, we offset the uncertainty we have in our sample estimates by building a certain amount of confidence in our new estimate of the true distribution of mean January flows. The amount of confidence is a management decision and in this case has been established as 95%.

If we wanted to be 95% confident that we have captured in our estimate of the true percentage of years that augmentation will be needed in the future, how would we go about doing that?

The augmentation portion of the Rattlesnake Creek Management Program states that an augmentation year is established when the mean January flow is less than 25 cfs. This 25 cfs (LN(25cfs)=3.22) translates to about the 46th percentile for the distribution in **Figure 8**. In the same way that a confidence interval can be established on the sample mean, so can a confidence interval be established on a percentile of the sample distribution.

A normal 95% upper confidence limit for the 46th percentile of the sample distribution would be computed as

$$UCL_{1-\alpha,p} = \bar{x} + K_{\alpha,p}s$$

where $\bar{x}$ is the sample mean of the $x_i$ flow values in each of the $m$ measurement years from the stream gage site,

$$\bar{x} = \sum_{i=1}^{m} \frac{x_i}{m}$$

and $s$ is the observed sample standard deviation,

$$s = \sqrt{\sum_{i=1}^{m} \frac{(x_i - \bar{x})^2}{m-1}}$$

and $K_{\alpha,p}$ is the one-sided normal tolerance limit factor for (α) confidence and (p) percentile, both expressed as decimals. These $K_{\alpha,p}$ values were generated using a program titled *StInt*. This command-driven DOS program and user's manual is available at: http://www.public.iastate.edu/~wqmeeker/other_pages/wqm_software.html.

From Figure 8, $\bar{x}$ is 3.272, and $s$ is 0.75. The $K_{\alpha,p}$ value for the 46th percentile with an upper 95% confidence limit; $K_{0.95,0.46} = 0.2$. Therefore,

$$UCL_{0.05,0.46} = 3.272 + 0.2 * 0.75 = 3.42$$

Exponentiation of the resulting limit yields 30.6 cfs.

Using 30.6 cfs rather than 25 cfs as the minimum flow requirement and applying this new minimum flow requirement to the 31 years on record we find that 17 of the 31 years would be designated as augmentation years. Assuming that, as before, one augmentation year would be excluded under the drought contingency and in one augmentation year augmentation would not be needed because minimum flow requirements would be met during the augmentation period, the actual number of augmentation years would be 15 out of the 31 years of record (15/31 = 48%). This translates into about half the years in any period (e.g., 5 years of augmentation in a 10 year period).

Therefore, if we wanted to be 95% confident that we have captured in our estimate of the true percentage of years that augmentation will be needed in the future, we would increase our estimated percentage of years that augmentation would be needed from the historical estimate of 39% (about 4 in 10 years) to 48% (about 5 in 10 years).

### ***Establishing Confidence in the Magnitude of Augmentation Estimate:***

From the previous analysis of the 31-year historical record we established that during those years that would have been designated as augmentation years, the average quantity of water used to augment Rattlesnake Creek was 1,146 acre-feet. Again, the problem with concluding our analysis at this point is that, with a finite number of samples, past performance is no guarantee of future returns. We once again can use statistics to build a certain amount of confidence into future expectations utilizing the information provided in our sampling of the historical data.

If we wanted to be 95% confident that we have captured in our estimate the true quantity of augmentation water necessary to meet the expected augmentation needs in the future, how would we go about doing that?

We start with a distribution analysis of the calculated quantity of water augmented to Rattlesnake Creek for the 13 years[1] that augmentation would have occurred during our 31 year period of record (**Figure 10**). Although at first glance these data do not appear to be normally distributed (our sample size is quite small and some degree of caution in this conclusion is advised), our Shapiro-Wilk test (Prob<W=0.2033) does indicate that they are.

At this point we have a sample of data (13 years of estimated augmentation quantity) that are now normally distributed. The distribution analysis in **Figure 10** has again provided us a sample mean and a sample standard deviation as an estimate of the population (true) mean and population (true) standard deviation. The sample mean falls at the 52nd percentile of our distribution. Using the information in the distribution analysis, we proceed as we did in the frequency analysis, except this time we will set an upper 95% confidence level on the 52nd percentile of the distribution.

From Figure 9, $\bar{x}$ is 1,115 af and $s$ is 619 af. The $K_{\alpha,p}$ value for the 52nd percentile with an upper 95% confidence limit, in this case; $K_{0.95,0.52} = 0.552$. Therefore,

$$UCL_{0.05,0.52} = 1{,}115 + 0.552 * 619 = 1{,}460 \text{ acre-feet}$$

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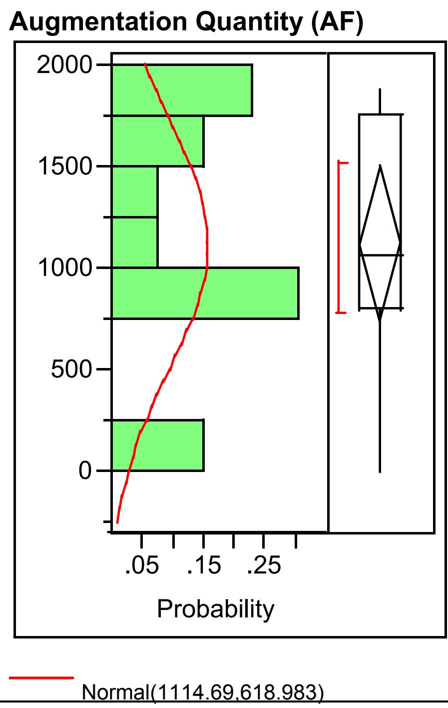
[1] Our previous historic assessment of the frequency of augmentation suggested that there were only 12 actual augmentation years in the historic 31 year record, but recall that one of the years (1987) was excluded from this total because it required no augmentation. Since the flows in Rattlesnake Creek exceeded the minimum flow requirement according to the augmentation strategy in the Rattlesnake Creek Management Program, this year should now be included in the accounting for the magnitude of augmentation; however the quantity of water augmented for this year is 0 acre-feet.




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 1861.0 |
| 99.5% | | 1861.0 |
| 97.5% | | 1861.0 |
| 90.0% | | 1837.4 |
| 75.0% | quartile | 1752.5 |
| 50.0% | median | 1061.0 |
| 25.0% | quartile | 792.0 |
| 10.0% | | 43.6 |
| 2.5% | | 0.0 |
| 0.5% | | 0.0 |
| 0.0% | minimum | 0.0 |

**Moments**

| | |
|---|---|
| Mean | 1114.6923 |
| Std Dev | 618.98282 |
| Std Err Mean | 171.67495 |
| upper 95% Mean | 1488.7399 |
| lower 95% Mean | 740.64473 |
| N | 13 |

**Fitted Normal**

Shapiro-Wilk W Test

| W | Prob<W |
|---|---|
| 0.913280 | 0.2033 |

**Figure 10**: Estimates of augmentation quantity from historical analysis

## Location of Stream Discharge Issues

Using the information that KDA/DWR and GMD5 collected when they did their seepage runs down the length of Rattlesnake Creek in the 1990's we can determine the flow gains and losses between stretches of stream. The seepage run results that were collected during the general time period that augmentation would have occurred are plotted in **Figure 11**. For the stream reach of Rattlesnake Creek under consideration, flows are generally lowest upstream of Highway 281 and then increase to the Zenith gage location. The largest incremental increase in flow is, again, between Site #1 and #5 (**see Figure 12** to locate these sites); the sites at Highway 281 and the next site downstream.

The reaches where stream flow is being gained and lost is important because the most effective and cost efficient place to discharge augmented water to Rattlesnake Creek is at a point below which the stream is consistently gaining flow. Augmentation to a gaining reach provides assurance that a large portion of the augmented quantity actually arrives at its intended destination. Alternatively, a much smaller fraction of an augmented quantity of water would actually arrive at its intended destination if discharge from augmentation were to occur in a losing stream reach. In a losing reach, a portion of the augmented water would be lost to recharge of the aquifer underlying the stream. Based upon the data available from the KDA/DWR and GMD5 seepage runs, the best location to discharge augmentation water would be below Highway 281. The closer the discharge point(s) to Quivira the lower the anticipated loss to groundwater recharge and evapotranspiration during transit.

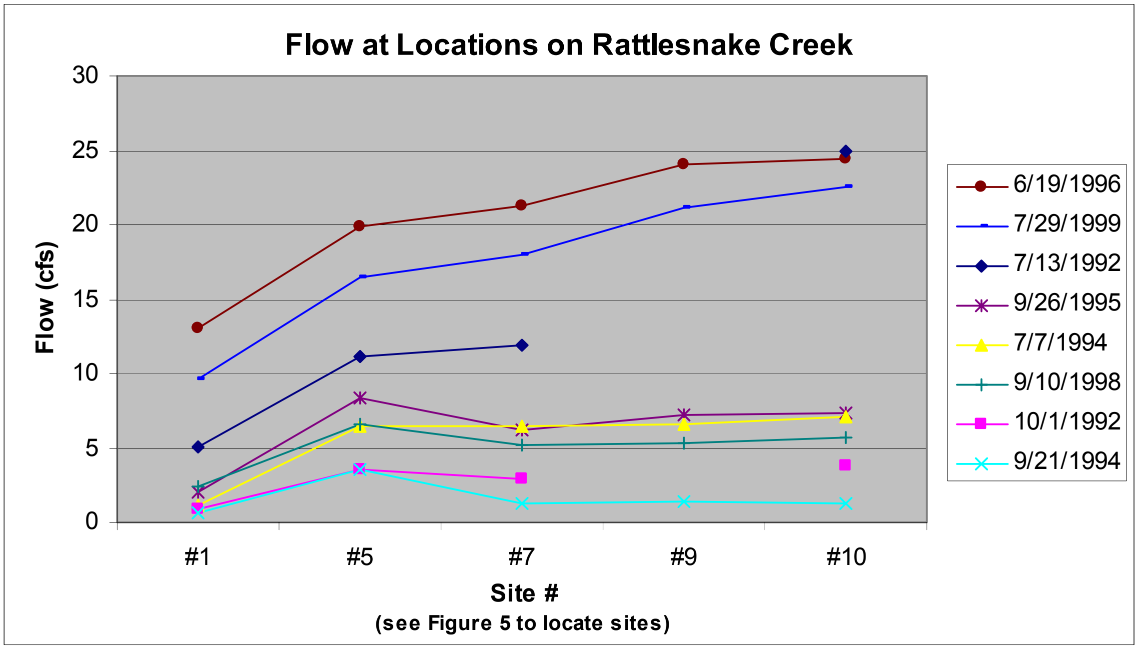



**Figure 11**: Stream flows measured on Rattlesnake Creek in the 1990s

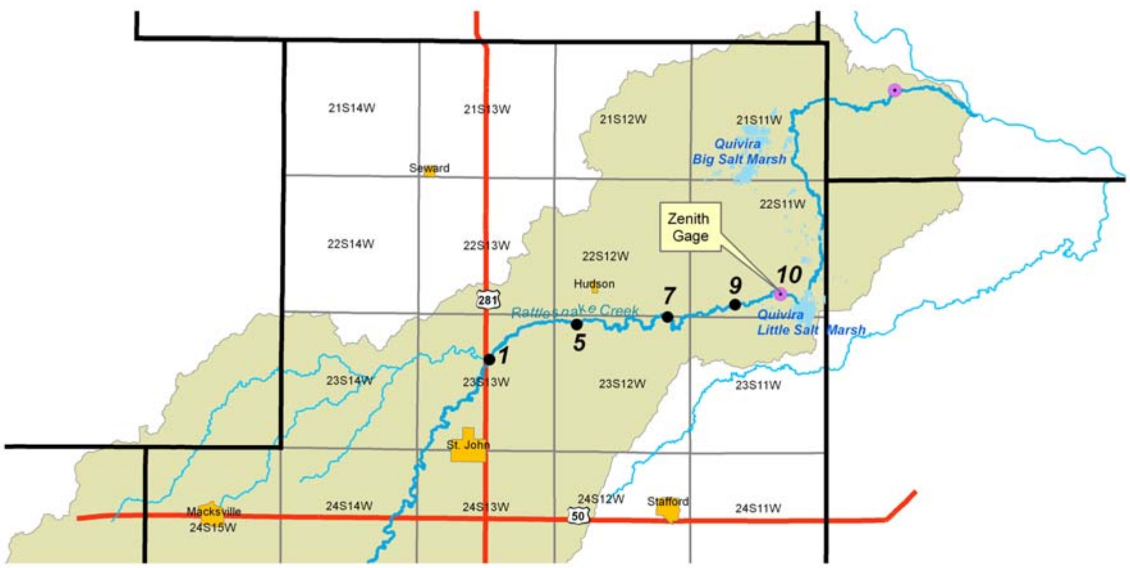



**Figure 12**: Chloride sample and flow measurement locations on Rattlesnake Creek

## Augmentation Costs

In 2001 and 2002 Big Bend GMD5 spent a considerable amount of time and money developing an estimate for the cost of Rattlesnake Creek augmentation. During the final phase of that study, GMD5 contracted with Kansas Livestock Association Environmental Services, Inc. to engineer the augmentation design and provide cost estimates. The KWO cost estimates in this report are essentially updates to the pertinent portions of that GMD5 study.

### *Water Rights Costs*

The information previously established about the quality, frequency and magnitude of augmentation creates the framework and guidelines for augmentations costs. From a water quality standpoint the KWO recommends the use of freshwater for augmentation. The reasons for this recommendation are:

1) using a freshwater source for augmentation would actually dilute the chloride concentration in the current base flows so that the target flow would always be less than the relationship established between base flows and chloride concentrations thereby actually improving the water quality of Rattlesnake Creek when augmentation occurs.

2) the potential monitoring requirements are operationally much less complex and consequently less costly with a freshwater source of augmentation as compared to the alternate mineralized source of augmentation.

This recommendation of a freshwater source for augmentation also establishes the 'optimal location' from which water should be withdrawn. Since Rattlesnake Creek commonly gains flow starting at Highway 281 and this point also generally divides the fresh water and mineralized sources, augmentation withdrawals and discharge should occur upstream of Highway 281 but as close to it as possible without incurring recirculation of augmented water.

The Rattlesnake Creek subbasin is closed to any further new water appropriations (excluding small use appropriation outside the 4-mile stream corridor; GMD5 Regulation 5-25-15); therefore, augmentation must come from existing water rights in the watershed. The KWO recommends that, rather than leasing water rights, existing water rights be purchased. Purchasing water rights for augmentation will reduce the consumptive use of water in the Rattlesnake Creek stream corridor (a primary goal of the RCMP) and reducing the consumptive use in the corridor can help improve baseflow to the creek through time. The RCMP 4-mile stream corridor's targeted water use reduction is 3,737 acre-feet (see **Appendix, Table A1**, for RCMP water use reduction goals). The purchase water right recommendation in this augmentation report is estimated to save, over the long term, about 840 acre-feet annually in water use in the corridor (see **Appendix, Table A2**, for this calculation).

Leasing water rights for augmentation is more complicated from a legal and management perspective and does not reduce consumptive use in the stream corridor to the same level as the purchase option, since irrigation from leased wells would occur in those years that are not designated as stream augmentation years. Also, leases would necessarily have to be renewed from time to time and once the plumbing for augmentation is constructed during the initial lease period, the value of a particular well to the augmentation project is increased by that well's plumbing cost (plus the cost of plumbing an alternate well if a lease agreement could not be renewed).

To estimate the potential costs of augmentation, a sample of 23 water rights in the previously defined 'optimal location' were selected and reviewed. The median number of acres certified under these water rights was 130, the median certified quantity of water was 195 acre-feet and the median rate was 880 gpm (**Table 1**). These median values, coupled with the projected quantity of water necessary for augmentation; the frequency with which that augmentation is anticipated; and the rate of augmentation (**Table 2**), create the starting point for the augmentation cost estimate.

**Table 1**

| **Summary results for wells sampled from general target area** | | |
|---|---|---|
| Median Rate | 880 | gpm |
| Median Quant. | 195 | af |
| Median Acres | 130 | acres |
| n | 23 | water rights |

**Table 2**

| **Projected Augmentation Targets** | | |
|---|---|---|
| Target Quant. | 1,457 | af |
| Max Quant. | 1,861 | af |
| Max Rate | 21 | cfs |

KDA/DWR has specific regulations (K.A.R. 5-5-9) regarding a change in the use made of water from irrigation to another use. The input values for this regulation are from **Table 1**. In **Table 3**, the number of water rights was varied until the calculated median and maximum quantity and rate satisfied the projected augmentation needs in **Table** 2. The result indicates that 12 water rights would need to be purchased to meet augmentation needs.

Because of the drought contingency in the RCMP augmentation strategy and the previous assessment of the historic distribution of potential augmentation quantity, the likelihood of ever needing to augment the entire 2,100 acre-feet in the augmentation strategy is very remote. In fact, using the normal distribution curve established in **Figure 7**, the chance of needing to augment 2,100 acre-feet is less than 2%. Therefore, the KWO believes the maximum reasonable quantity of water needed for augmentation is less than 2,100 acre-feet and we have used the historic maximum as the target high for augmentation (1,861 acre-feet).

The number of water rights in the 'optimal location' for augmentation is relatively small. Scarcity of product will drive the price of the product up. GMD5's last estimate (early 2002) in their study of this augmentation project estimated the price per acre-foot of water under the water right purchase option at $1,000. Because of the market dynamics in the target area KWO believes a reasonable price may now be around $1,250 per acre-foot.

**Table 3**

| Application of 5-5-9 to Determine Number of Water Rights (WRs) Needed for Augmentation Project | | | | | | |
|---|---|---|---|---|---|---|
| **KAR 5-5-9** | | | | **Projected Augmentation Targets** | | |
| Median Acres Certified for WR | 130 | ac | | | | |
| SF Co. 50% Net Irr. Requirement | 1.03 | ft | | | | |
| SF Co. 80% Net Irr. Requirement | 1.21 | ft | | | | |
| Straight UMW Change | 133.9 | af | | | | |
| ***Quantity-check*** | | | | | | |
| **KAR 5-5-9 (5-Yr Allocation)** | | | | | | |
| 5-yr Allocation | 669.5 | af | | | | |
| Max Quant (5-yr Alloc'n) | 157.3 | af | | | | |
| Water Rights | **12** | | | | | |
| Median Quantity from WRs | *1,606.8* | af | | Target Quant. | **1,457** | af |
| Max Quantity from WRs | *1,887.6* | af | | Max Quant. | **1,861** | af |
| Total Quantity from WRs | 8034 | af | | | | |
| ***Rate-check*** | | | | | | |
| Rate | 880 | gpm | | | | |
| Max Rate from WRs | *23.57* | cfs | | Max Rate | **21** | cfs |

**Table 4** shows that using the $1,250 per acre-foot value, the purchase price of 12 water rights is $2,925,000.

**Table 4**

**Estimate WR Purchase Cost**

| | | |
|---|---|---|
| Median Irrigation WR | 195 | af |
| Total AF Purchased (12 WR) | 2,340 | af |
| Est. Cost to purchase 1 AF | $1,250 | $/af |
| Total Purchase Cost | **$2,925,000** | |

## *Engineering and Construction*

The diversion works plan originally developed for GMD5 was to install and connect 4 wells in loose clusters and divert water from those groups of wells into a single supply line to Rattlesnake Creek via a stream discharge structure engineered to minimize the scour and bank erosion at the augmentation discharge point. For 12 water rights, 3 of these discharge points would be required. **Table 5** updates the construction costs for such a design. Almost all construction items have increased substantially from the 2002 GMD5 cost estimates, most notably the installed price of PVC pipe whose cost has been inflated by the effects of hurricanes in the Fall of 2005 on its manufacture and availability.

**Table 5**

| Diversion Works Cost Estimate (redrill 12 wells, connection systems and stream discharge systems) | Quant | Unit | Unit Cost | Item Cost |
|---|---|---|---|---|
| Test Drill | 12 | Ea | $800 | $9,600 |
| Meter | 12 | Ea | $,1050 | $12,600 |
| 16" Cased and Gravel Packed Well | 960 | Ft | $60 | $57,600 |
| Test Pump and Develop Well | 12 | Ea | $600 | $7,200 |
| 110 HP Diesel Pumping Plant and Fixtures | 12 | Ea | $9,800 | $117,600 |
| 10" Dia PVC Pipe (Schedule 40; 3' cover; installed) | 3900 | Ft | $26 | $102,570 |
| 12" Dia PVC Pipe (Schedule 40; 3' cover; installed) | 3900 | Ft | $31 | $122,148 |
| 15" Dia PVC Pipe (Schedule 40; 3' cover; installed) | 3900 | Ft | $52 | $202,059 |
| 18" Dia PVC Pipe (Schedule 40; 3' cover; installed) | 19800 | Ft | $71 | $1,398,474 |
| Stream Discharge Structure (@ 20 Cu Yds Ea) | 60 | Cu Yd | $366 | $21,960 |
| 500 Gallon Fuel Tank on Skids | 12 | Ea | $400 | $4,800 |
| 1000 GPM Pump with Bowl and Shaft Drive | 12 | Ea | $13,000 | $156,000 |
| Total Cost | | | | $2,212,611 |

### *Annual Operations and Maintenance*

The KWO recommends that GMD5 be responsible for the operation and maintenance of Rattlesnake Creek augmentation.

The annual operation and maintenance costs are based on the projected 1,460 af necessary for augmentation at an augmentation frequency of 50% (five years out of ten). This quantity would average about 730 af/yr and forms the basis for the fuel cost estimate. A USGS continuous water quality monitoring gage would be needed to insure compliance with chloride limitations associated with the augmented water. **Table 6** summarizes the operation and maintenance costs.

**Table 6**

| Estimated Annual Operating Costs | |
|---|---|
| Fuel Costs | $34,239 |
| GMD5 Overhead | $45,000 |
| USGS Continuous WQ Monitoring Gage | $12,500 |
| Total Annual Cost | $91,739 |

## Plan/Report Limitations and Uncertainty

The uncertainty in the estimates in the frequency and quantity of augmentation water was established at an error level of 5%. However, any long-term climate change that would affect the distribution of annual precipitation (and consequently streamflow) would violate some of the assumptions used to set the confidence intervals on the frequency and magnitude of the projected augmentation needs.

The largest amount of uncertainty in the augmentation cost estimate would be associated with the costs of water rights, PVC pipe and the general effect of fuel prices on all items.

## Alternatives to Augmentation Strategy

The estimated water use reductions established by the RCMP (see **Appendix, Table A1** for these water use reduction goals) were set,

> to achieve long-term sustainable management in the Rattlesnake Creek subbasin, as well as where suggested reductions in water use would have to occur to achieve the desired effect. (Page 3, RCMP)

and that the 4-mile stream corridor water use reduction goal of 3,737 acre-feet was established,

> in order to obtain a target 10 year average January streamflow of 25 cfs at the Zenith Gage. (Page 3, RCMP)

Since the current estimate of the cost of augmentation, excluding annual operations costs, is about $5.1 million, one can use this water use reduction goal for the stream corridor and back-calculating the water right purchase quantity necessary to meet the water use RCMP reduction target of 3,737 acre-feet in the stream corridor. Using the current water right purchase estimate of $1,250 per acre-foot, the entire water use stream corridor reduction target from the RCMP could be met by using the current augmentation cost estimate of $5.1 million plus one year of annual operation costs to purchase and retire water rights.

## APPENDIX

**Table A1**

| Rattlesnake Management Alternative Numbers and Funding (Table reproduced, as updated in January 2005, from Rattlesnake Creek Management Program Proposal) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Groundwater Unit** | | **4-mile Corridor** | | **Basinwide** | | **Totals** | |
| **Program Goals** | | | | | | | | |
| Total Appropriations within Target Area | 118,989 | AF | 42,798 | AF | 59,281 | AF | 221,068* | AF |
| Avg. WU/Yr. (72% of Total Apprn) | 83,967 | AF | 31,144 | AF | 43,078 | AF | 158,189 | AF |
| Total Appropriations Goal in Target Area | 99,951 | AF | 37,662 | AF | 54,835 | AF | 192,448 | AF |
| Average Water Use per Year Goal (72% of Appropriations) | 70,532 | AF | 27,407 | AF | 39,847 | AF | 137,786 | AF |
| Savings Needed From Current Appropriations to Reach Goal | **19,038** | AF | **5,136** | AF | **4,446** | AF | **28,620** | AF |
| Water Use Savings Needed to Reach Goal | **13,435** | AF | ***3,737*** | AF | **3,231** | AF | **20,403** | AF |

* Note that the total appropriations value calculated by KDA/DWR in this table is not the same value provided on Page 7 of this report. The difference is that the KDA/DWR number doesn't include a portion of the Rattlesnake Creek subbasin in Ford and the western part of Kiowa County.

**Table A2**
**Calculation of Anticipated Water Use Saving under Water Right Purchase for Augmentation Recommendation**

| | | |
|---|---|---|
| Median WR Quant. | 195 | af |
| Water Use as % of Total Appropriation (From RCMP Table A1 above) | 72 | % |
| Calculated Frequency that Augmentation DOES NOT occur | 50 | % |
| # of WR to be Purchased | 12 | WRs |
| Long Term Water Use Saving in 4-Mile Corridor | 842.4 | af |