South Platte River Streamflow
and
The South Platte River Compact

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Final Project
CVEN 5454
May 3, 2005
Project Description

The South Platte River Compact, signed in 1925 by the states of Nebraska and Colorado, was created to “remove all causes of present and future controversy” between the two states with respect to the waters of the South Platte River.

One of the provisions of the compact states:

Between the first day of April and the fifteenth day of October of each year, Colorado shall not permit diversions from the Lower Section of the river … to an extent that will diminish the flow of the river at the Interstate Station, on any day, below a mean flow of 120 cubic feet of water per second of time …

_South Platte River Compact, Article IV, Paragraph 2_

The “Lower Section” of the river is defined to be the South Platte River reach from the western boundary of Washington County (near Balzac, CO) to the Colorado-Nebraska state line. This is also known as Water District 64. The “Interstate Station” is defined to be the “Julesburg Bridge” stream gage station.

This compact has historically been administered to curtail all diversions in District 64 that have an appropriation date junior to June 14, 1897, when the flow at the Julesburg Bridge is less than 120 cfs between April 1 and October 15. Figure 1 shows a time series plot of the total number of days per year the flow of water was 120 cfs or less (and therefore, the compact was in effect), between the years 1927 (when the compact was first administered) and 2002. Only seventy-six years of data within this time period will be evaluated, as there is no data available for some years in the specified time period.

The time series plot appears to indicate that the flow at the Julesburg Bridge is increasing, as there is a general downward trend in the total number of days the flow is at or below 120 cfs. The cause of this increase in flow at the state line could be due to any number of factors, including but not limited to: change in the State’s administration of water rights, change in diversion patterns, change in use patterns (i.e. possibly increased return flows near the state line), or an overall increase in streamflow due to weather patterns. For the purposes of this study, it is assumed that the Compact’s dates of effect are April 1 through October 31.

The scope of this project will be limited to a statistical summary of monthly streamflow data between 1927 and 2002 and a brief linear regression comparison of monthly streamflow data to the number of days the compact is in effect for the particular month. If these data are linearly related, then further analysis can be done on a monthly basis to determine which parameters have the greatest impact on compact calls.
**Initial Observations of Data**

**Distribution of Data**

The mean, 10% trimmed mean, variance and skew of the monthly streamflow and compact data are given in Table 1. A cursory glance at this data can give some information about the data and its distribution.

**Location**

The monthly mean streamflow at the Julesburg Bridge differs greatly from the 10% trimmed mean and median. Because calculation of mean is highly influenced by outliers, this difference shows that the data likely has skewed outliers and is not normally distributed. This hypothesis is supported by the high value of skew.

**Spread**

The spread of the data can be shown by the range and by the sample variance and standard deviation, calculated below with 75 degrees of freedom \((N - 1 = 76 - 1 = 75)\). Calculation of skew also shows the flow data to be highly positively skewed.

<table>
<thead>
<tr>
<th>1927-2002</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
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<tbody>
<tr>
<td><strong>Julesburg Bridge Flow (cfs)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>45.6</td>
<td>89.4</td>
<td>117.0</td>
<td>27.8</td>
<td>16.6</td>
<td>21.0</td>
<td>25.8</td>
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<tr>
<td>Trimmed Mean</td>
<td>39.9</td>
<td>64.6</td>
<td>91.8</td>
<td>15.5</td>
<td>11.9</td>
<td>17.0</td>
<td>21.8</td>
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<tr>
<td>Median</td>
<td>23.9</td>
<td>17.5</td>
<td>22.8</td>
<td>5.3</td>
<td>4.5</td>
<td>9.2</td>
<td>12.2</td>
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<tr>
<td>Maximum</td>
<td>230.8</td>
<td>842.7</td>
<td>1003.1</td>
<td>429.7</td>
<td>159.9</td>
<td>161.4</td>
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<tr>
<td>Minimum</td>
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<td>2.5</td>
<td>2.4</td>
<td>1.4</td>
<td>1.2</td>
<td>0.8</td>
<td>1.9</td>
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<td>Range</td>
<td>227.4</td>
<td>840.2</td>
<td>1000.8</td>
<td>428.3</td>
<td>158.7</td>
<td>160.6</td>
<td>204.3</td>
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<tr>
<td>Variance</td>
<td>2825.69</td>
<td>30645.24</td>
<td>36185.00</td>
<td>4979.12</td>
<td>1011.02</td>
<td>960.19</td>
<td>1083.23</td>
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<tr>
<td>Standard Deviation</td>
<td>53.16</td>
<td>175.06</td>
<td>190.22</td>
<td>70.56</td>
<td>31.80</td>
<td>30.99</td>
<td>32.91</td>
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<td>Skew</td>
<td>1.98</td>
<td>2.85</td>
<td>2.69</td>
<td>4.71</td>
<td>3.13</td>
<td>2.60</td>
<td>3.03</td>
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<tr>
<td><strong>South Platte River Compact Effect (days)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>8.2</td>
<td>14.3</td>
<td>12.0</td>
<td>22.2</td>
<td>25.0</td>
<td>18.0</td>
<td>12.2</td>
</tr>
<tr>
<td>Trimmed Mean</td>
<td>7.6</td>
<td>14.2</td>
<td>11.7</td>
<td>22.8</td>
<td>25.9</td>
<td>18.2</td>
<td>11.9</td>
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<tr>
<td>Median</td>
<td>2.0</td>
<td>14.5</td>
<td>8.0</td>
<td>29.0</td>
<td>30.0</td>
<td>21.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>30</td>
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<td>30</td>
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<td>Minimum</td>
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<td>30</td>
<td>31</td>
<td>31</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Variance</td>
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<td>127.37</td>
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<td>117.56</td>
<td>76.79</td>
<td>138.01</td>
<td>157.43</td>
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<td>11.29</td>
<td>12.02</td>
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<td>8.76</td>
<td>11.75</td>
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<tr>
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<td>0.01</td>
<td>0.39</td>
<td>-0.90</td>
<td>-1.58</td>
<td>-0.35</td>
<td>0.37</td>
</tr>
</tbody>
</table>

**Boxplots**

There are a number of tests that can be performed to determine the distribution of the data. Visual tests include histograms and boxplots. Monthly distributions of the data are shown in the boxplots in Figure 2. These figures visually show what the above calculations predict. Figure 1a shows that the streamflow data is highly positively skewed with the whiskers showing the 95 percentile of the data and the circles showing actual data points in the 5% tails of the data. Medians of the data are given by the horizontal line within the box, while the mean values are plotted over the boxplot as a red line. The streamflow data is highly skewed and consequently, mean data is not a good indicator of position and should not be used as a predictor for future flows.
The compact data appears only to be slightly skewed, sometimes positively, sometimes negatively, with the mean inconsistently coinciding with the median value.

**Distributions of Data**

**Histograms**

Monthly distributions of the data are shown in the histograms in Figure 2. Again, the monthly streamflow data clearly displays a highly positively skewed distribution. The compact data, however, sometimes displays a positively skewed distribution, sometimes a negatively skewed distribution, and sometimes is bimodal.
Selecting a month with highly skewed distribution, say April, the streamflow histograms can be plotted with a number of fitted probability distribution functions (PDFs) including normal, log normal, gamma and Weibull distributions. These plots are shown in Figure 3.

Figure 3 shows that the lognormal and Weibull probability distribution functions visually appear to fit the data. Further K-S testing was done to quantify the goodness of fit using a 95% confidence interval. These results are shown in Table 2. Because the p-values for the lognormal and Weibull distributions are greater than $\alpha=0.05$, these two distributions can be accepted with a 95% confidence.

The compact data does not visually appear to possess any of the above three distributions, so the tests were not run on this data.

**Nonparametric Distributions**

Nonparametric probability distributions can also be fit for the two sets of data. Histograms of monthly values for streamflow and compact impact is shown in Figure 4 with Non-Parametric PDFs fitted on top of the plots. Note that these distributions match the variability of distribution in the compact data.
Comparison of Data Over Time

As neither of the data sets show normal distributions, the t-test and f-tests were not performed on the data.

Since I am interested in looking at how the compact’s effects have changed over time, I split the data into two datasets for the years 1927-1964 and 1965-2002. Figure 5 shows box plots of all April through October streamflow and compact data and smooth bootstrap means for the earlier and later years.

Figure 4: Histograms of monthly streamflow and compact effect data for 1927 through 2002 with non-parametric probability distribution functions calculated for each distribution.

Figure 5: Boxplots of original data and means of smooth bootstrap samples for streamflow (left) and compact effect (right).
As previously discussed, the compact effect has been less over the past 40 years than it had previously been. Comparison of means of smooth bootstrap samples confirms this hypothesis.

A timeseries plot of streamflow data does not appear to have followed the same trend, though the boxplots in Figure 5 appear to show that the last 40 years have had higher streamflows. The mean of the 1927-1964 streamflow data is 215.3 cfs, while the mean of the 1965-2002 streamflow data is 471.1 cfs.

The means of the smooth bootstrap samples do not confirm this as it shows the means of the last 40 years to be much lower than that of previous years.

The boxplots of the original data seem to show a correlation between the streamflow data and the compact effect data. This is what we would expect because the compact's effect was calculated from the streamflow data.

**Relationship of Monthly Data**

**Linear Regression**

To see if there is a linear correlation between monthly average streamflow data and the average number of days the compact is in effect, the data was first plotted on an x-y axis. This plot is shown in Figure 6.

The data do not appear to display a linear correlation, though this may be expected as they do not have the same PDF.

This would suggest that compact effect could not be estimated from monthly streamflow averages and that daily analysis must be done.

Calculating the best-fit line using least sum of squares regression, the following equation is obtained.

\[
\text{# Days Compact in Effect} = 18.58 - 0.05 \times \text{Monthly Streamflow Total (cfs)}
\]

Running an F-test on the model to see how effective the model is gives an F-statistic of 150.64 (degrees of freedom = 1; 530). Because this value falls far outside the theoretical range (0.00395 > f-statistic > 3.93811), we can conclude that our model is distinctly different from our error.

Though our model does appear to have correlation between monthly total streamflows and the number of days the compact is in effect for that given month, the relationship does not appear to be linear.
Conclusion

Daily streamflow values of the South Platte River are used to evaluate whether the South Platte River compact goes into effect, which occurs when streamflow is at or below 120 cfs. Though the general trend of streamflow over the last 75 years appears to be going up and the number of days the Compact is in effect each month appears to be going down, the relationship does on appear to be linear on a monthly basis and therefore analysis of possible causes of this phenomenon can not be linearly related on a monthly basis.