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Medicine Bow Mountains, North Platte River Basin

Relationships of Hydro-Climate Indices (HCI) to Volumetric Flow in North Platte River Basin

COLORADO WATER CONSERVATION BOARD

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INTRODUCTION

In January 2012, a Dewberry team prepared a report entitled, “On the Predictive Value of Hydroclimate Indices to Water Supply – A Technical White Paper” (Henz and Geiger, 2012) for the Platte River Restoration and Implementation Program (PRRIP). It dealt with the potential value of using hydro-climate indices (HCI) during the first half of the Water Year (WY) for anticipating periods of very low stream flow volume in June on the Platte River system. During the period of 1947 – 2011 the Platte River system experienced four multi-year low flow periods as identified by a comparison of June streamflow discharge. A repeatable pattern developed in three hydroclimate indices (HCI) during these periods. The Pacific Decadal Oscillation (PDO), Multi-variate ENSO Index (MEI) and the Atlantic Multi-Decadal Oscillation were all in a negative phase when the multi-year low flow periods occurred in the Platte Basin. Later, strong relationships were noted between the Arctic Oscillation and the Palmer Drought Severity Index (PDSI) with above average and below average Platte River flow regimes.

Both the Colorado Water Conservation Board (CWCB) and the PRRIP expressed an interest in whether a repeatable relationship existed between HCI and flow in the Platte River basin. If such a relationship existed, could it be used in January to anticipate whether the Spring runoff volume would be above or below average flow values? The need for this information is discussed briefly in the next section.

THE NEED

Colorado Needs

The Platte River basin acts as a major water source for Colorado, Nebraska and Wyoming. In Colorado, the South Platte River and its tributaries provides water supplies for the heavily populated Front Range region that stretches from Fort Collins to the Denver metro area as well as the extensive agricultural areas in northeastern Colorado. The Colorado Water Conservation Board (CWCB) plays an active role in the Platte Basin during both drought and flood periods. CWCB administers flood plain regulation and flood insurance programs which are very crucial during flood periods. CWCB also acts as a focal point for Colorado’s Drought Mitigation and Response Plan. Advanced knowledge of periods of flood or drought and their impacts on water supply is an active and continuing interest of the CWCB. Figure 1 shows the Platte River system in Colorado, Wyoming, and Nebraska. This project focuses on the early Water Year anticipation of North Platte River Basin flows.

The CWCB has expressed an interest in developing more quantitative and reliable means of anticipating periods of drought and flooding based on short term climate patterns. This need was highlighted by the lack of advance anticipation of the “flash drought” of 2012 that impacted the entire state of Colorado. The state’s agriculture, water supply and tourism industries were severely impacted by the drought.

Nebraska Needs

In Nebraska, the impacts are similar with the Platte River acting as a major water source for the state’s agricultural business and many near-river communities that stretch the length of the state. The Platte River Recovery Implementation Program (PRRIP) plays an active role in three key activities impacted by climate impacts on water supply: increasing stream flows in the central Platte River during relevant time periods, enhancing, restoring, and protecting habitat lands for the target bird species and accommodating certain new water-related activities.

The program’s objective is to use incentive-based water projects to provide sufficient water to and through the central Platte River habitat area to assist in improving and maintaining habitat for the target species. Flow re-timing will be accomplished in part by releases from the Environmental Account (EA) in Lake McConaughy. The EA is a portion of the water stored in Lake McConaughy that is set aside and managed by the Fish and Wildlife Service for the benefit of the target species.

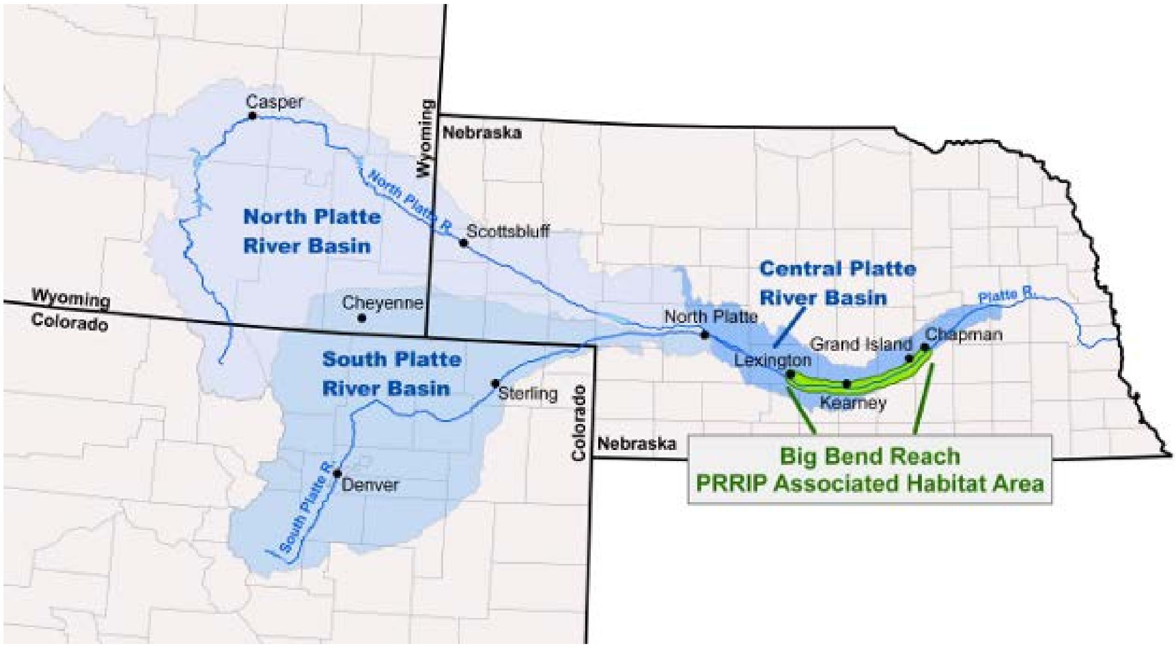

Figure 1 – Diagram of the Platte River system in Wyoming, Colorado, and Nebraska.

Figure 1 shows the PRRIP program areas in Wyoming, [1] Colorado and Nebraska. Since the flow in the Platte at Grand Island is a key factor in the PRRIP's success, the development of a process that could anticipate the onset and end of dry/drought periods and wet/flood conditions would be very helpful to the program in establishing its annual target flow requests. This project represents the first step in developing a capability to anticipate flow volumes.

DATA

Hydro-climate Indices

The hydro-climate indices used in this study were pre-screened from a set of over a dozen potential predictors. Due to the limited resources for this study, the key selected HCI showed the strongest relationships and are listed below:

1. Pacific Decadal Oscillation (PDO):
   http://jisao.washington.edu/pdo/PDO.latest

2. Arctic Oscillation (AO):
   http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii.table

3. Mutli-Variate ENSO Index (MEI):
   http://www.esrl.noaa.gov/psd/enso/mei/table.htm

4. Palmer Drought Severity Index (PDSI):

   Lower Platte
   http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries.pl?ntype=2&typediv=3&state=+48&averaged=11&division=8&year1=1948&year2=2013&anom=0&iseas=0&mon1=0&mon2=0&typeout=1&y1=&y2=&plotstyle=0&Submit=Create+Timeseries

   Upper Platte
   http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries.pl?ntype=2&typediv=3&state=+48&averaged=11&division=10&year1=1948&year2=2013&anom=0&iseas=0&mon1=0&mon2=0&typeout=1&y1=&y2=&plotstyle=0&Submit=Create+Timeseries

The link which follows the HCI identification provides the data sources used in this study. Each data source reports the updated monthly HCI values between the 10^{th} and 20^{th} of the month. The process which is described strives to allow flow volume regime identification between January 10^{th} and 20^{th} of the new Water Year.

METHODOLOGY

This study focused on examining combinations of physically related hydro-climate indices that could be used to identify if a water year's spring volumetric flow in the North Platte Basin would be average, below average or above average in January. Dewberry examined many HCI and upper air flow parameters, singularly and in combination, to identify which ones related most strongly to volumetric flow regimes in the North Platte Basin. Discussions on the analysis processes and development of a "forecast volumetric flow" model follow.

Analyzing Gauge Data for the North Platte for Years 1941-2013

To determine a normal year versus dry or wet years in the N. Platte Basin, gauge data for the N. Platte at Lewellen, NE was analyzed to determine the average, median, and standard deviations of the data set. A single value for the "runoff year" was developed by taking the daily mean for each day, converting it into acre feet per day, and then summing each daily volume for the months of May, June, and July, which results in a volume of runoff for the runoff season. The volume was then sorted and ranked by occurrences for statistical analysis. Applying a normal distribution, a high skew in the data set resulted in an exceptionally large standard deviation that was larger than the mean. If one standard deviation below the mean was computed it results in a value that was less than the lowest recorded value on record.

A different method was used to select an average year by computing the geometric mean. The geometric is commonly applied to datasets with large outliers to gain a better representation of what the average or above average value may be. For this data set, the geometric mean fit closely with the median of the data set, which is more in line with what would be expected when a normal distribution is applied for analysis.

The largest flow volume per runoff year on record is 85 percent greater than the geometric mean, while the lowest flow volume per runoff year is 380 percent less than the geometric mean. A break[1] in the data set for lower volumes occurs at the 20th percentile or a flow volume of 100,000 acre-feet per runoff season. At this value, there is an 80 percent chance that the flow will be equaled or exceeded in any year. 100,000 acre-feet per runoff year also correlates with being 80 percent less than the geometric mean of all years.

Wet and Dry Years were based the development of an exceedance curve of total streamflow volume moving past

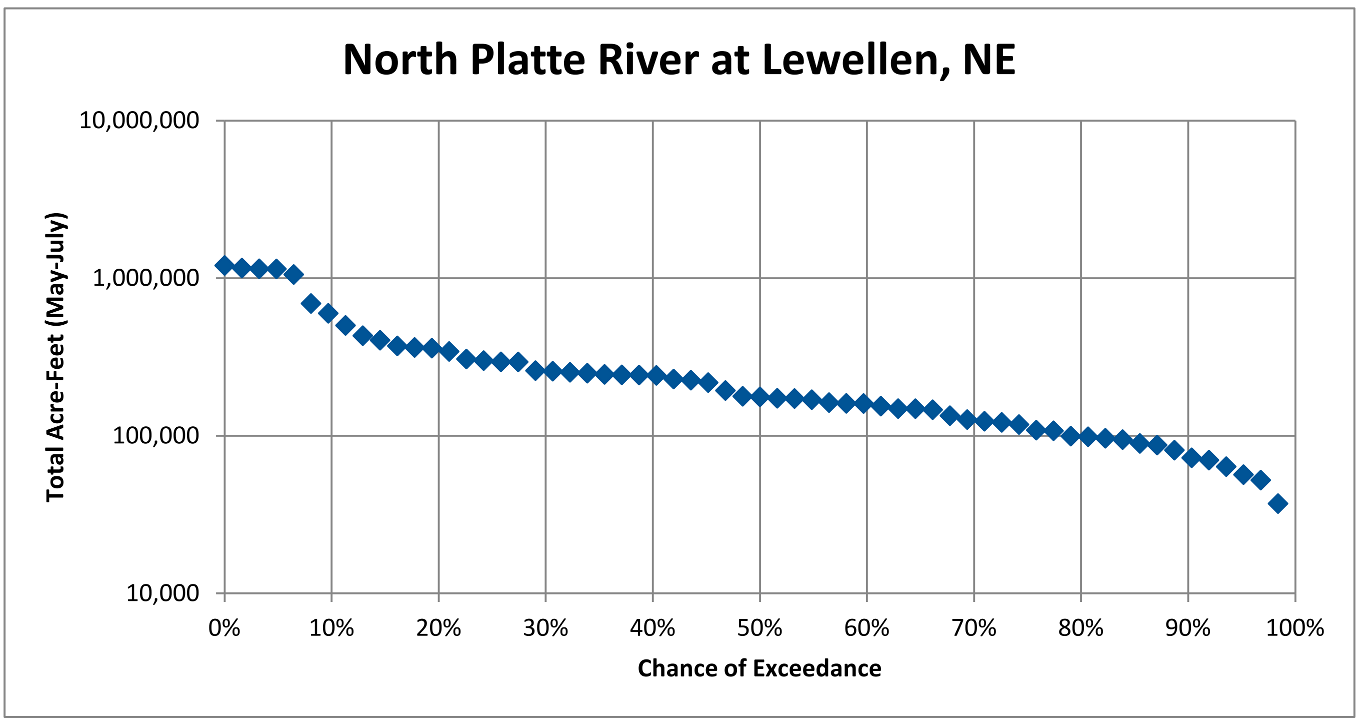

Figure 2 - Exceedance graph for the May-June-July volumetric flow measured at Lewellen NE gauge

the NE DNR gage at Lewellen, NE. This volume was calculated using the total volume over the months of May, June, and July, and is presented in units of acre-feet (af). Dry years were classified as those years with a probability of exceedance greater than 85% (100,000 af), while wet years were classified as those with a probability of exceedance less than 20% (350,000 af). The remaining years were classified as average. The next step in the analyses was to relate these flow regimes and values to the various selected HCI.

Evaluation of the HCI relative to the North Platte Basin spring volumetric flow

Henz, et al, 2012 identified that various HCI were either singularly or in combination related to high and low flow regimes in both the North and South Platte River basins. Further it was noted that if these HCI were in phase or out of phase the collective relationship changed. This study evaluated the quantitative relationship between the flow regimes and the HCI. The results of these evaluations are noted in the following paragraphs.

PDO/MEI Phase – Are the indices of PDO and MEI in phase? Yes or no?

PDO – Pacific Decadal Oscillation, MEI – Multivariate ENSO Index
To determine if PDO and MEI were in phase, the phase of each index was considered (PDO for February of the previous year, MEI for September and October of the previous year). If PDO was in cold phase and MEI was in La Nina phase, then PDO and MEI were defined as in phase. Likewise, if PDO was in warm phase and MEI was in El Nino phase, then PDO and MEI were defined as in phase. If PDO was in cool phase and MEI was in El Nino phase, then PDO and MEI were defined as out of phase. Likewise, if PDO was in warm phase and MEI was in La Nina phase, then PDO and MEI were defined as out of phase. If PDO was neutral and MEI was neutral, PDO and MEI were defined as neutral, but out of phase for the purpose of this study.

“Basin” Palmer Drought Severity Index (Basin PDSI) – Basin Average was calculated using the November/December Upper Platte Average + November/December Lower Platte Average. The average from those two basins is our basin average PDSI used in our decision flow chart. Values greater than, or equal to, 2” are considered wet conditions, and values less than, or equal to, -2” are considered drought or dry conditions. Values between -2” and 2” were considered average within the goals of the research.

4-month Arctic Oscillation (AO) – Four month AO was calculated as the AO average for the months of September – December. Values greater than 0.5 (positive AO), and values less than -0.5 (negative AO) are evaluated within our decision flow chart. Values between 0.5 and -0.5 were considered neutral.

The results of these evaluations are tabulated in the attached spreadsheet by WY and resulted in the development of a simple flow regime forecast model that could be applied during January of the WY.

Model Development

Analysis began by plotting the variable values against each other. From these comparisons, we were able to determine, by percentage, variables that would lead to a reasonable answer for a wet or dry year. The variables that we found to be of reasonable significance include: PDO/MEI in phase/out of phase, Basin Average Palmer Drought Severity Index, and 4-month AO average (September – December). The descriptions above indicate how each of these variables was evaluated on an individual basis. By utilizing the statistics calculated from variable comparisons, we created the decision flow chart that led to 3 possible flow solutions; wetter than average, average, or drier than flow regimes. Figure 3 shows the resulting step-by-step application of the flow forecast.

The values for each of the HCI are available from the web links provided earlier in this report. The historic values used in this study are included in the attached spreadsheet and are summarized in Appendix A. The result of the model forecast is non-quantitative and simply identifies the spring flow regime as wetter average or drier than average. The verification of the forecast process is shown in Table 1 and listed by WY in Appendix A. While the process is simple, it provides a 73 percent correct forecast, for the time period evaluated.

The table notes if the forecast misses are “positive” or, in effect, predict a drier outcome than actually observed. In that

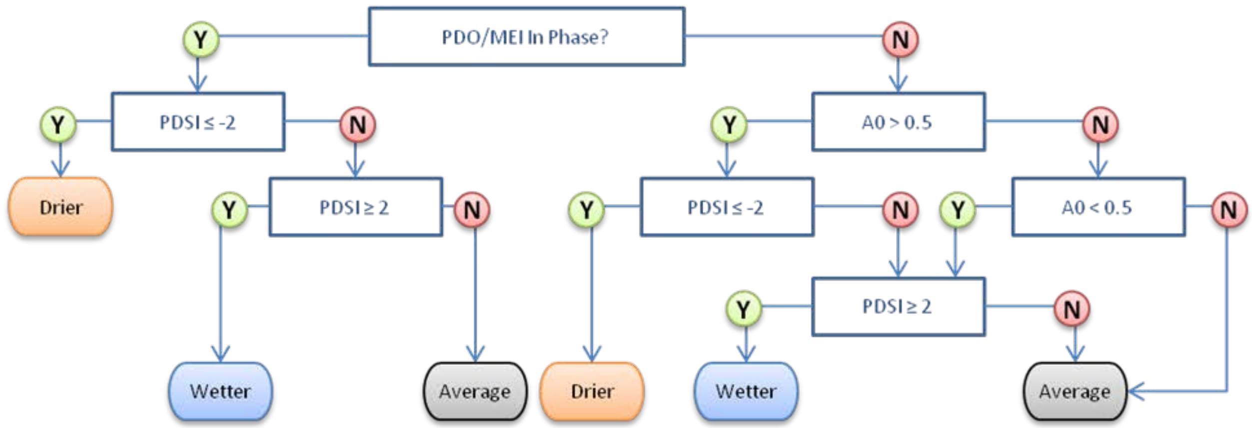

Figure 3 - HCI process model to determine the May-June-July volumetric flow regime measured at Lewellen NE gauge

Table 1 - Verification of the simplified HCI-North Platte Spring Flow model for WY 50/51 to WY12/13

Years of Record	Number of Hits	Number of Positive Misses	Hits + Positive Misses	Number of Total Misses
63	46	10	56	7
	73%	15.9%	88.8%	11.2%

* a “positive miss” occurs when the actual result is greater than the forecasted result. The two cases examined here occur when a “dry” forecast results in an “average” year and when an “average” year ends as a “wet” year.

case the forecast flow outcome is rather robust. Such a qualitative result can be made more useful by looking at the stratification of the PDSI and the observed spring flow values for each of the climate regimes identified.

A key factor in determining the climate regime for winter precipitation involves whether the PDO and the MEI are either in or out of phase. If they are in-phase then the left branch of the decision-tree is followed; if they are out-of-phase the right branch is followed. Depending on the value of the PDSI, a different set of flow regimes is determined. It is clear that the PDSI has a strong impact on determining the actual flow regime of the spring runoff.

Dewberry stratified the PDSI values and the observed spring flow for each of the flow regimes: “drier”, “average” and “wetter” in Figures 4-6 respectively. Dewberry notes that, while the R-squared values are low, some quantitative estimate of the spring flow volume is attainable by using the figures. Using the flowchart shown previously, we are able to make forecasts for the upcoming water year. Let’s work through an example for the 2013/2014 Water Year we are currently experiencing.

If we go to the existing HCI links we can obtain values for the current year and then work through the forecast flow chart. Information is available in Appendix A for the reader to facilitate this example. For example, if we were to forecast for this upcoming 2014 water year, this is how our forecast would be determined:

Is PDO/MEI in phase? No.
Is AO > 0.5? Yes.
Is PDSI < or = -2? No.
Is PDSI > or = 2? No.

Using the flowchart and the answers to those four conditions, our forecast would identify 2014 as an “Average” run-off year. If we go to the diagram for average years and then go to the x-axis showing PDSI values at 1.31 and go up to the line, an estimated spring volumetric flow would be ~225,000 acre feet. The forecast range would be ~150,000 to 290,000 acre feet (af) for the WY13/14 spring runoff volume.

Clearly the answer won’t be known until early July but for planning purposes at PRRIP, the flow appears to average to slightly above average. Similarly the same exercises could be accomplished for other climate outcomes. It is quite likely that a deeper evaluation of the data could result in a more quantitative approach to the forecast spring runoff volume forecast.

CONCLUSIONS

The evaluation shows that a clear and strong relationship exists between hydro-climate indices and the spring runoff volume on the North Platte River basin. The resulting mid-January forecast of the spring runoff volume in terms of above, below and average values is about 73 percent or almost three out of four. A proxy technique to estimate the spring flow volume was developed for use until a more detailed model can be developed.

An important corollary to this study is that similar relationships are very likely to exist on the South Platte River basin and other major Colorado river basins. Given the critical nature of spring runoff volume to river managers this technique offers a very positive outcome for evaluation compared to other techniques that wait until the April decision window.

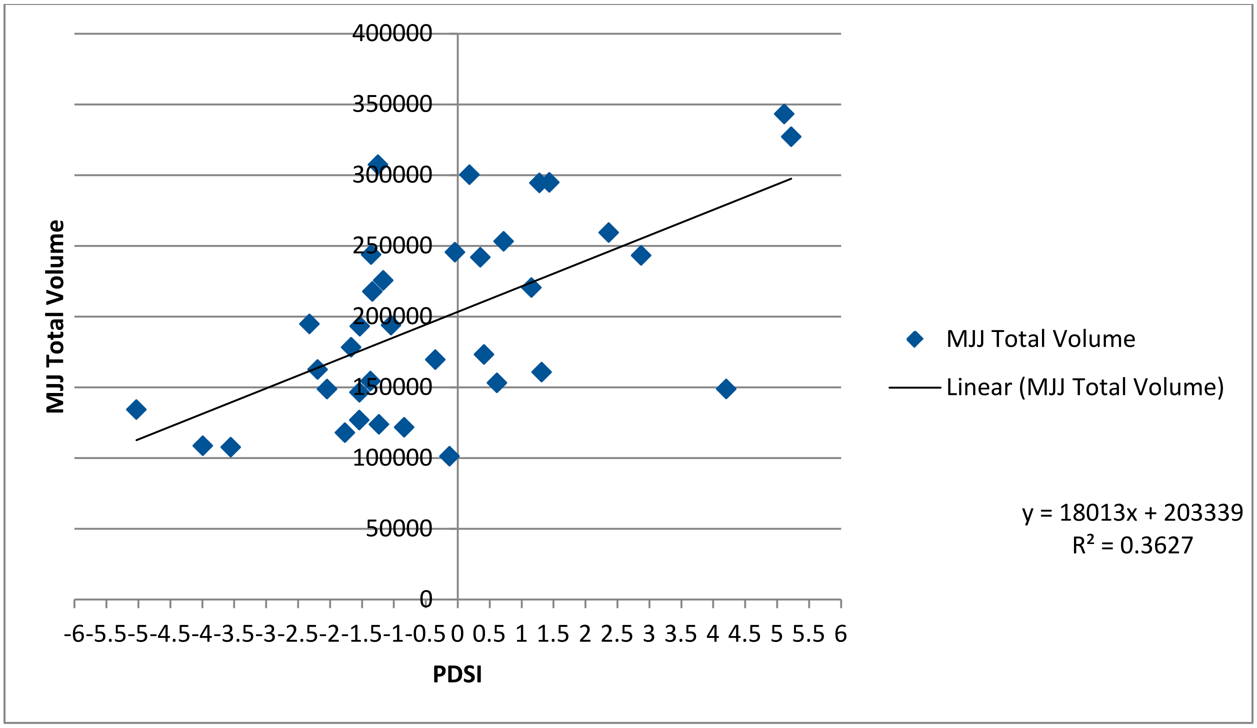

Figure 4 - Plot of the PDSI and the observed spring volumetric flow in acre feet for the North Platte River Basin at Lewellen gauge for average year's regime

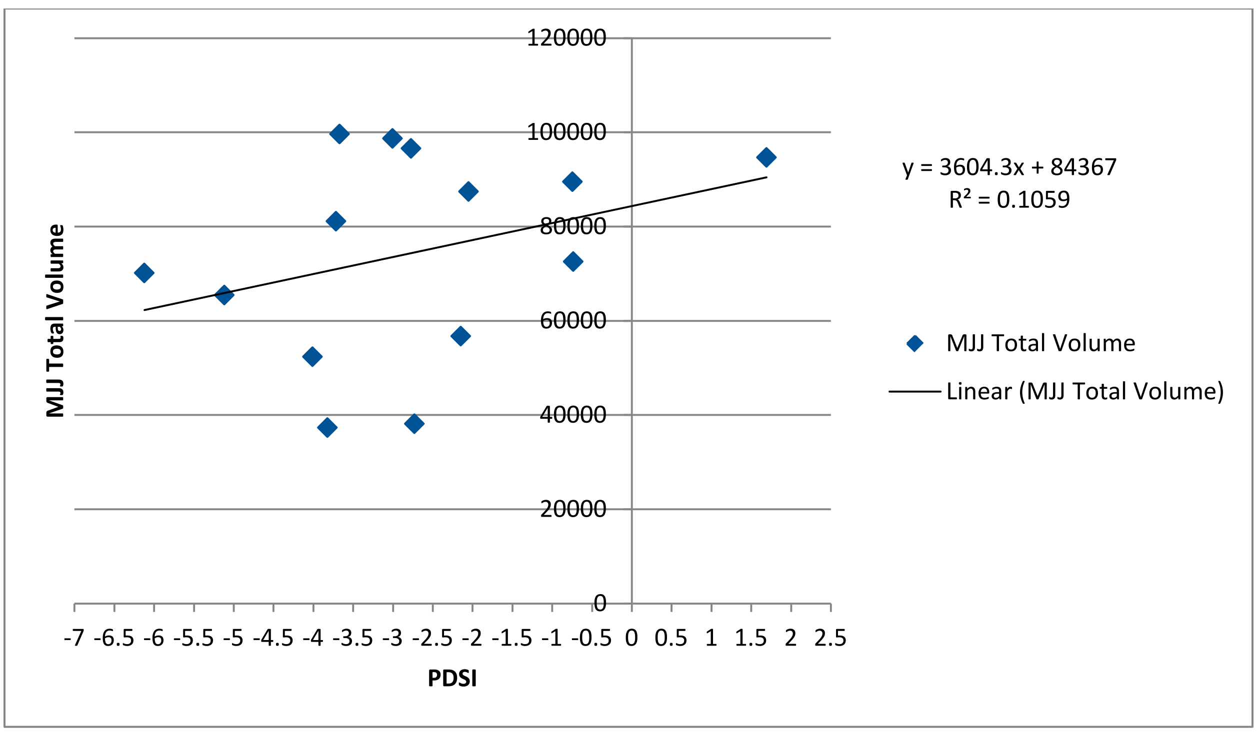

Figure 5 - Plot of the PDSI and the observed spring volumetric flow in acre feet for the North Platte River Basin at Lewellen gauge for dry year's regime

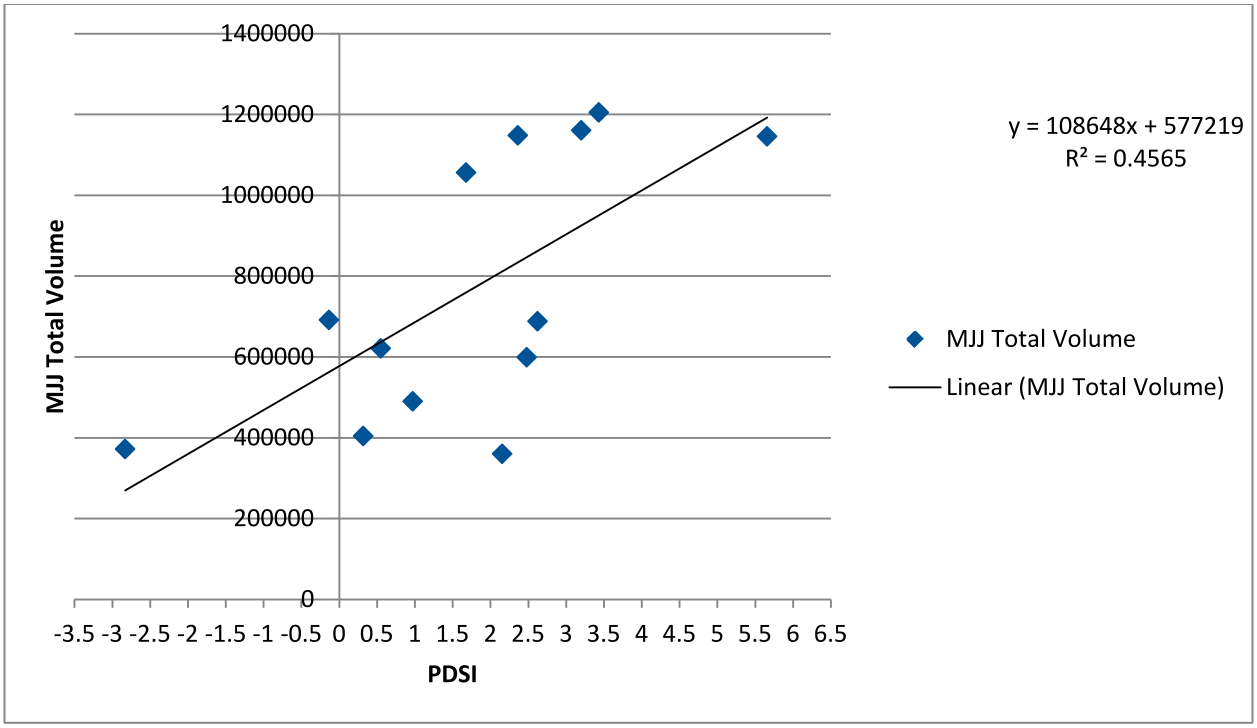

Figure 6 - Plot of the PDSI and the observed spring volumetric flow in acre feet for the North Platte River Basin at Lewellen gauge for wet flow year's regime

APPENDIX A – DATA USED IN HCI AND FLOW REGIME ANALYSIS

Year	Decision Tree	Water Year	May-June-July Total Volume (af)	Forecast	Actual Result	Hit/Miss	Positive Miss?
1950	YNN	**1951**	253,205.68	Avg	Avg	Hit	
1951	YNYY	**1952**	360,356.33	Wet	Wet	Hit	
1952	NNYN	**1953**	146,511.23	Avg	Avg	Hit	
1953	NNN	**1954**	87,452.52	Avg	Dry	Miss	Minus
1954	NNN	**1955**	134,318.65	Avg	Avg	Hit	
1955	YYN	**1956**	98,720.78	Dry	Dry	Hit	
1956	YNN	**1957**	241,937.41	Avg	Avg	Hit	
1957	NNN	**1958**	259,402.13	Avg	Avg	Hit	
1958	YNN	**1959**	123,881.48	Avg	Avg	Hit	
1959	NNYN	**1960**	72,588.17	Avg	Dry	Miss	Minus
1960	NNN	**1961**	108,731.50	Avg	Avg	Hit	
1961	NNYN	**1962**	300,301.90	Avg	Avg	Hit	
1962	YNN	**1963**	117,992.46	Avg	Avg	Hit	
1963	YYN	**1964**	99,658.97	Dry	Dry	Hit	
1964	NNN	**1965**	372,257.33	Avg	Wet	Miss	Plus
1965	YNN	**1966**	121,794.83	Avg	Avg	Hit	
1966	NNYN	**1967**	307,384.98	Avg	Avg	Hit	
1967	NNN	**1968**	243,246.52	Avg	Avg	Hit	
1968	YNN	**1969**	160,782.51	Avg	Avg	Hit	
1969	YNN	**1970**	294,861.16	Avg	Avg	Hit	
1970	NNN	**1971**	1,160,783.87	Avg	Wet	Miss	Plus
1971	YNN	**1972**	294,498.18	Avg	Avg	Hit	
1972	YNN	**1973**	1,056,312.93	Avg	Wet	Miss	Plus
1973	NNN	**1974**	343,230.79	Avg	Avg	Hit	
1974	YNN	**1975**	217,768.47	Avg	Avg	Hit	
1975	YNN	**1976**	154,453.16	Avg	Avg	Hit	

1976	YYN	**1977**	148,800.19	Dry	Avg	Miss	Plus
1977	YNN	**1978**	243,851.49	Avg	Avg	Hit	
1978	YNN	**1979**	173,254.76	Avg	Avg	Hit	
1979	NYNN	**1980**	404,487.22	Avg	Wet	Miss	Plus
1980	YNN	**1981**	126,904.33	Avg	Avg	Hit	
1981	YYY	**1982**	162,625.18	Dry	Avg	Miss	Plus
1982	NYNY	**1983**	1,148,327.49	Wet	Wet	Hit	
1983	YNYN	**1984**	1,145,887.79	Wet	Wet	Hit	
1984	YNN	**1985**	169,615.04	Avg	Avg	Hit	
1985	NNYN	**1986**	691,626.62	Avg	Wet	Miss	Plus
1986	NNN	**1987**	245,535.48	Avg	Avg	Hit	
1987	YNN	**1988**	225,611.22	Avg	Avg	Hit	
1988	YYY	**1989**	81,150.94	Dry	Dry	Hit	
1989	YYN	**1990**	96,604.38	Dry	Dry	Hit	
1990	NYNN	**1991**	193,974.40	Avg	Avg	Hit	
1991	NYNN	**1992**	101,331.06	Avg	Avg	Hit	
1992	YNN	**1993**	153,197.61	Avg	Avg	Hit	
1993	YNYN	**1994**	148,867.63	Wet	Avg	Miss	Minus
1994	YNN	**1995**	490,301.37	Avg	Wet	Miss	Plus
1995	YNYN	**1996**	327,146.59	Wet	Avg	Miss	Minus
1996	NNYN	**1997**	621,263.94	Avg	Wet	Miss	Plus
1997	NNN	**1998**	220,533.46	Avg	Avg	Hit	
1998	YNYN	**1999**	688,367.72	Wet	Wet	Hit	
1999	YNN	**2000**	193,198.85	Avg	Avg	Hit	
2000	YYN	**2001**	194,835.24	Dry	Avg	Miss	Plus
2001	YYN	**2002**	37,355.26	Dry	Dry	Hit	
2002	NNYN	**2003**	65,481.29	Avg	Dry	Miss	Minus
2003	YYY	**2004**	38,172.46	Dry	Dry	Hit	
2004	YNN	**2005**	89,541.14	Avg	Dry	Miss	Minus

2005	YYN	**2006**	56,764.89	Dry	Dry	Hit	
2006	NYY	**2007**	52,397.98	Dry	Dry	Hit	
2007	NNN	**2008**	107,730.15	Avg	Avg	Hit	
2008	NNN	**2009**	178,341.05	Avg	Avg	Hit	
2009	YNYY	**2010**	599,311.03	Wet	Wet	Hit	
2010	YNYY	**2011**	1,205,079.19	Wet	Wet	Hit	
2011	YNN	**2012**	94,693.00	Avg	Dry	Miss	Minus
2012	YYN	**2013**	70,173.00	Dry	Dry	Hit	