Statistical Examination of Water Data in the Coconino Plateau for Use as Sustainability Indicators

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Executive Summary

Water data were gathered from various sources including the Water, Wastewater, Reuse, and Stormwater Annual Report, the National Climate Data Center, the Natural Resources Conservation Services, and the United States Geological Survey Water Data Support Team. The data included precipitation and snowfall for Flagstaff Airport and Arizona Climate Division 2, stream flow for Wet Beaver Creek and Oak Creek, and depth to groundwater in the Lake Mary aquifer. These data were then entered into Microsoft Excel (2010 Microsoft Corporation, Redmond, WA) and stream discharge data were separated into surface water and groundwater components using Excel. Seasonal averages, yearly averages, and 3 month moving averages were selected as appropriate filters and were applied to each data set. Overall observation on data quality, completeness, and attributes were recorded. Using the filtered data sets, graphs were created, linear regression analysis was performed, and trends were examined and recorded. JMP (SAS Institute Inc., Cary, NC) statistical software was also used to examine both linear and transformed log-fit curves for the data set. Anomalies were also calculated in Excel for each filter in each data set and were graphed in the form of a bar graph. The cumulative sums of these anomalies were examined as well and were put into a line graph to observe behavior. Pacific Decadal Oscillation (PDO) index values were also entered into Excel and were plotted against the anomalies of each data set in a XY scatter plot. In addition, both PDO indices and anomaly values were plotted against time as a line graph. Using seasonal averages from each data set, seasons were observed individually in Excel to see if a trend from year to year in one particular season could be found. Similarly, monthly, or raw, data were used to observe the trend of each individual month over time.

Initial examination of the filters yielded qualitative observations. The linear trend analyses in both JMP and in Excel yielded linear best fit lines with R^2 values and slopes. An information chart was created to summarize these results. From the anomalies, periods or dates when water level, stream flow values, or precipitation values were abnormally high were identified. An information chart was created to summarize these results. The PDO vs. Anomaly analysis yielded a scatter plot and a line graph. In all cases, the XY scatter plots yielded graphs with data points clumped about the origin and in most cases the line graphs yielded trends that did not show similar overlaps. Data graphed from each season gave graphs that showed how one particular season's water patterns changed from year to year and overall observations were recorded in the information chart but no overall trend was identified. Similar results occurred with the data graphed for each individual month.

In the linear trend analysis the high variability, the small R^2 and the small slope for all data sets prevented the conclusion that a linear trend is present from being drawn. This points towards the conclusion that linear trend analysis not effective for these water data. Although the anomalies and their sums gave visual representation of water behavior, it was not possible to draw any conclusions about whether water levels and precipitation patterns have increased or decreased over time based on anomalies and their sums. The XY Scatter plot yielded graphs with data points clumped around the origin which indicated no correlation. Due to this, no conclusion about how PDO index values and the water data that was tested. In the line graphs, the sections of overlapping trends may indicate that there is some relationship in PDO values and the water data but the overlaps were not consistent and overall were not present. Due to this, conclusions could not be drawn about whether or not there is a relationship between PDO index values and the water data that were tested. No overall conclusion could be drawn about the month to month analysis or the season to season analysis.

Throughout all the analyses that were conducted, no conclusions were drawn about overall trends. The lack of trends observed is likely because the water behavior is typically complex and has many interacting components. Precipitation data that were analyzed were not necessarily representative of the watershed area. Also evapotranspiration rates, runoff, soil type, and vegetation could all effect how the precipitation relates to the water levels. The current data and the analyses conducted are not sufficient to identify trends in the data and these data set and water sources cannot yet be used as sustainability indicators.

The research performed in this project could be extended or continued into the future by examining how City of Flagstaff water use relates to groundwater levels, how population of the Coconino Plateau area relates to groundwater levels, examining accuracy of interpolation of base flow components of stream data, or using a model to make predictions. Information from such studies could lead to the development of triggers and possibly using the data as a sustainability indicator.

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Introduction

Water scarcity is an issue that has been looming over the southwestern United States for decades. As the population of this region of the country continues to grow, it is becoming increasingly important that residents use the limited water supplies sustainably. The Coconino Plateau Water Advisory Committee was formed in 2004 in response to the need for sound water resource management and conservation strategies in the southwestern US, namely the Coconino Plateau. The committee has four main strategic planning focus areas: Conservation, Legal and Regulatory, Environmental Needs, and Supply and Growth. To achieve goals that were set in these focus areas, it became apparent that the development of a sustainable water budget was necessary. The Coconino Plateau Water Advisory Committee assigned the Technical Advisory Committee the duty of developing a sustainable water budget for the Coconino Plateau. To obtain an accurate and practical water budget to help guide future policy and management, there must be a firm foundation of science. The purpose of this research was to determine what conclusions could be drawn using current hydrological monitoring data records. A variety of sources were examined and statistically analyzed to determine trends in water behavior and possible steps for the future.

Background

The scarcity of water in the southwestern United States has led to better management of water resources, which includes the monitoring of water levels. A variety of methods have been developed to quantify and interpret data from these water resources. There are also sustainability requirements that must be met for the Southwestern US to develop or even maintain current populations. One method of monitoring sustainable water use is using measurements from groundwater sources as sustainability indicators. In this technique, precipitation and groundwater data are examined and analyzed to determine when water supplies are below a level that can be considered sustainable. This unsustainable level is called a trigger. If the threshold of the trigger is exceeded then the water source can be better managed and used as an indicator of when there is a surplus of water or when water supply dips into a deficit. In 2007, Steven Rice conducted a study in which he performed geochemical and physical analyses on 16 springs in the Verde Valley area. After collecting and analyzing spring discharge, water-quality parameters, and isotope and anion data from each spring, he developed triggers for these springs that were then used as sustainability indicators for the Verde Valley (7). This study was an indication that perhaps groundwater supported streams in the Coconino Plateau area could also be used as sustainability indicators.

The Lake Mary Aquifer is a fractured sandstone aquifer lying in the semi-arid environment of the Coconino Plateau. In a study by Sarah Kelly, significant sources of recharge were determined for the Lake Mary Aquifer. These sources of recharge were dominantly from seepage from surface sources, not from infiltration of precipitation (3). Given this recharge mechanism for groundwater, it was hoped that the Lake Mary Aquifer data or the ground water component of perennial stream flow data could be used as a sustainability indicator for the Coconino Plateau. If the data examined in this study were deemed sufficient, a trigger could be developed, the source could be used as an indicator, and a sustainable water budget for the Coconino Plateau could be further developed.

Purpose and Objectives

There is a great deal of data available relating to hydrologic monitoring in the Coconino Plateau and surrounding area. Utilizing these data is helpful and necessary for the Coconino Plateau Water Advisory Committee to successfully develop a sustainable water budget. However, it was not previously known if the data at hand were sufficient to develop statistically significant interpretations. The purpose of this project is to examine these data sets in a variety of manners and draw conclusions from them. First, the raw data were examined for completeness, resolution, and period of record. Second, appropriate filters were developed for the data sets and applied. These filters were aimed at revealing trends or patterns in the data that might be otherwise unapparent. These various filters were graphed and statistically analyzed to try to determine properties, patterns, and behaviors that the data exhibits. Finally, recommendations were made to the committee about future studies, water collection methods, and other information that will be needed to continue towards the development of a sustainable water budget.

Methods

To begin this study, data sets were gathered from various sources. Some data from the Lake Mary Aquifer were used. From the data available for Lake Mary, the Lake Mary Pumping Well 3 and Lake Mary Pumping Well 1 were chosen for examination. These choices were due to recommendations from Brad Hill and Dr. Abe Springer who advised that these data sets were the only data sets that were complete enough for the purpose of this report. Lake Mary Well 1 and 3 data were taken from the 2010 Report to the Water Commission (2). Lake Mary Pumping Well 1 Data was collected from a thesis by Sarah Kelly (3). The two Lake Mary Pumping Well 1 data sets were examined separately as well as combining them into one data set. If there was a cell where both Brad Hill's data set and Sarah Kelly's data set had a value, the average of the two points was taken to create a point in the new, combined set. These sets served as data that represented groundwater levels.

Stream flow data were also selected. At the start of the project, the Oak Creek at Sedona gauge number 95044 and the Wet Beaver Creek gauge number 15060202 were examined.

However, those sets were soon switched to the Oak Creek near Sedona gauge number 9504420 and Wet Beaver Creek near Rimrock gauge number 09505200 as these gauges were similar to the original gauges but had longer and more complete periods of record. These data sets were acquired from the United States Geological Survey Water Data Support Team (10). These specific gauges were chosen because the data had a rating of “good” and again, Dr Springer suggested that they be examined due to their completeness. In addition, the creeks were perennial, meaning that they flowed throughout the entire year. Due to this characteristic, they had both a surface water component and a ground water component and could be examined as a data set representing ground water.

Precipitation and snowfall data were also mined for this project. Using the National Data Climate Center website, data sets for Flagstaff Airport Monthly Precipitation, Flagstaff Airport Monthly Snowfall, and Arizona Climate Division # 2 Monthly Precipitation were collected (5). In addition, data sets from the SNOTEL site at Mormon Mountain were also used. Data sets for Average Monthly Snow Water Equivalent, Monthly Minimum Snow Water Equivalent, Monthly Maximum Snow Water Equivalent, and Average Monthly Precipitation data sets were used as well, which were gathered from the Natural Resources Conservation Services website (9).

Once the data sets were gathered, they were put into a Microsoft Excel file (4). In Excel they were categorized and filtered. There were three filters chosen to place on the data. The data were examined as raw data, as a seasonal average, as a three-month moving average, and as a yearly average. Seasons were categorized as follows: Spring: March to May, Summer: June to August, Fall: September to November, and Winter: December to February. For the three-month moving average, each data point was averaged with the previous point and the next point to form a new data point. This method of filtering creates a smoothing effect without changing the overall shape of the raw data. The yearly average was interpolated by taking every data point in a calendar year and averaging them. In all cases, if there was an empty cell or if a data point was missing, that cell was still taken into the average. These filtered data sets were then used in various analyses for the remainder of the project.

After these filters were in place, all the data sets were plotted using Excel (Appendix 1). They were then examined and a Qualitative Data Inventory was created, which listed properties of each data set and each filter placed on the data sets (Appendix 2). It included positive qualities of the data, negative qualities of the data, places where errors might occur, and other observations that were potentially useful.

The stream flow data sets, Oak Creek near Sedona and Wet beaver Creek near Rimrock, were then separated into a base flow component, which theoretically represents ground water, and a surface water component, which represents precipitation runoff. The method for doing so was taken from a paper by Kyle Blash (1). For every three month period, the minimum value was found. In between each minimum value, a linear trend was created to connect each minimum point to the next consecutive minimum point. By doing so, a new data set was interpolated which consisted of the lowest values that were consistently present in the data. This new data set was taken to be the base flow of the stream flow data.

Analysis to try to find linear trends was then applied. Using Microsoft Excel a best linear fit line was then added to the graphs. A slope and an R^2 value was determined for each data set and each filter within that data set as well (Appendix 3). Observations and conclusions were recorded in a “Trend Analysis” document (Appendix 4). After examining these graphs, some data were selected for further investigation. Other data sets were excluded from further observation and analysis. SNOTEL data were set aside due to the fact that it only recorded snowfall and the period of record was only from 1982 to 2009. The Lake Mary Pumping Well 1 data set from Brad Hills report and the Lake Mary Pumping Well 1 data set from Sarah Kelly were not analyzed past this point; only the combination of those two data sets was further examined because the two sets were similar to the combination data set and the combination was much more complete.

The data sets for which analysis continued were as follows; AZ Climate Division # 2 Precipitation, Flagstaff Airport Snowfall, Flagstaff Airport Precipitation, Oak Creek near Sedona Base Flow, Oak Creek near Sedona Stream Flow, Wet Beaver Creek near Rimrock Base Flow, and Wet Beaver Creek near Rimrock Stream Flow. These data sets were then loaded into JMP and analysis for both a linear best fit and a transformed logarithmic fit were applied. The analyses were done for each filter in each data set. From the analyses, a slope and an R^2 value was recovered in each case (Appendix 5)(8). Then JMP results were compared with Excel results. Observations, conclusions, and comparisons between the JMP results and the Excel results were recorded in a document called, "Trend Analysis using JMP" (Appendix 6).

Anomalies were also calculated in Excel for each filter in each data set. The average of the period of record was calculated and then was subtracted from each data point to make a new data point. If the original data point was below average, the new data point was negative. If the original data point was above average the new data point was positive. These anomalies were plotted in the form of a bar graph.

The cumulative sums of these anomalies were examined next. Each anomaly data point was summed with all previous anomalies. This cumulative sum was then plotted in a line graph. If the anomaly was positive, it made the cumulative sum greater and gave the line an upward trend. If the anomaly was negative, it made the cumulative sum smaller and gave the line a downward trend (Appendix 7). The trends of these sums and the bar graphs with the associated anomalies were examined and the observations were recorded in a “Sum Trend Notes” document (Appendix 8).

Pacific Decadal Oscillation (PDO) patterns were also considered during this research. PDO index values were downloaded and entered into Excel (6). Then they were compared to the calculated anomaly values to see if a relationship could be distinguished. For each filter, two analyses were performed. Each data set was plotted against the PDO index values in a XY scatter plot, which was independent of time. In addition, both were plotted against time in a line graph (Appendix 9). They were then examined to see if there was any correlation between the two data sets. The observations were recorded in a document titles “PDO vs Anomalies Notes” (Appendix 10).

Each season was observed individually in Excel to see if a trend from year to year in one particular season could be found. The Seasonal Average filter was chosen from each data set. Then, the sets were separated by season. For example, a new data set was created for “Spring” which only contained data points from the spring of each year. This was done for Spring, Summer, Fall, and Winter in each data set (Appendix 11). They were then plotted in a line graph and examined for trends or patterns. These observations were recorded in a document called “Season to Season Notes” (Appendix 12).

The trend of each individual month over time was examined. The raw data, which was in a monthly format, were used. For each data set, individual months were plotted throughout the period of record. For example, January data points from each year were taken aside and put into a new table. These January values from each were then plotted in excel as a line graph. The behavior of the January values were then observed and recorded. This was done for each month, January through December, for each data set (Appendix 13). The observations were recorded in a "Month to Month Notes" word document (Appendix 14).

Results

Initial examination of the filters yielded qualitative observations. Notes were taken on the resulting data sets. These notes were recorded in the Qualitative Data Inventory (Appendix 1). The Qualitative Data Inventory notes include information about period of record, positive attributes for using a certain kind of data set, negative attributes of the data sets, completeness of the data sets, accuracy of averages, and possible sources of error during analysis.

The linear trend analyses in both JMP and in Excel yielded linear best fit lines. These trend lines had respective R^2 values and slopes (Table 1).

Table 1: Summary of observations from linear trend analysis

Site	Observations
Wet Beaver Creek near Rimrock Data	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes needs to be considered. Largest R^2= 0.0131, from the JMP Transformed Fit Log of the Seasonal Average data. Steepest slope=-0.135 from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope =-1.63E-10 from the JMP Transformed Fit Log of the Raw Data.
Wet Beaver Creek near Rimrock Base Flow Data	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. Also, the R^2 values from this data set are larger than the R^2 values from the Wet Beaver Creek Stream Flow data set. This might be due to the fact that these values represent base flow, which has much less variation than overall stream flow, which includes surface water component. However, the small R^2 values and variability in slopes make needs to be considered. Largest R^2=0.145 from the JMP Transformed Fit Log of the Yearly Average data. Steepest slope=-0.0284 from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope=-1.17E-10 from the JMP Transformed Fit Log of the Raw Data.
Oak Creek	All the filters from this data set in all tests have small negative slope. This gives a good

near Sedona Data	indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes needs to be considered. Largest R^2= 0.0371 from the JMP Transformed Fit Log of the Seasonal Average data. Steepest Slope = -0.867from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope= -4.40E-10 from the JMP Transformed Fit Log of the Raw Data.
Oak Creek near Sedona Base Flow Data	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes needs to be considered. It is also important to note that these R^2 values are stronger than the R^2 values from the Oak Creek Stream Flow data set. This may be due to the fact that these values represent base flow and have much less variation than overall stream flow, which includes surface water component. Largest R^2= 0.221from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Steepest Slope= -0.156 from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope=-1.36E-10 from the JMP Transformed Fit Log of the Raw Data.
Flagstaff Airport Precipitation	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes needs to be considered. In general, the linear trends in this data set have stronger R^2 values than the linear trends in the Arizona Climate Division #2 precipitation data set do. However, the transformed fit log analyses from this data set have a weaker R^2 value than the transformed fit log analyses of the Arizona Climate Division #2 precipitation data set. Largest R^2=0.0628 from the JMP Transformed Fit Log of the Yearly Average data. Steepest Slope= -0.00773 from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope=-2.42E-10 from the Excel linear analysis, the JMP Linear Fit, and the JMP Transformed Fit Log of the Raw Data.
Flagstaff Airport Snowfall	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes make needs to be considered. Largest R^2= 0.0244 from the JMP Transformed Fit Log of the Yearly Average data. Steepest Slope= -0.0440 from both the Excel linear analysis and JMP Linear Fit of the Yearly Average data. Flattest slope=-1.19E-10 from the JMP Transformed Fit Log of the Raw Data.
AZ Climate Division # 2 Precipitation	All the filters from this data set in all tests have small negative slope. This gives a good indication that the linear trend over time is a slight decrease. However, the small R^2 values and variability in slopes needs to be considered. In general, the linear trends in this data set have weaker R^2 values than the linear trends in the Arizona Climate Division #2 precipitation data set do. However, the transformed fit log analyses from this data set have a stronger R^2 value than the transformed fit log analyses of the Arizona Climate Division #2 precipitation data set. Largest R^2= 0.0672 from the JMP Transformed Fit Log of the Yearly Average data. Steepest Slope= - 0.00591 from the

	JMP Transformed Fit Log of the Yearly Average data. Flattest slope=-1.23E-10 from the JMP Linear Fit of the Moving Average.

A more complete and detailed description of the results can be found in Appendix 6 and the graphs of these analyses can be found in Appendix 5. In these extensive notes, R^2 values and slopes are recorded for each filter as well as observations on each filter's analysis individually.

Anomalies were calculated and plotted in the form of a bar graph. From these anomalies, it was possible to identify periods or dates when water level, stream flow values, or precipitation values were abnormally high. In addition, plotting the cumulative sums of the graphs allowed for examination of the trends in a slightly different manner. Periods when water values were above average, below average, or around average for a period of time became visible by examining the slope of the graph's line. These graphs were observed and notes were recorded (Table 2).

Table 2: Summary of notes on the anomalies and cumulative sums of the data

Site	**Observations**
Wet Beaver Creek Stream flow	Major above average spikes on bar graphs common among all filters are in 1973, 1978, 1980, and 1992. The line graphs on all filters except yearly seem to have similar overall trend: Cumulative sum graph is around average from the start of the period in 1961 until around 1978, then stream flow if consistently above average until around 1981 causing an upward trend. Then, cumulative sum says steady until around 1993 where there is a sharp spike, then an overall negative slope, or a below average time period until 2009. The yearly average has a sum of anomalies that is steady around average until about 1977 then it increases until 1979. It stays constant until 1982 then der4eseses until 1990. It increases from 1990 to 1993 then remains steady until 1998 when it decreases until 2009.
Wet Beaver Creek Base flow	There is a major spike in the bars graphs of all filters in 1972. All filters have very similar trends which indicates the trend is likely reliable. The cumulative sum of anomalies stays around average from 1961 until about 1972 when it spikes. Then, it stays stable until around 1985 when it begins declining until 2009. The maximum accumulation of above average anomalies occurs in the mid-80s.
Oak Creek	Major above average spikes on bar graphs common among all filters occur in 1993,

Stream flow	1995, and 2005. The trend in all filters is similar so the trend is likely accurate. From 1981 to 1982 there is an increase, and then from 1982 to 88 the graph stays steady. Then the graph decreases until 1993. There is a sharp spike in 1993 and the graph remains steady from 1993 to 1998 with a small spike in 1995. From 1998 to 2009 the graph gradually decreases with a small spike in 2005. The maximum occurs in the mid-90s.
Oak Creek Base flow	The major above average spike on bar graphs common among all filters occurs in late 1982 or early 1983. The trend in all filters is similar so the trend is likely accurate. The graph is relatively steady close to the average from the start in 1981 until 1982 when it increases until 1984. From 1984 to 1988 the graphs remains relatively constant, and then it goes into a period of decrease until around 1990. It when increases until 1994 with a spike at 1993. From 1994 to 1998 it stays constant then declines until 2009 with a small spike in 2005. The maximum occurs around the mid 80s.
Lake Mary Well 3	No major spikes common among all graphs, possibly due to lack of data points. Raw data graph differs from other filters. Raw data cumulative sum graph stays steady from the start of the period of record in 1965 until 1988, and then the graph gradually decreases until 1993. There is a minimum in 1993 then the graph increases until 2004 then says relatively steady until 2006 where it hits its maximum. The graph decreases until 2009. The seasonal, moving, and yearly averages have graphs that stay steady until 1984, and then increase until 1990. It remains steady until 1992 where it hits a maximum then decreases until 2003. It stays relatively steady until 2007 then increases to 2009. These drastically different graphs tell me that different filters dhow very different results. Since the data points are so scattered, these different groupings show very different but not accurate results.
Lake Mary Well 1	The major above average spike on bar graphs common among all filters occurs in 2001. The cumulative sums of anomalies graphs among all filters are similar. The graphs are steady from the start of the period of record in 1962 until about 1970 and then they begin to decrease. They decrease until 1989 and hit a minimum in 1989. After that, the graphs increase until the end of the record period in 2005.
Arizona Climate Division # 2 Precipitation	All the bar graphs of anomalies do not have above average spikes in common. They each have above average spikes that stand out, but the spikes are not common to all graphs. However, the sums of anomalies graphs still have similar trends across all the filters. They begin in 1962 with an initial decrease but then staying relatively flat until 1978. After 1978 they increase until 1992 with a small dip around 1990. The graphs stay steady from 1992 to 2001 when the graphs decrease until 2004 or 2005 where a small spike occurs. After that they decrease until the end of the time period in 2009. The raw data graph is very jagged. The seasonal and moving average graphs are smoother, and the yearly average is the smoothest.
Flagstaff Airport	The major above average spike on bar graphs common among all filters occurs in 1992 or 1993. The cumulative sums of anomalies graphs among all filters are similar. The

Precipitation	graphs remain steady from the start of the period of record in 1962 until 1972. The graphs increase from 1972 until 1986 where it remains steady until 1992. There is a large upward spike in 1992 where it remains mostly stable until 1994 where it hits its maximum. Then there is a steady decrease until the end of the period of record in2009 with a small spike in 2004.
Flagstaff Airport Snowfall	All the bar graphs of anomalies do not have above average spikes in common. They each have above average spikes that stand out, but the spikes are not common to all graphs. The cumulative sums of anomalies graphs differ among filters in this data set. The raw graph and the moving average graphs are similar which is not surprising since they are essentially using all the same data points. Those two graphs begin in 1962 by decreasing until 1963. They remain stable until 1970 when they experience a sharp downward spike from 1970 to 1972 when there is an upward spike. Then the graphs remain steady until 1976 where there they decrease until 1977. Then they increase from 1977 to 1980 and stay steady until 1983. They decrease from 1983 to 1985 then stay steady until 1988. They decrease until 1990, then increase from 1990 to the end of the period of record in 1998. The seasonal graph is steady from 1961 to 1974 then increases until 1981. It remains steady until 1989 when it begins to increase until 1992. It remains steady from 1992 to 1994 where it reaches its maximum. Then it decreases until the end of the period of record in 1998. The yearly graph decreases from 1962 to 1964. It spikes in 1965, and then stays steady until 1971. There is a decrease from 1972 to 1973, and then it stays relatively stable until 1978. In 1978 the graph begins to increase and continues increasing until 1982. It stays stable into 1983 then decreases from 1983 to 1984. From 1984 to 1988 the graph stays stable then decreases until 1990. It increases from 1990 to 1992 then decreases from 1992 to the end of the period of record in 1998.

A more detailed examination of each individual graph can be found in Appendix 8 and the graphs that the information was taken from can be found in Appendix 7.

In each case, the PDO vs. Anomaly analysis yielded a scatter plot and a line graph. These graphs can be found in Appendix 9. In all cases, the XY scatter plots yielded graphs with data points clumped about the origin. In some cases, the line graphs had periods in which the two data sets showed overlap when plotted against time. However, in most cases the graphs yielded trends that did not show similar overlaps. More detailed notes can be found in PDO vs. Anomaly Notes (Appendix 10)

Data graphed from each season gave graphs that showed how one particular season's water patterns changed from year to year. This gave the graphs new characteristics and allowed for new observations (Table 3).

Table 3: Summary of patterns of change by season

Site	Description
Flag Airport Precipitation	All seasons show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years.
Flag Airport Snowfall	Most seasons show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Summer, however, had 0 for every year except 92, 96, and 97
AZ Climate Division 2 Precipitation	All seasons show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years.
Wet Beaver Creek Steam-flow	Spring and winter show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Summer and fall are relatively stable, showing no upward or downward trend over time, except for anywhere between 4 and 7 high spikes values. There doesn't seem to be any pattern in these spikes and most spikes are not consistently in the same year across the different seasons.
Wet Beaver Creek Base-flow	Summer shows no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Spring has some zig-zags, but it is more flat and has 3 major spikes. Fall and winter are relatively stable, showing no upward or downward trend over time, except for spikes at 72-73 and 78-79, spikes also common to the spring season.
Oak Creek Stream-flow	The spring season shows no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Summer, fall, and winter are relatively stable, showing no upward or downward trend over time, except for anywhere between 1 and 4 high spikes values. There doesn't seem to be any pattern in these spikes and most spikes are not consistently in the same year across the different seasons.
Oak Creek Base-flow	Most seasons show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Fall, however, could possibly have a slight downward trend along with the zig-zags, but the trend is not very clear or strong.
Lake Mary	The spring, fall, and winter seasons show no obvious trend, onlyan up and down zig-zag pattern showing larger or smaller values between years, from 62-84, then distance to water

Well 1	seems to increase over time but it is difficult to tell as the data points are scattered and disconnected. Summer does not have enough data points (only 16 over a 42 year period) to conclude anything about season to season behavior.
Lake Mary Well 3	All months do not have enough data point to conclude anything about month to month behavior (anywhere between 6 points in some months to 11 in others over a 34 year period).

More complete notes on each graph specifically can be found in Appendix 12 and the graphs of this data can be found in Appendix 11.

Plotting the data for each individual month represented the same data in a different manner, which allowed further examination of the behavior of the data in each particular month over the period of record. This opened up the possibility for new trends to emerge (Table 4).

Table 4: Summary of observations of monthly trends

Site	**Description**
Flag Airport Precipitation	Most months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Some months show periods of sustained higher precipitation; March in late 70s, July from early sixties to 1990, October early 60s to 70s and mid-70s to mid-80s.
Flag Airport Snowfall	Most months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. June and July have all zeroes. August has one non-zero value and September has two non-zero values and
AZ Climate Division 2 Precipitation	Most months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Some months show periods of sustained higher precipitation; March from late 70s to early 80s and August from the early 50s to the early 60s, then high from early 70s to the early 90s.
Wet Beaver Creek Steam-flow	Most months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Other months (May, July, August-December) are relatively stable, showing no upward or downward trend over time, except for anywhere between 1 and 5 high spikes values. There doesn't seem to be any pattern in these spikes and the spikes are not consistent in the same year across the different months
Wet Beaver Creek Base-	Some months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Most months (January-April, September-

flow	December) are relatively stable, showing no upward or downward trend over time, except for a spike in 72-73 and a small one in 78-79.
Oak Creek Stream-flow	Many months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. Other months (January, February, September-December) are relatively stable, showing no upward or downward trend over time, except for anywhere between 2 and 4 high spikes values. There doesn't seem to be any pattern in these spikes and the spikes are not consistently in the same year across the different months.
Oak Creek Base-flow	Most months show no obvious trend. There is an up and down zig-zag pattern showing larger or smaller values between years. January shows a possible slight downward trend overall in addition to the zig-zag pattern, but the trend is not strong. June show a period of sustained higher values from 98 to 05, and September-December seems to be fairly level from 95 to 03.
Lake Mary Well 1	Most months do not have enough data point to conclude anything about month to month behavior (anywhere between 5 points in some months to 14 in others over a 44 year period). In the months that have more data points (January, March, April, October-December), the distance to water seems to increase over time but it is difficult to tell as the data points are scattered and disconnected.
Lake Mary Well 3	All months do not have enough data point to conclude anything about month to month behavior (anywhere between 1 point in some months to 7 in others over a 34 year period).

More complete notes on each graph individually can be found in Appendix 14 and the graphs of this data can be found in Appendix 13.

Summary and Recommendations

In the linear trend analysis, the small R^2 and the small slope for all data sets prevented the conclusion that a linear trend is present. Also the high variability in results between filters indicated that the trends that are indicated by the linear best fit line are not significant. The lack of conclusions that were drawn from this analysis and the high variation in results point towards the conclusion that linear trend analysis was not effective for analysis of the data used in this study. The inability of a linear trend to capture behavioral patterns of water data is likely due to the stochastic nature of hydrology and the strong seasonal influences associated with precipitation and water availability.

It was not possible to draw any conclusions about whether water levels and precipitation patterns have increased or decreased over time based on anomalies and their sums. It was not possible to draw conclusions on how ground water levels, creek flow, and precipitation related to one another based on this analysis. However, the anomalies and the plots of the cumulative sums did provide a nice illustration of the characteristics of the data. It allowed for examination of the random manner in which the data behaved. Large above or below average spikes were detected if any existed and based simply on the slope of a line, whether water levels were consistently above average or consistently below average could be determined. Also, it was easier to see how long a period of above average data persisted using this method, which could be helpful to other studies.

The XY Scatter plot yielded graphs with data points clumped around the origin which indicated no correlation. Due to this pattern, no conclusions were made correlating PDO index values and the water data. In the line graphs, the sections of overlapping trends may indicate that there is some relationship in PDO values and the water data. However, these overlaps were not consistent and overall were not present. Due to this, conclusions could not be drawn about whether or not there is a relationship between PDO index values and the water data that were tested.

The hope in plotting the data for each individual month analysis was that isolating each month would allow inspection of the data without seasonal variation as a factor. However, in most cases it was difficult to pick out any obvious trends through time. Most graphs displayed a zig-zag pattern as a result of alternating higher or lower values from year to year. This pattern did not reveal anything about the more long term, general behavior. In some cases periods of sustained (5 years or more) high values or low values were identified, which could be helpful in recognizing when water is scarce or abundant. However, this analysis did not reveal and pronounced trends and the analysis did not allow for strong conclusions about general trends.

Similar to the month to month observations, season to season observations allowed the data to be inspected under a different filter. This filter also allowed for the examination of trends while eliminating seasonal variations, which might have otherwise skewed results. Unfortunately, after comparing how the seasons changed independently, conclusions could not be drawn about any of the data sets. Some seasons with abnormally high spikes in stream slow, precipitation, or water level were identified. However, the graphs did not generally reveal any strong upward or downward trends in the data as was hoped. Again, the zig-zag pattern was produced by seasons having higher or lower values from year to year.

Throughout the examination of the data, some insight was gathered as to how the data should best be collected. Overall, consistency is the most important attribute of the data collection process. It was nearly impossible to form any trustworthy conclusions about the well water data as it was very unsystematic in the dates when data were collected. For example, there were some periods of time when data were collected every month but other periods were only one data point was present in a three year period. This effected how the averages were calculated and likely led to some data points that were misrepresentative of the actual water patterns. In some instances, a given seasonal average used three data points in the calculation to construct the average but in others the seasonal average consisted of only one or even no data points. This could have severely skewed the resulting graphs and analysis.

After examination of many filters on these data sources, it was decided that seasonally recorded data is the lowest resolution data that can be used in this sort of analysis. Seasonality seems to affect the patterns of water data and thus, measurements from each season are necessary. Groundwater data recorded monthly is more desirable than data recorded seasonal as it makes for more accurate averages and more trustworthy interpolations, but seasonal data would likely be sufficient.

Throughout all the analyses that were conducted, no conclusions were drawn about overall trends. The lack of trends observed in the analyses allowed for some conclusions to be drawn about the water data. The trends that determine the water data behavior are likely very complex and have many interacting components. The current data and the analyses conducted are not sufficient to identify trends in the data. Due to this insufficiency, these data sets and water sources cannot yet be used as sustainability indicators. Not enough is known about what natural and human caused disturbances affect their behavior and how they respond to changes.

The lack of conclusive results in this analysis does not mean that no relationship exists between the data sets that were used. There may have been variables that affected the behavior of the data sets that were not accounted for in the analysis. The precipitation data that were analyzed may not have contributed to the groundwater data that was examined. Also evapotranspiration rates, runoff, soil type, and vegetation could all effect how the precipitation relates to the water levels. None of these factors were considered in this analysis, leaving large room for errors.

The research performed in this study could be extended or continued into the future by including additional parameters for analysis. A relationship that might be useful to examine is how city water use relates to groundwater levels. If a relationship can be detected between these two variables, it may tell give us some information about how the aquifer responds to use and to what extent. This information could be helpful if this water source is ever used as an indicator. A similar relationship worth investigation is the relationship between the population of the Coconino Plateau, area groundwater levels, both in the Lake Mary Aquifer and in the base flows of the perennial streams. Again, if a relationship can be detected, it can provide information about how the water resources respond to human influences.

The base flow data of the perennial streams investigated in this report was interpolated. The accuracy of this interpolation could be investigated as well. The technique could be performed again using a different period of time when searching for minimum values. This could change what minimums are detected and potentially how much of the seasonal flow from runoff is included in the interpolated data set. This in turn could give different trends and perhaps make relationships stand out in a new manner.

This project allowed for the conclusion that the behavior of groundwater, both in the aquifer and in the base flow of creeks, is very complex and has many variables that were not accounted for in the analysis performed. Due to this conclusion, creating a model or using an existing model that includes all of these variables may serve as an effective tool in determining groundwater behavior. This type of model should incorporate variables such as precipitation levels, infiltration rates, recharge rates, and evapotranpiration rates into its prediction. This could then be compared to actual values and properties of the groundwater could then be determined. Such information could lead to the development of triggers and possibly using the data as a sustainability indicator.

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Appendices

Appendix 1: All raw data sets and filters

Appendix 2: Qualitative data inventory

Appendix 3: Linear trend analysis in excel data and graphs

Appendix 4: Linear trend analysis notes

Appendix 5: Linear trend analysis in JMP data

Appendix 6: Linear trend analysis in JMP notes

Appendix 7: Sum of anomalies data and graphs

Appendix 8: Sum of anomalies

Appendix 9: Pacific Decadal Oscillation data and graphs

Appendix 10: Pacific Decadal Oscillation vs. Anomalies notes

Appendix 11: Season to season data and graphs

Appendix 12: Season to season notes

Appendix 13: Month to month data and graphs

Appendix 14: Month to month notes