

Water Supply Indices: Year Types for the Scott River Basin



A Report for the Scott River Watershed Council

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Water Supply Indices: Year Types for the Scott River Basin Table of Contents

1.	Background	1
1.1	Report Organization.....	1
2.	Project Area	1
3.	Example Year Types.....	3
3.1	Water Supply Planning Years.....	4
3.2	Year Types in California.....	4
4.	Developing Year Types for the Scott River Basin.....	5
4.1	Single Year Type	5
4.1.1	Interquartile Range.....	6
4.1.2	Standard Deviation, σ	6
4.1.3	Expert Judgment	7
4.2	Statistical Methods: IQR and Standard Deviation	7
4.3	Expert Judgment	10
4.3.1	Comparison of Methods.....	12
5.	Multi-Year Types.....	16
6.	Limitations with Year Typing.....	18
7.	Extreme Events	19
8.	Groundwater	21
8.1	Groundwater Data.....	21
8.2	Groundwater-Surface Water Relationships	24
9.	Conclusions.....	25
10.	References.....	26

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1. Background

Effective management of water resources requires planning, and planning requires two basic concepts: (1) the status of current conditions and (2) an estimate of future conditions. Both of these pieces of information are typically benchmarked to long-term conditions to improve decision-making capabilities. The two tasks identified by the Siskiyou County Resources Conservation District (RCD) as important in water resources management – year type designations and runoff forecasting – seek to quantify these critical pieces of information. Runoff forecasting is addressed in Deas and Tanaka, 2005. The topic of year type designation is the focus of this report.

Year types are used as a means of classifying forecasted flows in a river to assist managers in water supply allocation decisions for agricultural, urban, environmental, and other uses. Year types, or indices, are essentially a means of describing the volume of water originating in a river or basin in response to differing hydrologic conditions (DWR, 2005) and are also a useful way to quickly and consistently describe the water supply conditions in a basin. Water supply conditions, as identified by different year types, may trigger different criteria that impact operations or other requirements. Further, a year type may be modified as the season progresses enabling managers to make adjustments to how the system is managed. Year types form a simple, yet powerful tool to quantify and manage water supplies within a basin, as well as an effective means of communicating such activities to stakeholders and agencies.

1.1 Report Organization

This report presents a description of the project area, identifies examples of year types in other California basins, develops representative year types for the Scott River Valley for both single and multiple year types, presents some basic limitations of year type applications in water resources planning and management, highlights the role of extreme events in year type designation, and briefly explores groundwater conditions in the basin that may prove useful in year type considerations.

2. Project Area

The Scott River watershed, located in Siskiyou County of Northern California (Figure 1), encompasses approximately 425,000 acres of irrigated agriculture, wooded forest, urbanized lands, other lands, and waterways. The main economic industries in the watershed are irrigated agriculture (primarily alfalfa), timber, and cattle. Fort Jones and Etna are the main urbanized areas with populations of approximately 660 and 780, respectively, as of the 2000 Census (U.S. Census, 2003a; 2003b). Fort Jones and Etna are linked to one another and to the town of Yreka by Highway 3, which runs through the Scott Valley floor.

The Scott River watershed is dominated by a Mediterranean-type climate with summer being warm and dry and winter being cold and wet. Precipitation is mainly concentrated in the winter months and falls primarily as rainfall on the valley floor, while significant snowfall occurs on the surrounding mountain ranges, resulting in snowmelt runoff during the early spring months. The Scott Valley does not have any significant surface water storage facilities, but there is approximately 300 to 400 thousand acre-feet (taf) of groundwater storage, which is recharged annually by the Scott River, tributary streams, and by infiltration of precipitation and snowmelt (DWR, 2003).

The Scott River, a tributary to the Klamath River, is the major water resource feature in the basin. It is fed by a number of smaller tributaries, which include Kidder, Moffet, Mill, Sugar, and French Creeks. It is estimated that there are over 700 miles of streams within the basin. Urban and agricultural water needs are met through diversions from surface water sources or from pumping of groundwater. The Scott River and tributaries also serves as habitat for coho salmon (*Oncorhynchus kisutch*) and fall run Chinook salmon (*Oncorhynchus tshawytscha*), as well as steelhead trout (*Oncorhynchus mykiss irideus*). Coho salmon are a federal and state protected species under the respective Endangered Species Acts. Year type designations could assist local agricultural business enterprises, resource managers, other interested parties, and stakeholders to assess water availability in light of existing demands on the resource, as well as to support a proposed water trust (Black, 2005).

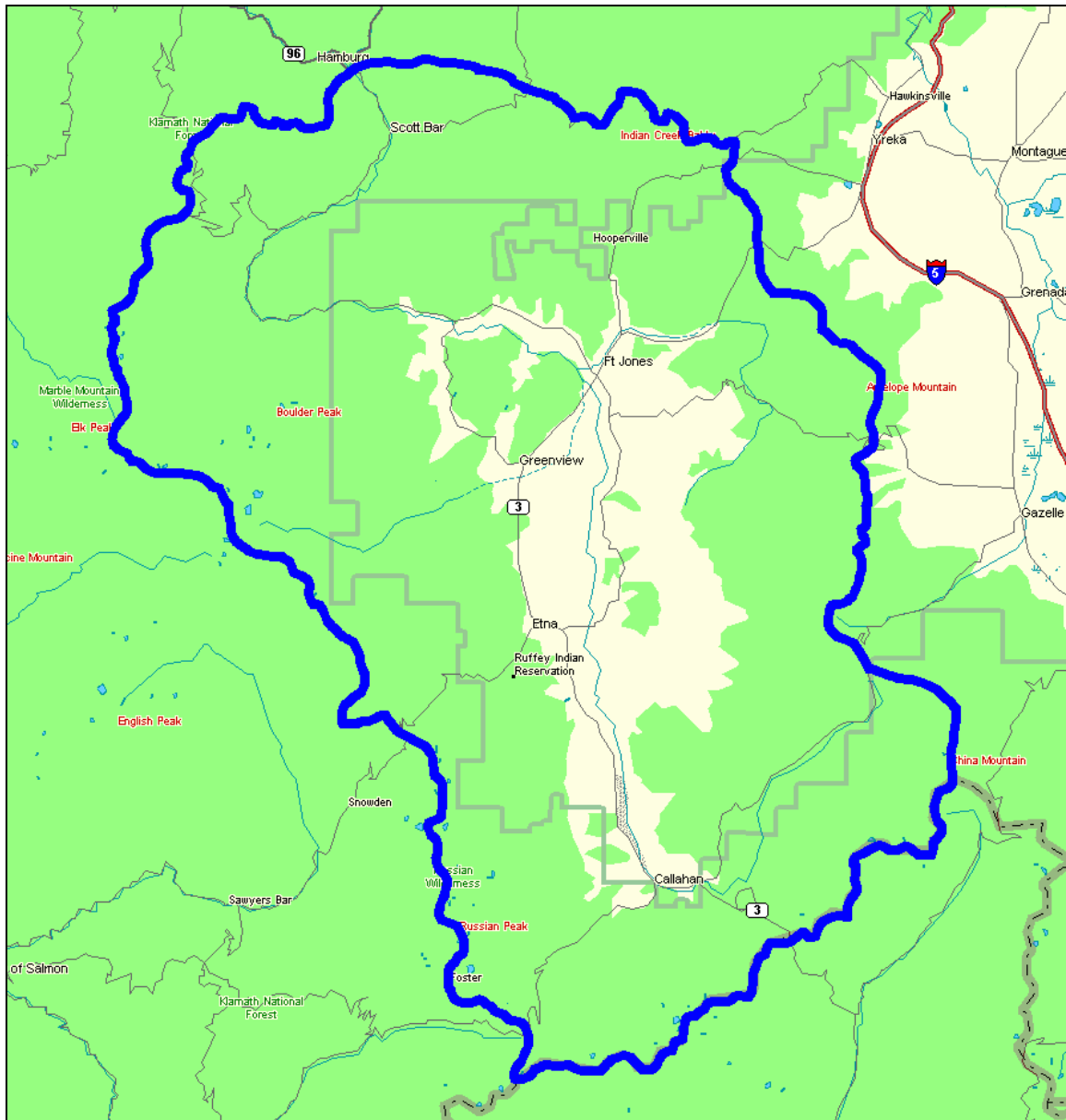


Figure 1. The Scott River Watershed (Base Map from DeLorme® Topo Quads).

3. Example Year Types

Year types or indices can be developed based on several hydrologic and/or meteorological attributes. Typically, years types are identified with respect to a long-term average conditions: when conditions are well below average, they may be termed “dry,” while if they are above average, they are termed “wet.” There are many permutations or “tiers” that may be used to describe the water supply conditions for a basin. The index is generally related to one or more of several variables, including, but not limited to: rainfall, snowfall, runoff, reservoir storage, and in some cases groundwater storage. There are other types of indices that are similar to year types; these include the Palmer Drought Index (PDI) and the Standardized Precipitation Index (SPI). The PDI is a water balance index that considers precipitation, evapotranspiration and runoff, while

the SPI considers only precipitation (Guttman, 1998). The emphasis of these indices is to measure drought. Both the PDI and SPI are non-basin specific, allowing for comparisons between geographically large regions. This is useful for managing water resources in over a large geographic range. However, neither of these systems are readily translated to the year types used in most California water basins.

Outlined below is a definition of water supply planning “years,” and several examples of year types in California.

3.1 Water Supply Planning Years

The twelve month period defining the water supply planning “year” may differ considerably depending on the basin, hydrology, and institutional structure. Most water supply activities are not based on the calendar year (January through December), nor are they typically based on the precipitation year (July 1 through June 30). Rather, water supply activities often refer to “water years” or “runoff years.” A water year extends from October 1 through September 30 of the subsequent year. Water years are often used in precipitation dominated systems. A runoff year extends from April 1 through March 30 of the following year. Runoff years are predominately used in basins where snowfall is a dominant feature, or there is significant surface water storage – a condition that can be defined on April 1st to assist in water resources planning in management over the subsequent months. In both the water and runoff years, the Gregorian date (year) designation is assigned according the year with the most months. For example, water year 2005 extends from October 1, 2004 through September 30, 2005, while runoff year 2005 extends from April 1, 2005 through March 30, 2006.

3.2 Year Types in California

Some of the major river systems or basins in California that have published year type information include the Trinity River, Klamath River, Sacramento River, San Joaquin River, Russian River, and the Mono Basin. This is not an exhaustive list, but it does provide a representative range of systems.

For the Trinity River, known runoff from October through March is combined with a forecast of April through September flow (based on snowfall information) to estimate the flow in the river during the remainder of the year (TRRP, 2006). For other rivers, such as the Klamath River, a forecasted flow combined with the measured snow pack is used to estimate the flows during the high demand season of spring through early fall (USBR, 2005). In some basins, such as the Mono Basin, the April 1st snowmelt forecast for flows in multiple streams is used to determine the overall water supply conditions in the basin for subsequent months (SWRCB, 1994). The Russian River, which has no snowmelt component, uses inflow to storage reservoirs during the winter months to estimate annual flows for the water year (SWRCB, 1986).

Systems like the Sacramento and San Joaquin Rivers have large reservoirs that provide carry-over storage. As such, those rivers have a water year type system that combines known unimpaired runoff, forecasted unimpaired runoff, and the previous year’s water year index value (DWR, 2005). Existing storage also plays a role in the application of

these indices on the Sacramento and San Joaquin River, because if the previous year was wet, then the indices will be higher (larger number) and lower if it was a dry year.

Once the year type designation has been developed, resource managers generally define tiers denoting a variety of water supply conditions ranging from dry to wet. Most river systems use a four or five tiered classification system, though some basins have a more or less detailed break down. Table 1 is not an exhaustive list of water year types used, nor is it a complete list of all basins that have a water year type classification system in California; however, it does identify a wide range of designations and is representative of what is commonly found in use today.

Table 1. Water Year Type Classification Systems for Representative Rivers & Basins.

Water Year Type Classification Systems				
Trinity	Klamath	Russian	Sacramento/San Joaquin	Mono Basin
▪ Critically Dry ▪ Dry ▪ Normal ▪ Wet ▪ Extremely Wet	▪ Dry ▪ Below Average ▪ Average ▪ Above Average ▪ Wet	▪ Critical ▪ Dry ▪ Normal	▪ Critical ▪ Dry ▪ Above Normal ▪ Below Normal ▪ Wet	▪ Dry ▪ Dry-Normal I ▪ Dry-Normal II ▪ Normal ▪ Wet-Normal ▪ Wet ▪ Extreme Wet

4. Developing Year Types for the Scott River Basin

Two year type approaches are presented herein: a single year type designation, where information the year type is based solely on information available for the current year; and a multiple year type designation, where information from the current conditions as well as previous year's information is used.

4.1 Single Year Type

To develop a single year type approach for the Scott River basin, available hydrologic and meteorological information was reviewed (see Watercourse, 2005). The primary hydrologic data considered were impaired and unimpaired runoff, and precipitation (rainfall and snowfall). Impaired runoff did not provide a consistent record because different hydrologic conditions can lead to similar impaired runoff conditions and vice versa due to variability in agricultural water use (including utilization of groundwater to meet demand). Although unimpaired flow information was available (DWR, 1998), it was not readily available for recent years. Annual precipitation was considered, but summer precipitation is relatively modest and is thus not very informative in assessing water supply conditions. (Summer rains can be beneficial, but they are difficult to plan for or rely upon.) Previous studies (Deas and Tanaka, 2005) have indicated that annual unimpaired runoff is well related to October through March precipitation. Thus accumulated October through March precipitation was used as the basis for formulating year types.

There are numerous approaches that can be used to identify tiers defining different hydrologic conditions (e.g., see Table 1). To identify various year types as wet, normal,

dry, etc. a method is required to differentiate among various water supply conditions. Several are outlined herein. The intent of this report is not to endorse a method, but to provide the description of the methods so that local resource managers can ultimately identify a year type approach that will best represent valley interests and management strategies. To differentiate year types, three approaches were used:

- Interquartile Ranges
- Standard Deviation
- Expert Judgment

The first two options are statistical methods. The last relies on data, experience, and local knowledge. There are many options that could be explored using statistics, available data, and expert knowledge. The above methods can easily lead to a classification system (tiers) with any number of categories.

4.1.1 Interquartile Range

The interquartile range is determined by first dividing a data set in two (i.e., finding the median). Subsequently, divide the upper and lower in half (i.e., determine the median of each half). This approach defines the lower quartile or 25th percentile (Q_1), the median or 50th percentile (Q_2) and the upper quartile or 75th percentile (Q_3). The interquartile range (IQR) is defined as:

$$IQR = Q_3 - Q_1$$

And provides a measure of the spread of the data.

For example, take the data set {2, 5, 8, 9, 10, 12, 16}. The median is the 4th value, so $Q_2 = 9$. The 25th percentile corresponds to the 2nd value, so $Q_1 = 5$. The 75th percentile corresponds to the 6th value, so $Q_3 = 12$. Thus the $IQR = Q_3 - Q_1 = 12 - 5 = 7$.

4.1.2 Standard Deviation, σ

Standard Deviation (σ) is a measure of the spread of data about the mean of the data set, and is directly related to variance. A smaller standard deviation means that the data is clustered more closely around the mean of the data set. For a normal distribution, approximately 68.2% of the data should lie within one standard deviation of the mean, 95.4% should lie within two standard deviations, and 99.6% should lie within three standard deviations. Standard deviation is calculated using:

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

Where n is the number of data points in the data set and $\bar{x}$ is the average value of the data set.

For example, take the data set {2, 5, 8, 9, 10, 12, 16} where $n = 7$.

$$\bar{x} = \frac{1}{7}(2+5+8+9+10+12+16) = 8.9$$

$$\sigma = \sqrt{\frac{1}{7}((2-8.9)^2 + (5-8.9)^2 + (8-8.9)^2 + (9-8.9)^2 + (10-8.9)^2 + (12-8.9)^2 + (16-8.9)^2)} = 4.6$$

The average value ($\bar{x}$) is 8.9, $n = 7$, and the standard deviation is 4.6.

4.1.3 Expert Judgment

Expert judgment involves examining the historical record and identifying conditions where there are statistical or natural breakpoints. This is often carried out by generating a non-exceedence (or exceedence) plot. A non-exceedence plot is generated by sorting all the existing data in ascending order (lowest to highest) and then assigning a probability to it. Although there are several methods of determining probabilities, the Weibull distribution is a common approach (Stedinger, 1993) wherein the data are ranked in ascending order and plotting positions determined using the following formula:

$$\text{Probability of Non-Exceedence} = \frac{\text{Rank}}{n + 1}$$

Where 'n' is the number of points in the data series. By definitions, non-exceedence probabilities cannot be zero or one-hundred. Expert judgment can be used to identify hydrologic or meteorological conditions representing different categories (year types) for various water supply conditions by identifying discontinuities in the slope of the plot, or by selecting non-exceedence probabilities that are consistent with management objectives. An example of the latter is identifying a dry year type as having a 10 percent non-exceedence value.

4.2 Statistical Methods: IQR and Standard Deviation

The accumulated October 1 through March 31 precipitation record at Fort Jones spans from runoff year 1936 to present (for the purposes of this report 1936 to 2004 is used). This provides 69 years of data to work with (Figure 2).

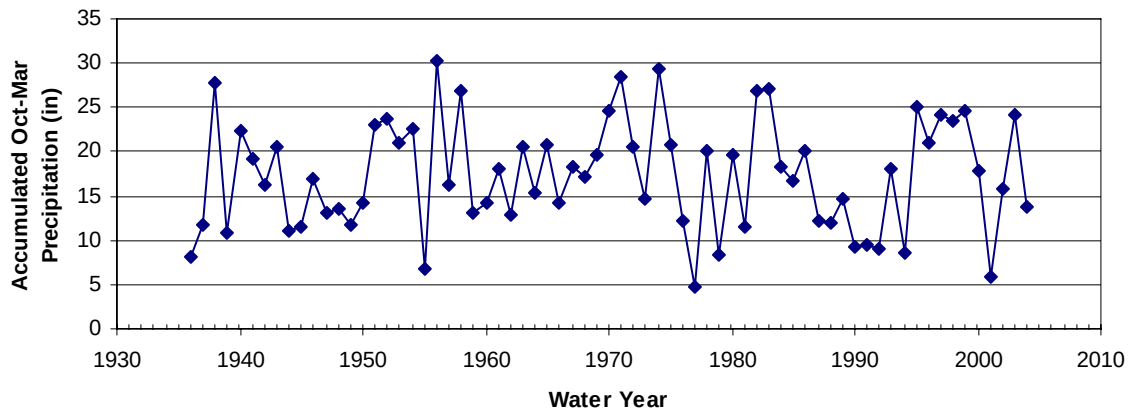


Figure 2. Accumulated October 1 through March 31 Precipitation at Fort Jones.

The basic statistical values for the time series are:

- Maximum Value = 30.3 inches
- Minimum Value = 4.8 inches
- Mean = 17.4 inches
- Median = 17.2 inches
- 25th Percentile, Q_1 = 12.2 inches
- 75th Percentile, Q_3 = 21.7 inches
- Inter-Quartile Range, IRQ = 9.5 inches
- Standard Deviation, σ = 6.2 inches

The precipitation data are not absolutely normally distributed, but the data can be reasonably approximated by a normal distribution. The distribution is slightly skewed (Figure 3) about the mean value with more values within the first standard deviation lower than the mean ($-\sigma$) than higher than the mean ($+\sigma$).

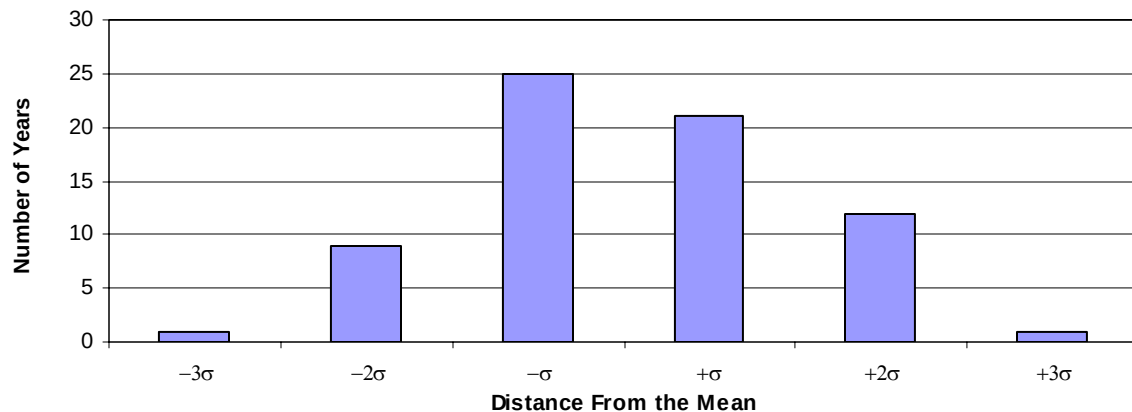


Figure 3. Distribution of Data Set Around the Mean (17.4).

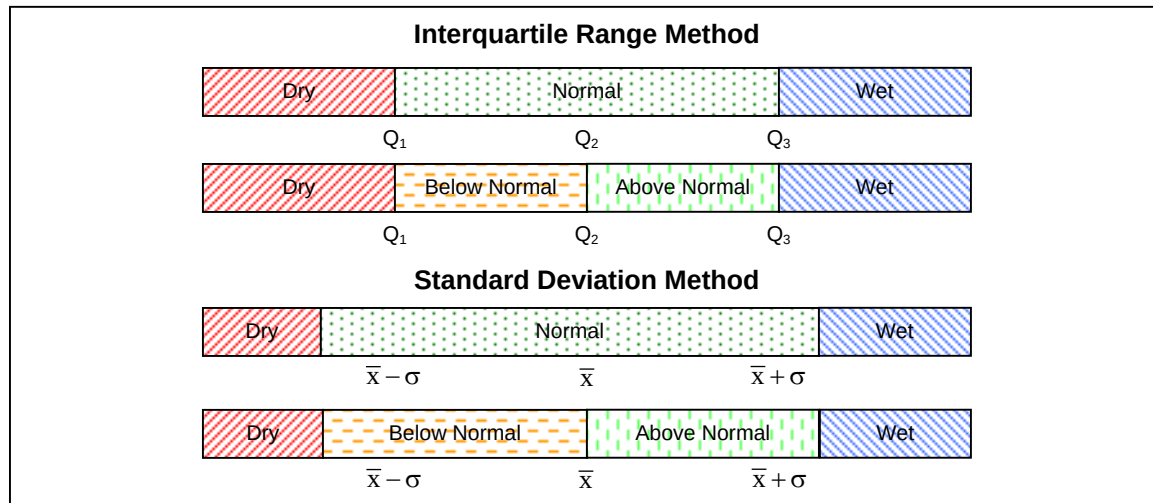
Using the interquartile range and standard deviation of the October through March precipitation at Fort Jones, two sets of year type categories will be developed:

- A three tiered system: wet, normal, and dry, and
- A four tiered system: dry, below normal, above normal, and wet year.

The individual tiers can be designated by other labels as appropriate, and using such information, it is readily feasible to identify additional tiers as necessary. The three and four tier year types are shown in Table 2 and depicted graphically in Figure 4. The breakpoints between tiers will be slightly different for the two methods due to different statistical approaches. These differences in the methods may provide desired flexibility for resource managers to partition year types in the Scott Valley.

Table 2. Year Type Categories for the IQR and Standard Deviation (σ) Methods: statistical concept.

Three Type			Four Type		
Year Type	IQR	σ	Year Type	IQR	σ
Dry	$X < Q_1$	$X < \bar{X} - \sigma$	Dry	$X < Q_1$	$X < \bar{X} - \sigma$
Normal	$Q_1 \leq X < Q_3$	$\bar{X} - \sigma \leq X < \bar{X} + \sigma$	Below Normal	$Q_1 \leq X < Q_2$	$\bar{X} - \sigma \leq X < \bar{X}$
Wet	$Q_3 \leq X$	$\bar{X} + \sigma \leq X$	Above Normal	$Q_2 \leq X < Q_3$	$\bar{X} \leq X < \bar{X} + \sigma$
			Wet	$Q_3 \leq X$	$\bar{X} + \sigma \leq X$

**Figure 4. Year Type Categories by Method: statistical concept.**

Extending the statistical concept identified above to the Scott River basin data for October through March precipitation at Fort Jones, water year categories are numerically defined in Table 3.

Table 3. Year Type Categories for the IQR and Standard Deviation (σ) Methods based on Fort Jones October through March Precipitation.

Three Tier Year Type			Four Tier Year Type		
Year Type	IQR	σ	Year Type	IQR	σ
Dry	$P_{o-m} < 12.2$	$P_{o-m} < 11.2$	Dry	$P_{o-m} < 12.2$	$P_{o-m} < 11.2$
Normal	$12.2 \leq P_{o-m} < 21.7$	$11.2 \leq P_{o-m} < 23.6$	Below Normal	$12.2 \leq P_{o-m} < 17.2$	$11.2 \leq P_{o-m} < 17.4$
Wet	$21.7 \leq P_{o-m}$	$23.6 \leq P_{o-m}$	Above Normal	$17.2 \leq P_{o-m} < 21.2$	$17.4 \leq P_{o-m} < 23.6$
			Wet	$21.7 \leq P_{o-m}$	$23.6 \leq P_{o-m}$

P_{o-m} : October through March Ft. Jones precipitation – all values in inches

Applying these criteria to the historical time series, a complete year type designation was constructed for both methods. Generally, the two methods were similar, with the IQR method predicting more dry and wet years, and the σ -method predicting more normal years (Figure 5 and Figure 6). Out of the 69 years, the water year type designation was the same 84% of the time when using the three tier system and 83% of the time when using the four tier system.

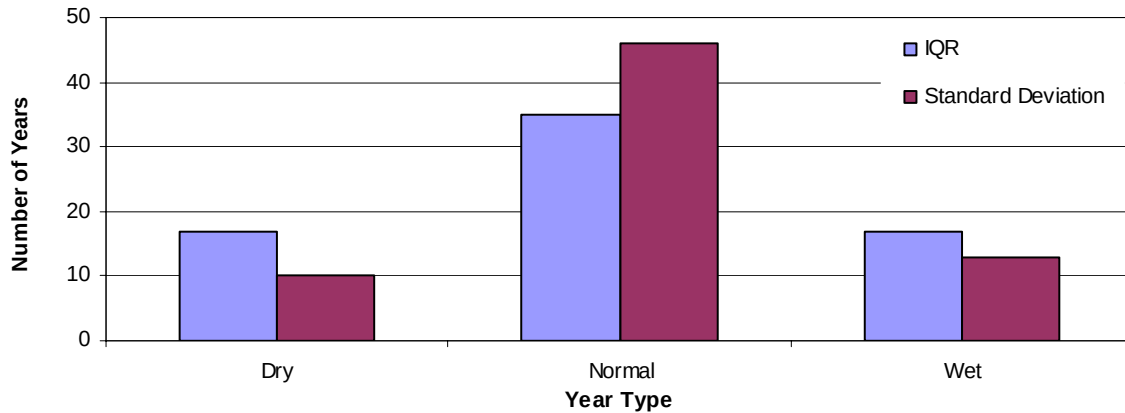


Figure 5. Three Year Type, Statistical Method Comparison.

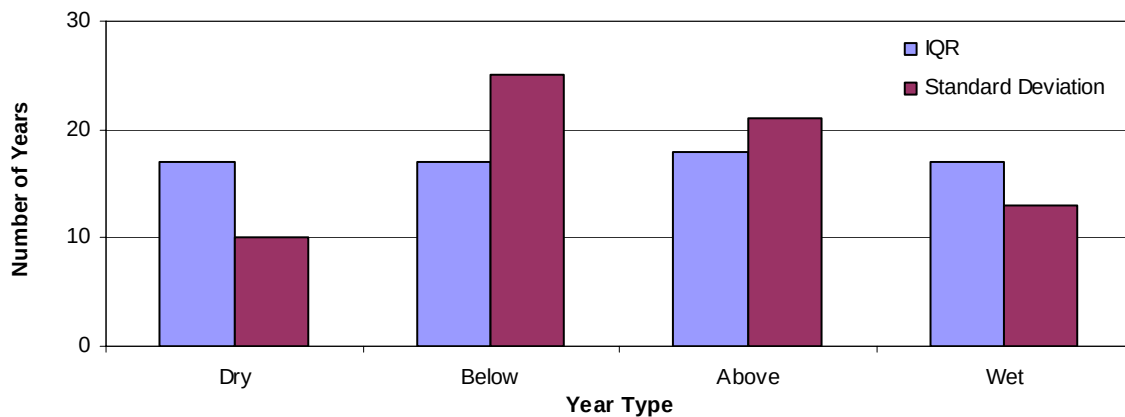


Figure 6. Four Year Type, Statistical Method Comparison.

4.3 Expert Judgment

One approach to applying expert judgment in identifying year types would involve constructing an exceedance plot and analyzing the information to determine where the most likely breakpoints between hydrologic (or meteorological) conditions occur. The exceedance plot for the October through March 31 accumulated precipitation at Fort Jones is shown in Figure 7. Careful review of the plot suggests that there are several locations where the slope of the line changes or there are abrupt changes, or steps, in the plot.

One interpretation of these data are to assume a median (50th percentile non-exceedance) as a breakpoint, accompanied by two additional breakpoints within each group to define four year types (dry, below normal, above normal, and wet), as shown in Figure 8. The breakpoint segregating dry and below normal was placed at the 14th percent non-exceedance value where a discontinuity suggest that years below this point are distinctly different than years above this point. Likewise a breakpoint differentiating above normal and wet years was located at the 75th percent non-exceedance value. This breakpoint could have been located at the discontinuity at the 90th percent non-exceedance value as well. Careful review of the data and local knowledge of the year types and associated

operations that occurred about the 75th and 90th percent non-exceedance values could lend valuable insight into the final selection.

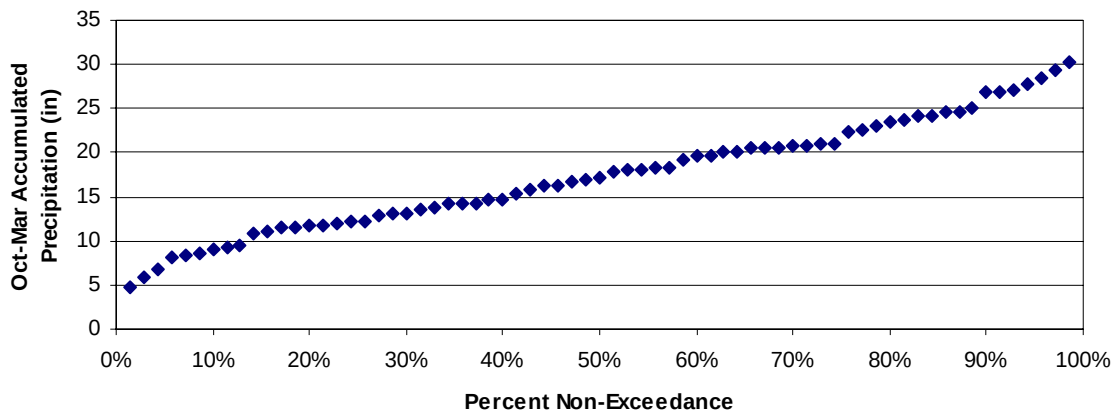


Figure 7. Non-Exceedance Probability Plot

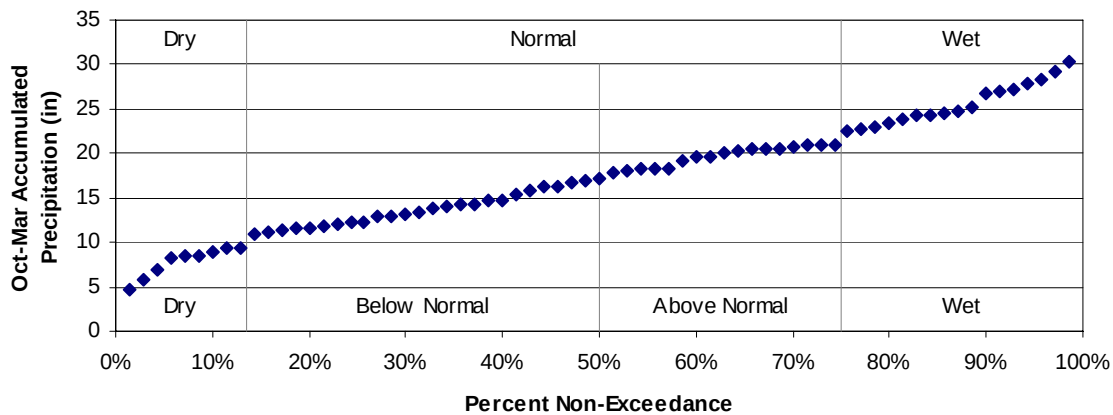


Figure 8. Locations of Approximate Breakpoints Using Expert Judgment.

A three and four year type systems was developed using the same descriptions as applied in the IQR and σ -methods (Table 4). For the four year type system, there were no distinct breakpoints to separate below normal from above normal, so the 50% non-exceedance value was chosen. One thing to note with the proposed system (Figure 8) is that the categories are not equal in size (i.e., a dry year type has a 14% chance of occurring, while wet year type has a 25% chance of occurring). The proposed breakdown also has a very large normal (below normal and above normal) category (from 14% to 75%). These values could be modified to more appropriately incorporate experience in the basin and to reflect the overall objective or application of the year type criteria.

Table 4. Expert Judgment Sample Classification System with Three and Four Year Types.

Year Type	October through March 31 Accumulated Precipitation (in)	Non-Exceedence Probability	Year Type	October through March 31 Accumulated Precipitation (in)	Non-Exceedence Probability
Dry	$X < 10.2$	$X < 14\%$	Dry	$X < 10.2$	$X < 14\%$
Normal	$10.2 \leq X < 21.7$	$14\% \leq X < 75\%$	Below Normal	$10.2 \leq X < 17.2$	$14\% \leq X < 50\%$
			Above Normal	$17.2 \leq X < 21.7$	$50\% \leq X < 75\%$
Wet	$21.7 \leq X$	$75\% \leq X$	Wet	$21.7 \leq X$	$75\% \leq X$

In this case the expert judgment system classified 9 of the years as dry and 17 of the years as wet for both the three and four tier system. The remaining 46 years are normal (or a combination of below and above normal in the four tier system).

4.3.1 Comparison of Methods

Non-exceedence plots of accumulated precipitation values and tabulated data were used to compare the three methods. The IQR- and σ -methods are presented Figure 9 and Figure 10, respectively, while the expert judgment system was presented previously in Figure 7. In all the figures the three category system is indicated on the top of the plot, while the four category system is presented along the bottom.

Comparison of these three methods indicates that there is a fair amount of variability and that the statistical methods do not necessarily agree with the expert judgment approach,

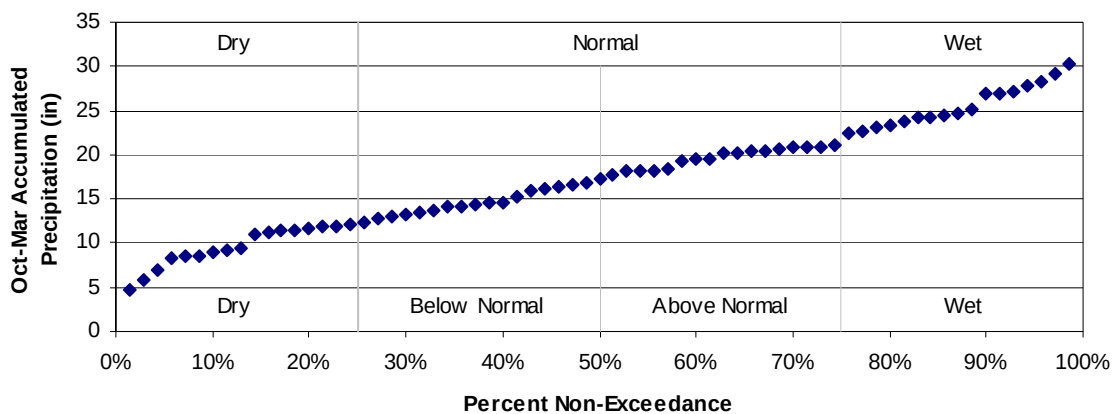


Figure 9. IRQ-Method Plot of Non-Exceedence Probability.

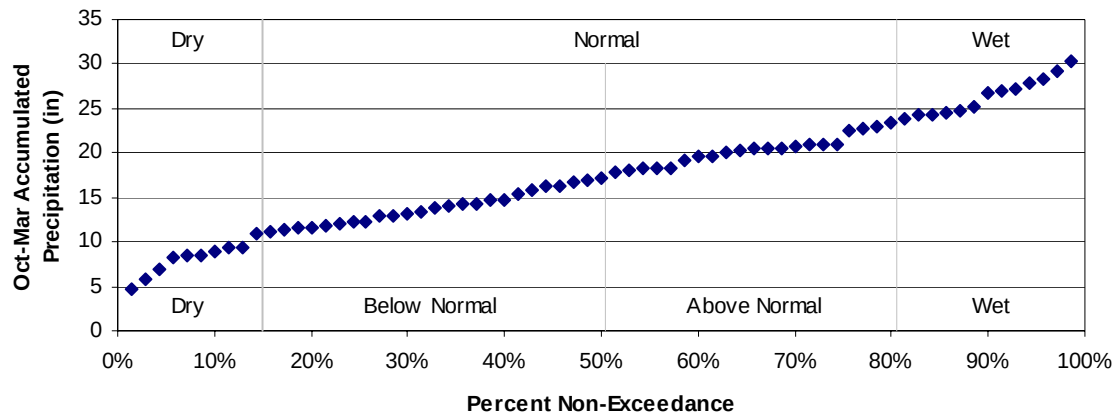


Figure 10. σ -Method Plot of Non-Exceedance Probability.

As it can be seen from

Table 5 there are going to be some instances where the three different methods will designate a year with a different label. The driest and wettest years, along with closest to the average, will be in agreement regardless of the method used, but those closer to the breakpoints may be different.

Overall, all three methods predicted the same type of year 83% of the time in the three classification system and 81% of the time in the four classification system (Table 6). The IQR method tends to predict more wet and dry years regardless of the classification system used. The standard deviation method tends to predict the most years in the normal (or below and above normal) years. The expert judgment system predicts the fewest dry years.

Table 5. Water Year Type Comparison.

Water Year	Oct-Mar Accumulated Precipitation (in)	Three Water Year Categories			Four Water Year Categories		
		IRQ	σ	Expert Judgment	IRQ	σ	Expert Judgment
1936	8.19	Dry	Dry	Dry	Dry	Dry	Dry
1937	11.85	Dry	Normal	Normal	Dry	Below	Below
1938	27.79	Wet	Wet	Wet	Wet	Wet	Wet
1939	10.92	Dry	Dry	Normal	Dry	Dry	Below
1940	22.42	Wet	Normal	Wet	Wet	Above	Wet
1941	19.28	Normal	Normal	Normal	Above	Above	Above
1942	16.18	Normal	Normal	Normal	Below	Below	Below
1943	20.62	Normal	Normal	Normal	Above	Above	Above
1944	11.16	Dry	Normal	Normal	Dry	Below	Below
1945	11.47	Dry	Normal	Normal	Dry	Below	Below
1946	16.85	Normal	Normal	Normal	Below	Below	Below
1947	13.17	Normal	Normal	Normal	Below	Below	Below
1948	13.46	Normal	Normal	Normal	Below	Below	Below
1949	11.66	Dry	Normal	Normal	Dry	Below	Below
1950	14.3	Normal	Normal	Normal	Below	Below	Below
1951	23.05	Wet	Normal	Wet	Wet	Above	Wet
1952	23.81	Wet	Wet	Wet	Wet	Wet	Wet
1953	20.92	Normal	Normal	Normal	Above	Above	Above
1954	22.68	Wet	Normal	Wet	Wet	Above	Wet
1955	6.85	Dry	Dry	Dry	Dry	Dry	Dry
1956	30.29	Wet	Wet	Wet	Wet	Wet	Wet
1957	16.34	Normal	Normal	Normal	Below	Below	Below
1958	26.83	Wet	Wet	Wet	Wet	Wet	Wet
1959	13	Normal	Normal	Normal	Below	Below	Below
1960	14.24	Normal	Normal	Normal	Below	Below	Below
1961	18.17	Normal	Normal	Normal	Above	Above	Above
1962	12.86	Normal	Normal	Normal	Below	Below	Below
1963	20.52	Normal	Normal	Normal	Above	Above	Above
1964	15.3	Normal	Normal	Normal	Below	Below	Below
1965	20.84	Normal	Normal	Normal	Above	Above	Above
1966	14.12	Normal	Normal	Normal	Below	Below	Below
1967	18.29	Normal	Normal	Normal	Above	Above	Above
1968	17.23	Normal	Normal	Normal	Above	Below	Above
1969	19.59	Normal	Normal	Normal	Above	Above	Above
1970	24.53	Wet	Wet	Wet	Wet	Wet	Wet
1971	28.37	Wet	Wet	Wet	Wet	Wet	Wet
1972	20.46	Normal	Normal	Normal	Above	Above	Above
1973	14.69	Normal	Normal	Normal	Below	Below	Below
1974	29.26	Wet	Wet	Wet	Wet	Wet	Wet
1975	20.87	Normal	Normal	Normal	Above	Above	Above
1976	12.26	Normal	Normal	Normal	Below	Below	Below
1977	4.78	Dry	Dry	Dry	Dry	Dry	Dry
1978	20.19	Normal	Normal	Normal	Above	Above	Above
1979	8.45	Dry	Dry	Dry	Dry	Dry	Dry
1980	19.6	Normal	Normal	Normal	Above	Above	Above
1981	11.54	Dry	Normal	Normal	Dry	Below	Below
1982	26.88	Wet	Wet	Wet	Wet	Wet	Wet
1983	27.2	Wet	Wet	Wet	Wet	Wet	Wet
1984	18.19	Normal	Normal	Normal	Above	Above	Above
1985	16.65	Normal	Normal	Normal	Below	Below	Below
1986	20.14	Normal	Normal	Normal	Above	Above	Above
1987	12.15	Dry	Normal	Normal	Dry	Below	Below

Table 5. Water Year Type Comparison (continued).

Water Year	Oct-Mar Accumulated Precipitation (in)	Three Water Year Categories			Four Water Year Categories		
		IRQ	σ	Expert Judgment	IRQ	σ	Expert Judgment
1988	11.96	Dry	Normal	Normal	Dry	Below	Below
1989	14.65	Normal	Normal	Normal	Below	Below	Below
1990	9.29	Dry	Dry	Dry	Dry	Dry	Dry
1991	9.42	Dry	Dry	Dry	Dry	Dry	Dry
1992	8.98	Dry	Dry	Dry	Dry	Dry	Dry
1993	18.1	Normal	Normal	Normal	Above	Above	Above
1994	8.54	Dry	Dry	Dry	Dry	Dry	Dry
1995	25.08	Wet	Wet	Wet	Wet	Wet	Wet
1996	21	Normal	Normal	Normal	Above	Above	Above
1997	24.27	Wet	Wet	Wet	Wet	Wet	Wet
1998	23.38	Wet	Normal	Wet	Wet	Above	Wet
1999	24.7	Wet	Wet	Wet	Wet	Wet	Wet
2000	17.78	Normal	Normal	Normal	Above	Above	Above
2001	5.85	Dry	Dry	Dry	Dry	Dry	Dry
2002	15.9	Normal	Normal	Normal	Below	Below	Below
2003	24.22	Wet	Wet	Wet	Wet	Wet	Wet
2004	13.75	Normal	Normal	Normal	Below	Below	Below

Table 6. Comparison of Results for the Three Methods.

Year Type	IQR-Method	σ -Method	Expert Judgment	Year Type	IQR-Method	σ -Method	Expert Judgment
Dry	17	10	9	Dry	17	10	9
Normal	35	46	43	Below Normal	17	25	25
Wet	17	13	17	Above Normal	18	21	18
				Wet	17	13	17

5. Multi-Year Types

Another method of categorizing a years is to include information from the previous year, e.g., the year type from the previous year. Incorporating such information can provide valuable insight on antecedent conditions and how they may affect current year water supply conditions: e.g., a dry year type may provide a very different response if the previous year was wet versus a condition when the previous year was dry. A multi-year water year type can be complex. For example, using a three year type system to classify any single year results in nine potential two-year types (Table 7).

Table 7. Nine Two-Year Water Year Type Classifications and Color Scheme.

Water Year Type		
Previous Year	Current Year	Two-Year
Dry	Dry	Dry-Dry
Dry	Normal	Dry-Normal
Dry	Wet	Dry-Wet
Normal	Dry	Normal-Dry
Normal	Normal	Normal-Normal
Normal	Wet	Normal-Wet

Wet	Dry	Wet-Dry
Wet	Normal	Wet-Normal
Wet	Wet	Wet-Wet

The nine category system presented above can be applied to the 69-year historic record (note, the two year system can only accommodate 68 years of record because conditions prior to 1937 are not known) (Table 8). Using the IRQ-, σ -, or expert judgment methods yields at least one year that falls into one of the nine multi-year categories.

Table 8. Dual-Year Type Comparison.

Water Year	Oct-Mar Accumulated Precipitation (in)	Three Water Year Categories		
		IRQ-Method	σ -Method	Expert Judgment
1937	11.85	Dry-Dry	Dry-Normal	Dry-Normal
1938	27.79	Dry-Wet	Normal-Wet	Normal-Wet
1939	10.92	Wet-Dry	Wet-Dry	Wet-Normal
1940	22.42	Dry-Wet	Dry-Normal	Normal-Wet
1941	19.28	Wet-Normal	Normal-Normal	Wet-Normal
1942	16.18	Normal-Normal	Normal-Normal	Normal-Normal
1943	20.62	Normal-Normal	Normal-Normal	Normal-Normal
1944	11.16	Normal-Dry	Normal-Normal	Normal-Normal
1945	11.47	Dry-Dry	Normal-Normal	Normal-Normal
1946	16.85	Dry-Normal	Normal-Normal	Normal-Normal
1947	13.17	Normal-Normal	Normal-Normal	Normal-Normal
1948	13.46	Normal-Normal	Normal-Normal	Normal-Normal
1949	11.66	Normal-Dry	Normal-Normal	Normal-Normal
1950	14.3	Dry-Normal	Normal-Normal	Normal-Normal
1951	23.05	Normal-Wet	Normal-Normal	Normal-Wet
1952	23.81	Wet-Wet	Normal-Wet	Wet-Wet
1953	20.92	Wet-Normal	Wet-Normal	Wet-Normal
1954	22.68	Normal-Wet	Normal-Normal	Normal-Wet
1955	6.85	Wet-Dry	Normal-Dry	Wet-Dry
1956	30.29	Dry-Wet	Dry-Wet	Dry-Wet
1957	16.34	Wet-Normal	Wet-Normal	Wet-Normal
1958	26.83	Normal-Wet	Normal-Wet	Normal-Wet
1959	13	Wet-Normal	Wet-Normal	Wet-Normal
1960	14.24	Normal-Normal	Normal-Normal	Normal-Normal
1961	18.17	Normal-Normal	Normal-Normal	Normal-Normal
1962	12.86	Normal-Normal	Normal-Normal	Normal-Normal
1963	20.52	Normal-Normal	Normal-Normal	Normal-Normal
1964	15.3	Normal-Normal	Normal-Normal	Normal-Normal
1965	20.84	Normal-Normal	Normal-Normal	Normal-Normal
1966	14.12	Normal-Normal	Normal-Normal	Normal-Normal
1967	18.29	Normal-Normal	Normal-Normal	Normal-Normal
1968	17.23	Normal-Normal	Normal-Normal	Normal-Normal
1969	19.59	Normal-Normal	Normal-Normal	Normal-Normal
1970	24.53	Normal-Wet	Normal-Wet	Normal-Wet
1971	28.37	Wet-Wet	Wet-Wet	Wet-Wet
1972	20.46	Wet-Normal	Wet-Normal	Wet-Normal
1973	14.69	Normal-Normal	Normal-Normal	Normal-Normal
1974	29.26	Normal-Wet	Normal-Wet	Normal-Wet
1975	20.87	Wet-Normal	Wet-Normal	Wet-Normal
1976	12.26	Normal-Normal	Normal-Normal	Normal-Normal
1977	4.78	Normal-Dry	Normal-Dry	Normal-Dry
1978	20.19	Dry-Normal	Dry-Normal	Dry-Normal

1979	8.45	Normal-Dry	Normal-Dry	Normal-Dry
1980	19.6	Dry-Normal	Dry-Normal	Dry-Normal
1981	11.54	Normal-Dry	Normal-Normal	Normal-Normal
1982	26.88	Dry-Wet	Normal-Wet	Normal-Wet
1983	27.2	Wet-Wet	Wet-Wet	Wet-Wet
1984	18.19	Wet-Normal	Wet-Normal	Wet-Normal
1985	16.65	Normal-Normal	Normal-Normal	Normal-Normal
1986	20.14	Normal-Normal	Normal-Normal	Normal-Normal
1987	12.15	Normal-Dry	Normal-Normal	Normal-Normal
1988	11.96	Dry-Dry	Normal-Normal	Normal-Normal
1989	14.65	Dry-Normal	Normal-Normal	Normal-Normal
1990	9.29	Normal-Dry	Normal-Dry	Normal-Dry
1991	9.42	Dry-Dry	Dry-Dry	Dry-Dry
1992	8.98	Dry-Dry	Dry-Dry	Dry-Dry
1993	18.1	Dry-Normal	Dry-Normal	Dry-Normal
1994	8.54	Normal-Dry	Normal-Dry	Normal-Dry
1995	25.08	Dry-Wet	Dry-Wet	Dry-Wet
1996	21	Wet-Normal	Wet-Normal	Wet-Normal
1997	24.27	Normal-Wet	Normal-Wet	Normal-Wet
1998	23.38	Wet-Wet	Wet-Normal	Wet-Wet
1999	24.7	Wet-Wet	Normal-Wet	Wet-Wet
2000	17.78	Wet-Normal	Wet-Normal	Wet-Normal
2001	5.85	Normal-Dry	Normal-Dry	Normal-Dry
2002	15.9	Dry-Normal	Dry-Normal	Dry-Normal
2003	24.22	Normal-Wet	Normal-Wet	Normal-Wet
2004	13.75	Wet-Normal	Wet-Normal	Wet-Normal

The most common category was “Normal-Normal.” The dual year type system indicates that the majority of the years (26% for IQR, 44% for σ , and 40% for expert judgment) are “Normal-Normal.” The least common are the extreme difference (“Wet-Dry” and “Dry-Wet”) combinations. Dry periods and wet periods are apparent, but it appears that the IQR method shows more sensitivity than the σ approach for either extreme (dry or wet) and more sensitivity than the expert judgment approach for dry periods. If the identified criteria do not provide sufficient detail for resource managers, the breakpoints for the three tiers can be modified. Additionally, an additional tier (four tiers) could be added to increase resolution.

The benefit of a two-year water year type system is the ability it provides managers to describe the current conditions in light of previous year conditions and consider future consequences. For example, if the previous year was “Dry” and the upcoming year is also “Dry” then managers may consider how to manage the system for a prolonged period of low flows. Even if a single year type is adopted, it may be useful to track multiple year conditions to gain insight into potential carryover effects of soil moisture and groundwater conditions.

6. Limitations with Year Typing

Year type classification systems are useful for managers to quickly describe the state (or forecasted state) of the system and convey this information to interested parties. Nonetheless, limitations of year type designations are important to consider. One of the key limitations that are present in any of the methods presented above is that the range of variability within a tier may be considerable. For example in the IQR method, a normal

year is assigned when the accumulated precipitation (October-March) at Fort Jones is between 12.2” and 21.7.” Deas and Tanaka (2005) identify that this corresponds to unimpaired flows ranging from 329 taf to 691 taf per year – a considerable range. Managers must account for the variability within a tier, as well as consider if conditions are near a breakpoint.

As noted above, accumulated precipitation at Fort Jones is used as a surrogate for unimpaired flow. However, accumulated precipitation is not necessarily a perfect substitute or predictor of unimpaired flows. Deas and Tanaka (2005) identify a linear regression relationship between the accumulated precipitation and the unimpaired flow estimates for the year. The r-squared was between 0.878 and 0.913 (depending on if the intercept to y-axis is forced to be zero). This translates to meaning that between 12.2% and 8.7% of the variability in total annual unimpaired flows is not explained by the accumulated precipitation. When the regression results were compared to the historic record, the equation was found to generally over predict flows for low precipitation values and under predict for high precipitation values.

In terms of year types, it means that under certain situations a water year could be preliminarily labeled one type, but the actually flows observed at the end of the water year could be higher or lower than what is associated with the year type. Such modification to the year types should be expected – and accommodated as necessary – by resource managers. Even if unimpaired flows were directly available, year types may change due to variations in land use, meteorological conditions, marked precipitation after April 1, changes in groundwater use, or other factors.

For example, using the IRQ methods the precipitation in 1947 was 13.17 inches while in 1949 the precipitation was 11.66 inches. The result would be that 1947 was classified as a “Normal” year, while 1949 was a “Dry” year. However, the estimated unimpaired flows were higher in 1949 (293 taf versus 219 taf). So under the IRQ-method unimpaired annual flows between 200 taf/yr and 300 taf/yr could be either “Dry” or “Normal”. The same discrepancies exist for the difference between “Normal” and “Wet” years and for the σ -method. Unless unimpaired flows are used directly and the water year type is updated monthly after April 1, this problem will exist regardless of the method selected.

7. Extreme Events

One other issue that should be considered when developing water year types and response plans to those water year types is the presence of extreme events. Generally extreme events can be described as large flood events (high flows) or severe droughts (low flows or extended low flows). Each extreme event has certain features in common, but they also have very significant differences. Namely flood events require crisis (short-term) planning, while droughts require emergency (long-term) planning.

For the Scott River, the estimated unimpaired total annual flows are dominated by flows between 250 and 900 taf. For the 50-years of unimpaired flows there are five below 250 taf and five above 900 taf. Focusing first on the low flow periods; the flows for those five years range from 123 taf to 218 taf. From Figure 11, it can be determined that there

is only a 10% probability that the unimpaired flow in the Scott River will be less than 250 taf. On the high end, the flows range from 927 taf to 1,150 taf. There is a 90% probability that flows will be less than 927 taf. Generally speaking, for the Scott River, the extreme dry or wet periods appear to only occur with a 10% probability (10% probabilities of flows being less than 250 taf and 10% probability of flows being greater than 900 taf).

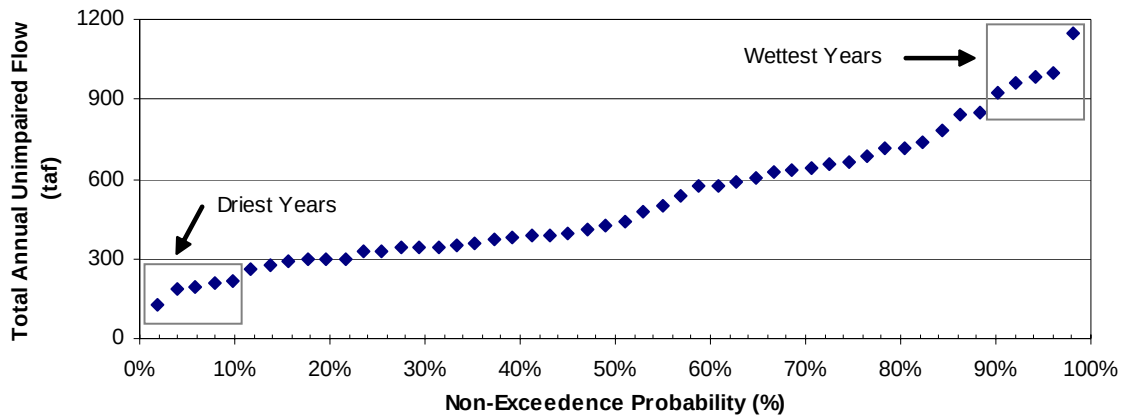


Figure 11. Non-Exceedence Probability Plot for Unimpaired Annual Flow (DWR, 1998).

Two different situations arise: single year events and multi-year events. In the case of low flows, single year droughts and multi-year droughts can have very different consequences. Single year drought conditions can often be offset by increased groundwater pumping, conservation, and other methods. Multi-year droughts require more innovative solutions and often require more substantial changes to operations. Flooding is generally a single event crisis; each flood event is dealt with at the time it occurs. However, if conditions in the basin remain extremely wet for multi-years, then the potential for flooding increases. The groundwater basin is already saturated or nearly saturated and unable to store additional water. The water that might have infiltrated into the aquifer cannot do so and remains in the surface water system.

For both the driest years and wettest years there are examples where two consecutive years are present (Table 9). 1991 and 1992 are the 2nd and 5th driest years on record. 1982 and 1983 are the 5th and 3rd wettest years on record. (Groundwater records for 1992 were unavailable; however, 1983 groundwater levels were among the highest recorded. Groundwater is discussed further below.)

Table 9. Five Driest and Five Wettest Years.

Five Driest Years		Five Wettest Years	
Water Year	Unimpaired Annual Flow (taf)*	Water Year	Unimpaired Annual Flow (taf)*
1977	123	1982	927
1991	190	1956	963
1994	193	1983	986
1955	210	1958	1,001
1992	218	1974	1,150

*DWR (1998)

Information on extreme events, particularly the few wettest and few driest years can be useful in defining year types. Specifically, resource managers often try to fit *all* years in the historical record into a year-type scheme. It may not be prudent to include all years, particularly if there are notable outliers. For example, close examination of Figure 11 indicates that the driest year is appreciably drier than the second driest year. Likewise the wettest year is notably wetter than the second wettest year. It may be more useful to identify these very extreme, low probability years, as events that are addressed separately in the planning process. That is, in a watershed or basin-wide water resources plan it may be more useful to incorporate operations associated with broad year type designations that represent the vast majority of the observed conditions (e.g., wet, normal, dry year types), and separate or distinct measures for dealing with the extreme events. This approach avoids two critical planning maladies:

- 1) “diluting” the importance of extreme events when they are simply incorporated, or lumped, into the dry or wet year types
- 2) encumbering the dry and wet year type operations by trying to accommodate one or two extreme events (when ideally the extreme events could be “set aside” and appropriate operations developed for remaining non-extreme dry or wet years).

8. Groundwater

There are a variety of parameters that could be used to determine a water year type in the Scott Valley. The representative rivers (discussed above) have a few major differences that impact any forecasts made. The Trinity, Klamath, Sacramento, and San Joaquin all have appreciable surface water storage capabilities. Both the Trinity River and Klamath River classification systems use the inflows into Trinity Lake and Upper Klamath Lake, respectively, to determine the water year type. The Sacramento and San Joaquin River classification systems do not use flows into a reservoir, but do take into consideration the over-year carrying capacity in the reservoir by using the previous year’s water type indices in the determination of the current water year type. Meaning that the wetter the previous year was, the higher the storage in the surface facilities is likely to be.

The Scott River does not have appreciable surface water storage capabilities, which would limit the ability to directly transfer a classification system from a large storage capable system to the Scott Valley. Despite the lack of surface water storage, the Scott Valley does have a large groundwater basin. The Scott Valley sits atop a 300 to 400 taf groundwater basin (DWR, 2003). Groundwater basins generally respond to hydrological variability much slower than surface water reservoirs, but like surface facilities, do provide a means of over-year storage. To examine potential relationships between groundwater and surface water and the potential of incorporating groundwater into a year type system, available data were briefly investigated.

8.1 Groundwater Data

DWR maintains records for nine testing wells located in the Scott River Valley, seven of which appear to still be active. The depth from the reference point to the water surface was generally measured in the early spring (April) and in early fall (October). Some of the data sets span from 1953 to the present, while others are considerably shorter (e.g., 2004 to present) (Table 10). The depth from the reference point to the water surface was

generally measured in the early spring (April) and in early fall (October). The stations are scattered throughout the basin, but the largest concentrations appear to be near Fort Jones (Figure 12).

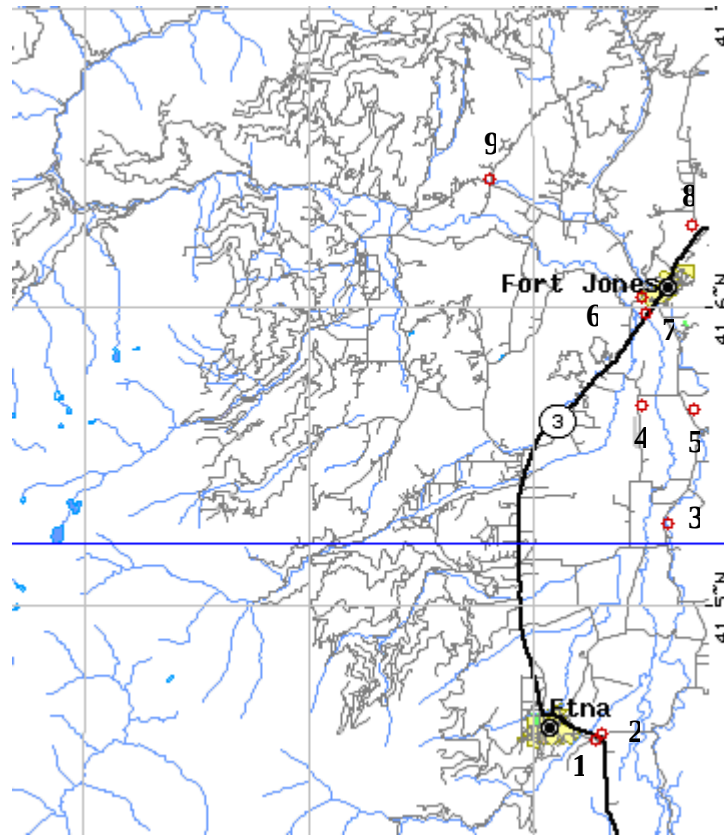


Figure 12. Scott Valley Groundwater Monitoring Well Locations (source: CDEC).

Table 10. Well Number and Period of Record.

Well # on Figure 12	State ID Well Number	LL Easting	LL Northing	Period of Record
1	42N09W27N002M	122.8728	41.4554	1994 to Present
2	42N09W27N001M	122.8703	41.4571	1965 – 2001
3	42N09W02A002M	122.8391	41.5264	1965 – 2004
4	43N09W23F001M	122.8505	41.5667	1953 - Present
5	43N09W24F001M	122.8288	41.5649	1965 – Present
6	43N09W02P002M	122.8511	41.6031	2004 – Present
7	43N09W02Q002M	122.8493	41.5977	2003 – Present
8	44N09W25R001M	122.8280	41.6272	2002 – Present
9	44N09W28P001M	122.9199	41.6428	1965 - Present

All of the groundwater monitoring wells displayed a similar seasonal pattern: the water table is closer to the ground surface in April than in October (Figure 13). In general it appears that during the irrigation season, the groundwater basin is pumped and the water table drops correspondingly. During the non-irrigation season groundwater is replenished by seasonal precipitation. This cyclical pattern is present in most years (Figure 14). When the groundwater basin is the filled to its greatest annual capacity (represented as the smallest depth to groundwater: distance between the water table and

the ground surface) is unclear, as data are generally only present for April and October. At a few selected sites, measurements were taken for the months between April and October for one or two years, but there is insufficient data to draw any strong conclusions (Figure 15). None of the wells were sampled in winter or early spring months.

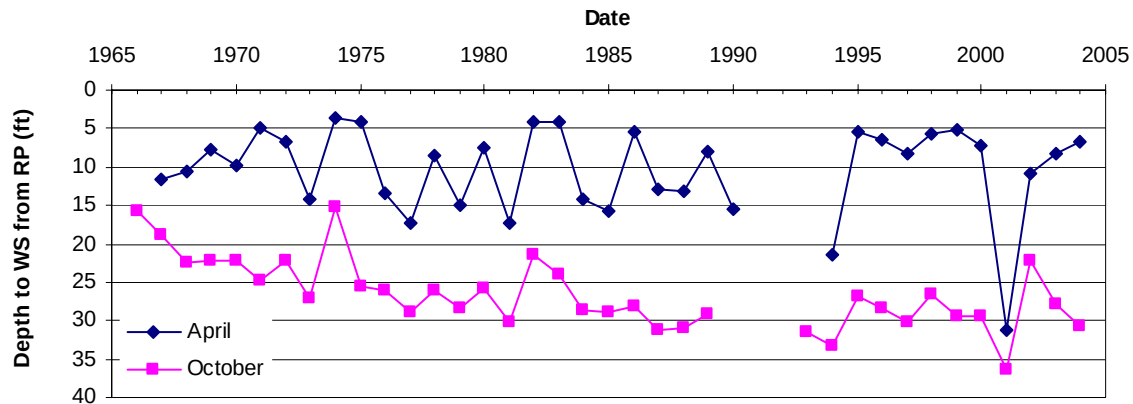


Figure 13. Depth to Water from the Reference Point at Well #9.

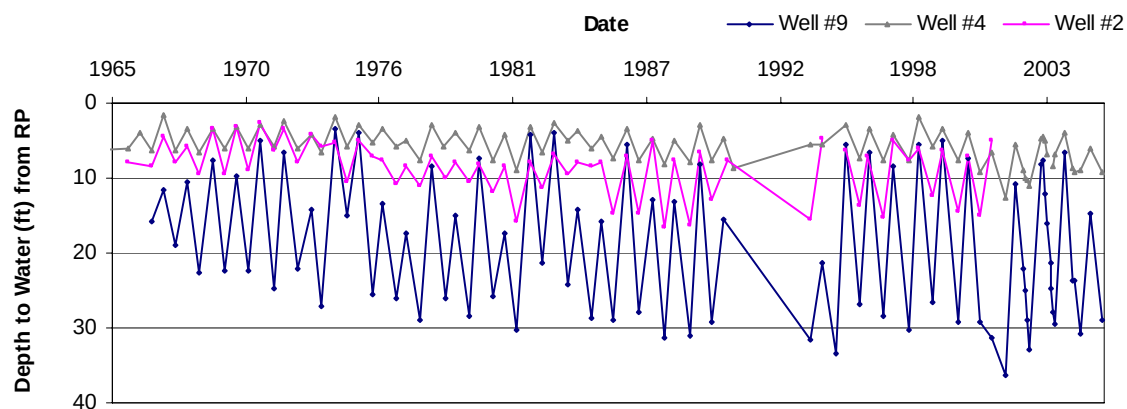


Figure 14. Depth to Water for Three of the Monitoring Wells, 1965 to Present.

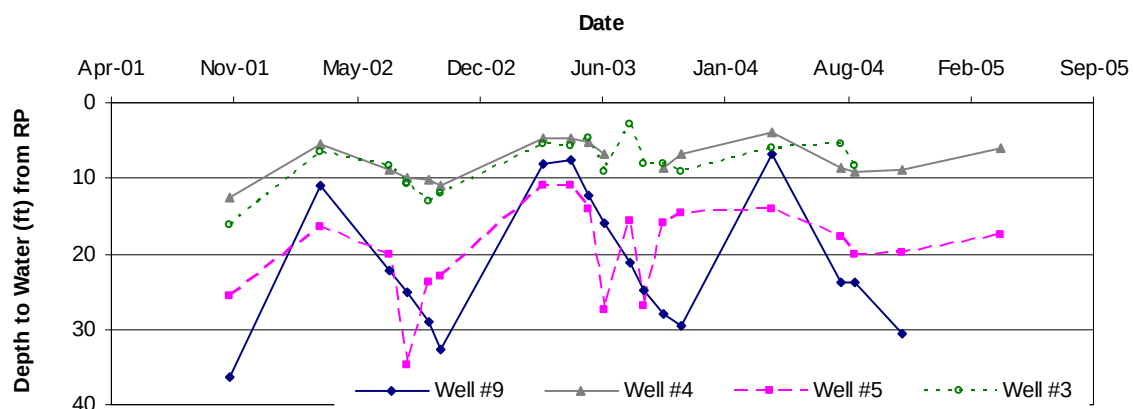


Figure 15. Depth to Water for Four Monitoring Wells, Detail.

The longest period of record exists for Well #4 (1953 to present). Three other data sets of relatively long monitoring periods include Well #9 (1965 to present), Well #5 (1965 to present), and Well #2 (1965 to 2001). The data notes indicate that in 2001 Well #2 collapsed; however, a nearby well (Well #1) began recording data in 1994. An analysis of the two data sets indicate that the water table was consistently higher at Well #2 than Well #1 (Figure 16). The maximum difference was 5.5 feet, the minimum difference was 3.2 feet, and the average difference was 3.8 feet. Despite the slight variability in the differences in measurement, these two wells could be used together to estimate water table levels near Etna from 1965 to the present.

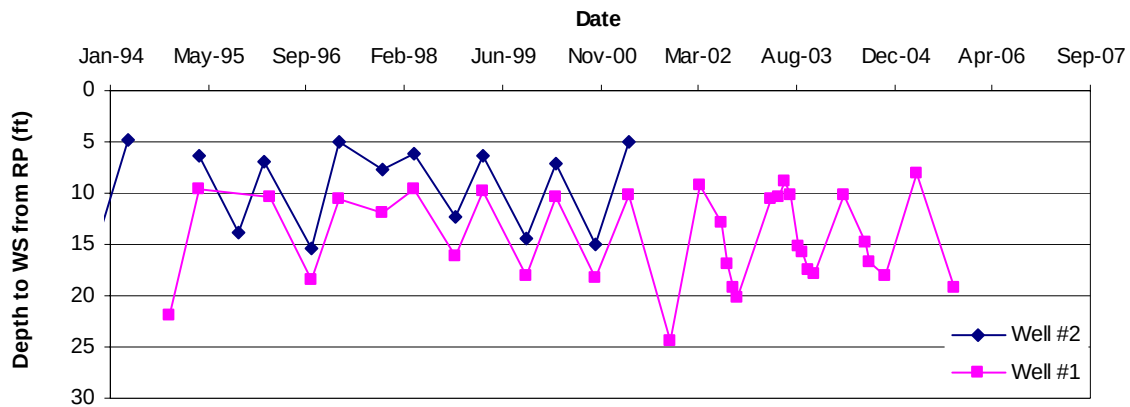


Figure 16. Comparison of Data at Well #1 and Well #2.

Generally the depth to water increases the further downstream along the river corridor the station is located. In other words, depth to water at Well #9 (north-west of Fort Jones) is consistently greater than at Well #2 (near Etna) (Figure 14).

8.2 Groundwater-Surface Water Relationships

To explore potential relationships between surface water and groundwater unimpaired flow at Fort Jones (DWR, 1998) was compared with depth to groundwater in the month of April. Wells at several locations were examined. For example, near Etna the depth of the water table in April did not relate well to total annual unimpaired flows in the Scott River (R^2 of 0.0822). Near Fort Jones the relationship improved, but there was still considerable scatter in the data (R^2 of 0.6157). The relationship improves at the site furthest downstream in the Scott Valley (Well #9), but was still not as good an indicator as the accumulated precipitation (R^2 of 0.914 versus R^2 of 0.715). These findings indicate that April groundwater levels show some correlation to higher estimated total unimpaired flow (Figure 17). This very basic review of groundwater data was not intended to interpret overall groundwater conditions, response to groundwater pumping, geological factors, or other facets of this complex system. However, because there appears to be at least some correlation between surface water runoff and groundwater levels, there may be some aspect of groundwater storage that could be useful in defining year types in the Scott Valley.

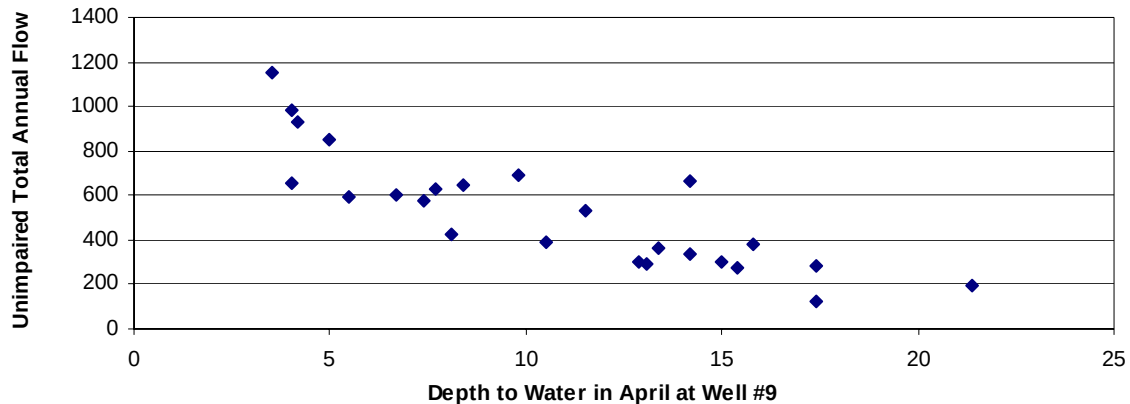


Figure 17. Depth to Water Surface Compared with Unimpaired Total Annual Flow.

9. Conclusions

Year types form a simple, yet powerful tool to quantify and manage water supplies within a basin, as well as an effective means of communicating such activities to stakeholders and agencies. For most systems, three to four year types are generally sufficient, especially from a water supply perspective; however, any number of year types can be developed. Identification of project objective and application of year types will assist resource managers in selecting appropriate approaches.

There are a variety of ways to determine what the threshold values should be when defining year types (e.g., wet, normal, and dry years). Statistical methods (e.g., IQR and σ -methods) are often the easiest to explain and subject to less perceptual bias. Much more complex statistical methods than those presented herein can be pursued. Expert judgment is useful for systems where there are strong clusters or relationships within the data. Regardless of the method selected year type classifications should reflect the experience of water resource managers and stakeholders. Water year types for wet, normal, dry, and for wet, above normal, below normal, and dry conditions were developed and compared for all systems. These approaches, although not exhaustive, provide a range of options for resource managers in the Scott Valley to identify appropriate year type indices for use in year-to-year operations as well as for multiple year periods.

In addition to determining if a year is a wet, normal, or dry (or some other classification decided by resource managers), managers should be aware of and prepared for extreme events. Extreme events, such as flooding or severe droughts, require advanced planning to be managed in the most efficient way possible. However, flood events typically require crisis (short-term) planning, while droughts require emergency (long-term) planning. It may be more useful to identify these very extreme, low probability years, as events that are addressed separately in the planning process. This approach avoids two critical planning maladies:

- 1) “diluting” the importance of extreme events when they are simply incorporated, or lumped, into the dry or wet year types

- 2) encumbering the dry and wet year type operations by trying to accommodate one or two extreme events (when ideally the extreme events could be “set aside” and appropriate operations developed for remaining non-extreme dry or wet years).

Groundwater is an important component in the Scott River Valley. It supplies critical storage in a system that has no appreciable surface storage, and can provide an important supply during normal and drought periods. Limited data exists for groundwater levels in April and October for sites along the Scott River. The short nature of these records provides limited information about long-term trends and conditions in the basin, but are a good starting point for future work. There appears to be at some correlation between surface water runoff and groundwater levels in portions of the basin. As such, there may be some aspect of groundwater storage that could be useful in defining year types in the Scott Valley. Thus, the existing stations should be continued to be monitored, and if possible monitoring should occur more frequently than twice a year. Monthly depths to the water table would be ideal; this would assist in better capturing the annual drawdown and refill cycle.

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