C-WIN-3 - 2nd REVISED

SWP AND CVP OPERATIONS, THE INDICES THAT GOVERN THEM AND THEIR VALIDITY

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INTRODUCTION

In State Water Resources Control Board Decision 1485, an index was promulgated for the classifying of water year types. This index provides varied tables, and sets of values for a variety of Delta protection standards. No supporting analysis was cited to show how and why this index, and its, water year type derivative were established. The Water Year Index is specified by the following formula:

$$INDEX = 0.4*X + 0.3*Y + 0.3*Z$$

Where: X = Current ~~calendar~~ water year's April-July Sacramento Valley unimpaired run-off

Y = Current ~~calendar~~ water year's October-March Sacramento Valley unimpaired run-off

Z = Previous ~~calendar~~ water year's index

Once an index has been calculated, its value is used to determine one of five water year types: Wet, Above Normal, Below Normal, Dry, and Critical. This water year type designation is then used to set a multitude of water quality and flow standards throughout the Delta. Variations on this type of designation (e.g. the Shasta Index, American River Index, and the Trinity River Index) are also used in a multitude of operational and flow release standards for reservoirs throughout the Sacramento Basin. All of these indexes are used as well in the CALSIM II model.

D-1485 also specifies that when it is too early in the water year to have observations in hand for April-July and October-March, run-off forecast values should be based on "normal" precipitation for the unknown parts of the water year. "Normal" precipitation is not precisely defined, nor is it specified how it is to be used to calculate a value for run-off.

It is clear from a careful examination of the requirements of D-1485 that water year type is a very important parameter in managing the water resources of the Delta. Because of that high level of importance, it is fair to question both the reliability of this index and the wisdom of using it to manage the operation of the SWP and CVP.

SACRAMENTO BASIN HYDROLOGY

It is clear that the Water Year Index is profoundly dependent on the characteristics of the Sacramento Basin Hydrology. The three most important derivatives of that hydrology - particularly in regard to forecast reliability - are run-off flows for April-July and October-March, the reliance of the previous year's Water Year Index, and the notion of "normal" precipitation. If we take the statement "normal" precipitation to mean "normal" run-off, then we may perform some analyses to address these important characteristics.

A careful, quantitative examination of Sacramento Basin Hydrology was performed using the 4-river index as a surrogate for total Sacramento Basin run-off. Figure B-1 is a graph of the run-off history based on the 4-river index. A rudimentary look at the distribution of annual run-off from the 98-year record shows that the data divides into distinct groups; a drier year group comprising 56% of the years and a wet year group comprising 44% of the years as shown in figure B-2. Very few years are found near the average or "normal" value, in fact, the average value is at the relative minimum between the drier group and the wet group. Each of these groups does exhibit characteristics of a more normal distribution when taken separately.

Accordingly, each group was analyzed as a separate distribution and a statistical test was performed to determine the likelihood that they might actually be drawn from a single population. Table B-3 presents the characteristics of each of these groups.

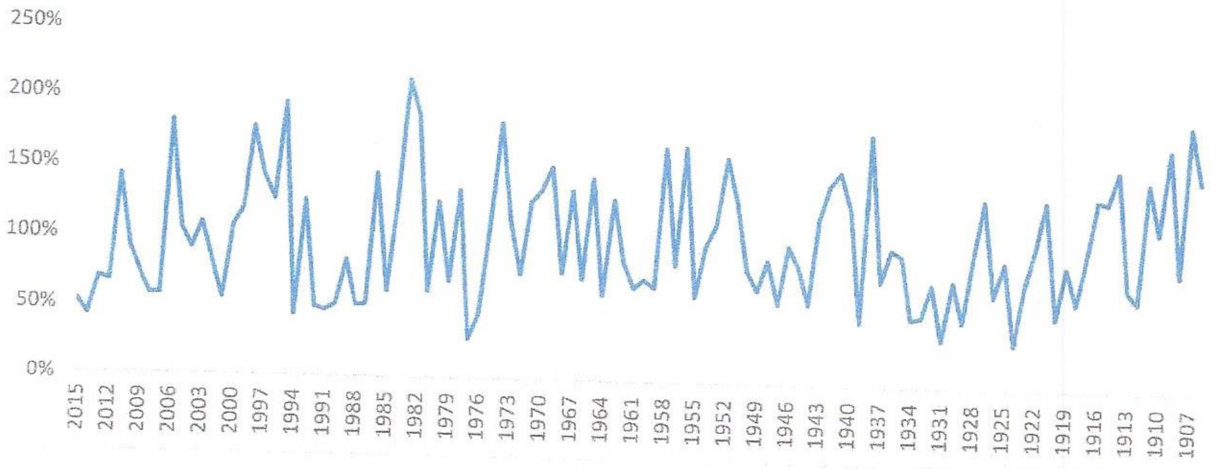


Figure B-1
Sacramento 4 River Index
% of Historical Average

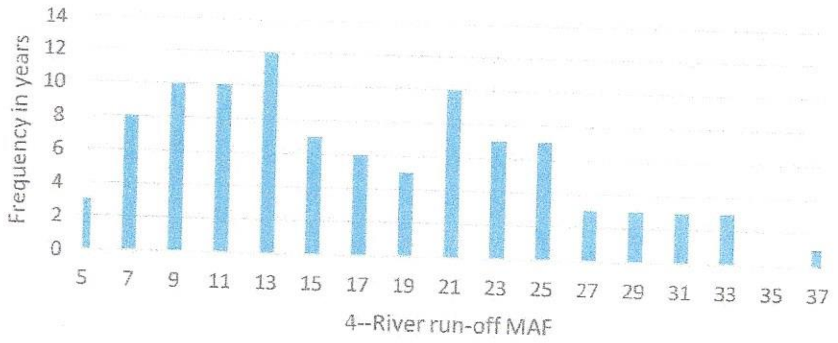


FIGURE B-2
ANNUAL SACRAMENTO 4-RIVER RUN-OFF, 98 YEARS

Table B-3
Statistical Characteristics of Wet and Dry Groups
4-River Index (MAF)

Dry

Wet

Mean	12.18	25.55
Standard Deviation	3.27	4.65
Std. Error of Mean	.441	.709

The standard t-test between means showed less than a 1% chance that the means of these two distributions came from a single population.

VALIDITY OF INDEXES

The water year index formula comprises three terms, two dealing with the current water year run-off and the third being a weighted run-off of the previous year's water year index. We investigated the validity and reliability of the three terms as predictors of the current water characteristics.

Influence of Previous Water Year

To test the validity of using the previous year's water year index, we determined if there was any significant serial correlation between successive years within the 98-year record of annual run-off. The serial correlation co-efficient [R] was found to be 0.084, which indicates no significant serial correlation, even though drought sequences of up to 5 years and wet sequences of several years were noted. (The probability that there was a real correlation was much less than 1%). The persistence of wet and dry sequences probably reflects shifts in the jet stream that may be stable for several years before shifting. This, in turn reflects typical Pacific, synoptic weather patterns. With such an insignificant correlation co-efficient we must conclude there is very little chance that a previous year's run-off has any effect on predicting the run-off of a successive year. *This conclusion requires that the last term in the formula for water year index must be eliminated from the equation.* If we eliminate the last term in the equation there is little need to use any weighting coefficients because the remaining two terms comprise all but about 4% of the expected total run-off for the current water year. The remaining task is to estimate run-off for the unknown months to come.

Forecasting Future Months of the Water Year

The ability to forecast run-off accurately for future months depends on the information at hand. Upon entering a new water year, there is very little information available, especially given the fact that data from the previous water year is not relevant. There is potential information in the measurements of snow pack but snow in the Sierra Nevada and southern Cascades only begins to accumulate in late winter and early spring. The only factual information early in the water year is the current measure of run-off, which in the fall is extremely low. Since the distribution of annual run-off really comprises two independent distributions, it is virtually impossible to designate in which domain, dry or wet, the coming water year falls.

Each of these distributions has its own "normal" begging the question: which one should be chosen for forecasting purposes? D-1485 states that when a forecast value is needed for the formulation it should be based on the value for normal precipitation. *We have shown that there is no "grand normal" for run-off.* (Usually the average or mean value is meant by this term); it is therefore very likely that there is no such thing as a "grand normal" for precipitation. Precipitation data exhibits extreme variation, and because the physical relationship between precipitation and run-off is not linear and is dependent on such parameters as antecedent moisture in the soil, precipitation is probably not a good choice for basing a forecast.

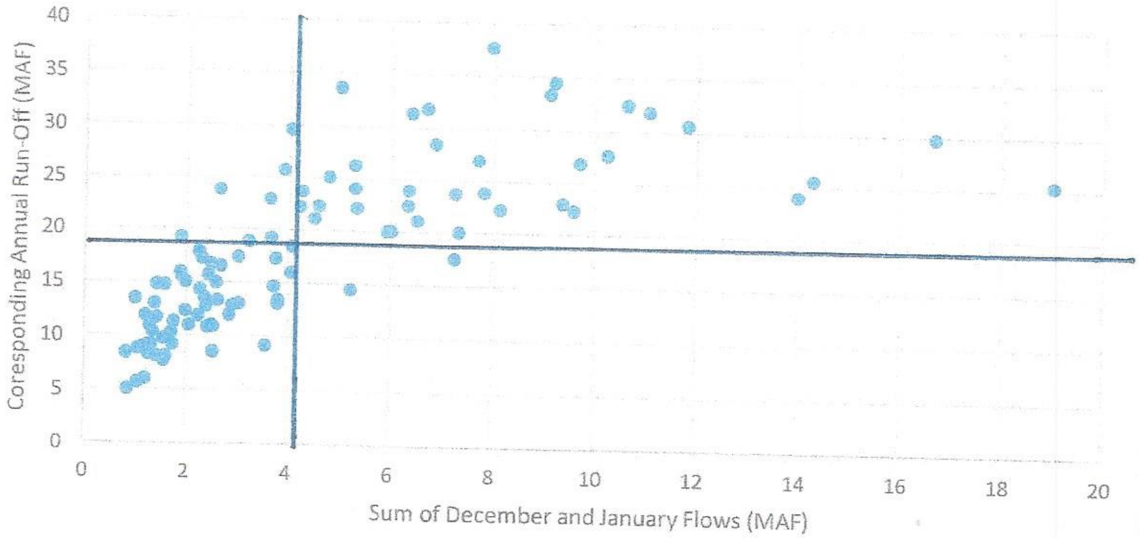
The most prudent choice is to assume that the coming water year will be dry until there is sufficient data to state otherwise. Assuming that the coming water year will be wet runs a 56% or higher chance of being wrong, hardly a prudent assumption given the importance of obtaining a reliable supply from the SWP. If the average for the dry group is chosen for the initial forecast there will be roughly a 25% chance of over-estimating the subsequent run-off. Prudence would dictate that perhaps a 5% chance of such a mistake would be tolerable. At a 5% chance the basis for the forecast would produce annual run-off in the range of 7-8 MAF. In terms of the 4-river index; actual run-off would be 20% to 25% higher. In effect, *a forecast* *range this low would likely cause a suspension in SWP and CVP operations for the first few months of the new water year*, though some export might be possible if there is reservoir storage to support it in these early months.

How soon in the water year can it be stated with some confidence how the water year will play out? October and November produce little to no excess run-off. The first month with the potential for large run-off is December followed by an even more likely run-off in January, February, March, April, and May when snow melt really begins in earnest (and possibly June) are the main run-off producers. Therefore, we must look at the earliest run-off months for an indicator.

An investigation was begun to find early indicators to assess the likelihood of a dry or wet future water year. We first examined whether the run-off of December alone would suffice. Our findings were inconclusive. The same DWR data base from which the annual run-off data was used to generate the graph in Figure 1, also contains the record of monthly run-offs which was used in this investigation. That was inconclusive. We then examined the sum of December and January run-off, and *we found that the sum of December and January could reliably predict if the coming water year would be dry*. A maximum threshold of 3.9 MAF for the sum would capture all but 2 of 55 dry years, which indicates a less than 5% chance of error. That same threshold also falsely designated 6 of 43 wet years as dry. However, that error is not critical since the unfolding water year could easily allow positive corrections in operations.

A scatter plot of the map of total annual run-off versus the sum of January and December run - off is presented in Figure B-3 on the following page. Axes are drawn vertically at a value of 3.9 and horizontally at the grand average of total run-off, creating four quadrants labeled dry winter-wet spring, wet winter-wet spring, wet winter-dry spring, and dry winter-dry spring. Most of the data points are found in either the dry winter-dry spring or wet winter-wet spring designations, which effectively constitute the dry and wet groups used in our analysis. The lack of data points in the other two quadrants confirms that these two groups are distinct. The figure also shows the few data points not in the populated quadrants, demonstrating the low likelihood of error in using the 3.9 MAF locus as a decision basis for declaring a dry winter-dry spring in the early part of the water year.

Figure B-3
Annual Run-off
-vs-
Cumulative December & January



With further examination of the dry group distribution, we found a bounding locus that contains the entire dry group set except for two points. The equation of this locus is:

RUN-OFF = 2.877*DEC-JAN + 2.67

Where: **RUN-OFF** = minimum annual run-off, MAF

DEC-JAN = sum of December and January run-off, MAF

provided **DEC-JAN** is less than or equal to 3.9 MAF

This equation provides a minimum run-off for the dry group with only about a 5% chance of a lower run-off. With this equation, prudent SWP operations can be devised for the months past January until subsequent run-off data can supersede it. It may be possible to find additional bounding equations to guide SWP operations, assuming December and January data are already known. This process may be repeated for successive months and should converge on the actual run-off by the end of the run-off season.

The analyses above establish several constraints in developing prudent SWP operations:

1) No reliance can be placed on a previous water year's run-off in forecasting run-off for a given water year.

2) If run-off through January for a given water year is low (less that 3.9 MAF) it is very likely that the remainder of the water year will be low.

3) There is no meaningful value in referring to the grand average of the hydrologic record as "normal". The record indicates strongly that there are two distinct groups that cluster below and above the grand average, each with its characteristic average or normal value.

4) The equation for calculating the Water Year Index is without merit; the same applies to its derivative, Water Year Type.

POTENTIAL EFFECTS ON SWP OPERATIONS

Winter Pumping

Because low winter run-off through January indicates the very strong likelihood of a dry year overall, winter pumping through January should be minimal if not altogether suspended until further run-off data shows that pumping can be done without jeopardizing the reliability of future deliveries or threatening Delta health. The prudent level of pumping from the Delta during such low periods of winter run-off remains to be investigated.

Overall Project Yield

Since dry years predominate the record, and no confident statement can be made at the beginning of a water year concerning expected project yield, the project yield should be base-lined on the amount that can be reliably exported given the expectation that the ensuing water year will be dry. *This finding necessarily will lead to an export level that is much lower than the current value of 4.1 MAF.* The project can now be studied to determine the amounts of surplus water that can be safely delivered until winter run-off is sufficient to conclude that the total water year will be wet. This implies that the safe level of export will be continuously evaluated as the water year progresses.

Reservoir Operations

Because the designations of water year type are based on a calculated water year index which has been shown to have no validity, *all reservoir operations must be re-examined to determine prudent levels of release* *and storage.*

SWRCB Regulations and Constraints

Because so many of the regulations and constraints that have been promulgated by the SWRCB are based on the flawed water year type, *all such regulations and constraints must be re-visited.*

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Arve R. Sjovold graduated with a B.A. in Physics from the University of California, Berkeley in 1956. For 41 years he specialized in operations research and systems analysis as a Research Scientist. He retired in 1996 from Tecolote Research Inc. in Santa Barbara, CA as Chief Cost Scientist