RUNOFF FORECAST ERROR UNCERTAINTY AND SOME OF THE WAYS IT CAN AFFECT SNOWMELT WATER SCHEDULING DECISIONS IN THE SIERRA

by
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ABSTACT

Forecasting runoff and scheduling reservoir releases for PG&E's hydroelectric system, located in California's Sierra and Southern Cascade Watersheds, requires that watersheds be subdivided into subbasin reaches between diversion dams to facilitate computation of daily unimpaired sidewater inflow for each subbasin reach. Computation of daily unimpaired subbasin sidewater flow allows hydro schedulers to construct a feasible operation plan that optimizes water releases from upstream reservoirs for purpose of maximizing hydroelectric value while satisfying multiple constraints such as are often imposed for instream flows, whitewater rafting, planned maintenance, and recreation. What occurs with subbasin daily flow computation is large variance among successive daily flows. This variance is seldom explainable by hydrologic events alone. However an explanation can be found, when one reviews propagation of error uncertainty and daily storage change taking place at upstream reservoirs. In addition the April through July seasonal runoff forecast has a tendency to carry the full standard error of the estimate forward into the final ablation phases of snowmelt. At that point, the relative magnitude of the error compared with remaining flow yet to come causes large error uncertainty that often affects optimal final seasonal filling of reservoirs.

INTRODUCTION

Hydro Schedulers at PG&E, an investor owned regulated gas and electric utility, forecast and schedule runoff to rivers extending from the upper Pit River near the Oregon border southward along the Sierra to and including the Kern River at Lake Isabella. Regression type methodology is utilized to produce April- and sometimes May- through July seasonal runoff forecasts. These forecasts are based on the April 1- and sometimes the May 1 snow index and are expressed as a percentage of the snow course average which is utilized as a state variable. Historic weather extensions follow a ten-day weather forecast and are used to predict snowmelt runoff as probabilistic extended streamflow. The seasonal probabilistic forecasted quantity is then disaggregated into monthly flow quantities, and further reduced to daily amounts with expected likelihood of occurrence. An adjustment algorithm is utilized to fit the actual daily values recession curve with that which is being forecast. In addition to dynamic weather changes, almost continuous cycling in mountain heating and cooling influenced from advective marine air movement through California's coastal mountain gaps typically causes a series of peaks and troughs in snowmelt runoff. This makes it difficult to determine remaining flow quantity based solely on the recession curve of melt runoff. While remaining weather uncertainty continuously diminishes as snowmelt ablation progresses, certainty in remaining flow doesn't necessarily improve in the same proportion of increased certainty as does remaining weather. The problem of carrying error uncertainty forward toward the end of the season appears to occur when one makes the simple subtraction of actual flow-to-date from the forecasted seasonal quantity. The error of the regression estimate which is expressed by the standard error carries almost the entire error uncertainty forward into the final month of the melt forecast, and it is very difficult to remove prior to the final stages of snowmelt. At some point the plus or minus 8-15% standard error proportion of the total seasonal forecast begins to dwarf the remaining flow yet to come. The error uncertainty in terms of absolute value can sometimes reach plus or minus 75-125 percent of the remaining flow involved with reservoir 'topping-off'. For reservoir managers who are attempting seasonal reservoir filling or 'topping-off', dealing with this large relative error uncertainty in relation to remaining flow yet to come can result in either unanticipated spill, possibly past one or more hydro electric powerhouses, or failure to completely fill the reservoir to desired reservoir levels. In a state such as California where water is sometimes likened to gold in terms of value, hydro schedulers/forecasters are challenged to find ways to improve forecast accuracy and precision. While no 'magic bullet' solution to this problem is offered in this paper, some techniques for dealing with error uncertainty are now coming into more common use at PG&E. Most of these techniques rely heavily on the hydrologist intervening with alternative tools at various phases of the melt process such as tracking snow sensor melt recession and focusing on reducing cumulative error uncertainty during the final phases of melt recession. Techniques can also be used which focus on reducing the resolution incompatibility problem and propagation of error uncertainty in compilation of unimpaired flows. These are best addressed if there is an awareness and statistical understanding that such problems are often the culprit that haunt some of our lives with highly variable

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daily unimpaired flows and sometimes even negative inflows for some low flow streams on certain days. An awareness of the problem, the development and use of innovative coping techniques has and will continue to improve forecast accuracy at PG&E. This paper will address the problems of error uncertainty from the perspective as experienced at PG&E. It will express thousands of acre feet (TAF) as cubic hectometers where 1 TAF equals 1.2335 cubic hectometers (hm^3) and is equal to 1.2335 million cubic meters (m^3). The terms error and uncertainty will be utilized interchangeably. The term error as used in this paper doesn't necessarily originate from mistakes or blunders in measurement or computation, but instead refers primarily to error as utilized in the scientific community and is utilized to describe the inevitable uncertainty that attends all measurements (Taylor, 1997).

AN ILLUSIVE AND SOMETIMES UNDER APPRECIATED PROBLEM IN UTILIZING HYDROLOGIC DATA AND STANDARD HYDROLOGIC METHODOLOGY

The tendency and want to believe in one's own or someone else's finely developed hydrologic model and associated data input, whether sophisticated or not, may sometimes lead to a perception that obtaining a single answer and seeing it in print or on the screen implies that it must be right and that 'this is as good as it gets' with regard to getting an answer. In realistic real time decision making, rarely is something as clear cut and simple as a simple model/single answer. Depending upon one's application and use of the results, the caveat ..'user beware' might be more appropriate when using hydrologic data especially with a daily time step and performing statistical analysis or computing daily unimpaired runoff. Compared with other disciplines such as financial accounting, solving textbook problems with a given numerical data set, and even some types of engineering, seasonal runoff forecasting and hydro scheduling deal mostly with statistical 'snapshots' of various phases of the hydrologic cycle and as such has the tendency to take on the aura of being a 'virtual minefield' of accumulating error uncertainty, where almost nothing is as it might first seem. Some of us may find it awkward to perform our daily routine water management tasks with hydrologic data ...almost all of which in reality contain measurement uncertainty, and since they are statistically derived, should be expressed in probabilistic terms of plus or minus some error range. In hydrologic seasonal runoff forecasting, one frequently sees extended streamflow output expressed in probabilistic terms with regard to remaining weather uncertainty, but the defining variables and methodology is sometimes incompletely accounted for in terms of error uncertainty, and its use in terms of propagation of error uncertainty as the season progresses may sometimes get insufficient attention.

A GENERALIZED SEASONAL RUNOFF EQUATION

Multiple-, principle components regression, or some other statistical technique is often chosen as a tool to predict the April through July snowmelt or Water Year seasonal runoff. The independent variables for an April through July equation are often based on a *snow index group* to account for the "actual-to-date" hydrologic state and depending upon the forecaster's choice, a *precipitation index group* is often utilized for describing and accounting for remaining weather uncertainty. Historic data sets for the two independent variable data sets can then be correlated with historic runoff for the period, and an equation can be developed for predicting April through July runoff or after April,... the May through July runoff.. Previous month'(s) or/and year's runoff can also be included as a lag component especially if improvement is shown. At PG&E we then take the probabilistic array of forecasted seasonal runoff values(one value/exceedence) and run it through additional regression tools to disaggregate the season runoff forecast array into monthly and daily flows for each of several exceedence levels. Adjustment is made in the process which can respond to ten days of weather forecast input and the final step is to provide probabilistic daily runoff output data/files (Grygier, et al., 1993).

THE STANDARD ERROR OF THE ESTIMATE

Often the dilemma which water management schedulers and reservoir operators encounter is that almost the entire data and methodology error uncertainty in the statistical seasonal forecast equation is 'pushed' ahead into the month of seasonal reservoir filling or "topping-off reservoirs" as it is referred to at PG&E. While remaining weather uncertainty continues to diminish as the season progresses, the runoff forecast methodology error and data uncertainty for the most part remain undiminished. The magnitude of the standard error not only remains the same, but with regard to remaining flow yet to come and the accuracy needed for topping-off reservoirs, it's 'relative fixed size' is growing quickly with regard to remaining flow. A standard error of the estimate that is 23.4 hm^3 (19.0 TAF) or plus/minus 7% of a 326.9 hm^3 (265.0 TAF) April through July runoff forecast which has a likelihood of 31.7% chance of being equaled or exceeded in absolute value, will increase from 7% to 30% relative error uncertainty when the seasonal equation is utilized as input for predicting the remaining melt recession and the true remaining flow quantity ('actual' which remains) has receded to only 77.7 hm^3 (63 TAF). However plus or minus one standard error of the estimate represents only 68.3% of a normal Gaussian Curve, and therefore there is a 31.7% likelihood that an absolute value of 23.4 hm^3 (19.0 TAF) error will be equaled or exceeded (Bevington, et al). The remaining weather uncertainty in terms of runoff variance may have diminished (depends on the date) to maybe only 3% of the initial 326.9 hm^3 (265.0 TAF) runoff forecast or plus or minus 9.9 hm^3 (8 TAF) (one standard deviation) of the remaining 77.7 hm^3 (63 TAF) April through July seasonal runoff forecast at time of reservoir topping off, but that uncertainty in relation to the actual remaining 77.7 hm^3 (63 TAF), is almost 13% error uncertainty. The two uncertainties must be added in quadrature (Taylor, 1997) . The error uncertainty has now grown to over 32% uncertainty relative to the forecasted remaining flow.

$$\sqrt{(23.4\ \text{hm}^3)^2 + (9.9\ \text{hm}^3)^2}$$

$= 25.4\ \text{hm}^3$ (20.6 TAF) error uncertainty

25.4 hm^3 / 77.7 hm^3*(remaining flow)* * 100 = 32.7% error uncertainty (approximately +- one standard deviation)

In order to determine that which remains in the seasonal runoff forecast yet to come, the forecaster/scheduler or reservoir operator often simply subtract that which is computed as actual unimpaired runoff to date from the seasonal projection(Maidment, 1993). For example, one might take the April through July runoff forecast of 326.9 hm^3 (265.0 TAF) on May 11th and subtract the April 1 through May 10th of 217.0 hm^3 (179.5 TAF). The person then often assumes that the difference between actual and forecasted is the quantity most likely yet to come. If the unimpaired flow computation is for a downstream reservoir that has storage upstream, then the computation must handle reservoir storage as a delta change in storage. If one or more upstream reservoirs is relatively large in relation to the seasonal runoff forecast, then reservoir storage reading error uncertainty will likely become significant. Reservoir managers often compute monthly unimpaired or natural flow by simply adding the monthlies to get the total 'actual' unimpaired flow to date. If the upstream reservoir which has a maximum storage capacity of 191.2 hm^3 (155 TAF) contains 18.5 hm^3 (15 TAF) storage on March 31, 104.8 hm^3 (85 TAF) on April 30, and 178.9 hm^3 (145 TAF) on May 31, then a storage error uncertainty of ½ of one percent in each of the readings would propagate error uncertainty in the following manner(beyond 1 or two readings, successive changes in storage quickly dampen the period variance and error begin to cancel themselves):

Assuming only one upstream reservoir:

April Change in Storage + *May* Change in Storage

$$((0.005 * 104.8\ \text{hm}^3) - (0.005 * 18.5\ \text{hm}^3)) + ((0.005 * 178.9\ \text{hm}^3) - (0.005 * 104.8\ \text{hm}^3)) =$$

$$\sqrt{(0.524)^2 + (0.925)^2} + \sqrt{(0.894)^2 + (0.524)^2} =$$

$1.063 + 1.036 = 2.10\ \text{hm}^3$ (1.70 TAF) error uncertainty

Assuming the subtraction for an imported cross basin tunnel flow into the basin of 43.2 hm^3 (35TAF) in April and 49.3 hm^3 (40 TAF) in May with assumed gage error uncertainty of plus of minus 4%.
Then:

April + May

$$(0.04 * 43.2\ \text{hm}^3) + (0.04 * 49.3\ \text{hm}^3) = \sqrt{(1.728)^2 + (1.972)^2}$$

$= 2.6\ \text{hm}^3$ (2.12 TAF) error uncertainty

This imported flow once again must be gauged and accounted for at the downstream forecasted point as part of total basin outflow.

Basin Outflow as measured at downstream gage was (again let's assume a plus or minus 4% error uncertainty):

April + May

$$(0.04 * 86.3\ \text{hm}^3) + (0.04 * 94.9\ \text{hm}^3) = \sqrt{(3.45)^2 + (3.80)^2}$$

$= 5.13\ \text{hm}^3$ (4.16 TAF) error uncertainty

Natural Unimpaired 'actual' flow since March 31 = 129.5 hm^3 (April) and 119.6 hm^3 in May with 77.7 hm^3 remaining. As a result of compiling the monthly unimpaired flow through May 31, 9.83 hm^3 (8.0 TAF) error uncertainty has now entered and is additive to any other existing uncertainty.

$$\sqrt{(25.40)^2 + (2.10)^2 + (2.12)^2 + (4.16)^2} = 25.9\ \text{hm}^3\ (21.0\ \text{TAF})$$

Thus that which initially appeared as a plus or minus 7% standard error of the estimate with a 31.7 % chance of being equaled or exceeded in absolute value or in reality a 7.0% error has grown by a factor of almost 5 times to an accumulated 33% error uncertainty relative to remaining flow yet to come.

THE PROBLEM OF DETERMINING UNIMPAIRED SIDEWATER INFLOW IN A SYSTEM OF CASCADING POWERHOUSES AND DIVERSION DAMS

Figure 1 illustrates the problem often encountered with computing unimpaired subbasin sidewater inflows between diversion dams. This illustration is similar to the cascaded stairway of powerhouses which can be found on PG&E's North Fork Feather River.

PG&E has the challenge of forecasting and scheduling subbasin natural flow for subbasin sidewater reaches between diversion dams. Frequently diversion dams represent operational flow points and therefore are often chosen as decision points for scheduling hydroelectric operations on the river. Compilation of subbasin sidewater flows between diversion dams have historically been very noisy with computational error uncertainty for the lower downstream reaches often exceeding 50-70% of what would seem reasonable (Freeman, 1979). This problem of error propagation at PG&E is dealt with in a variety of ways. Some of the ways that we have historically dealt with this problem are to simply make a reasonable estimate of what the hydrologist believes the subbasin should yield, changing how we monitor powerhouse flows, and utilizing nearby naturally unimpaired occurring steams when and where possible for correlation. SCADA produced 15 minute and hourly interval monitoring is beginning to remove a lot of the ambiguity that plagued our data a few years ago. However, much remains to be done with regard to developing software that will capture and take advantage of increased availability of readings.

Forecasters who compute a single point at the downstream reach of a river, often do not suffer the same error uncertainty described above. However, when computing daily unimpaired flows for a single downstream flow point, they still may have a major source of uncertainty that may enter into the compilation of unimpaired flows. This uncertainty, caused by upstream change-in-storage calculations is more time specific and with multiple readings will tend to balance itself out with time canceling out specific error uncertainty over a period of several successive readings.

Daily Flow ThroughA Typical Lower River Reach in a Cascaded Hydroelectric Schematic

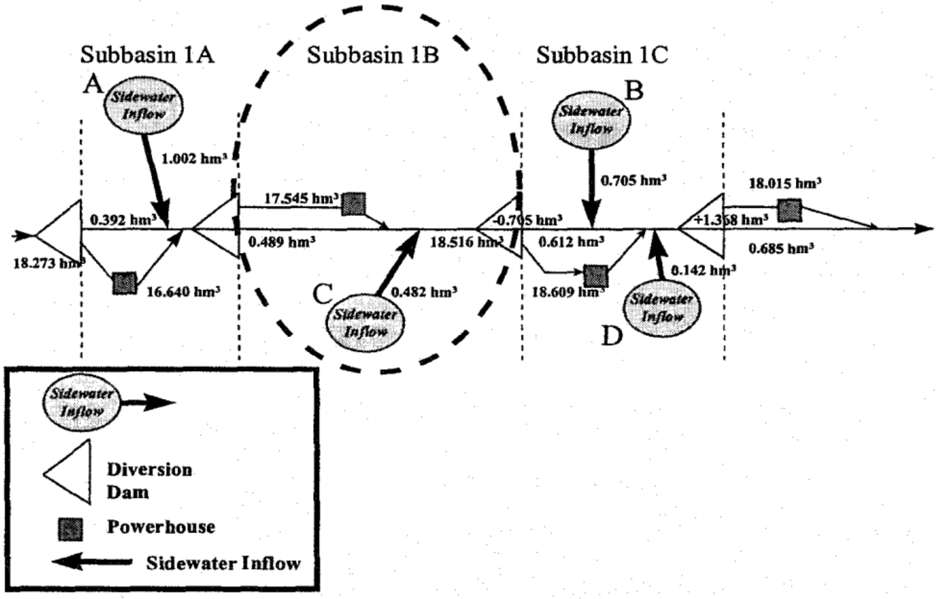


Figure 1. Illustration of how even supposedly accurate flows (within +-4% accuracy can create large relative error when determining smaller sidewater inflow).

SIDEWATER UNIMPAIRED NATURAL FLOW COMPUTATION

Error uncertainty in terms of resolution is present with such calculations regardless of the time step utilized (Yevjevich, 1972). Operational decision making which is utilized for probabilistic hydro scheduling in today's energy market currently relies heavily on daily water movement accounting for water management decisions that include recreation goals, in-stream flows, and contractual commitments. The other major block of decision making focuses on water movement based on current and future market price tradeoffs with incremental value of stored water. Daily optimization of water movement requires accurate sidewater definition for bidding hour- and day ahead energy. This currently is an active area in which PG&E is focusing its efforts to deal with the error uncertainty problem of accurately defining sidewater inflow between powerhouse diversion dams.

The error uncertainty problem emerges in computation of daily unimpaired subbasin sidewater flows(Freeman, 1979). It reaches greatest significance in the lower river reaches where large flows moving through the main river course cause resolution incompatibility in accurately defining the much reduced in magnitude sidewater inflow entering from numerous sidewater tributaries between diversion dams.

The following example shown in figure 2 is based on figure 1 and will serve to illustrate the principle:

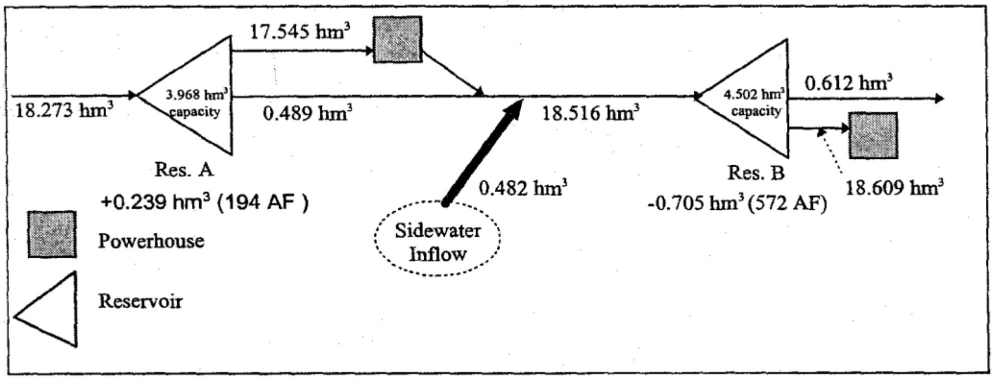


Figure 2. A closer look at the hypothetical schematic displayed in Figure 1

From figure 2, utilizing an assumed 4% error uncertainty for all river flows, a 1% accuracy for all powerhouse flows, and ½% error uncertainty for storage's gives the following:

Res. B

4.40 hm^3 +-0.022 hm^3;	3.70 hm^3 +- 0.018 hm^3
Previous Day	Today

Combined error uncertainty in quadrature = +-0.0284 hm^3 (23.0 AF)

INFLOW	OUTFLOW
17.545 hm^{3}w/1% uncertainty or 0.175 hm^3	18.609 hm^{3}w/1% uncertainty or 0.186 hm^3
0.489 hm^{3}w/4% uncertainty or 0.020 hm^3	0.612 hm^{3}w/4% uncertainty or 0.0240 hm^3
0.195 hm^3	0.210 hm^3

In quadrature,

$$\sqrt{(0.195)^2 + (0.210)^2 + (0.028)^2} \qquad = +- 0.287\ \text{hm}^3\ (233\ \text{AF})$$

Since the 'actual sidewater' is +-0.287 hm^3(233 AF) of the 'true' sidewater flow, it's accuracy is best defined as 0.482 hm^3(391 AF) +-0.287 hm^3(233 AF) or (+- 60%). The actual flow will equal or exceed 0.769 hm^3(624 AF or be equal to or less than 0.195 hm^3(158 AF) about 1/3 of time. This magnitude of error uncertainty causes significant noise in determining sidewater inflows for keeping forebays and afterbays in balance with day- or hour-ahead bidding.

RESERVOIR STORAGE CHANGE AND DAILY TIME STEP INSTABILITY

When there are relatively large upstream reservoirs, compilation of unimpaired natural flows needed for reservoir management and water accounting can encounter significant error uncertainty when computing unimpaired flows for the total basin to a downstream flow point. This often becomes very obvious with daily water accounting, but in most cases is less of an annoyance when computing monthly unimpaired natural runoff. The problem of error uncertainty with daily unimpaired flow calculation also enters when the total of upstream storage involve a delta change between two time periods. For example in computing daily unimpaired runoff, the total upstream storage difference from the previous day must be determined. I will show an actual example below from PG&E's north fork Feather River Lake Almanor Storage utilizing published data.

Example of Daily Storage Change at Lake Almanor

9/1/95 | 9/2/95

1,255.97 hm^3 (1,018.22 TAF)(1368.35 m elevation) ; 1,251.48 hm^3 (1,014.58 TAF)AF(1,368.31 m elevation)

Difference = 4.49 hm^3 (3,640 AF)(0.04 m elevation)
...this equates to: 0.321 hm^3 (260 AF)/0.003m(0.01 feet) elevation

If Lake Almanor storage with an approximate surface area of 105.22 km^2 (40.6 sq. mi.) contains a typical +-0.0152 m (0.05 feet) one standard deviation error uncertainty due to wind fetch, instrument accuracy, wave surge, or deviation in time of reading, then the two readings taken together for computing daily storage difference will have up to 0.0215 m (0.07 feet) error uncertainty at the one standard deviation uncertainty level which when considered as combined uncertainty in quadrature computes to equaling or exceeding about +-0.0215 m (0.07 feet) or +-2.267 hm^3 (1,838 AF error uncertainty for a given day). Thus when an error uncertainty in storage change of 2.267 hm^3 (1,838 AF) is applied to computing the daily unimpaired runoff downstream at the North Fork Feather River into Lake Oroville, it has potential to create very noisy daily flows. If the combined total outflow from Poe Diversion Dam on 9/2/95 was 0.154 hm^3 (125 AF) +-4% or +-0.006 hm^3 (5.0 AF) to the river for instream flow and the diversion to Poe PH at the diversion Dam was 6.344 hm^3 (5.141 TAF) +-1% or +-0.063 hm^3 (51.4 AF)then when combined in quadrature, the result equals an approximate error uncertainty at the one standard deviation level of +-0.063 hm^3 (51.4 AF) . Therefore utilizing only the single storage reservoir of Lake Almanor (there are actually 4 other moderate sized Lakes on the Basin each in excess of 24.66 hm^3 (20,000 AF) capacity that have maximum combined storage of totaling 187.42 hm^3 (152,000 AF) which need daily delta storage changes), the combined error uncertainty for the day can be computed as:

2.267 hm^3 (1,838 AF) + 0.061 hm^3 (51 AF) *or in quadrature* = 2.267 hm^3 (1,838 AF)

If for example, the calculated natural unimpaired flow for the day was 3.118 hm^3(2.528 TAF), then the error uncertainty for the day has about 32% likelihood that the flow will equal or exceed 3.118 hm^3 (2,528 AF) +-2.267 hm^3 (1,838 AF)(73% error uncertainty). Since the storage readings over several days balance out, there is a constant 'random' daily 'noise' variance component that will not greatly exceed +-2.267 hm^3(1.838 TAF) for any given month. While the day-to-day variation in terms of relative resolution for the short term has about a 1-in-three likelihood to equal or exceed a 73% variance from the actual, the monthly has only 1/30(31) of the daily relative error in proportion to it's monthly total flow.

Dealing with this type of error mainly impacts short term decision making that relies heavily on accurate definition of daily flow. Most impacted will be processes that require and utilize the daily time step for short term decision making. This would apply to most daily hydrologic models, daily hydro scheduling optimization for hydro generation, and daily flows generated for any and all analysis and studies that require accurate definition of daily flow.

CUMULATIVE ERROR UNCERTAINTY AND ITS SIGNIFICANCE TO HYDRO ELECTRIC SCHEDULING

Most of PG&E's headwater Reservoirs in the Sierra Nevada Mountains are relatively small in relation to drainage area and precipitation amount. They fill and spill in those years with slightly above average or more precipitation. Late summer and fall pricing for hydroelectric power is normally also at its highest during the late summer and early fall months so it behooves PG&E to maximize storage at the conclusion of snowmelt runoff in order to capture maximum hydroelectric value from the water. Therefore when possible, PG&E will attempt to 'top-off or maximize reservoir storage' on the day, during snowmelt recession, that inflow will not increase above the capacity of one or more downstream powerhouses. This is a common hydro resource optimizing goal, but requires an accurate determination of forecasted runoff rate during snow ablation. Determining remaining unimpaired inflow yet to come requires an accurate forecast normally within about 3.7 hm^3 (3.0 TAF) for a reservoir of the size discussed above. However, a reasonable expected forecast standard error of the estimate as indicated above was shown as 25.9 hm^3 (21.0 TAF) or about 1/7 the resolution needed for optimum reservoir operation. In PG&E's case if the reservoir fills before the unimpaired inflow can be controlled, then the water will be spilled past downstream powerhouses with little or no hydroelectric value. If the reservoir is not filled and downstream powerhouses have to be run less than full capacity in order for reservoirs to fill, this may in some cases represent significant value loss especially if earlier, prior to topping-off, water was being 'bypassed' past some fully loaded powerhouses in order to get 'partial energy' in anticipation of high likelihood for spill later as the hedged alternative option.

This error uncertainty in runoff prediction complicates PG&E's reservoir topping-off operations. The goal is to 'top-off' the reservoir on the day(s) when the receding snowmelt inflow matches one or more the downstream powerhouse's full flow capacity. Because of safety considerations downstream, additional sporadic 'on-off' again spill following topping-off, needs to be avoided. In some cases the risk from additional spill may be unacceptable and in those cases filling the reservoir 'brim-full' may add unacceptable risk to public safety downstream. In such cases a less-than-full reservoir may be an acceptable target.

Effective hydroelectric scheduling on watersheds with a cascaded stairway of powerhouses and diversion dams such as northern California's North Fork Feather River requires that the watershed be divided into several operational forecasting sub units and unimpaired runoff is calculated for each of the subbasin reaches. For the North Fork Feather River, PG&E computes subbasin natural flows to about 12 reaches of the river. This requires that subbasin natural unimpaired sidewater be estimated in order that upstream reservoir releases can be planned for minimizing unanticipated spills of stored water past downstream powerhouses already at full load. Because of very large flows entering and leaving downstream river reaches in late spring, adding and subtracting sidewater inflows from reaches between diversion dams creates significant resolution error uncertainty sometimes in excess of 50% of the actual flow. With the current need to provide 36 hour ahead generation schedules, the manner in which data was previously handled has changed to merging the longer term planning model with Excel spreadsheets and utilizing optimizing solvers in real time to keep water release balanced with uncontrolled sidewater flow. When the forecasted subbasin reaches are reassembled into a probabilistic array of operating schedules, these forecasted unimpaired flows are added incrementally proceeding downstream. If the upstream error uncertainty compared with remaining runoff is 35%, then water flow in the reaches downstream is often in error equaling or exceeding 50-75% of actual. Often the computed flows are so noisy that reasonable estimates work better than simply utilizing flow data for calculations.

ALTERNATIVE LATE SEASON FORECASTING TOOLS

During average and wetter than average years as snowmelt takes place and a flow recession begins to develop, PG&E's hydro schedulers operate and make reservoir releases which attempt to fill the reservoir on the day when the inflow can be controlled through one or more downstream powerhouses. At PG&E, it is referred to as the topping-off date. If prior to that date too much water is released and later the reservoir cannot be filled without reducing water releases, then water which had previously been spilled past one or more downstream powerhouses prior to the discovery that the forecast is short, will have been wasted and significant hydroelectric value may have been lost. If on the other hand, releases from the reservoir were less than full powerhouse capacity downstream and the forecast is in error and the reservoir spills, significant hydroelectric value can again be lost.

In order to avoid the uncertainty of dealing with the full regression standard error of the estimate at time of determining that topping-off date, alternative methodology is being tried at PG&E which would utilize additional tools that look at conditions closer to the desired target date that contain less error uncertainty. One such method which can be utilized in combination with the seasonal regression forecast is to utilize the maximum snow water equivalent taken from snow sensor data and utilize a second regression equation based on percent of seasonal flow remaining when the snow water equivalent(SWE) reaches 20 percent of maximum SWE (see figure 3). The correlation seem to work relatively well (see figure 4) and because the actual flow which remains is greatly reduced along with remaining weather uncertainty, the standard error of the estimate is also reduced and is much more appropriate in magnitude with regard to remaining runoff quantity.

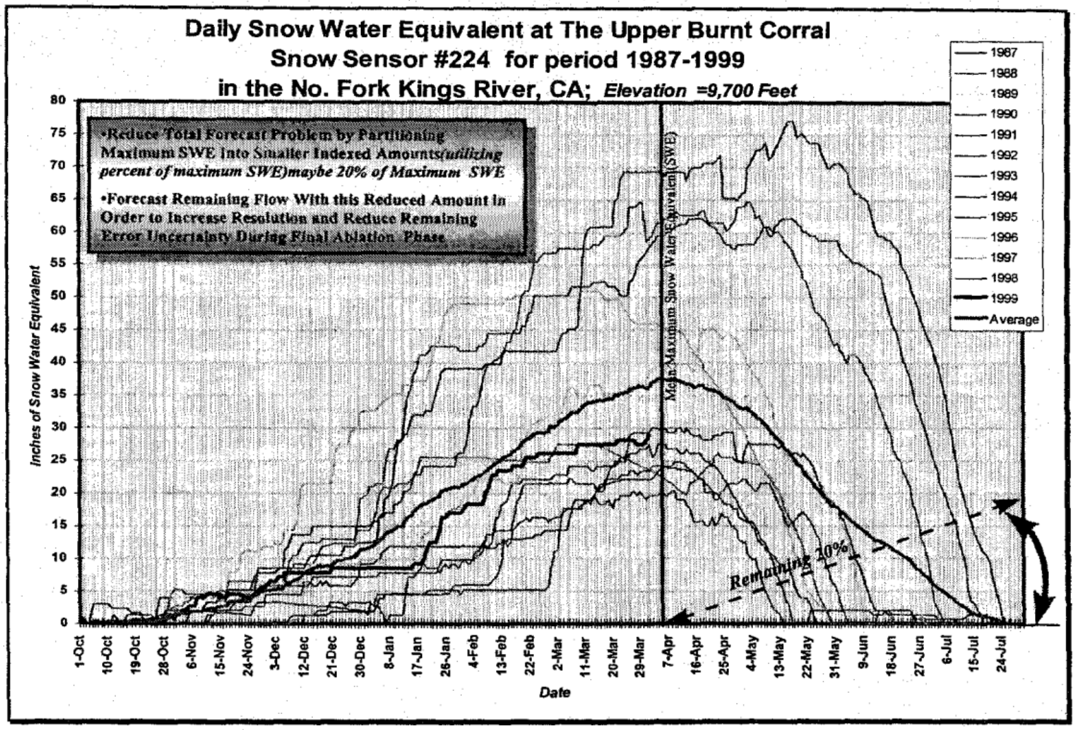
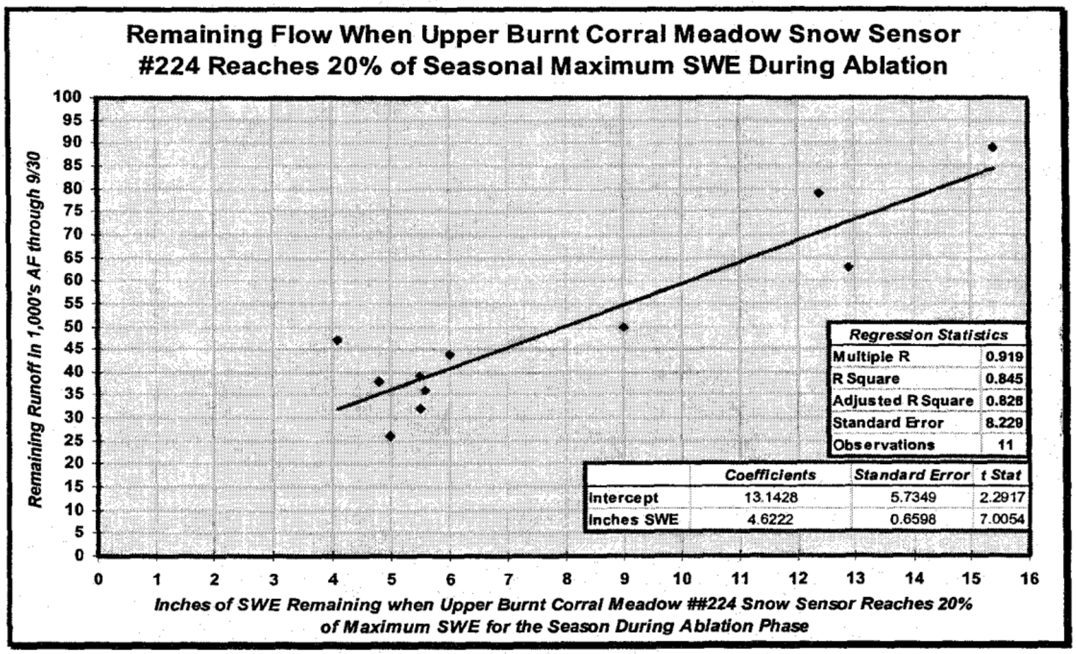


Figure 3. Reducing the problem to 1/5 size to force the methodology standard error of the estimate down to a smaller relative size which is more consistent with remaining water yet to come.



Regression Statistics	
Multiple R	0.919
R Square	0.845
Adjusted R Square	0.828
Standard Error	8.229
Observations	11

	Coefficients	Standard Error	t Stat
Intercept	13.1428	5.7349	2.2917
Inches SWE	4.6222	0.6598	7.0054

Figure 4. With a ten year April through September mean runoff of 0.284 hm^3 (230 TAF), the forecast can now focus with increased resolution on the remaining 60.44 hm^3 (49 TAF) mean flow with much reduced standard error and error uncertainty.

DEALING WITH ERROR UNCERTAINTY

The problem of error uncertainty is a serious one at PG&E. It results in significant long term average annual loss of energy value. The forecaster/hydro scheduler has some limited options, all of which are being explored for possible implementation.

- Develop routines that perform averaging of hourly real time storage readings for a designated period before computing a daily storage reading.
- Develop new routines which will focus on '*what's happening now*' regarding snow sensor and flow information rather than subtracting total actual unimpaired inflow to date from the seasonal runoff forecast. Flow recessions for similar type years and flow recession on nearby watersheds with a slightly different area/elevation relation can provide comparisons that can assist with removing considerable error uncertainty.
- Provide easy adjustment ability for forecaster/hydro scheduler's to deviate from model output as needed. New information is constantly becoming known during the day-to-day operations which is not included in the model algorithms. This reinforces the need to regard forecast and scheduling models increasingly as tools used to assist in decision making and that total reliance on such may have to deal with the reality of what actually happens. Observing snow sensor data, analyzing the actual recession curve and adjusting the forecasted daily recession curve to fit the observed is normally helpful.

CONCLUSIONS

Hydro generation forecasting and scheduling at PG&E requires that runoff forecasts be produced and updated weekly on about 75 points in the Sierra. Daily unimpaired flows are needed to perform daily and hourly bidding. Data resolution problems and cumulative error uncertainty can occur in the process of seasonal runoff forecasting, especially when downstream sidewater between diversion dams must be determined in a daily time step. Minimizing cumulative compilation uncertainty and reducing resolution disparities require an awareness of the causal effects that result in and increase the range of error uncertainty. Unimpaired natural flow compilation for subbasins can sometimes avoid the need for using upstream storage changes. Utilizing an average of multiple reservoir readings for a given reservoir for the same time period each day is anticipated to improve accuracy. Alternative techniques which utilize snow sensors during the melt recession in addition to monthly snow surveys can be helpful. Subtracting the actual flow to date from the forecasted seasonal runoff forecast contains error uncertainty with regard to the compilation of actual unimpaired natural flow.

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