

'Hydro-fuels-', Maintenance-, and Pricing Risk Management  
- Changing Times in Snow Zone Water Management

by

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ABSTRACT

In August 1996, the California Legislature passed legislation (AB 1890) that established new policies and restructured California's electric industry. The Bill established an Independent System Operator (ISO), a Power Exchange (PX), a rate-reduction financing program, a public benefits program, and called for increased system reliability. With the deregulation of California's electric utility industry taking place, the water management team at Pacific Gas and Electric Company (PG&E), an investor owned utility, is facing a new challenge. Future pricing uncertainty will likely become as important to snow zone reservoir management as seasonal remaining weather uncertainty has traditionally been for forecasting snowmelt runoff and maximizing hydro generation in the past. While PG&E has been utilizing probabilistic extended streamflow predictions for some time in making hydroelectric scheduling decisions, it has only recently begun to look at how weather uncertainty will be handled by energy traders that are selling electricity into the California Power Exchange and eventually into a futures market. Electricity futures market pricing (one to three months ahead) is beginning to have a significant effect on how much risk an operator may be willing to take with regard to storing water in anticipation of a better price at some future date. In a sense, water is perishable with regard to use for hydro generation. If stored, there is risk that the weather could turn wet and that water may be spilled past fully loaded powerhouses.

INTRODUCTION

PG&E forecasts and schedules the headwater drainage for approximately 25 rivers in California's southern Cascades (4 rivers), Sierra Nevada Mountains (19 rivers), and north Coastal Range (2 rivers). Including Partnership Projects, PG&E's forecast and scheduling controls water releases from about 163 reservoirs and 88 powerhouses which total approximately 12,769 GWh for PG&E and 4,211 GWh for Partnership Projects. The watersheds range in geographic location from the McCloud and Pit River Basins in the southern Cascades of northern California to the Kern at the southern-end of the Sierra.

Current snowpack water equivalent data and antecedent wetness are used to represent the hydrologic state of the subbasins. Approximately 35 years of historic precipitation and temperature indices are utilized to represent the uncertainty of future remaining weather. The current weather forecast for the next six to eight days is input as a transition between the current hydrologic state and historic weather extensions. The resulting 35 streamflow extensions are statistically handled as cumulative probability distributions. As the season progresses, remaining weather uncertainty and thus the range of exceedence levels likewise decrease. The seasonal output is then processed through a disaggregation routine (Grygier et al., 1993) which utilizes a regression approach and distributes the

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seasonal into monthly volumes. The monthly volumes are based on a historical relationship between seasonal quantity and monthly distribution.

The change from the regulated to the competitive environment requires that PG&E enter into a bidding system with the newly formed California Power Exchange for the first time. PG&E must accurately determine the cost of energy production and offer a portfolio of resources which include hydro. Bidding gas-fired thermal energy is fairly straightforward. Costs of natural gas for thermal generation can be predicted and supply is fairly certain. However, in order to accurately determine the cost of producing hydro generation, bidders will have to address the cost of lost opportunity in order to decide whether or not to bid hydro. In order to become effective in a competitive environment, it is necessary for PG&E's Water Managers to accurately forecast an uncertain "fuel" stored as a distributed snowpack and augmented from the still unformed vapor which forms over the eastern pacific.

### CHALLENGES OF COMPETITION

When there is no guaranteed rate of return for energy produced, each and every Megawatt hour (MWh) is at risk with regard to the day-ahead bidding strategy. Flexibility of bidding hydroelectric production into the PX will remain limited on some watersheds due to a large number of constraints. Irrigation releases for downstream usage and instream flows for fisheries and other aquatic biota will likely limit bidding flexibility for some watersheds.

Pricing and weather uncertainty are two of the largest variables in the equation. In the case of remaining weather uncertainty, about 60% of the wet season remains as of January 1. Weather forecasters admit low certainties with regard to predicting spring weather more than 7-10 days ahead.

On any given day in the late winter through early spring period all water at PG&E must be handled such that if a large storm were to develop, the overall water would be managed in a manner that fully accounts for remaining weather uncertainty. This requires that forecasters/schedulers utilize optimizing/probabilistic models to realistically incorporate risk management.

Pricing uncertainty also complicates how the hydro system is run. Electricity futures market pricing one to three months ahead has an effect as to how much water is carried over in storage in anticipation for a better price at a future date. Both spot and term pricing are utilized in probabilistic pricing accounting.

### ENERGY TRADING, SPOT MARKET, FUTURE TERM TRADING, AND THE INTERIM BIDDING PROCESS

Water scheduling at PG&E has in recent years changed from an older deterministic type of modeling (Ikura and Gross, 1984) to a fully probabilistic type scheduling program that optimizes for both generation produced and pricing value. It becomes increasingly more complex when both pricing and weather uncertainty become involved. Energy trading frequently utilizes current price changes to analyze and determine hydro operation strategy changes. In addition to the spot market, longer term trading takes place. Electricity futures market pricing one-to-three months ahead are beginning to have significant effect on how much risk one is willing to take in regard to storing water in anticipation of a better price at a future date. Water which is held in storage for a period of time is at risk of spill if the remaining weather becomes wetter than expected. In some senses, water is perishable with regard to use for hydro generation. If it is stored, there is risk that the weather could turn wet and the water may be spilled past power houses already running at full capacity or load. In California during the 5-year transition over the next five years beginning 1/1/98, the interim bidding process will consist of bidding

into the Power Exchange in series of iterative day-ahead bids. During wetter years, water is frequently released to obtain partial generation past one or more powerhouses with spill past other downstream fully loaded powerhouses. While this type of operation is basically a trade-off of getting some energy at the current market price with a known or given energy loss, it maximizes the opportunity to risk-manage the hydro-fuel resource for maximum generation. At PG&E the practice of probabilistic risk taking is considered to capture an additional 8-10 percent energy over the long term which includes both dry and wet years.

Storing water in anticipation of higher energy prices in the future is a tradeoff with regard to risk of either spilling it later or losing some to evaporation. Because water is somewhat perishable if stored and later spills, payoff tables that include probability can be constructed to assist with the decision making.

#### RISK MANAGEMENT OF BOTH WATER AND PRICING

Unlike fossil fuel, water when utilized as a hydro-fuel for hydroelectric production is considered to be a "freebie" in the world of energy. Since water as a 'fuel' has no direct book value, it is not valued as an asset on consolidated balance sheets. It does however represent an 'opportunity cost' in the form of opportunity lost if mismanaged. Since water management is performed probabilistically to account for remaining weather uncertainty, probabilistic hedging and risk-taking are part of the tools which the hydrologist utilizes to effectively manage the hydro resource.

At PG&E, water is managed primarily with a probabilistic risk level approach associated with each of the three states of water: liquid, solid, and vapor. 1) Water as a liquid is relatively easy to measure on the watershed as lake storage and is measured by staff readings. 2) Water as a solid is somewhat defined by point measurements taken on snow surveys, and by snow sensors. However, measurement of snow to determine potential runoff is less exact in terms of an areal representation for a given basin, and forecasts must be made that account for evapotranspiration, groundwater recharge, and possible other losses that affect snowmelt runoff, but 3) water in the form of precipitation that is yet to come is one of the most difficult to measure and handle correctly. The reason for this difficulty stems from remaining weather uncertainty. Because rain-on-snow events take place fairly regularly in the Sierra Nevada and because of the intensity and amounts of rainfall, it is very difficult to plan for runoff from rain-on-snow events. A certain amount of reservoir space needs to be reserved for this type of event. Remaining weather uncertainty in California is highly dependent on the position of the jetstream. If a high pressure ridge develops and blocks the storm track over California for even a few weeks during the 5-month November through March period, the likelihood of the season ending up dry greatly increases. Release of stored water through powerhouses early in California's wet season is mainly one of risk management tradeoff between spot and anticipated future pricing of energy as well as remaining weather uncertainty. Many of California's rivers have irrigation or domestic water rights and contractual requirements that significantly limit how water is managed for hydroelectric production.

#### FOCUSING ON WHAT IS IMPORTANT TO BECOMING COMPETITIVE

Several changes are being made in regards to how water is managed at PG&E. An increased emphasis is being placed on the ability to make fast decisions with a minimum amount of information. A philosophy of 'ready, aim, fire' rather than a 'ready aim, aim, aim....aim' approach is being taken toward water management. Emphasis is being placed on developing the ability to rapidly focus on the right information rather than studying everything in great detail. The Internet and internal databases now provide a tremendous amount of information. While most of the information has value toward making a decision, the nature of most operational decision making for maximizing value added often requires deciding on what information is most important and letting the other information drop. Both the ability to focus quickly on pertinent information and act rapidly on that information will provide competitive advantage in the deregulated energy market.

Security of strategic information, gaming, and market power are some of the issues that are now being considered by both regulators and PG&E. Under a regulated market with a guaranteed rate of return, no special efforts were made to withhold real and near real-time flow and storage data or operational information. A bidding environment requires that in order for competition to work correctly, flow and storage information in real- or near real-time has strategic implications that can compromise pricing in the bidding process. For example, if the analysts on the floor of a trading exchange or a buyer under bilateral agreement determines that water must be moved the following day in order to prevent spill, the day-ahead bidding price might drop in recognition of the seller's need to run the water through a powerhouse or lose it. This need to withhold flow and storage information by hydroelectric companies could end the current trend for operational water data being exchanged freely. At PG&E, temperature, precipitation, and snow data will likely continue to be shared as it is obtained. While this information does provide a basis for estimating runoff, it in itself does not by itself provide any strategic planning information, but only an indication of the hydro-fuel potential.

Decision making under uncertainty will extend beyond the period of remaining, unknown weather and will likely involve pricing for both the spot and future market and timing of facility maintenance. In addition to large-scale probabilistic forecasting and scheduling models, the forecaster/scheduler's set of beliefs and attitudes toward risk-taking will greatly influence decision making under uncertainty. The need for probabilistic planning water operations in a daily time step will require that PG&E move beyond its current seasonal models with monthly desegregation to conceptual simulation models. Currently PG&E utilizes an in-house snowmelt model called SWIFT (Grygier et al., 1997) that takes the disaggregated seasonal runoff forecast and converts the monthly time step into a daily time step. It focuses on snow melt but does not provide any soil moisture accounting. Our current plan is to calibrate and use the U.S. Geological Survey's Modular Modeling System on our river systems.

PG&E has developed its own extended streamflow prediction module that allows the forecaster/scheduler to make many operational decisions directly based on statistical information. The hydroelectric operation at PG&E is based almost entirely on probabilistic optimization between remaining weather uncertainty and future pricing. Additional uncertainty with regard to optimization of maintenance timing will be a focal point for future development. The first step is to develop the ability to probabilistically test accelerated maintenance schedules. When optimized against both future anticipated pricing and remaining weather uncertainty, it is hoped that this area of hydro operations can be improved in terms of value added. The trend will be toward setting work schedules that optimize commercial availability.

Risk-taking with regard to remaining weather uncertainty can be optimized using PG&E's SOCRATES model (Jacobs et al., 1995), but because the model optimizes only a portion of the total uncertainty, the scheduler's attitudes and beliefs toward risk-taking must be given appropriate consideration. The scheduler must decide appropriate risk taking with regard to maintenance scheduling, future pricing uncertainty, forecast methodology error, data inaccuracy, and the ability to successfully bid-in optimized movement of water on a day-ahead basis. Flow variability may develop which lies outside of the historical sample population of monthly data for years contained in the sample set.

In order to achieve control over the forecasted and scheduling results, the ability to adjust SOCRATES outputs has been added, and constraints have been fashioned so that each constraint in the optimization process has a value that ranges from one to ten. A value of one is the softest in terms of satisfying the constraint, and a ten is a completely rigid constraint which the model will attempt to meet even if it causes one or more other scheduled goals to fail. Assignment of various levels of priority to operating constraints is a very necessary part of using a probabilistic scheduling model. If only rigid upper, lower, and fixed bounds are used, the SOCRATES model tends to abort on dry exceedence cases, and a valid optimization toward monetary payoff cannot be achieved. The user can influence the probability that a certain firmness be placed on a specific constraint causing it to either be accommodated or drop out at some level of uncertainty. Irrigation releases and other constraints are often compromised somewhat during extremely dry years.

## CALCULATING UNIMPAIRED SIDEWATER RUNOFF BETWEEN DIVERSION DAMS

This problem in scheduling water for generation optimization has not been resolved. It will likely become much more significant in attempting to declare hourly schedules for the day ahead. The problem arises from large amounts of water entering and leaving forebays and afterbays in the lower ends of large rivers. Slight errors in measuring large volumes of water magnify the effect considerably when computing the difference between the upstream and downstream flows in order to calculate sidewater inflow to the reach (Freeman, 1979). It is not uncommon for errors to range from 30-60% in determining sidewater accretion. There does not seem to be a good way to resolve this problem other than taking very accurate measurements of flow entering and leaving the reach. One should be fully aware of potential for large errors to occur during calculations for subbasin unimpaired flows.

## THE MAINTENANCE PROBLEM

The manner in which maintenance planning is being performed is beginning to change at PG&E. In the past, maintenance was scheduled early in the season prior to having much 'feel' for the type of year about to be experienced. Maintenance was primarily scheduled around normal outages for routine inspections, repair work, and needed repairs and the availability of crews to perform the needed work. Maintenance decisions have historically had priority over operations and the focus was on technical availability. Today maintenance planning is increasingly based on the concept of water as hydro-fuel and the cost of 'lost opportunity' if the maintenance planning is not optimized with regard to probabilistic water availability and anticipated pricing. In order to accomplish this, the maintenance planners have had to work as a team with energy trading, forecasters/schedulers, business planners, and bargaining representatives that will actually perform the work. Tomorrow's model will likely be one in which operations decisions drive maintenance with a focus on commercial availability.

To be more effective in optimizing water as a hydro-fuel, incorporating weather uncertainty, and obtaining the highest value from the water by generating on-peak energy five days/week for 16 hours/day, maintenance will be performed in future years on weekends, holidays and during weekdays. Maintenance will be pushed into off-peak hours and late at night. This will require that successful union negotiations take place to facilitate this attempt to better optimize maximizing generation value.

One might liken the business need for routine turbine maintenance with an analogy of how often one changes the oil in his/her car. If a trucker had an opportunity during a 4-week period to make almost twice the normal amount of money by keeping a truck in service, the trucker would likely accept the risk of adding additional miles and delay changing oil. In other words the trucker would take on additional risk in order to get the higher payoff for the period. Likewise, powerhouse operators and planners during good hydro years with abundant water may want to take on additional risk with and delay performing routine maintenance. Under the current regulated environment, there is a strong tendency to schedule our work by the calendar. Tomorrow the criteria for success will likely be one of management by business value.

## PROBABILISTIC FORECASTING, EXTENDED STREAMFLOW PRODUCTION, AND PROBABILISTIC HYDROELECTRIC SCHEDULING

Today's high speed computers have opened up the opportunity to perform seasonal streamflow forecasts at the probabilistic level. In order to accomplish this, the historic weather from the past 30-35 years are added to the present snowpack and PG&E's proprietary SWIFT model is utilized to produce 30-35 seasonal runoff forecasts. The snow course measurements are adjusted from the date of the survey utilizing incremental precipitation to the first of the month and also converted into percents

of normal in order to standardize their weighting. The resulting seasonal runoff forecasts are then disaggregated into monthly quantities utilizing a regression approach based on historic distribution for similar seasonal amounts. They are then rank ordered into levels of exceedence probability. The median range values can be adjusted if the forecaster/scheduler believes that he/she has additional information that will improve the mathematical computations. The exceedence probabilities are then adjusted to proportionally fit the adjustment. PG&E's seasonal runoff forecasting program performs a new regression analysis each time that a forecast is made. All years are included during the first pass. Once the program determines the wetness for a particular year, a second pass regression is performed with outlying years removed. The program attempts to retain at least a sufficient number of years for a statistically valid forecast.

Once the probabilistic schedule has been run it is then reviewed by the forecaster/scheduler for reasonableness and if needed a new run can be performed with modified constraints. The hydro database that supports the forecasting and scheduling is updated each day and an updated forecast can easily be performed for any day of the month to capture the effects of the most recent storm. The scheduling model has current and future expected prices for energy produced such that both water as a hydro-fuel and pricing can be optimized. PG&E's SWIFT model predicts daily snowpack runoff from a seven-day weather forecast and then takes the temperatures and precipitation for the past 30-40 years to produce multiple daily extensions of streamflow. This array of extended streamflow forecasts are then statistically rank ordered and statistical analysis is performed to provide information on the most likely date of peak flow, how much the peak flow will be, how much water will be expected during the next month, two months, three months, etc. in terms of exceedence levels. Also, because powerhouses have limited capacity for flow, the model will use that capacity to determine the most likely date that the inflow can be completely passed through the powerhouse without spill. PG&E utilizes that probabilistic date as the most likely date to completely fill the reservoir to some desired lake level.

The concept of handling water runoff as a hydro-fuel in a probabilistic sense and assigning a future value to the generation produced in terms of peak and off-peak energy provides a highly efficient energy-value capture rate based on information and knowledge available at the time that operation decisions are made. Future development at PG&E will likely focus on developing transition type tools for the energy traders to quickly capture and utilize the probabilistic information from SOCRATES and SWIFT. They will integrate this with rapidly developing real time information that concerns information regarding a competitor's capability to quickly react to changing pricing on the Power Exchange. The probabilistic output will likely serve as guidelines for fast decision making regarding assembling a portfolio of energy declaration for the bidding process.

#### SNOW, RAIN-ON-SNOW, FLOWS, AND SPILLS

California frequently experiences warm rain-on-snow storms during the December- through early-March period. These result from warm semi-tropical fronts that carry large amounts of moisture northwest into California. If they combine with cool air descending into California from the Gulf of Alaska, they can develop into flood producing storms with high precipitation. Five-day storm amounts can be in the 102-114cm (40-45 inches) range, with the February 1986 and New Years storm of 1997 as examples. During the 8-day period between December 27, 1996 and January 3, 1997, over 102 cm (40 inches) of precipitation was recorded in northern California's Feather River Basin. During this storm, air temperatures were warm enough to cause significant snow melt at elevations up to about 2132 meters (7000 feet) elevation. Considerable rain induced snowmelt occurred from most watersheds in northern California. During such storms, powerhouses are often shut down to prevent excessive debris and sediment from damaging the turbines. In 1997, the storms that hit California caused large amounts of water to be spilled from the large multipurpose reservoirs at the base of the Sierras in order to maintain flood space. After two of the wettest December and January months on record, California then experienced the driest February through April period on record in central California. As a result what appeared to be an almost certain 'guarantee' of an above normal water year has fizzled into restricted water allocations to irrigators throughout the State. For PG&E, the

probabilistic forecasting and scheduling models fairly quickly revealed the need to reduce reservoir releases.

When such storms are beginning to take shape out over the Pacific, forecaster/schedulers at PG&E make an additional effort to release water depending on the likelihood of anticipated storm amounts. Future ability to successfully declare capability for bidding will require that weather fronts be factored into the forecasts for the next 7-10 days before the models assume historic weather extensions. This assumes that the weather forecasts are updated frequently.

#### PLANNING FOR SNOWMELT RUNOFF IN THE OPTIMIZATION OF GENERATION VALUE

Decisions on how water can be managed to optimize hydroelectric generation requires probabilistic information regarding timing and quantity of forecasted snowmelt. Maintaining sufficient space in reservoirs for spring runoff often means that midwinter runoff may be spilled past some powerhouses which are already at capacity in anticipation of additional runoff from the snowpack as predicted by snow surveys. Based on snowpack measurements and the remaining uncertainty of additional snow accumulation, probabilistic decisions are made, and water may be spilled. If the weather turns dry, a definite loss of energy production can occur. However, the practice of controlled spills past some fully loaded powerhouses in order to get some energy from higher elevation high-head powerhouses is a common practice at PG&E. While the greatest remaining weather uncertainty occurs during the early part of the season, decisions to make controlled spills are often necessary based on a probabilistic expectation of later monetary loss. This potential for later loss depends upon some probability of additional expected snow. The decision often requires a tradeoff of values between taking a certain low-value loss at the present time versus a much greater loss in the future times some probability times some future expected value.

#### UTILIZING BIG SYSTEM MODELS WITH SMALL DECISION SUPPORT TOOLS

PG&E's SOCRATES scheduling model is updated daily with all data needed for an updated run at any time. However, it will likely be used on a weekly basis for at least the near future. The complexity of large models and systems tend to keep them somewhat limited to primary use as the basic decision support for input to a lot of smaller, faster, and easily developed software tools to assist with real time decision support.

Energy traders may get information regarding certain market opportunities at the last minute and want to quickly know whether or not to act on such information in order to capture market opportunity. In order to analyze the potential payoff in the fastest manner, one possibility would be to use an expert system or neural net. The expert system would select an approach from an array of small subprograms and reach an appropriate response based on all information and level of uncertainty at that time. The challenge would be to link each of the small subprograms with information available from the larger models. An inquiry by a trader might cause the large SOCRATES program to "automatically" try particular constraints and report back to the traders whether or not the particular 'opportunity' brings added value to utilization of hydro-fuel.

#### SUMMARY AND CONCLUSIONS

Beginning on January 1, 1998, PG&E's forecasters/schedulers will be challenged with probabilistic forecasting and scheduling for bidding into a Power Exchange. The Power Exchange will require that generation be bid into the pool for the day ahead. Correct declaration of capability by the producer will become very important in order to meet the bids made by energy traders. The ability to preserve full opportunity to maximize generation value will depend largely on the uncertainties of future remaining weather, future pricing uncertainty, and the ability to minimize cost of lost opportunity. Maintenance planning, how and when it is performed, will become a significant part of the overall

optimization process. Future pricing uncertainty is about to be addressed as part of the overall probabilistic scheduling process at PG&E.

PG&E is moving from a regulated to a competitive environment. Current monthly scheduling will take place much more frequently with the basic time step for decision making shifting from a monthly- to a daily time step. Forecaster /schedulers will have increased control over their model results and they will be able to change predictions as needed to get reasonable results. Fast less-than-perfect decision making will likely become the norm. Lake storage and snow water equivalent will be handled as part of the hydrologic state of the watershed and can, as such, be determined with some certainty. The remaining uncertain future weather cannot be measured and is therefore handled probabilistically utilizing extensions of actual historic weather to produce a cumulative probability distribution.

Rain-on-snow events occur with almost annual frequency in California, but very large events seem to occur about every 10-15 years. Large variability in climate causes much greater emphasis to be placed early in the season on managing for levels of exceedence, while later in the season the accuracy of the data and the forecast methodology become significant 'players' on which forecasters/schedulers must focus.

Competition will require that water scheduling and most real-time and near-real-time flow data be kept secure. If maintenance, water schedules, or real-time data was provided outside of PG&E, it would have potential to influence pricing, and as such, much of the value derived from strategically optimizing the system for maximum value could be compromised.

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