PITFALLS OF FORECASTING WATER-YEAR TYPE CLASSIFICATION IN NEW HYDROPOWER LICENSES

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ABSTRACT

Hydropower facilities typically operate under 30-year licenses from the Federal Energy Regulatory Commission. In the recent licenses that have been obtained by Pacific Gas and Electric Company (Company), a key part of the license is the setting of the minimum streamflow regime in the river reaches that are affected by project facilities such as dams and diversions. Current ecological concepts value inter- and intra-annual variation in streamflow that reflects the large year-to-year variation in water-year magnitude. Statistical analyses of annual inflows to a down-stream reservoir reveal the range of variation and allow the definition of water-year types with exceedence boundaries. Runoff forecasting based on snow resources allows the definition of water-year types as the winter progresses, and streamflows are implemented accordingly. Monthly forecasts are sensitive to a variety of error sources during the 4-5 month forecast period. Errors in water-year type designation can disrupt plans for biological studies, construction schedules, and adversely affect reproduction success of amphibian and other aquatic species. Errors in forecasting and license inflexibility can also result in implementation of streamflows that are higher than necessary and cost the Company millions of dollars. Collection of accurate data from well-designed snow course, snow sensor, and climate stations is essential to minimize forecast error. Comparative analysis between forecasts produced by different methodologies and forecasters is also recommended.

INTRODUCTION TO RELICENSING

In the next decade, the licenses for approximately 30 hydroelectric projects in California will expire and go through a relicensing process overseen by the Federal Energy Regulatory Commission (FERC). Many of these projects involve significant resources, from water and riparian habitats to recreation and scenic resources to historic and cultural resources. Many of these projects were built more than 50 years ago, well before environmental legislation such as the National Environmental Policy Act, the Endangered Species Act, the National Historic Preservation Act, and the Clean Water Act were in place. The relicensing process provides an opportunity to evaluate environmental conditions and to incorporate current scientific information into the licenses for these hydroelectric projects.

Several agencies have key responsibilities in the relicensing process for hydroelectric projects and are typically involved in the relicensing process. FERC has overall responsibility for issuing and ensuring compliance with a FERC license. FERC normally issues licenses for 30-50 years. Through section 4(e) of the Federal Power Act, the USDA Forest Service is authorized to include mandatory conditions in the FERC license that the Forest Service deems necessary for the adequate protection and utilization of National Forest System lands (16 USC § 791(a)). Other agencies that are normally involved in FERC relicensing include the USDI Fish and Wildlife Service, which is authorized under the Federal Power Act to prescribe fish passage requirements in the FERC license (16 USC § 803(j)); the USDI Bureau of Land Management, which manages federal lands throughout the state; the California Department of Fish and Game, which provides resource and wildlife protection in the state; the California State Water Resources Control Board, which has mandatory conditioning authority for ensuring compliance with the Clean Water Act and the Basin Plan; and the California Department of Boating and Waterways, which provides for recreational access and public safety.

Numerous non-governmental organizations (NGOs) are also regularly involved in hydroelectric project relicensing, including Friends of the River, American Whitewater, Cal Trout, Trout Unlimited, the Natural Heritage Institute, and other watershed-based interest groups.

Paper presented Western Snow Conference 2003

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Although FERC recognizes several distinct relicensing processes, the Company has recently employed a hybrid version of the traditional relicensing protocol. Under the hybrid process, the Company establishes a collaborative group that advises the Company on the key resource interests and concerns that the participating agencies and NGOs have, and recommends studies to be performed. The studies result in information that is used to develop the minimum streamflow regime, flow pulses for geomorphic and other purposes, and non-flow resource measures. Because of the range of resource interests and concerns, the list of studies can be extensive and be very costly perform. Studies typically cover the following areas:

- Fish Surveys
- Amphibian Habitat Availability and Use
- Macroinvertebrate Surveys
- Water Temperature and Water Quality
- Minimum Reservoir Pools
- Dissolved Oxygen
- Unimpaired Hydrology
- Flow Fluctuation Rates
- Geomorphology
- Riparian Habitat
- Threatened, Endangered, and Sensitive Species
- Recreation Streamflow Preferences and Information
- Recreational Access and Facility Needs

The ecological literature is replete with citations that link hydrologic variation with biotic diversity within the river ecosystem (Richter et al, 1997). Many agencies and NGOs believe that unchanging streamflow below project facilities may not be optimal, and recent licenses have streamflow regimes that reflect this belief. Mimicking the shape of the natural hydrograph was a principle objective in developing minimum streamflow requirements for inclusion in the new license. The literature suggests that many ecological objectives are likely to be addressed by reproducing the seasonal shape (intra-annual variation) and other important features (such as timing) of the natural hydrograph to the extent feasible while continuing the hydropower operation. Variation in flow magnitude from year to year (inter-annual variation) is also desired and reflects the range of annual runoff variability common in the maritime climate.

WATER YEAR CLASSIFICATION AND MINIMUM STREAMFLOW

Water-Year Types

Annual variability in runoff is inherent in maritime climates. Over the 27-year period of record for the North Fork Mokelumne River (NFMR) relicensing, annual runoff ranged from 233 cubic hectometers (hm^3, or 189 thousand acre feet (TAF)) to 2,200 hm^3 (1,800 TAF). To establish water-year types for the project, water years from the 27-year period of record were ranked by total annual runoff magnitude and separated into five water-year types: Wet, Above Normal (AN), Below Normal (BN), Dry, and Critically Dry (CD). Five water-year types were established for the Mokelumne basin, but only four types are specified in the Rock Creek-Cresta project. Endpoints can be established solely on exceedence values, or they can be keyed to project specific runoffs such as a runoff magnitude that is the divider between spill and no-spill conditions.

Minimum Streamflows

Minimum streamflow requirements should vary in magnitude based on the five water-year types. To provide adequate sample sizes for characterizing the annual runoff patterns, the five water-year types were combined into three water-year types to derive mean monthly unimpaired streamflow for the 440 km^2 (170 $mile^2$) sub-basin above Salt Springs Reservoir, as shown in Figure 1. The plot shows that the runoff from the Salt Springs sub-basin peaks in May in all three water year types. Also, May and June flows in the NFMR at Salt Springs are approximately the same in magnitude, and January and February flows in normal water year classes are approximately the same magnitude. These patterns were used as a template to design minimum monthly streamflows for the NFMR. Slightly different patterns were found in the adjoining Bear River/Cole Creek sub-basin due to its different physical attributes.

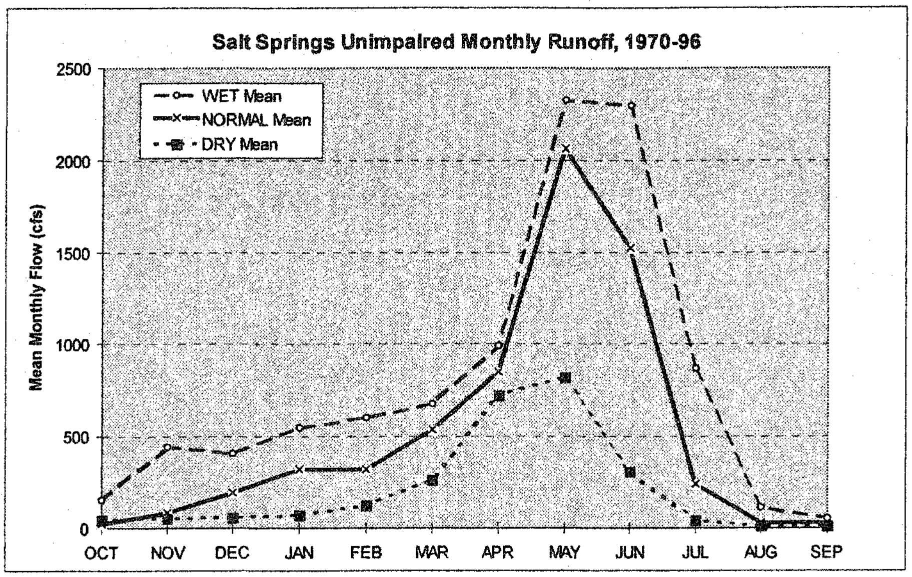

Figure 1. Salt Springs unimpaired monthly runoff

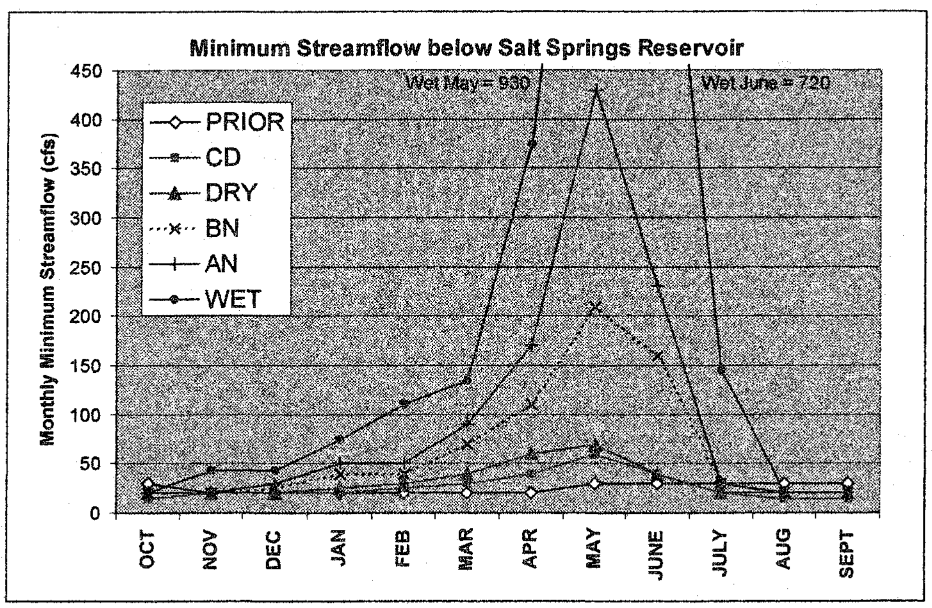

Figure 2. Minimum streamflows for the North Fork Mokelumne River below Salt Springs Reservoir

Although mean monthly flows show the runoff pattern, mean monthly values are not appropriate for use in establishing minimum streamflows for the various reaches within a basin. Unimpaired daily streamflow data from reaches within a basin are of great use, and should be examined for each month in multiple years from each of the three water-year types. For example, October mean daily streamflows at Salt Springs Reservoir for water years 1974, 1980, and 1982-84 were examined as being typical of wet water years. By cross-referencing with daily precipitation records to identify 5- to 15-day periods without rainfall, a minimum unimpaired streamflow of 0.56 cubic meters per second (cms, or 20 cubic feet per second (20 cfs)) was identified. This value was selected not because it was the lowest value in the unimpaired record across a number of years but because it was frequently observed as the baseflow value that typically occurred. This process was repeated for each month in all three water-year types, while also referencing the mean monthly curve for relative magnitude and pattern. Once the monthly minimum streamflows for the three water-year types were established, flows were interpolated between the three water-year types to get back to the five water-year types, as shown in Figure 2 (McGurk and Paulson 2001). The monthly minimum streamflows for the five water-year types, plus the minimum streamflows from the prior license, are shown in Figure 2. Increases in minimum streamflow requirements occur from February through the peak of snowmelt in June, and then decline to a constant level during summer and fall, consistent with the unimpaired hydrograph. The flow magnitudes and management complexity are significantly greater than the prior license minimum streamflow requirements of 0.56 cms in winter and 0.85 cms (30) cfs in summer. In Wet, AN, and BN water years, the major reservoirs typically produce spill flows of 14.2 to 56.6 cms (500 to 2000 cfs) in late May or early June. Although spills are not controllable by the Company, the sudden impact of spill flow is considerably reduced if flows are already elevated, as required in the new license conditions, before spill occurs. Under the new streamflow regime for Salt Springs, for example, May flows in the channel are between 6.0 and 26.3 cms (210 and 930 cfs), depending on water-year type, when the spill begins. The elevated spring streamflows were designed to keep the water in the downstream reach cold to inhibit pre-spill amphibian breeding and thereby avoid the dislodging of egg masses during periods of high flow originating from late storms or spill from snowmelt. Other aquatic species, such as trout, should also benefit from the new minimum streamflow regime. The aquatic ecosystem below many project facilities has been subjected to a regime less variable than the unimpaired condition for many years, and the effects of the new and more variable regime will be accumulated over the 30-year terms of most new licenses. It is reasonable to expect that some species may prosper under the new regime, and that others will not.

RUNOFF FORECASTING

Snow Surveys and Forecast Updates

Annual runoff for snow-dominated basins may be predicted based on factors such as winter snowpack, annual precipitation, and runoff in the prior year. For granite basins such as the NFMR, winter snowpack is an excellent means of forecasting April-to-July runoff. Manual snow surveys are performed three or four times per year, depending on the snow course, and models have been developed that correlate historical snow water equivalent (SWE) information with observed runoff. These models can be used to predict April-to-July runoff, and when combined with observed runoff from October through February, March, April, and May, annual runoff can be predicted. By comparing the forecasted annual runoff volume with the historical water-year type classification, water-year type can be forecasted after each snow survey. The subsequent month's forecast updates the earlier forecast, and the final water-year type is determined based on the May snow survey. The water-year type determined in May does not change until the following February for the NFMR, but other basin's licenses have different dates for forecast and update requirements.

Based on the forecasted water-year type in each of the forecast months, minimum streamflows and other management activities prescribed by the license are implemented. As snowpack conditions change due to a lack or plethora of storms, the Company may have to shift to minimum streamflow regimes associated with a new water-year type with each new forecast. When streamflows must be increased, the Company must be diligent in making the changes in advance of the due date to avoid non-compliance penalties.

Error and Variability

Water-year type is set by comparing the forecasted runoff to the water-year type dividing points that were established by analysis of the historical runoff. For example, a Dry water year in the Mokelumne license has an annual inflow to Pardee Reservoir of less than 639 hm^3 (518 TAF) but greater than or equal to 464 hm^3 (376 TAF). The monthly forecasts are based on the best snowpack information and estimates of accumulated unimpaired runoff information. However, both of these kinds of data have inherent estimation errors, and the forecast procedure also introduces error. Further, forecasts typically assume a median future precipitation scenario, and it is rare to find median precipitation in any given year. The span between the dividing points is typically several hundred hm^3, and minor runoff changes do not cause a change in forecasted water-year type. However, in the three years of the new Mokelumne license and the two years of the new Rock Creek-Cresta license, each has had several months where the forecast has been close to the dividing point between water-year types. Both licenses have had occurrences of changing from Normal or BN to Dry, and also from Dry to Normal or BN.

PITFALLS OF FORECASTING RUNOFF

Planning Problems

Operation of a large hydroelectric project is a complex process. The new Mokelumne license included a complex Stream Ecology Monitoring Plan, over $30 million of facility renovations, requirements to schedule and implement recreational boating releases while following ramping rates, and compliance with required minimum streamflows that change by month in 16 stream reaches. Many of these plans or operations are dependent on water-year type, so changes from month to month or errors in flow forecasting can have a large impact on staff time and operational costs. For example, during the dry January, February, and March of 2003, biological studies to monitor aquatic effects of mid-summer flow increases were canceled because they could not be done in Dry years. After precipitation in excess of 250% of normal occurred in April and the water-year type switched back to BN, plans had to be put back in place, contractors hired to do the work, and supervisory biologists pried away from other monitoring activity. Several weirs were scheduled to be started in June, and access was blocked by snow and by larger streamflows than could be diverted around the construction site.

The large April precipitation changed reservoir operations from a no-spill to a spill-likely condition, but forecasts were not definitive in terms of the likely magnitude and duration of the spill. The timing of the initiation of spill in May is somewhat controlled by radial spill gates at Salt Springs Reservoir, and the Company has a policy of attempting to avoid spill initiation during weekends when the several downstream campgrounds may be heavily occupied. It is common for campers to set up as near the edge of the river as is allowed, and spill flows of 56 cms (2000 cfs) can raise the water level in some areas to inundate the unwary. Simultaneously, amphibian surveys were scheduled both before and after spill to locate sensitive frog species and to determine if egg masses existed. Depending on the spill magnitude and placement of the egg masses, high flows can detach and destroy the egg masses. To accommodate the pre-spill survey, the spill had to be delayed from the several days before the weekend until after the weekend. As a result, the streamflow increased faster when spill was initiated and may have been larger. The difficulty in balancing these competing issues is lessened by accurate forecasting.

Forecast Revisions

On the Feather River in 2002, the May 1 runoff forecast was just above the dividing point between Normal and Dry. Minimum streamflows and recreational releases were locked in based on the May forecast. On May 14, the forecast was revised downward by 92 hm^3 (75 TAF), and the revised forecast fell below the dividing point to yield a Dry year classification. The water-year type, however, remained at Normal as required by the license, based on the initial May forecast. Higher minimum streamflows than should have been required were therefore released for the subsequent nine months. The increased release past the Rock Creek and Cresta powerhouses in the subsequent months was in excess of 24 hm^3 (19.5 TAF) and caused a loss of generation worth over $350,000. The initial May forecast is specified in the license as the decision point for setting the water-year type. There was no provision made for late-May adjustments of the forecast to be allowed to modify the classification. The decreased amount was only 2.3% of the dividing point value. Most forecasters would agree that errors of 5% are common when runoff forecasts are compared to actual runoff after the end of the water year. For this reason, <u>more</u> water-year types with smaller minimum streamflow increments between water-year types are preferable over <u>fewer</u> water-year types and larger increments.

Future Forecasting Needs

As FERC relicensing continues in the snow-dominated basins of the Sierra Nevada, runoff forecasting to determine water-year types is routinely included in the new licenses. Forecasts of runoff magnitude allow the licensee to provide more water for environmental and recreational needs when ample water exists, and to conserve water for hydropower operations when conditions turn dry. As detailed above, inaccurate forecasts can have major fiscal impacts on licensees, so maintaining or improving the existing private, state, and federal forecast procedures, staffing, and accuracy is highly desirable. If both state and federal budgets decline, the ability to continue critical components of the runoff forecasting process may be at risk. Existing equipment must be maintained, replaced, and improved. Snow data require extensive quality control efforts to control biases due to unusual weather sequences, equipment malfunctions, and other error sources. Installation of new equipment is needed in areas that contribute significant runoff and are difficult to access safely. Improved equipment needs to be developed and implemented to improve forecast accuracy as the demand for water information grows increasingly acute.

Experienced forecasters are needed to maintain forecasting tools, and both the tools and the long-term averages may need adjustment to incorporate climate-change effects on runoff timing. There is a great advantage to having several forecasts for a basin made by different forecasters who are using different forecasting tools and then compare results. Comparisons of forecasts in adjoining basins can help identify aberrant forecasts and aid forecasters in adjusting forecasts that appear unreasonably high or low and might be based on inaccurate data or errors in the data management process.

CONCLUSIONS

Runoff forecasting is becoming a critical part of hydropower operation as water-year type classification is incorporated into many of the new hydropower licenses. Minimum streamflow regimes, recreational releases, monitoring, and project operations are affected by the runoff forecasts that determine the water-year type. As the winter season progresses and the forecasts are updated based on new snow surveys and other information, water-year types can change and increase the complexity of hydropower operations. Errors in forecasts can have large economic impacts on licensees due to changes in the magnitudes of required minimum streamflows that are scaled with runoff magnitude. Forecast accuracy and timeliness are becoming more critical than ever due to the inclusion of water-year types into hydropower operations. Continued maintenance and deliberate quality control of the data are critical, and the current state and federal budget conditions are a concern. Improved forecast equipment and tools are needed to keep pace with the new demands for accurate and timely forecasts.

LITERATURE CITED

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