antecedent soil moisture conditions. Winter and spring streamflows reflect both antecedent soil moisture and winter low-elevation precipitation. Additionally, the authors derived a combined index of precipitation and snow (shown as triangles). Precipitation at Idaho City and McCall was used from June to December, and snow water equivalent at the Galena and Bear Basin sites was used after January. This information contains marginal skill in November that dramatically increases through the forecast season. The final dashed line shows the forecast skill when all variables are used together. Although the seasonality and magnitude of various skill components may change, this chart is qualitatively representative for many locations in the Pacific Northwest, Arizona, and New Mexico.

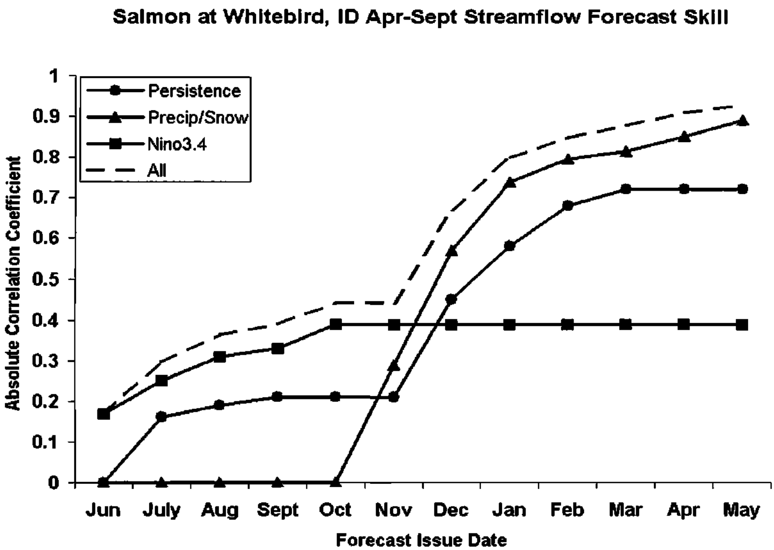

Figure 1. Progression of seasonal streamflow volume forecast skill versus issue date

To summarize, El Niño and soil moisture conditions contribute a low but still significant amount of skill to forecasts produced in June to November. Later in the season, snowpack is the best indication of the expected streamflow. It is not surprising that snow measurements have been the primary focus for water supply forecast agencies in the West. If agencies commit to producing early season hydrologic forecasts, however, proficiency in climate information, such as El Niño, is required.

"CLIMATOLOGISTS ARE FROM VENUS, HYDROLOGISTS ARE FROM MARS"

Figure 1 effectively illustrates a contrast between climate and snowmelt hydrology. The correlation between snowpack and streamflow is so strong that it is relatively easy to believe that the relationship is (almost) deterministic. By April 1st, an exceptionally heavy snowpack is virtually guaranteed to produce proportionately high streamflow, and similarly, low snowpack yields low streamflow. Before December or January, the hydrologist has little information "on the ground" upon which to base a forecast.

In contrast, the correlation between climate and streamflow is marginally significant, and one *must* think of the relationship probabilistically. While climate forecasters may find it loathsome to produce long-lead deterministic climate forecasts, many hydrologists fear that users might not accept a probabilistic streamflow forecast of this skill level, thinking that users would view them as "vague", "hedging", or "non-committal".

Hydrologists are also aware of the institutional barriers to using probabilistic forecasts. Many reservoir operating rules require a deterministic streamflow value. Water managers seeking to implement new dynamic operating procedures based on probabilistic forecasts encounter resistance from decades of tradition and external pressures to maintain consistency in operations. Such resource management, in the face of many highly conflicting interests, can result in rigid agreed-upon management practices, lest one party believe a new course of action is being taken at their expense to the benefit of others. Although some sophisticated water managers do consider risk and appreciate information about forecast uncertainty, a number of difficult challenges remain to those attempting to communicate probabilistic streamflow forecasts effectively. Some hydrologists would prefer not to issue a forecast that they suspect the user could not use or would misinterpret (Pielke Jr, 1999). The nature and scope of these challenges are explored further in the next section.

There is also a spatial scale contrast between climate forecasting and streamflow. The strong correlation between snowpack and streamflow requires close scrutiny of small spatial variations in snowpack when forecasting. As a result, hydrologists generally frown upon forecasting using snow measurements outside a basin's boundary. To the most extreme case, forecasters balk at using snow in central Arizona to forecast New Mexico streamflow although a weak correlation exists. Hydrologists lack knowledge about what new climate indices (e.g., the Arctic Oscillation, the Quasi Biennial Oscillation, Solar Cycles, etc.) are "in" their basin so that it makes sense to consider them when forecasting or which ones are "outside" of their basin and are spuriously correlated.

At the opposite end of the spectrum, climate forecasters typically focus on large-scale continental, if not global, patterns when making their forecasts. If the contours on a national forecast map match the observed contours, except that they are displaced, for example, 1000 km to the east, it is generally thought of as a successful forecast. If the connection between climate and streamflow is to be made, streamflow forecasters will need to think "bigger" and climate forecasters will need to think "smaller".

CULTIVATING SKEPTICISM, COMBATING PESSIMISM, RETAINING CREDIBILITY

While very long-lead water supply forecasting requires proficiency in climate variability, it also demands expertise in probabilistic forecasts and concepts. Although nothing prevents the generation of short lead-time probabilistic forecasts, the uncertainty in long-lead forecasts brings the issue to a head.

The water supply forecaster who issues a highly uncertain probabilistic climate-based streamflow forecast should be prepared to engage users who demand that the forecaster "come clean" and tell them "what the forecaster *really* thinks is going to happen". This discussion is, of course, ill-framed because all forecasts are at their root probabilistic. Deterministic forecasts are probabilistic forecasts with zero error bounds (i.e. complete confidence). A deterministic forecast may also be some point along the probabilistic forecast distribution, arbitrarily chosen by the forecaster (e.g. the mean, median, or mode).

The danger in allowing the forecaster to choose the "one number" is that the internal risk model of the forecaster may be different from that of the user. Unless the forecaster is intimately familiar with the user's operations, the forecaster is not qualified to judge what level of risk the user should accept. It is not the role of the forecaster to determine if and how water managers should use probabilistic forecasts to manage risk. Ultimately, the forecaster's efforts should be focused on quantifying and issuing the most unbiased, informative, and useful forecast possible (as discussed by Murphy, 1993).

While the scientific literature has repeatedly shown that probabilistic forecasts are more appropriate and articulate than deterministic forecasts, the authors recognize the rift within the operational community concerning the perceived low user demand for probabilistic forecasts and their inability to interpret them. In a recent case, a southwestern water manager, the Salt River Project, commissioned the development of an advanced climate-based water supply forecasting tool, but the user then developed a post-processor to convert the probabilistic output into a deterministic forecast.

If confronted with a user demanding a deterministic forecast, the hydrologist should consider if the user, in asking for the uncertainty to be removed from the forecast, tacitly wants the uncertainty to be removed from nature. After all, given enough time, money, satellites, and climate indices, one should be able to come up with the perfect forecast. The user, dissatisfied with the agency forecasts' large uncertainty, may seek out alternate opinions among, for example, the outputs of individual forecast tools or private consultants.

While it can be difficult to distinguish this user from the sophisticated user who accesses as much information as possible to supplement the official forecast, the former may suffer from "confirmation bias". This is a type of natural selective thinking encountered in a variety of contexts whereby one tends to notice and to look for what confirms one's beliefs and to ignore, not look for, or undervalue the relevance of contradictory evidence (Kahneman et al., 1982). The most dangerous combination is a user with a confirmation bias who relies upon forecasters who suffer from their own form of confirmation bias and who thus are willing to "go out on a limb" to attract customers with very confident (and thus presumably skillful) forecasts. When this water manager uses a "one number" deterministic forecast, which then greatly differs from the observed, the user is likely to foist responsibility for any negative outcome back onto the forecaster who presumably "read the signals wrong" or did not try hard enough.

Some operational water supply forecasters are skeptical of climate forecasts, often because of an instance in which the individual put faith in a climate outlook, and this resulted in undesirable consequences and regret. In one notable instance, in the fall of 2000, a strong La Niña was underway, combined with the cool phase of the Pacific Decadal Oscillation (PDO). These phenomena together provided the strongest possible climate-based indication that the Pacific Northwest would be wetter than average in 2001. For example, at the time, the driest of the other nine La Niña/cool PDO years since 1936 on the North Fork Flathead River near Columbia Falls (Montana) had April-September streamflow almost exactly 100% of average; the wettest year on record, 1974, at over 160% of average, was a La Niña/cool PDO year. For a variety of subjective reasons, the NRCS did not issue any early season forecasts in the fall of 2000. In the end, 2001 tied or broke records for the driest year on record in the Pacific Northwest, contrary to the climate forecast guidance. The North Fork Flathead experienced its third driest year on record at close to 50% of average flow. In retrospect, water supply forecasters felt that they had "dodged a bullet" by ignoring the climate forecasts. Many streamflow forecasters have a "What about 2001?" anecdote readily available as a justification as to why they do not rely on climate forecasts more heavily.

Forecasters and users alike must accept that, since the relationship between streamflow and climate is probabilistic, "No one can win them all." The threat of having a forecast "bust", however, strikes fear into all but the most steeled hydrologists. As Lewitt (1995) describes this situation: "[The event is not] entirely predictable, though it is possible to calculate the ranges of probability. Still, in every range there is the one in a billion chance, the blind shot that seems so improbable that we ordinarily discount it. And when it does happen, our sense of fair play is often more injured than our actual conditions." Who accepts responsibility when nature does not obey the predictions – the climate forecaster, the hydrologist, or the user? Given sufficiently negative consequences, even a long record of appropriate decisions can be negated by a single "bad" decision. Over the long term, however, if the climate information is properly used, the streamflow forecasts should improve in general.

While important, the Pacific Northwest example should not be overstated. At the opposite end of the spectrum from the user trying to strip nature of its uncertainty is the one who believes that long range predictability is impossible. One might encounter a hydrologist who perceives that "making a streamflow forecast in September, before any snow has accumulated, amounts to swinging before the ball has been pitched. One is bound to strike out." Such hydrologists may feel *Schadenfreude* (malicious joy) when a forecast disagrees with the observed because it confirms their negative impressions of climate forecasts and releases them from any need to change their current operations. A forecast user may adopt the same mis-perspective that if the future is completely uncertain, there is no need to deviate from business as usual. Even if a catastrophic event occurs, such users feel absolved of responsibility, as the disaster was an unforeseeable "Act of God". The use of fixed reservoir operating "rule curves" operates under the principle of minimizing risk in the face of complete future uncertainty. The reality of climate forecasts lies somewhere in between the extremes of complete uncertainty and complete predictability.

One key to interpreting and using probabilistic forecasts is to have a clear quantitative understanding of forecast uncertainty. Often, users have only a subjective notion of how close the observed ought to be to the forecast to consider it acceptable. If the observed deviates too far from this subjective tolerance, then the user denotes this forecast as a "bust". Whether a forecast is a "bust" or not, however, depends on whether the observed lies outside reasonable error bounds, which themselves depend on the forecast uncertainty. Users must be fully cognizant of this interrelationship to understand the magnitude of possible deviations of observed from forecast. In the end, there are no "bad" probabilistic forecasts, only unlikely outcomes.

A second key to understanding and using probabilistic forecasts is to realize that the chance of the observed ever equaling the deterministic forecast is essentially zero. Even under the best circumstances, one will always observe more or less than the forecast quantity, with probabilities described by the error distribution. Once this is understood, users can then develop, and when necessary implement, contingency plans in the event that more or less water is received than the forecast. This is true regardless of the chosen exceedance probability of the forecast quantity. Difficulties can arise if users and managers base their plans only on a single forecast quantity, ignoring the possibilities described by the forecast distribution. The danger in interpreting the "one number" forecast as "destiny" is particularly serious when involving long-range climate-based streamflow forecasts because the likely error is much higher than late-season snow-based forecasts.

PRACTICAL ADVICE TO WATER SUPPLY FORECASTERS

Climate forecasts have long represented an opportunity to improve seasonal water supply forecasts. For decades, however, climate forecasts have been perceived as having insufficient skill and specificity for use in the operational hydrology environment. While climate forecasts may not significantly improve water supply outlooks during the snowmelt period, they possess great strength in providing information prior to snowpack accumulation, as early as September. While these pre-season forecasts are highly uncertain, they remain an improvement over the next best alternative (i.e., no information at all).

Although some technical barriers to incorporating climate outlooks into the water supply forecasts exist, the primary challenge is a perceptual barrier. To utilize such highly uncertain climate information properly, forecasters and users both must understand water supply forecasts in probabilistic (rather than deterministic) terms. Regrettably, operational hydrologic, climate, and weather forecasters have struggled for decades to communicate forecast uncertainty effectively (O'Grady and Shabman, 1990; Sarewitz et al., 2000). Some progress has been made, particularly in the past decade or so, in the tabular and graphical display of forecasts to communicate more clearly the probabilistic nature of the forecasts. Continued efforts along these lines in both the academic and operational communities are needed.

While it is outside of the scope of this paper to determine if water managers should use long-lead yet uncertain climate-based water supply forecasts, it is safe to say that operational forecast agencies will inevitably start issuing them. Water supply forecasts were originally issued first in April, with March forecasts beginning in the 1950s, February forecasts in the mid-1960s and January forecasts in 1980. The historical trend towards longer lead-time forecasts suggests that the advent of December (or earlier) forecasts is overdue. The question remains not whether but how best to implement this system.

Operational forecast environments typically have several forecasters, each responsible for a limited subset of basins within the office's larger forecast area. At least one of these forecasters should have good to excellent proficiency in interannual climate variability, with a working knowledge of the tools used by the official climate forecasters at the Climate Prediction Center (CPC). During the forecast season this individual is encouraged to monitor and/or participate in the forecast development teleconferences CPC holds. This hydrologist can then brief the other hydrologists on the climate outlook, field questions about the forecast and develop a collective strategy on the implications for local streamflow. It might be possible for the climate-savvy forecaster to develop the pre-season forecast for all areas, alone, with subjective input from the other hydrologists.

This forecaster should be able to provide practical advice on using climate information in forecast equation development. For example, climate signals are typically large scale in nature (e.g., larger than 500 km across) except in coastal regions where the effects can be isolated. Therefore, if no streams in a region are correlated with climate except one, the correlation is likely spurious. Climate phenomena typically contain much persistence from month to month, and their high frequency variability usually does not contain relevant information. Therefore, exhaustive analysis of every combination of months of a climate index to find the optimal combination for forecasting (i.e. "Hunting and Pecking") results only in over-fitting. Three-month averages (such as September-November) of climate indices should suffice. Also, one should choose only climate indices that will be available at forecast time; currently the Southern Oscillation Index is operationally supported, whereas the Pacific Decadal Oscillation is updated irregularly by an academic institution.

Each office within the water supply forecast environment would benefit from an individual also proficient in advanced statistics and probability concepts as well as someone with an interest in visual display and communication of uncertain information. These members can develop a regionally appropriate strategy for emphasizing forecast uncertainty without overly discouraging users. They can also address whether early-season forecasts require a fundamentally different format from those issued throughout the regular season. Depending on availability, the agency may partner with the local NOAA Regional Integrated Sciences and Assessments project to serve as a user liaison. These projects have the interest and resources to develop and quantitatively test alternative forecast delivery formats. All forecasters should have a working knowledge of basic statistics and probability concepts;

popularly accessible works such as Bernstein (1998), Gilovich (1993), Kahneman et al. (1982), Plous (1993), or Pollack (2003) can also assist in giving forecasters basic non-technical tools and concepts to help communicate forecast uncertainty to users. The forecast environment should already be capable of historical forecast archival for the evaluation of forecast accuracy. There is no reason why this system cannot also include more uncertain, early season climate-based forecasts. Retrospective evaluations can measure the relative improvements of using climate information over existing practices. Hindcasting and simulated forecasting exercises (such as Baldwin et al. [this volume]) can help streamflow forecasters build realistic expectations (that is, not overly inflated nor unnecessarily pessimistic) of what will occur when using climate forecasts. If effective, there is a good chance that the climate forecasts will be properly applied, without regrets.

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