PAYETTE RIVER BASIN, IDAHO: HIGH-RESOLUTION MODELING AND GAUGING

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ABSTRACT

Idaho Power Company (IPC) is a hydroelectric based utility serving eastern Oregon and most of southern Idaho. Snowpack is critical to IPC operations and the company has invested in a winter orographic cloud seeding program for the Payette, Boise, and Upper Snake River basins to augment the snowpack. IPC and the National Center for Atmospheric Research (NCAR) are in the middle of a multi-year study to determine precipitation enhancement due to winter orographic cloud seeding in the Payette River basin. As part of this study, a target/control network has been established in the Payette River basin of Idaho using 15 SNOTEL gauges in or near the Payette River basin along with 14 IPC installed high-resolution precipitation gauges. The IPC precipitation gauges record to a hundredth of an inch (verses a tenth of an inch for SNOTEL) and can be used to determine precipitation enhancement from both individual storm systems as well as seasonal precipitation. Forecasts from a high resolution (1.8 km) WRF model, generated at the University of Arizona, for precipitation in the seeded and non-seeded areas will be compared against observed precipitation and used to determine the precipitation enhancement due to cloud seeding. Model to model and model to precipitation gauge comparisons will be compared in both seeded and unseeded areas in an effort to develop temporally and spatially explicit quantitative precipitation maps for the accumulation and variability in the basin. (Keywords: high-resolution, modeling, gauging, cloud seeding, Payette River)

INTRODUCTION

IPC is an investor owned, regulated electric utility with a service area that is little over 62,000 km^2 and covers most of southern Idaho and eastern Oregon. We provide service to a population of over 1 million and provide over 15,500,000 MWh/year. As a fully integrated utility, we generate the power, conduct interstate transmission of the power and distribute that power to our customers. Our primary production is from17 hydroelectric facilities with nameplate capacities over 1,700 MW (Figure 1). Year to year variations in snowpack in the higher elevations

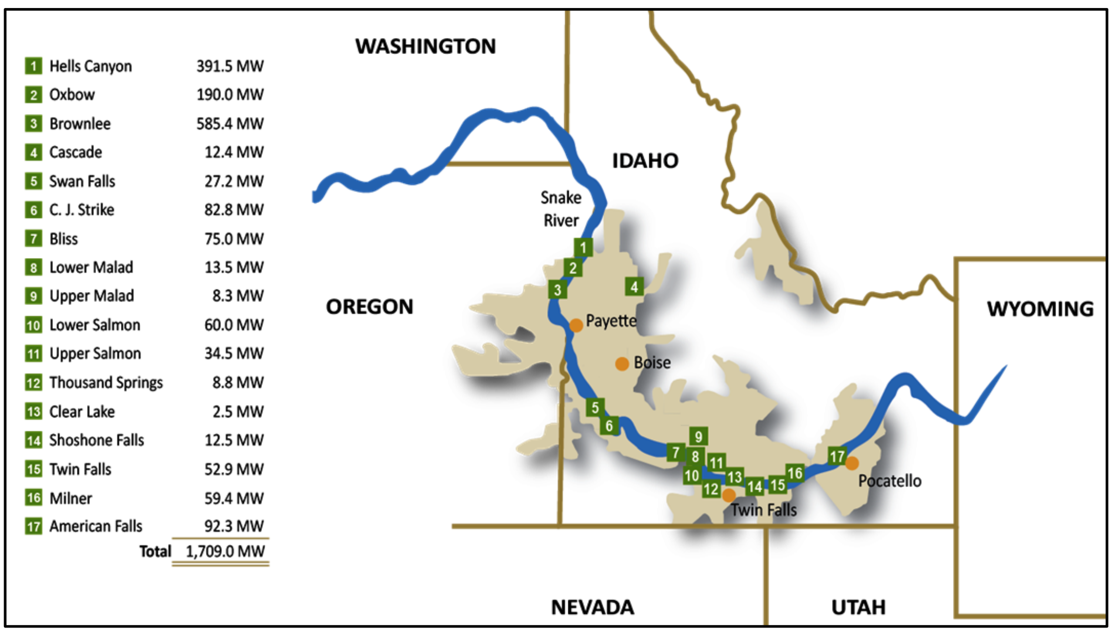

Figure 1. Idaho Power hydroelectric facilities and nameplate capacities

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throughout our service area, central Idaho and western Wyoming greatly influence the amount of hydrogeneration available each year. Figure 2 illustrates this fact with approximately one-third of the 2007 yearly generation coming from hydrogeneration due to the region receiving a less than normal precipitation. In 2011, we saw an opposite effect with nearly 60% of generations coming from hydrogeneration due to higher than normal precipitation. Because of this dependence, IPC conducts a wintertime orographic cloud seeding (enhancement) program in the Payette, Boise and Upper Snake River basins to augment the snowpack. Cloud seeding offers the potential to augment water supplies when needed, without the need for large capital investments in additional water storage facilities. It is also potentially one of the most cost-effective, nonstructural alternatives available to water managers.

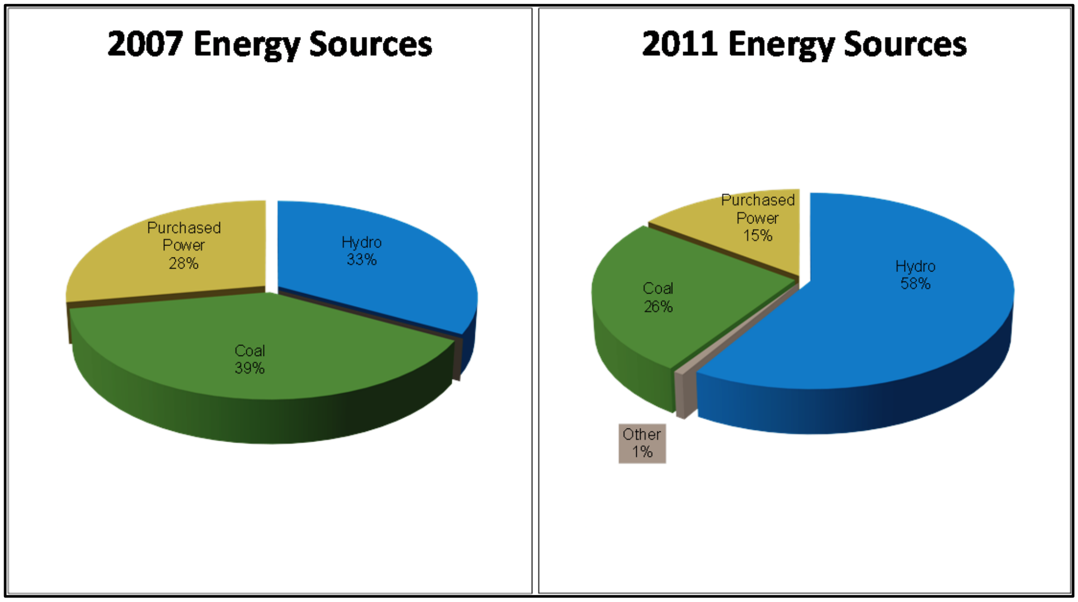

Figure 2. Idaho Power Generation Sources for 2007 and 2011, hydrogeneration variations caused by below normal and above normal (respectively) yearly precipitation.

Rauber (2013) stated that "the fundamental hypothesis underlying cloud seeding as a method to enhance precipitation from wintertime orographic cloud systems is that ***"a cloud's natural precipitation efficiency can be enhanced by introducing ice condensation nuclei (typically silver iodide(AgI)) into a layer of the atmosphere containing super-cooled liquid water in such a manner that new ice particles are created and then grow by diffusion, riming, and/or aggregation, can fall as additional snow on a specified target area***." Rauber then summarized scientific studies conducted to evaluate the hypothesis. Initial studies were conducted in the 1960s and 1970s (e.g., Mielke et al., 1970, 1971, 1981; Chappell et al., 1971; Elliott et al., 1978; Vardiman and Moore, 1978; Rottner et al., 1980, Mielke, 1995, Gabriel, 1995). Other studies (e.g., Hobbs and Rangno, 1979; Rangno, 1976, 1979; Rangno and Hobbs, 1980a and b, 1981, 1987, 1993) identified flaws in design or assumptions that weakened the results of the studies. Super and Heimbach (1983) conducted a well-designed study in the Bridger Range found as much as a 15% increase in precipitation.

For more than 20 years, there was a slowdown in winter orographic cloud seeding research and verification, but as cloud seeding programs expanded worldwide, the critical question as to its effectiveness arose again. In Australia, a randomized experiment was conducted (Morrison et al., 2009; Manton and Warren, 2011) with resulting precipitation increase between 5 and 14%. The National Center for Atmospheric Research (NCAR) and the State of Wyoming are presently conducting a multiyear project with the objective of evaluating the effectiveness of snowpack augmentation in the Medicine Bow and Sierra Madre ranges of Wyoming. Using these two mountain ranges, a crossover design was created in which one range is randomly chosen for seeding and the other becomes the control, resulting in paired cases. Initially designed to be a 5 year project the number of cases needed to provide statically significant results did not occur (due to the number of storms available to be analyzed) and the program has been extended an additional two years. Results from this study will likely be available in 2014 ("Wyoming Weather Modification Project Evaluation"). The Payette River Basin snowpack enhancement project was initiated based upon evidence of successful snowpack enhancement from past and ongoing research and the cost effectiveness of the associated increases in enhanced precipitation.

PAYETTE RIVER BASIN SNOWPACK ENHANCEMENT PROJECT

The Payette River Basin covers ~8,400km^2 with elevations ranging from 650 m – 3110 m and is located in central Idaho approximately 50 km NNE of Boise Idaho, the basin's 30-year average precipitation ranges from 300 mm – 1700 mm (Figure 3). Within the Payette River Basin, the Payette River snowpack enhancement area covers ~ 2430 km^2 and has elevations ranging from 960m – 2835m, additionally the average precipitation ranges between 600 mm – 1700 mm. The IPC cloud seeding program uses both aircraft and ground based remotely controlled generators to deliver silver iodide (AgI) crystals into super cooled liquid water in existing clouds to enhance the clouds effectiveness in forming snowflakes.

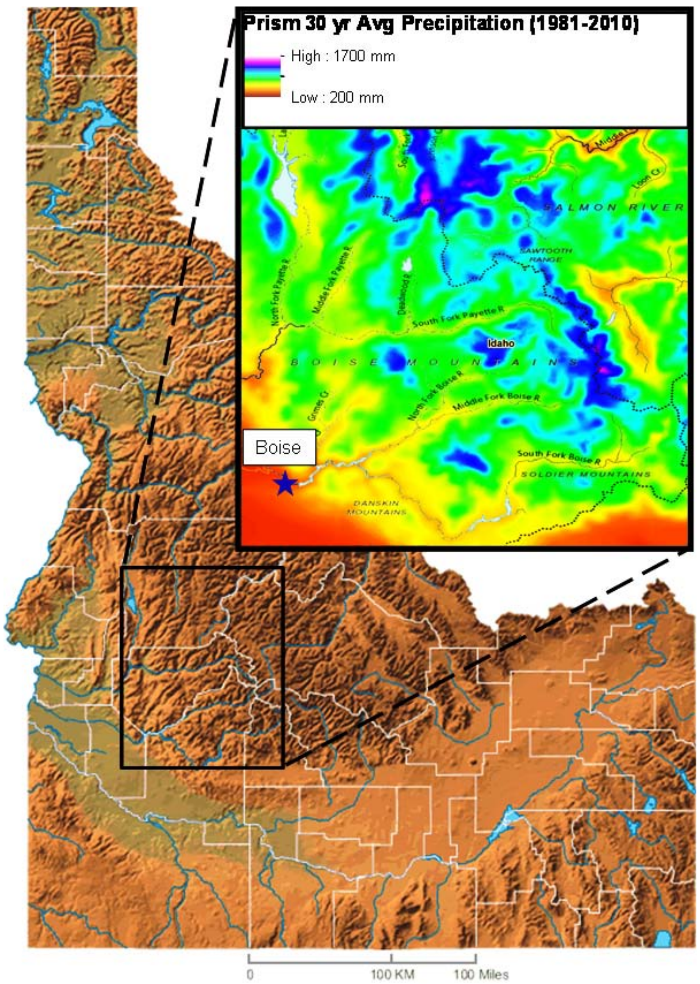

Figure 3. Map of the State of Idaho with an inset of the Payette River Basin and surrounding areas with the 30-year average precipitation shown.

ASSESSING THE EFFECTIVENESS OF ENHANCEMENT PROJECT

Target-Control Analysis

Historically, IPC has employed three techniques to determine the effectiveness of this program. The first of the three techniques used is a target-control analysis (TCA). TCA is conducted by determining a statistical relationship between a precipitation gauge site(s) outside of the enhance area (control sites) and gauge site(s) within the enhancement area (target sites) using data that existed prior to the start of cloudseeding operations. Once this statistical relationship is developed, the pooled control precipitation observations can be used to predict how much precipitation should have occurred at the pooled target sites through a linear regression. For our TCA, we used a pooled control precipitation from a number of SNOTEL sites outside of our target area and a pooled target precipitation from a number of SNOTEL sites within our target area for the period (water year (WY) – October through September) WY 1987 – 2002. Figure 4 shows this developed relationship for the TCA with the observed precipitation values shown as solid black dots, the linear regression trend line is shown as a solid black line. The developed statistical relationship proved to be a strong one with an R^2 of 0.9640, indicating that it is reasonable to use the control sites precipitation to predict the target sites precipitation.

By convention, positive effects from cloud seeding would fall above the developed regression line and negative effects from cloud seeding would fall below the developed regression trend line. Figure 4 also shows the results from cloudseeding for the operational WY 2003 – 2013, with all years falling above the regression trend line. The range of observed enhancement (from the TCA) ranges from 1.2% in WY2013 to 28% for WY2012. These results illustrate the effects of how different atmospheric conditions react to cloudseeding operations, sometimes you are able to produce significant enhancements and others times there is much less response.

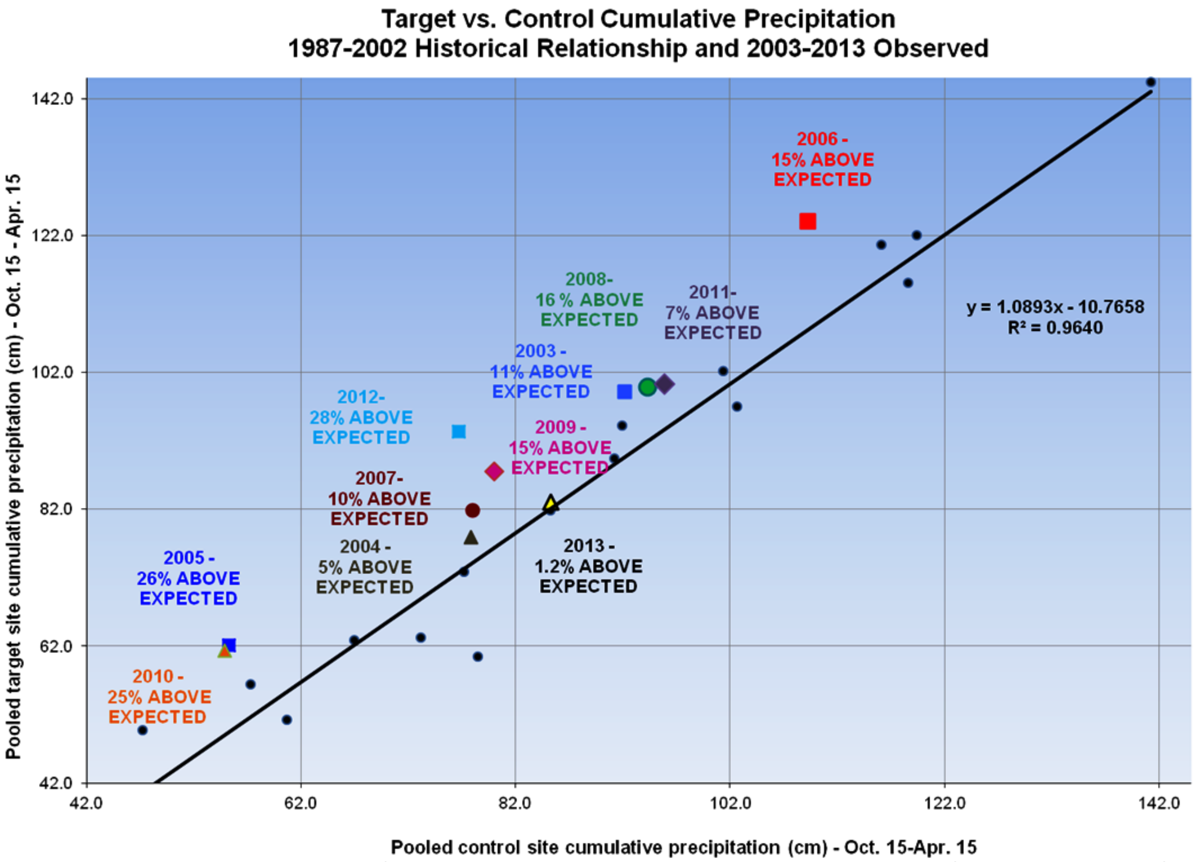

Figure 4. Target-Control Analysis for the Payette River enhancement area prior to and after the beginning of cloudseeding operations.

Double Mass Balance Analysis

An extension of the TCA is a statistical method known as Double Mass Balance Analysis (DMBA). To conduct the DMBA, use the regression equation developed during the TCA to "predict" how much precipitation should have occurred in the target area based upon the control area precipitation. Cumulate each successive year's predicted value and plot those as cumulative values. Once plotted, construct a linear regression trend line with a regression equation for that set of cumulated values. This process is accomplished separately for the pre-cloudseeding years and the cloudseeding years to identify if there is a difference in the slopes of the two regression trend lines. If there were a positive effect from the cloudseeding, you would expect that the value of the slope from the seeded years would be slightly larger than the non-cloudseeding years. The results of the DMBA are shown in Figure 5. The cumulative values from the non-cloudseeding years are shown as red triangles with the regression equation and R^2 shown below them and the cumulative values from the cloudseeding years are represented by green circles with regression equation and R^2 shown above them. A visual inspection of the data shows the seeded year's cumulative values sloping up and away from the non-seeded cumulative values, indicting a distinct difference in slopes; additionally the coefficient of the seeded regression equation is larger than the non-seeded regression equations coefficient (1.1185 vs. 0.9983).

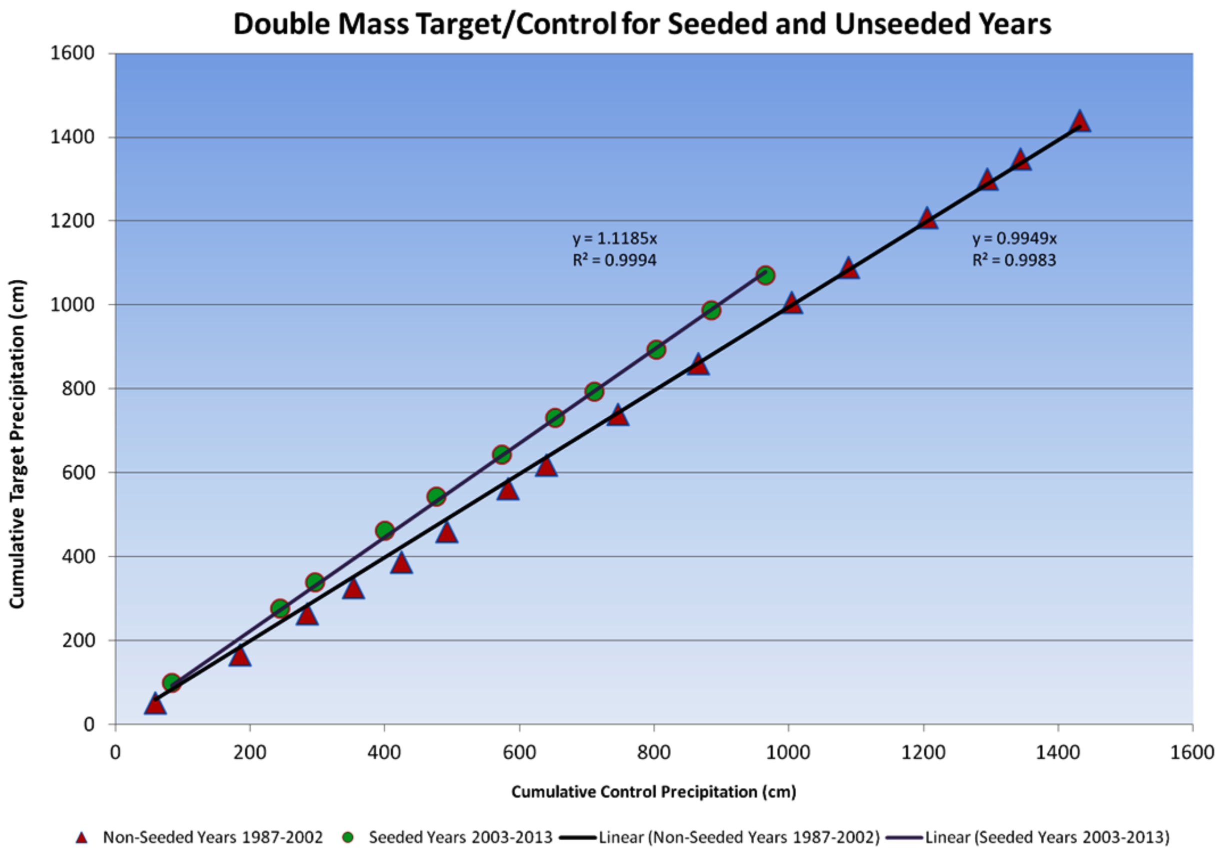

Figure 5. Double Mass Balance Analysis for the Payette River enhancement area. Slope analysis shows a distinct difference in slopes between pre-cloudseeding and post-cloudseeding, indicting positive influence from cloudseeding operations.

Both the TCA and DMBA are strong statistical methods for testing the effectiveness of the cloudseeding operations and both show positive effects during the period of cloudseeding for the Payette River Basin enhancement area. Unfortunately, not all basins have long-term data that exist prior to the start of cloud seeding, making it difficult to develop the statistical relationships required for the analysis. Additionally the developed relationships may not remain constant through time. Examples of things that may affect the relationships are wildfires at gauge sites, increased human traffic surrounding the gauge sites, maintenance by the Natural Resources Conservation Service (NRCS) at the SNOTEL sites (i.e. trimming trees and removing brush) or the site could be relocated for various reasons. An illustration of this occurred during the WY2014 winter. The Brundage Reservoir SNOTEL site in north central Idaho traditionally shows very similar conditions to its surrounding SNOTEL sites (i.e. nearly all will show similar percentages of normal, if one is near 75% of normal [the 30-year average] the surrounding sites will be within a few percentage points). During the WY2014 season, it was noticed that all of the surrounding sites were near 75% of normal and the Brundage Reservoir SNOTEL site was indicating 130% of normal. After discussion with the NRCS, they indicated that had cleared trees and brush from near the measurement location. In an effort to remove some of the concerns associated with the TCA and DMBA, as well as a desire to develop a physically based method to quantify our enhancement efforts, we began a combined effort of high resolution gauging and modeling in the Payette River Basin.

Trace Element Analysis

IPC in conjunction with the Desert Research Institute (DRI) and Boise State University (BSU) have conducted a series of field campaigns to collect snow samples throughout the Payette River Basin target and control areas to analyze for trace levels of silver in the snow. Both organizations utilize high-resolution laser ablation mass spectrometry to identify elements (e.g. silver, iron, carbon and others) to determine if levels are higher than normal back ground levels 0 – 5 parts per trillion [ppt]). The goal of this process is to address IPC targeting efforts. Theoretically there should be no (or very low levels of) silver found in the snow samples from the control sites outside of the target area and samples from within the target areas should have periodic samples with moderate to high concentrations (5 – 100 ppt) of silver that represent cloud seeding events. When snow from a site is contaminated by dust, you may see a higher than normal silver concentration, but you also will see higher than normal levels of other crustal elements (e.g. iron, copper, zinc).

HIGH-RESOLUTION GAUGING AND MODELING

In an effort to establish a robust way to quantify enhancement efforts and optimize its cloudseeding operations, IPC joined with the National Center for Atmospheric Research (NCAR) in a multi-year study to determine precipitation enhancement due to winter orographic cloud seeding in the Payette River Basin. As part of this study, a target/control network has been established in the Payette River basin of Idaho using 15 SNOTEL gauges in or near the Payette River basin along with 14 IPC installed high-resolution precipitation gauges. Along with the development of the resolution network, NCAR has developed a cloudseeding module to predict optimum cloudseeding times (Xue et al 2013a, 2013b).

High Resolution Gauges

In addition to 15 SNOTEL sites in or near the Payette River Basin, IPC installed fourteen high-resolution precipitation gauges at seven locations throughout the region. Each site has a Geonor T-200B Series and a NOAH II, ETI Precipitation Gauge, as well as instrumentation packages to measure temperature, relative humidity, wind speed and direction. The gauges are capable of recording at a 0.01-inch resolution (manufacturers say 0.001 inches); they record every 10 seconds and transmit (via satcom) every 15 minutes. One problem associated with measuring precipitation in snowy environments is capping of the gauge during heavy snow events. This can result in under reporting of precipitation amounts, when the gauge opening is blocked by snow. IPC tested different heat tape design at the BSU, Department of Geosciences Cryosphere Labs to prevent/limit capping. Figure 6 shows the effects of capping on a gauge in the Payette River Basin prior to the developed heat tape design. Figure 7 shows the location of the IPC gauges and some of the SNOTEL sites and the Payette River Basin.

High Resolution Modeling

IPC contracts the with University of Arizona's (UA) Department of Atmospheric Sciences to run the Weather Research and Forecasting model (WRF) at the resolution of 1.8 km over the entire IPC service area. WRF is run 4 times a day for data to be used in wind, hydrologic, solar and cloudseeding forecasts. As part of the WRF model runs, we are able to develop cumulative precipitation and snowfall values. Figure 8 shows the WY 2012 forecasted and observed cumulative snow water equivalent (SWE) for the Big Creek Summit SNOTEL site. This SNOTEL site is outside of IPC's cloudseeding target area and serves to illustrate the 1.8 km WRF's skill at predicting precipitation quantities with very little difference between the observed and forecasted precipitation values. Figure 9 shows the WY 2012 forecasted and observed cumulative snow water equivalent (SWE) for the Deadwood Summit SNOTEL site. This site is located within the IPC's cloudseeding target area shows a distinct difference between observed and forecasted precipitation values. The Deadwood site observed values represents a ~20% increase in precipitation that may be attributable to cloudseeding; this estimate is in line with the 28% enhancement predicted by the TCA results for WY2012. As part of its contract with IPC, UA is researching the WRF models ability to provide accurate temperature forecasts in the vertical. This effort is a focus for IPC because it greatly affects the models ability to accurately represent at what elevation the model begins snow development and accumulation while helping it to maintain the proper snow cover throughout the season. In addition, UA is researching which of the microphysics packages available for WRF provides the best representations for temperature, precipitation and wind forecasts.

Figure 6. Precipitation gauge in the Payette River Basin, both pictures are the same gauge from a slightly different angle. The left picture shows the stand the gauges sit on, the lower platform is at 10 feet above the ground. The right picture shows the gauge completely capped after a heavy snowfall, and notice the snow is up to the 10-foot platform.

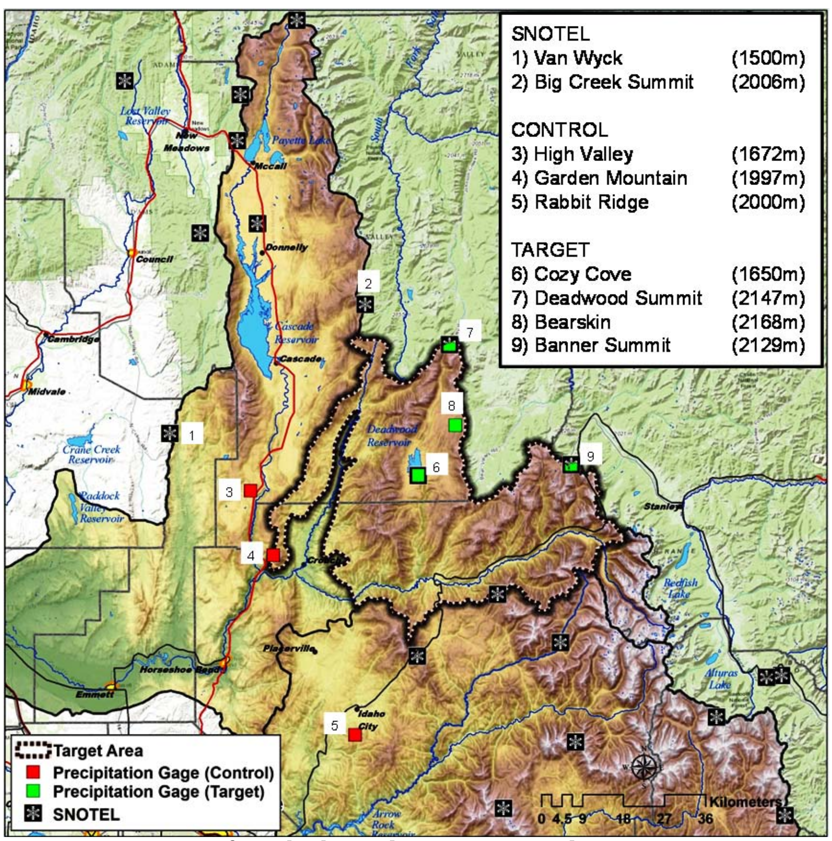

Figure 7. Location of IPC high-resolution gauges and SNOTEL sites.

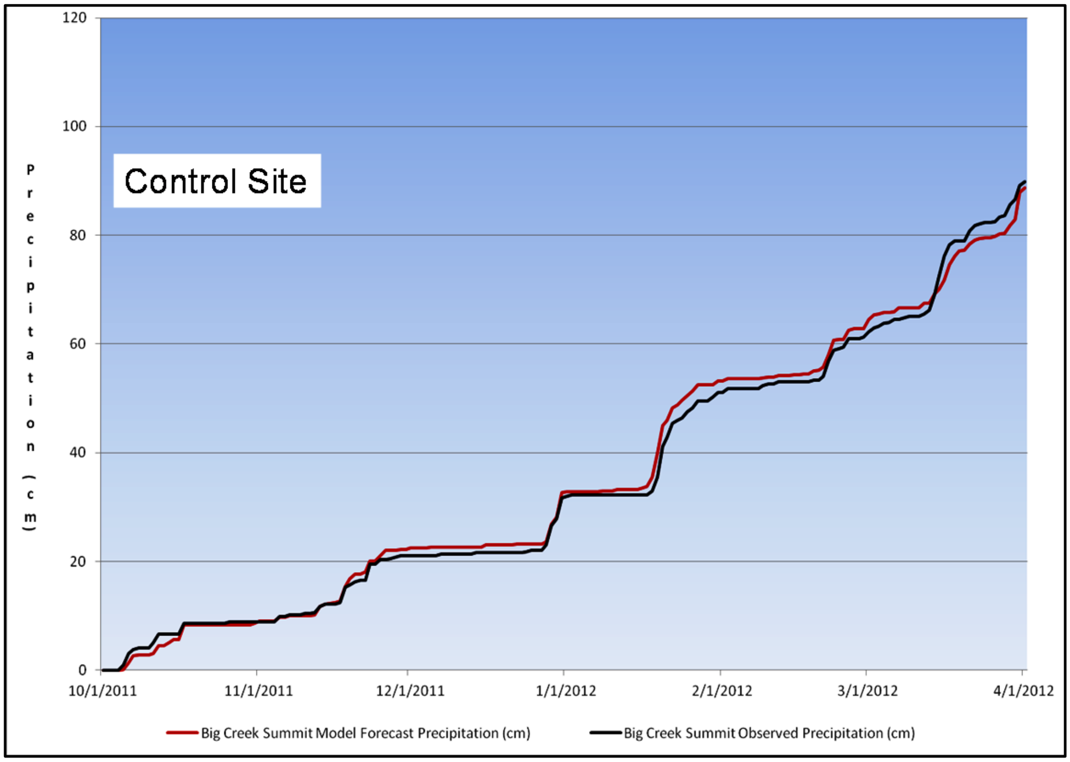

Figure 8. Comparison between the cumulative WRF forecast SWE and the cumulative observed SWE at the Big Creek Summit control site.

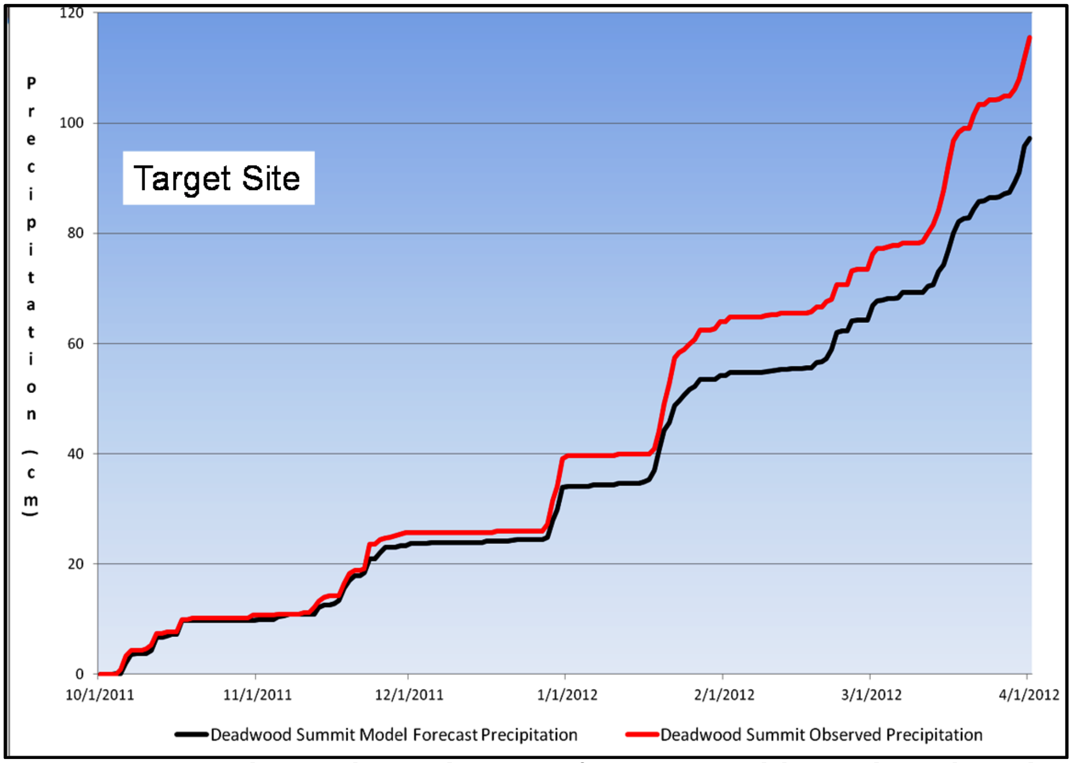

Figure 9. Comparison between the cumulative WRF forecast SWE and the cumulative observed SWE at the Deadwood Summit target site.

As part of its IPC research project, NCAR developed a module for the WRF model to predict when the optimum time for cloudseeding occurs, helping to enhance IPC operations and allowing for increased enhancement of basin wide snowpack (Xue et al, 2013a, 2013b). When combined together with the WRF, this module helps to provide two very useful spatially explicate products, basin wide yearly precipitation accumulation as well as basin wide yearly cloudseeding enhancements. Figure 10 shows the total precipitation forecasted by WRF (left picture) without cloudseeding and the increase from cloudseeding (right picture). Using ArcGIS to spatially extrapolate the increase in streamflow based upon projected precipitation increase, approximately 50,000 acre feet of water was produced. This falls in line with the slight increase predicted by the TCA analysis. Averaged across the 11 years (2003-2013) of cloudseeding, the average increase is ~300,000-acre feet for the Payette River.

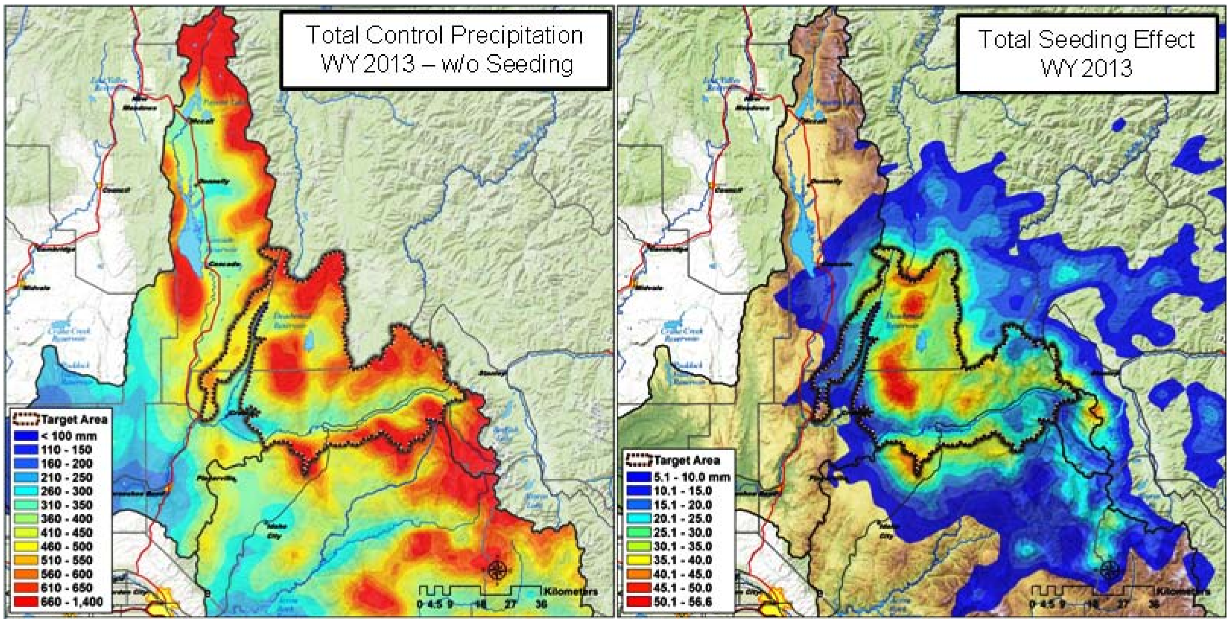

Figure 10. WRF derived cumulative precipitation without cloudseeding (left picture) and the increase in precipitation due to cloudseeding (right picture)

Future Work

Initial results from the first couple of years of the cooperative effort between IPC and NCAR have produced very favorable results; both IPC's ability to spatially quantify how much precipitation is falling in respective river basins as well as quantifying the amount of enhancement produced by IPC's cloudseeding activities. NCAR will continue refining how the module applies dispersion of the AgI and thus our understanding of our snowpack enhancement, while refining the cloudseeding case calling criteria to optimize IPC's efforts. Along with the work with NCAR, we will continue to work with BSU in a highly-focused effort to ground truth our targeting efforts through trace element analysis.

SUMMARY

IPC's cloudseeding program has proven to be very successful in enhancing snowpack throughout the Payette River Basin. Efforts with national level research institutes (e.g. NCAR, BSU and DRI) continue to show positive results for increasing the effectiveness of IPC's cloudseeding efforts. Increased effectiveness of the WRF model to accurately predict snowfall rates and durations along with producing highly precise basin-wide accumulations will enhance water and resource managers' ability to optimize their systems and ultimately help to keep IPC's electric rates some of the lowest in the country.

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