July 25, 2016

DRAFT Technical Memorandum

To: Deschutes Basin Study Work Group
Kyle Gorman, Region Manager for Oregon Water Resource Department
Rashawn Tama, National Resource Conservation Service

From: Niklas Christensen, PE, Watershed Professionals Network
Date: July 25, 2106

Subject: **Current Hydrologic Forecasting, Potential Improvements, and Next Steps**

1. Introduction

The Deschutes Basin Study is evaluating the impacts of climate change to the Basin's water resources and what actions may be implemented to optimize water availability for both instream and out of stream uses. Actions evaluated in the Basin Study include infrastructure changes (e.g., piping of canals) and transactional opportunities (e.g., leasing/transferring water). Improving hydrologic forecasting is also an action that may be implemented to optimize water availability for instream and out of stream uses. Although forecasting will not increase the total amount of water available, a better projection of what amount will be available in the future allows a water manager to make more informed decisions to optimize how the water is used (optimizing the use of water is described further in Section Primary Forecasting Opportunity).

As part of the Deschutes Basin Study, Watershed Professionals Network (WPN) organized a meeting with the personnel listed in Table 1 to discuss current snow observation and hydrologic forecasting procedures, as well as what potential improvements may exist for either. This memorandum, along with the meeting minutes in Attachment A, summarize the main discussion points from that meeting. Additionally, this memorandum proposes Next Steps that should be undertaken to implement forecasting improvements identified by the group.

While this memorandum focuses on what actions may be taken to increase the accuracy of forecasts, it should be noted that the utility of hydrologic forecasts are only as good as the degree to which the information can be put to use. For example, if a water manager was required to release a prescribed flow rate from a reservoir regardless of the inflow forecast, having a perfect forecast would have relatively little value since it would not actually impact operations. As such, the level of effort (budget, employees, etc.) to improve forecasting should be commensurate with the ability of a water manager's flexibility to manage to the forecast, and the ability of forecasting-based decisions to have a meaningful improvement in water resource conditions.

This memorandum is organized into the following sections:

1. Introduction
2. Primary Forecasting Opportunity
3. Current Forecasts Performed
4. Potential Improvements
5. Next Steps

Table 1. Personnel and agency[1] represented at April 13, 2016 Deschutes forecasting meeting.

Kyle Gorman, OWRD	Danny Marks, USDA	Mike Relf, Reclamation (phone)
Jonathan LaMarche, OWRD	Kate Fitzpatrick, DRC	Jennifer Johnson, Reclamation (phone)
Jeremy Giffin, OWRD	Rashawn Tama, NRCS	Chris Runyan, Reclamation (phone)
Tania Painter	Niklas Christensen, WPN	Cara McCarthy, NRCS (phone)
Tom Painter, NASA JPL	Melissa Webb, NRCS (phone)	

Notes: [1] Oregon Water Resource Department (OWRD), National Resource Conservation Service (NRCS), National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL), Deschutes River Conservancy (DRC), United States Bureau of Reclamation (Reclamation), United States Department of Agriculture (USDA), Watershed Professionals Network (WPN)

2. Primary Forecasting Opportunity

The author believes the primary opportunity for hydrologic forecasting to improve water resource conditions in the Basin is the Wickiup and Crane Prairie Reservoir winter inflow forecast, and therefore this opportunity is discussed in more detail here. The current protocol is for OWRD to use the regression-based forecast model developed by NRCS hydrologist in 1996 and present to the North Unit Irrigation District board an optimized release schedule which maximizes the probability of filling both reservoirs to the agreed upon target. From a water supply perspective, it is in NUID's best interest to minimize risk by erring on the conservative side of water releases as that's more likely to ensure the reservoir filling. The discussion, table, and figures below show increases in winter streamflow that could be achieved if the reservoirs were managed less conservatively and closer to the actual inflow forecast.

The Oregon Water Resource Department manages releases from Wickiup Reservoir with the goal of filling the two reservoirs by April 1 for the start of irrigation season. Filling the reservoirs before April 1 provides no water supply benefit, however, as shown in Figure 1 Wickiup Reservoir often reaches full pool before April 1. As shown in Figure 2, managing the reservoir conservatively like this results in lower winter flows early in the winter to ensure full pool. In WY 2015 for example, the average November and December release was 55 cfs, and as the reservoir reached full pool (achieved on March 9), releases ramped up in excess of 400 cfs. Having a forecast that accurately predicted the November through March inflow volume, and a program that allowed water managers to operate based on that forecast, could have allowed a steady 141 cfs release over that five month period (Table 2).

In WY 2014 the reservoir did not exceed 200,000 acre-feet until the start of April, however, it reached 190,000 acre-feet at the start of March and hence releases were in excess of 300 cfs for most of the month of March. Earlier in the inflow period releases from the reservoir were as low as 30 cfs (with a December average of 35 cfs), where a forecast based release would have been closer to 84 cfs. In WY 2016 the reservoir did not fill (primarily due to the low starting volume and residual drought conditions) and forecasting would not have been able to increase winter streamflow.

The WY 2014 and 2015 examples listed above are based on perfect forecasts which are unreasonable to expect. Although the Deschutes Basin is heavily groundwater-dominated, which lends itself to forecast accuracy, operations would need to be based on a probabilistic target of a forecast being met or exceeded (e.g., 90% chance of inflow being equal to or greater than). Additionally, in the Wickiup Reservoir example given here, it is likely some risk-sharing arrangement should be developed as well. It is within NUID's legal right to manage the reservoir to ensure filling, and any action to do otherwise should be supported by Basin Stakeholders. This "support" is discussed further under the Potential Improvements section, and could involve a framework to share the risk of Wickiup Reservoir potentially not filling.

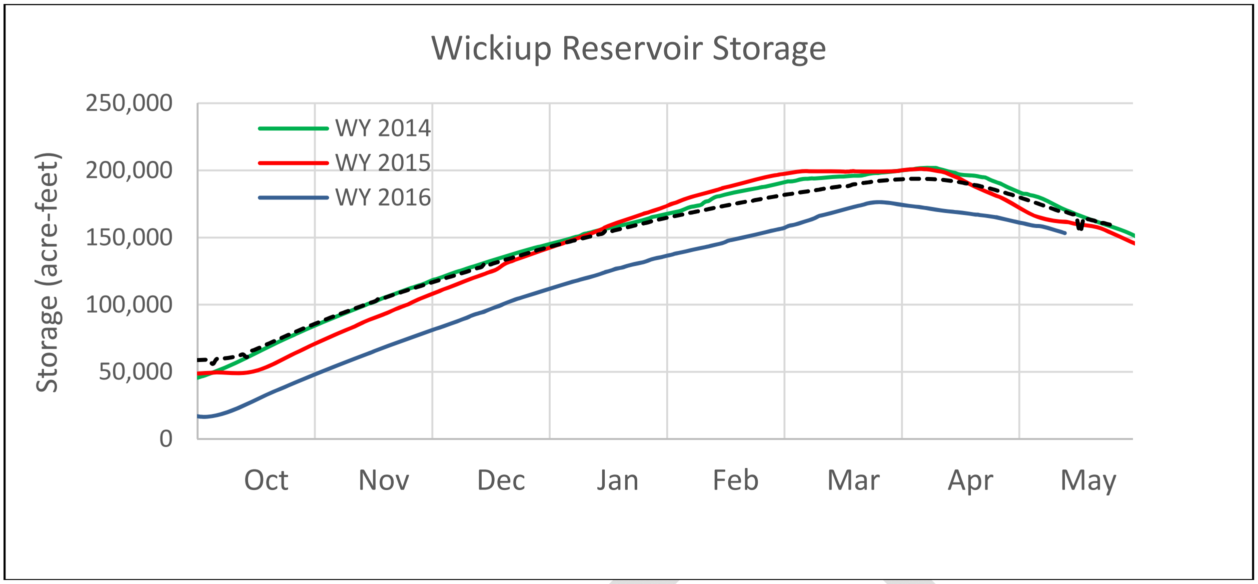

Figure 1. Wickiup Reservoir storage volume during water years 2014-2016 and average (2000-2016) year.

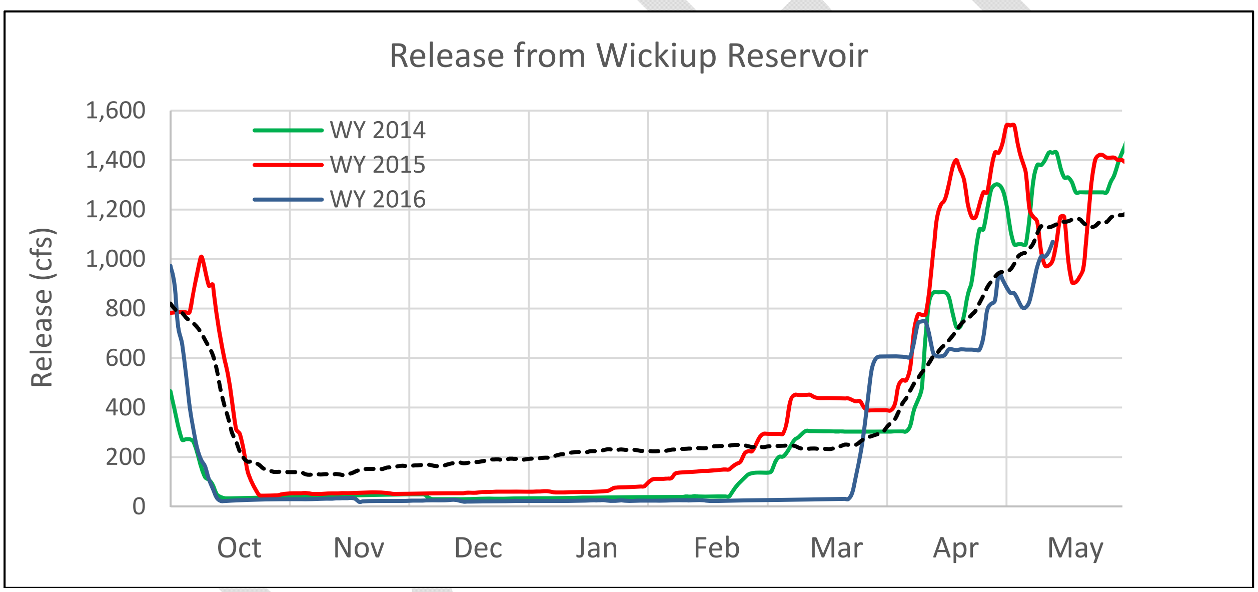

Figure 2. Daily releases from Wickiup Reservoir during water years 2014-2016 and average (1971-2016) year.

Table 2. Minimum daily release and minimum average monthly release during November through March, average monthly release

	WY 2014	WY 2015	WY 2016	Average[1]
Minimum daily release (Nov-Mar)	30.0	51.0	19.0	86.5
Minimum average monthly release (Nov-Mar)	34.8	54.0	23.0	142.2
Average monthly March release	254.3	387.4	77.0	244.6
Constant release (perfect forecast)[2]	83.8	140.6	35.2	203.5

Notes: [1] Average column based on water years 1971 through 2016.
[2] Constant release calculated by achieving the same April 1 storage volume as historical, but releasing a single, steady value during the November through March refill period.

3. Current Forecasts Performed

The forecasts currently being performed in the Basin are shown in Table 2 and 3. Although NRCS and Reclamation perform some analysis on forecast quality, both agencies indicated that additional analysis should be performed, including updating regression coefficients where applicable. This step (i.e. evaluating forecast quality through a retrospective analysis) is a recommendation in the Next Steps section.

Deschutes River:

Table 2. Agency performing, location, period, and method for forecast on the mainstem Deschutes River.

Agency	Location	Period	Method
OWRD	Wickiup	Nov. 1 – April 1	Regressions on SNOTEL and precip and inflows
NRCS	Benham Falls	April 1 to Sept 30	Regressions on SNOTEL, precip, streamflow
NWS RFC[1]	At mouth	__	Hydrologic modeling

Notes: [1]National Weather Service River Forecast Center

Crooked River:

Table 3. Agency performing, location, period, and method for forecast on the Crooked River.

Agency	Location	Period	Method
NRCS	Prineville Res.	Dec. – Aug.	Regressions on snowpack, runoff, and precip.
NRCS	Ochoco Res.	Dec. – June	Regressions on snowpack, runoff, and precip.
Reclamation	Prineville Res.	Jan. – Aug.	Regressions on snowpack, runoff, and precip.
Reclamation	Ochoco Res.	Jan. – Aug.	Regressions on snowpack, runoff, and precip.

In addition to the forecasts listed in Table 3, Reclamation has requested that the Northwest River Forecasts Center (NWRFC) start supplying a runoff volume forecast for both Ochoco Reservoir and Prineville Reservoir. The NWRFC forecast is currently in the developmental stage but should be available within the next year. Reclamation has also initiated a pilot project for the Crooked River that will investigate the risk of this system from climate change. A sub-task of the pilot project includes the University Corporation for Atmospheric Research (UCAR) developing experimental runoff volume forecasts for Prineville Reservoir.

4. Potential Improvements

Several potential improvements in data collection, forecasting methods, and forecast implementation were presented at the meeting and are discussed below.

Additional SNOTEL Sites

The Crooked River Basin above Prineville Reservoir covers approximately 2,700 square miles and ranges in elevation from 3,275 feet to 7,200 feet. The basin has two SNOTEL stations that are currently used for forecasting (green dots on Figures 3 and 4) plus one additional SNOTEL site that is not currently used for forecasting (purple dot on Figures 3 and 4). Adding additional SNOTEL sites would allow a more accurate assessment of actual snow water equivalent in the basin. As shown in Figures 3 and 4, the existing SNOTEL sites are only representative of the upper 10% of the basin's elevation, and do not cover the mountain area just to the east of Prineville Reservoir.

Deciding whether or not to add additional SNOTEL sites should include a thorough analysis of how and when the data will be used. SNOTEL data is typically used in statistical regression relationships that take 10 years (or greater) to train, and hence data from new SNOTEL sites may not be used in forecasting for years to come. Additionally, warmer wintertime temperatures associated with climate change are moving the elevation of the snowpack higher, and the existing SNOTEL sites are already predominantly focused on the upper elevation areas. Although the peak elevation of the basin is 7,200’ and the two highest SNOTEL stations are at elevations 5,850’ (Derr) and 6,230’ (Snow Mountain), only 2.2% and 1%, respectively, of the basin area is above these stations. The Next Steps section recommends performing a detailed cost:benefit analysis of the utility of adding an additional site.

Evaluating whether additional SNOTEL sites should be added should include evaluating why the existing Snow Mountain SNOTEL station is not currently used in the forecasting regressions. The Snow Mountain SNOTEL site covers a different geographical area and higher elevations than the two sites that are currently used and therefore would add valuable information to the forecasts. Reclamation has indicated that period of record was too short when the regression equations were originally developed, however, the site has now been operational for over 35 years (since 1979) and therefore could be added if the regression equations were updated.

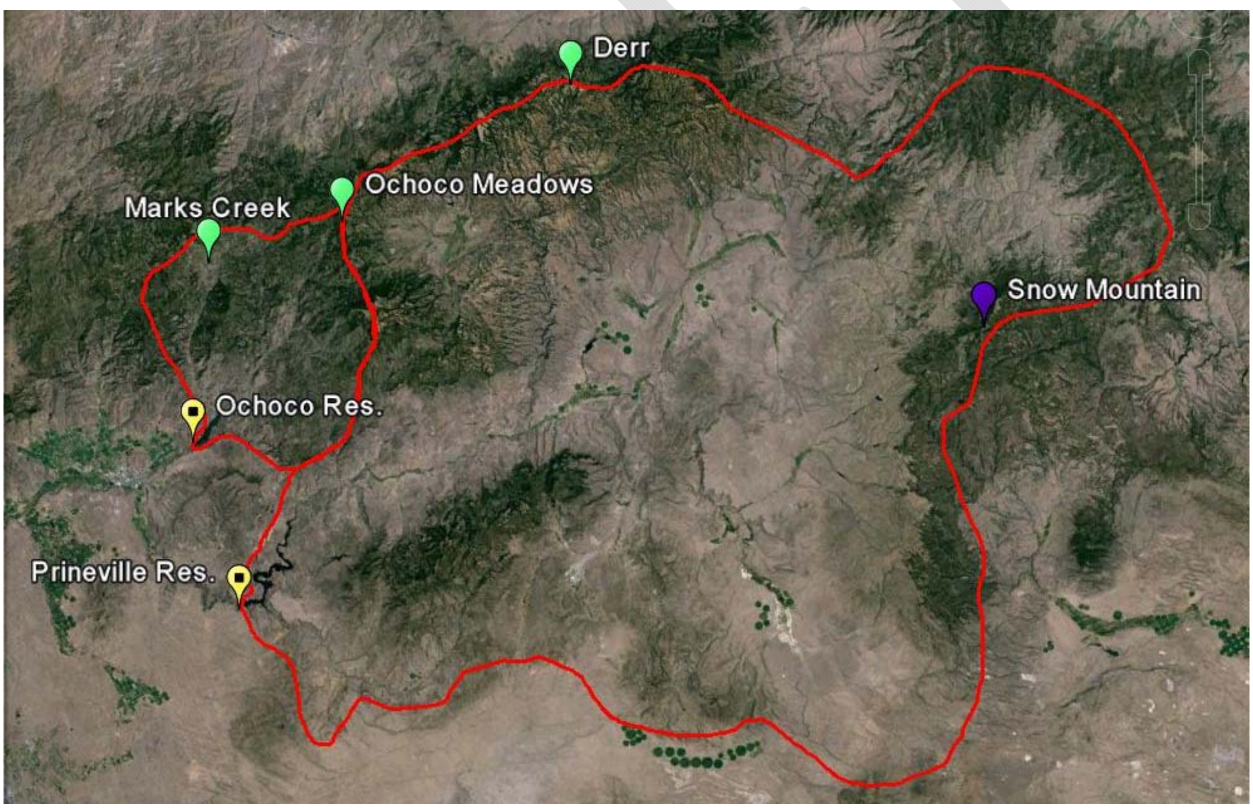

Figure 3. Location of actively used (green dots) and not used (purple dot) SNOTEL sites in the Crooked and Ochoco Basins.

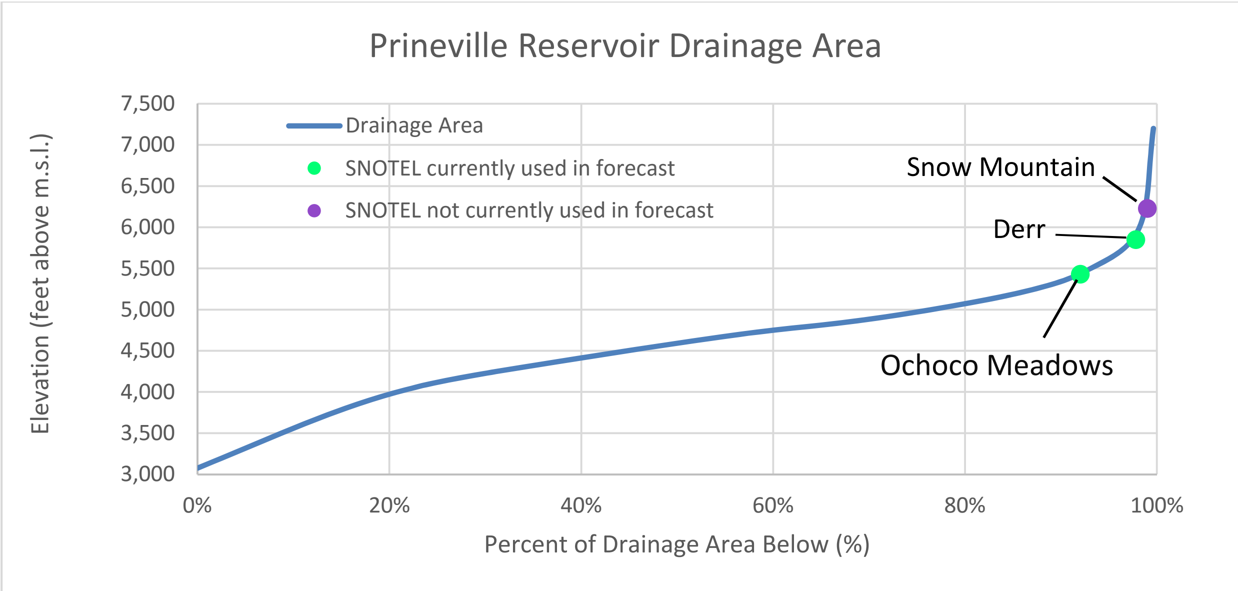

Figure 4. Area/elevation curve of Crooked River drainage area above Prineville Reservoir and elevation of SNOTEL sites in the Crooked Basin.

Implementing Aerial Snow Observations

The National Aeronautical and Space Administration Jet Propulsion Laboratory recently began an Aerial Snow Observation (ASO) program. The program uses an airborne Light Detection and Ranging (LiDAR) system to calculate the depth of the existing snowpack by subtracting the measured bare earth elevation from the measured elevation of snow surface. This requires a single bare earth measurement that all subsequent snow elevations are compared against. The snow elevation measurements can be made as infrequently as once per year (e.g., April 1) or can be flown more frequently as needed (e.g., the Tuolumne Basin currently has flights once per week during the melt season). Snow depth from the LiDAR measurement is currently being combined with modeled snow densities to derive the actual snow water equivalents, which in turn is used in a statistical analysis of SWE versus runoff. NASA ASO project lead (Tom Painter) estimated ASO flights in the Crooked Basis to cost roughly $300,000 per year.

Although the ASO program offers an incredible increase in spatial resolution compared to traditional SNOTEL measurements, it also has limitations that must be considered in implementing it in the Deschutes Basin. The Deschutes River is a groundwater driven system, and hence ASO snow depth measurements provide only a portion of the data required for a runoff forecast. Because of this, the author believes that if ASO-based forecasts were used in the Upper Deschutes Basin, it should be based on using the observed snow depths from ASO to update and correct physically-based hydrologic models.

The Crooked Basin is more of a snow-melt/surface-water runoff system, and therefore coupling ASO measurements with hydrologic modeling is less critical (i.e. a forecast based on snow cover would be more accurate in the Crooked Basin than the Upper Deschutes). Nonetheless, parameters other than snowpack (e.g., rain, antecedent soil moisture, etc.) still impact runoff in the Crooked and therefore would need to be accounted for outside of the ASO measurements.

Hydrologic Modeling

Well-calibrated physically-based hydrologic models have been shown to provide more accurate runoff forecasts than statistical regression-based forecasts, and therefore should be pursued as the long-term goal for forecasting methodology. Hydrologic modeling, however, is typically more time consuming and complex, and therefore a move towards this method should be driven in part by the need or ability to use the forecasts.

Nonetheless, the author believes that physically-based hydrologic model forecasts should be an end-goal for forecasting, and that the following activities may provide some justification (or intermediary steps) to move towards this. As part of the Basin Study, Reclamation is developing a well calibrated GSFlow hydrologic model of the Upper Deschutes (the GSFlow model does not include the Crooked Basin) that may be used in forecasting efforts. Additionally, universities and research organizations are developing experimental forecasts to test automated hydrologic modeling forecasting methods and may be able to perform forecasts for the Deschutes Basin using Reclamation's calibrated model. One organization, University Corporation for Atmospheric Research (UCAR), is currently seeking additional forecast locations based on interest from Reclamation and others. More information on the UCAR program can be found at: http://www.ral.ucar.edu/staff/wood/seasonal/

Forecast Locations

Although the major runoff locations of interest all have forecasts performed by one agency or another (Tables 2 and 3), the location that offers potentially the biggest water management opportunity based on forecast quality is not being performed by either NRCS or the NWS River Forecast Center. The Wickiup and Crane Prairie Reservoir winter inflow forecast is performed by OWRD only, and as described elsewhere in this document, the inflow forecast to those Reservoirs may provide benefits to winter flows in the Upper Deschutes. Since a primary objective of NRCS and NWS River Forecast Center is to provide forecasts, it may be worthwhile to have one of these agencies investigate the potential to provide a forecast at this location.

Create Framework for NUID to Share Risk of Wickiup Reservoir Not Having Adequate Storage Volume

The section below discusses opportunities to share NUID's risk of not having an adequate water supply in Wickiup Reservoir at the start of irrigation season. Historically the target has been a full reservoir on April 1, however, it should be noted that work in the Basin is moving towards evaluating NUID water supply as a whole (reservoir storage *plus* live flow) and future April 1 storage targets may be less than the full storage volume. That shift does not change the risk-sharing approach below, but would mean that a full reservoir may not be the target volume to use for release schedules or for when the risk-sharing arrangement is activated.

NUID receives approximately 75% of its water supply from Wickiup Reservoir, and hence from a water supply only perspective, it is in NUID's interest to store as much water as possible in the early part of the storage season. Specifically, a minimum release from the reservoir until full maximizes the probability of starting irrigation season with a full reservoir. Although an analysis of historic Wickiup Reservoir releases show higher than minimum releases usually still allows a full reservoir, it is NUID that takes the risk on what inflow to the reservoir will be from the present moment until the start of irrigation season. If future reservoir inflow is less than managed for, any deficit in storage volume from anticipated will require a reduction in use from NUID patrons.

Since increasing wintertime releases would benefit instream needs and some other stakeholders in the basin, there may be potential to share (i.e. take some of) NUID's risk of Wickiup Reservoir not filling. To meet regulatory requirements, irrigation districts in the basin are likely to invest in infrastructure projects specifically to increase wintertime streamflows. A preliminary analysis in the HCP shows that increasing streamflow below Wickuip Reservoir will cost approximately $XXM for every 100 cfs. Although not representative of all years, the example in the Primary Forecasting Opportunity Section of this paper for WY 2014 shows that streamflow could have been increased by 84 cfs during the winter (November through February) with no associated infrastructure projects or capital improvement costs. It should be stressed here that the 84 cfs is based on a perfect forecast which is unachievable, and in reality the streamflow increase would be some percentage less due to uncertainty in forecasting.

Basin partners sharing the risk of any water supply deficit would include the other irrigation districts, environmental interests, and of course NUID itself. These partnerships could include temporary water rights movements, which would provide senior water rights to NUID, or management agreements, which would reduce live flow diversions in senior irrigation districts and leave live flow for NUID. Together, they would ensure a minimum volume of water available to NUID. Improved forecasting will be critical to understanding when (i.e. which years) and what extent (i.e. what volume of water) partners should act under these agreements. Although proposing a potential risk-sharing agreement is beyond the scope of this memorandum, a risk-sharing agreement would target a frequency (e.g., 1 in 10 years) and level of risk to stakeholders (e.g., irrigation districts and instream needs could agree to a 5% reduction in their demand). A detailed hydrologic analysis is proposed in the Next Steps Section that would quantify increases in streamflow and potential decreases in diversions as a function of risk.

Evaluate Existing Forecasts and Update Regression Equations as Needed

Based on discussions at the April 13th meeting, it does not appear that OWRD nor NRCS have evaluated the accuracy of their historical forecasts. Performing this type of analysis would determine the accuracy and bias (if any) of forecasts and would inform what additional steps should be taken. If the forecasts are excellent, for example, then its unlikely Aerial Snow Observations or hydrologic modeling should be actively pursued. This analysis could be coupled with updating the regressions to include recent data as well as evaluating potential streamflow benefits and risk for a forecast based release for Wickiup Reservoir.

Increase Ability to Use Forecasts for Water Management

As stated in the introduction section of this document, the ability of hydrologic forecasting to contribute to meaningful improvements in water management are based on the degree to which forecasts can actually be used in decision making. For example, if a water manager is required to release (or store) a prescribed amount of water regardless of a forecast, then having a good forecast will not actually have the ability to impact the amount of water stored or released.

Specific actions are not discussed in detail here, but this is a general recommendation that may be useful as the Basin Study thinks holistically about the suite of actions in the Basin that may improve water resource conditions.

5. Next Steps

Based on the potential improvements discussed above, the 'next steps' below are recommended. It should be noted that some of the next steps proposed are agency specific, where it will be the choice of that agency to implement the next steps, while others are more general in nature and should be discussed with basin stakeholders for overall interest.

1. Perform a retrospective analysis of forecasts to evaluate forecast skill. Depending on results of analysis, expand regression variables as appropriate.

2. Depending on results from step one above, develop a framework where NUID can share the risk of Wickiup Reservoir not having enough water at the start of irrigation season with other stakeholders. This framework can then be used for discussion with NUID board members and other stakeholders to evaluate the acceptability of a potential risk sharing agreement. This step should include a detailed analysis of the historical hydrologic record to evaluate potential increases in wintertime flows and shortfalls as a function of level of risk (i.e. managing to a 99% probability of filling will result in lower streamflows and shortages than managing to a 90% probability).

3. NRCS implement a winter inflow forecast for Wickiup and Crane Prairie Reservoir.

4. Evaluate the cost-benefit of additional SNOTEL or automated weather sites in the Crooked River basin. This step is currently being performed by Reclamation.

5. OWRD, NRCS, and USBR evaluate the results from the retrospective analysis of forecasts. Depending on accuracy of forecasts, discuss a long-term plan to move away from regression equations to physically-based hydrologic modeling. If moving to modeling, could incorporate ASO and/or leverage UCAR's experimental forecast program.