TECHNICAL MEMORANDUM

Upper Crooked River Basin – SNOTEL Memo

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1.0 INTRODUCTION

1.1 Introduction:

The purpose of this Technical Memorandum (TM) is to provide a general overview of the potential benefits of installing additional Snow Telemetry (SNOTEL) stations within the Upper Crooked River Basin. This TM was funded under the direction of the Upper Deschutes Basin Study Team and will address the following topics:

- Overview of Current Snow Course/SNOTEL System
- Potential Benefits of Additional SNOTEL Data
- Potential Additional SNOTEL Locations
- Factors Relevant to Implementation
- Potential Future Actions

1.2 Stakeholders:

This TM was developed with collaboration from the following stakeholders:

- Ochoco Irrigation District (OID)
- Bureau of Reclamation (Reclamation)
- National Resources Conservation Service (NRCS)
- Oregon Water Resources Department (OWRD)
- Upper Deschutes Basin Study Team

2.0 OVERVIEW OF CURRENT SNOW COURSE/SNOTEL SYSTEM

The following describes the existing snow course and SNOTEL system in the Upper Crooked River Basin. An overview map of the system can be found in Attachment A.

2.1 Upper Crooked Watershed:

For purposes of this TM, the Upper Crooked Watershed will be described as the contributing watershed upstream of the City of Prineville, Oregon. The watershed is further delineated into two sub-watersheds that drain either into Ochoco Reservoir or into Prineville Reservoir.

The watershed area above Ochoco Reservoir is approximately 300 mi^2 with a mean basin elevation of 4,435 feet, minimum elevation of 3,010 feet and a maximum elevation of 6,950 feet.

The watershed area above Prineville Reservoir is approximately 2,760 mi^2 (of which, approximately 500 mi^2 is probably non-contributing) with a mean basin elevation of 4,530 feet, minimum elevation of 3,075 feet and a maximum elevation of 7,200 feet.

2.1 Existing Snow Courses:

There are three snow courses currently measured in the Upper Crooked River Watershed: Derr, Marks Creek, and Ochoco Meadows. Unlike SNOTEL stations, snow courses are measured manually and typically consist of approximately ten snow water equivalent (SWE) measurements that are averaged. The location of the snow courses can be found on the map provided in Attachment A of this document. The Marks Creek and Ochoco Meadows snow courses are located within the Ochoco Reservoir watershed while the Derr snow course is located in the Prineville Reservoir watershed. Ochoco Meadows is located east of the Marks Creek snow course and along a ridge dividing the Ochoco Reservoir and Prineville Reservoir watersheds. The Derr snow course is located in the northeastern part of the Prineville Reservoir watershed near the head of the North Fork of Beaver Creek. Monthly snow water equivalent (SWE) measurements for each snow course are collected by OID during the January through May time period, with results provided to NRCS and Reclamation.

Additional information for these snow courses was obtained from the NRCS website (http://www.wcc.nrcs.usda.gov/index.html) and can be found in Table 1. The percent of the Ochoco Reservoir and Prineville Reservoir watershed area below the elevation of the snow course is also provided for reference.

Table 1. Existing Snow Courses in the Upper Crooked River Watershed

Snow Course	Station ID	Lat./Long.	Elevation (ft)	Period of Record	Watershed Area % Below (PRV/OCH)
Marks Creek	20E01	44.49/ -120.39	4,850	1938-Present	70% / 73%
Ochoco Meadows	20E02	44.43/-120.34	5,190	1928-Present	87% / 88%
Derr	19E03	44.45/-119.93	5,860	1937-Present	97% / 98%

2.2 Existing SNOTEL Sites:

There are three currently operated SNOTEL sites located within the Upper Crooked River Watershed: Ochoco Meadows, Derr, and Snow Mountain. The Ochoco Meadows and Derr SNOTEL sites are in similar locations as their respectively-named and previously mentioned snow courses, which is a common occurrence to allow for record extension techniques. Record extension provides a method to synthesize a longer period of record for a newer SNOTEL site using the longer period of record of the nearby snow course. The Snow Mountain site is located

in the far eastern side of the watershed near the head of the South Fork of Beaver Creek and the watershed boundary. The runoff volume forecast generated by Reclamation does not currently utilize SNOTEL data from the Snow Mountain site due to the short record of this site during the development of the equations. The additional period of record for this site gained since the development of the forecast equations may provide an opportunity to increase the skill of the forecast. Additional analysis into whether improvements to the current forecast equations can be obtained by including the Snow Mountain data should be completed. Typically, the forecast skill refers to how well the forecast estimated the runoff volume compared to what actually occurred. Additional information for the SNOTEL sites was obtained from the NRCS website and has been provided in Table 2, including the percent of watershed area below the elevation of the SNOTEL site.

Table 2. Existing SNOTEL sites in the Upper Crooked River Watershed

SNOTEL	Site Number	Lat./Long.*	Elevation (ft)	Period of Record	Watershed Area % Below (PRV/OCH)	1980-2010 Avg. WY Precip. (in.)
Ochoco Meadows	671	44.43/-120.33	5,430	1980-Present	92% / 94%	29.0
Derr	440	44.45/-119.93	5,850	1980-Present	97% / 98%	29.6
Snow Mountain	767	43.95/-119.53	6,230	1978-Present	99% / 100%	27.9

3.0 POTENTIAL BENEFITS OF ADDITIONAL SNOTEL DATA

The following section provides a summary of the potential benefits additional SNOTEL data would provide as it relates to runoff volume forecasts, mid-elevation snow information, and flood operations.

3.1 Runoff Volume Forecasts

Runoff volume forecasts for Ochoco and Prineville Reservoirs are currently generated by Reclamation and NRCS. In the future, runoff volume forecasts are also planned to be provided by the Northwest River Forecast Center (NWRFC), however, this effort is still in the development phase.

Reclamation generated forecasts are developed by utilizing Multiple Linear Regression (MLR) and Principal Component Analysis (PCA) methods. NRCS generated forecasts are developed using PCA methods. The NWRFC forecasts are currently being developed using a trace ensemble method to predict runoff volumes.

All forecasting methods described above utilize a combination of meteorological data (including snow course/SNOTEL data) to develop runoff volume forecasts or to calibrate hydrological

models (in the case of NWRFC forecasts). Typically, the skill of a runoff volume forecast is highly correlated to the quality of meteorological data. As a result, additional data provided by a new SNOTEL site or sites is likely to improve the skill of the runoff volume forecast for both Ochoco Reservoir and Prineville Reservoir. It should be noted that a sufficient period of record (10 years or more) of any new site would be necessary before an improvement in the skill of the forecast would be realized.

3.2 Mid-Elevation Snow

Table 3 provided below summarizes the cumulative elevation distribution for the watershed above Prineville Reservoir and illustrates how the majority of the watershed is below an elevation of 5,500 feet. Currently, five of the six snow data collection sites in the Upper Crooked River Basin are located at an elevation that falls within the highest 20% of the watershed (5,000 to 7,200 feet). Although these locations are positioned well for measuring the deepest snowpack within the basin, they do not provide snowpack data for a large portion of the watershed that can accumulate snow. For example, the watershed above Prineville Reservoir has approximately 72% of the total watershed area falling within the 4,000-5,500 mid-elevation band, but only two snow courses are located within this zone (at elevation 4,850 feet and elevation 5,450 feet). Snow depths within this mid-elevation band can vary dramatically year-to-year and this band is typically where the rain/snow transient zone occurs. In addition, runoff of the mid-elevation snowpack generally initiates before runoff at higher SNOTEL sites is noticeable. Any additional measurements in this mid-elevation zone would be beneficial.

Table 3. Cumulative Elevation Distribution of the Watershed above Prineville Reservoir

Elevation (ft)	Watershed Area Above Elevation (WAAE)	Change in WAAE from Previous Elev.
3075	100%	-
3500	93%	7%
4000	79%	14%
4500	55%	24%
5000	23%	32%
5500	7%	16%
6000	2%	5%
6500	1%	1%
7200	0%	1%

During the winter of 2015/2016, SWE values measured at Ochoco, Derr, and Snow Mountain SNOTEL/snow course sites indicated deep snowpack values at the higher elevations of the basin while the Marks Creek snow course indicated minimal snowpack in the 4,800-foot elevation zone. Although the measurements at Marks Creek were accurate for the watershed at that

location, personal reports from residents in the Big Summit Prairie area (at an approximate elevation of 4,500 feet) indicated a much deeper snowpack of approximately two-feet.

With indicators for mid-elevation snowpack in the Upper Crooked River Watershed being limited to the Marks Creek snow course measurement (which as shown above can be an unreliable predictor of mid-elevation snowpack in the entire basin), additional SNOTEL data collected in the mid-elevation zone would be likely to provide an increase in the skill of the runoff volume forecasts.

3.3 Flood Operations

Runoff volume forecasts are utilized by reservoir operators to guide the refill rate of both Ochoco and Prineville Reservoirs based on the estimated runoff volume remaining in the basin. In addition, near real-time data provided by a SNOTEL site can be utilized during flood operations. Typically, seasonal peak flows occur in the Upper Crooked River Basin during mid-elevation rain-on-snow events where information indicating the elevation of the snowline and precipitation are critical. Additional mid-elevation snowpack, precipitation, and temperature data would help reservoir operators balance the refill and release of water during each runoff season. For any new site identified, any senor equipment that could be utilized during real-time reservoir operations should be included.

4.0 POTENTIAL ADDITIONAL SNOTEL LOCATIONS

4.1 Identification of Potential Sites

Potential SNOTEL site locations were developed through discussions with OID and Reclamation personnel with experience operating both Ochoco and Prineville Reservoirs. Although not completed during the development of this TM, additional analysis would be required at a later date to determine optimal locations for the potential sites. During the completion of future analyses, more site specific criteria should include investigation into the optimal elevation, aspect, vegetation type, exposure, and soil type of the location. In addition to these criteria, land ownership as well as locations of existing stream gaging and meteorological data collection sites in proximity to the new sites should be identified.

4.2 Utilization of Existing Out-of-Basin SNOTEL Sites

Existing SNOTEL sites that are not located within the Upper Crooked River Basin (i.e. the John Day River watershed) may provide a low-cost/high-benefit opportunity to improve the skill of the runoff volume forecast. During the development of forecast equations, utilization of meteorological data outside the forecast basin can increase forecast skill if correlations between the out-of-basin data and basin runoff are high. An analysis to determine if any out-of-basin sites could be utilized in the Upper Crooked River Basin forecasts was not completed during this task due to limited budget but should be completed before funding for additional sites is secured.

4.3 Conversion of an Existing Snow Course to SNOTEL Site

Conversion of an existing snow course to a SNOTEL site can provide near real-time data that also takes advantage of the historical record provided by the snow course. Typically, correlations between the snow course and SNOTEL measurements can be developed within 5 to 8 years, at which time the snow course could be discontinued if wanted. Snow course measurements are typically limited to the first of the month. During years in which the forecast changes dramatically between monthly measurements, real time data provided by a SNOTEL site would enable additional mid-month forecasts to help in reservoir operator's decision making. Another advantage to converting an existing snow course into a SNOTEL is that the existing special use permit of the snow course could be used to streamline the permitting process. The Marks Creek snow course may be a candidate for conversion to SNOTEL and this conversion has been encouraged by OWRD.

4.4 New In-Basin SNOTEL Sites

Possible new in-basin SNOTEL sites were chosen based on locations and elevation bands within the watershed that currently lack snowpack condition data. In additional to this, new sites were chosen based on their ability to develop elevational transects with existing SNOTEL sites to provide information about the variation in snowpack between two known elevations. Table 4 provided below lists the recommended "areas" for additional snowpack data collection which may improve runoff volume forecasts in the Upper Crooked River Watershed. The table is sorted from the highest priority area at the top of the table to the lowest priority area at the bottom of the table but, future analysis will be required to determine the optimal site location(s). In general, an optimal site will best represent the hydrology of the basin not currently captured by an existing station. Looking at Table 4, the 12 Mile Area is ranked higher than the Maury Mountain Area, but it should be noted that this is based on a high-level analysis and that after a more in-depth analysis is completed this ranking may be different. The general location of these areas are identified on the map provided as Attachment A.

Table 4. Possible New In-Basin SNOTEL Areas within the Upper Crooked River watershed.

Name	Lat./Long.	Preliminary Elevation (ft.)[1]	Miles from OCMO[2]	Miles from DERR[2]	Miles from SNWO[2]
12 Mile Area	43.95 / -119.98	~4,500	38	34	22
Big Summit Prairie Area	44.36 / -120.21	4,000-5,000	8	16	44
Wolf Mountain Area	44.33 / -119.72	4,500-5,500	31	12	28
Lookout Mountain Area	44.33 / -120.37	5,000-5,500	8	24	48
Maury Mountains Area	44.05 / -120.45	4,500-5,500	28	38	46
Mill Creek/Ridge Road Area	44.51 / -120.55	5,000-5,500	12	32	63

1. Preliminary Elevation was identified based on a rough estimation of the mean elevation near the general location of the site. The optimal elevation of the site may be different after a more thorough analysis has been completed.
2. OCMO = Ochoco Meadows SNOTEL, DERR = Derr SNOTEL, SNWO = Snow Mountain SNOTEL

5.0 FACTORS RELEVANT TO IMPLEMENTATION

5.1 Permitting

Installation of a new site will have varying degrees of permitting requirements based on site location. For example, if a site is located on United States Forest Service (USFS) or Bureau of Land Management (BLM) land, the permitting process will require completion of a NEPA analysis which may take up to two years to complete. Permitting and legal constraints posed by land ownership should be part of the site selection analysis, and may cause the most optimal data collection site to be infeasible. The final location selected should ensure that operation of the SNOTEL will continue in perpetuity due to the length of time necessary before the record can be incorporated into forecast equations.

5.2 Installation Costs

Total cost of a particular site depends on the type of data collected, access to the site and permitting and regulatory requirements. Some of the permitting costs may be covered by the governing agencies, but costs associated with the purchasing of equipment are typically the responsibility of the applicant. In general, and based on correspondence with NRCS, a standard SNOTEL site that measures temperature, precipitation, SWE, and includes near real-time monitoring via telemetry costs approximately $30,000.

5.3 Operation and Maintenance (O&M)

Based on correspondence with NRCS, typical annual O&M costs for a SNOTEL are approximately $3,000 and are generally paid for by the applicant. Additional discussion on paying for O&M costs as well as any cost sharing opportunities would need to be addressed during final analysis.

6.0 POTENTIAL FUTURE ACTIONS

If additional SNOTEL sites are pursued in the future and based on the findings provided in this TM, the following is a list of future actions that may be warranted:

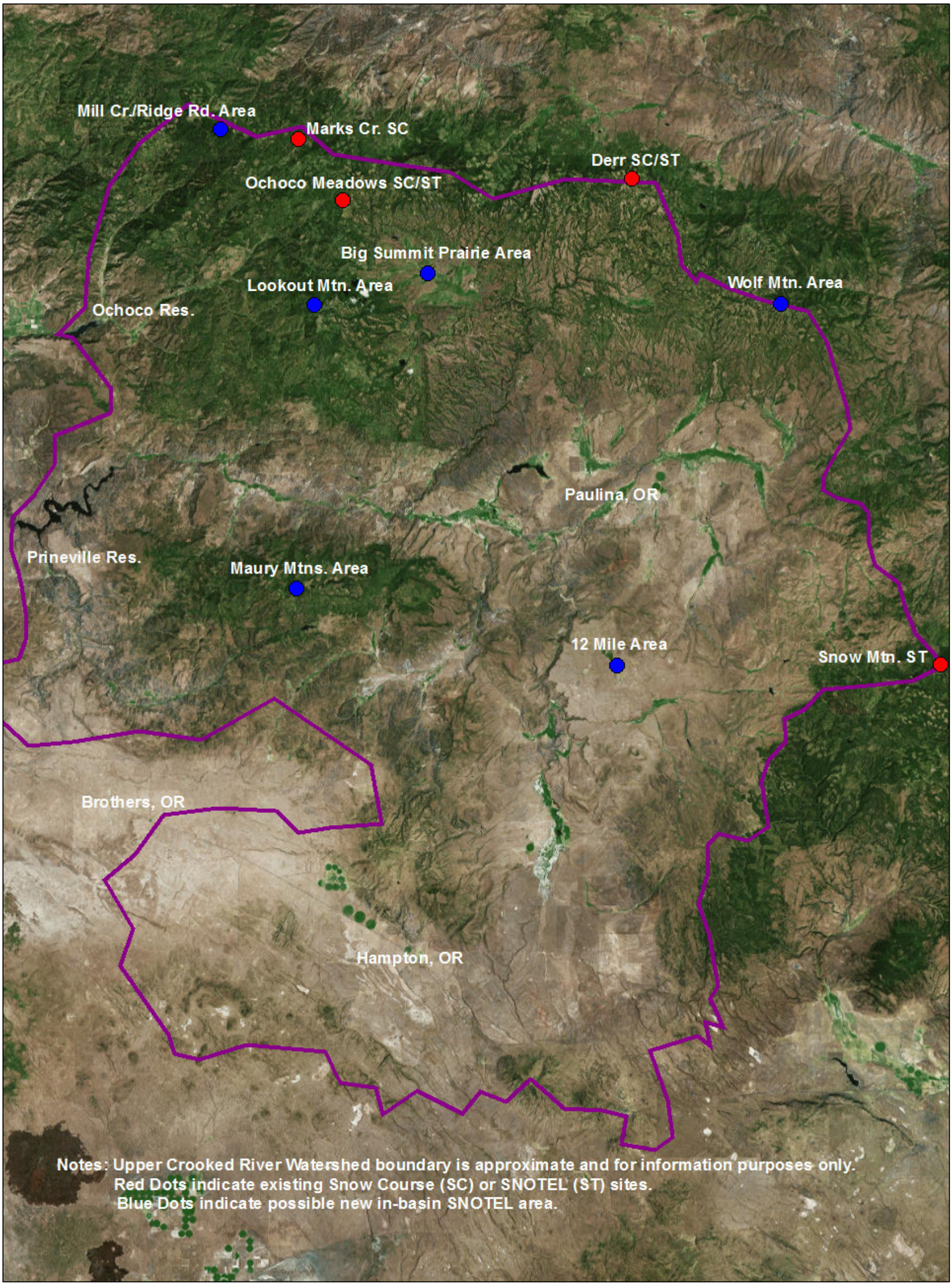
- Investigate existing out-of-basin SNOTEL sites to determine whether opportunities exist to include existing sites into the Upper Crooked River Basin forecast equations to provide a low-cost/high-benefit method of improving runoff volume forecasting skill.
- Determine if conversion of the Marks Creek snow course to a SNOTEL site is a viable option to improve runoff volume forecasting and aid in real-time reservoir operation.
- Develop Upper Crooked River Watershed specific information including updated elevation distribution maps, area/elevation curves, precipitation distribution maps, snow cover maps, location of transient snow zones, aspect analysis, soil maps, Threatened and Endangered (T&E) species land use, cultural resources and land ownership maps to aid in new in-basin SNOTEL site determination.

- Consider identified potential SNOTEL sites (Table 4) and more detailed site-specific information with assistance from NRCS (Oregon) to determine optimal new SNOTEL site locations based on target elevation, aspect, vegetation type, exposure, soil type, access, and land ownership of the location.
- Determine the appropriate funding mechanism(s) for additional studies, site installation, and annual O&M costs.
- Coordinate with all appropriate regulatory agencies/landowners about specific permitting requirements and costs.

Attachment A

Upper Crooked River SNOTEL/Snow Course Map

Upper Crooked River SNOTEL/Snow Course Map



0 4.75 9.5 19 Miles

RECLAMATION
Managing Water in the West