ArcGIS TECHNIQUE TO EVALUATE THE SNOTEL DATA NETWORK

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Abstract

The Natural Resources Conservation Service (NRCS) National Water and Climate Center (NWCC), in collaboration with Portland State University (PSU), is developing a tool to evaluate the spatial distribution and representativeness of the SNOw TELemetry (SNOTEL) network in the mountainous areas of the Western United States, with respect to physical basin characteristics. This tool will assist in determining possible locations of new data sites that will fill data voids, may improve the accuracy of water supply forecasts, and will allow for better parameterization of delineated spatial units used in a physically-based hydrologic model. The current SNOTEL network sites are focused in the higher elevations of the basins and are located in areas where the snowpack snow water equivalent (swe) can be used as a model parameter throughout the forecast season. Many of these sites were located at or near existing snow courses that were established in the early years of the Snow Survey and Water Supply Program. These remote sites work fine as index parameters for statistical forecast models. However, there is a lack of spatial and elevational definition for precipitation and temperature parameters over most of the Western watersheds. To exploit more effectively the benefits of these remote climate data collection platforms as input into a distributed-parameter hydrologic model, it is important to apply a technique that can be used to determine objectively the most advantageous locations. The technique analyzes a set of spatial data layers, including, but not limited to: Digital Elevation Models (DEMs), annual precipitation, vegetation types, forest density, land ownership and management, accessible roads, and basin aspect. From the combined, inherent influences of the spatial layers on watershed runoff and the current data collection density of the watershed, the forecast hydrologist assigned to the basin and NRCS field personnel are able to make an informed judgment as to where additional remote data collection sites might be located throughout the Western U.S.

INTRODUCTION

The Snow Survey and Water Supply Forecasting Program (SSWSF), administered by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), had its beginnings in the early 1900's, but the current responsibility to conduct snow surveys and provide forecasts of irrigation water supplies was authorized by Congress in 1935 (Helms et al., 2008). Since that time, NRCS has coordinated the cooperative effort of snow surveying and water supply forecasting in the contiguous Western U.S., including Alaska. The forecasting operations now reside in the National Water and Climate Center (NWCC) in Portland, Oregon.

Forecasting the seasonal water supply that flows from Western watersheds is an important function of NRCS. These forecasts are developed for hundreds of basins in the Western United States and are used by water managers to efficiently utilize their limited water resources. NRCS has historically developed statistical, regression-based models to estimate the volume of water that is expected from the mountain snowpack each runoff season. There are several parameters that are used to develop these equations, including seasonal rainfall, temperature, soil moisture, and climate teleconnections, but the snowpack snow water equivalent (swe), or the amount of water present in the snowpack, is the most important index used to estimate the expected runoff. Western snow surveyors have been installing and measuring snow courses for the purpose of estimating water supplies for over 100 years.

Serviceability and accessibility were the two key considerations used by early snow surveyors when establishing new snow courses. Additionally, most of the snow courses were placed at higher elevations where the snow information would be available throughout the entire forecasting season. This is important if the snow courses are to be valuable and consistent indices for snowmelt runoff throughout the forecast season.

Many water users and managers are no longer content to have water supply forecast updates once or twice a month, which is a limitation of the manually read snow course measurements. They have requested more frequent updates. The desire for more data and personal safety concerns were the driving forces in developing the SNOTEL network. Daily snowpack and climate information gathered from these sites allows for more frequent forecast updates, along with the ability to use hydrologic models to develop hydrograph-based products, such as peak flow, timing of peak, and streamflow threshold flows, which are often times critical in managing the water resources.

NRCS is in the process of implementing the Precipitation Runoff Modeling System (PRMS) on several basins over the Western U.S. The framework that will support this effort is the USDA Object Modeling System (OMS) (Ahuja et al., 2005). The successful application of PRMS will allow the NWCC forecast hydrologists to use daily snow and climate data to provide daily water supply products through hydrograph analysis. PRMS is a modular design, distributed parameter, physical process watershed model (Leavesley and Stannard, 1995; Leavesley et al., 2005). The NRCS forecast hydrologists have found through experience that the current SNOTEL network, though providing valuable data for hydrologic modeling, is sometimes spatially challenged when dealing with the input needs of PRMS. The network needs additional sites to distribute precipitation and temperature adequately across the forecast basins. It is no longer sufficient to have sites located just at existing snow courses, unless it can be shown that they have the capability to improve the forecast products and reduce forecast error.

Conceptually, there are at least three main sources of forecast error. These are: (1) climate error (uncertainty about subsequent weather conditions), (2) model error, and (3) data error. Developing a consistent process of adding additional climate measurement sites throughout the West is an attempt to deal with the data error and the model calibration error component of the model error. It has been documented that different configurations of precipitation gage locations lead to different forecast errors because each configuration gives different errors in the estimate of the precipitation at spatial grid points (Peck and Schaake, 1990). The variability of the long-term mean precipitation over an area can be accounted for in part by the digital elevation model (DEM) and in part by the mean annual precipitation layer. A DEM is a digital representation of ground surface topography or terrain. The basin analysis application is a tool that can be used to suggest climate site locations, based on hydrologic and climatic spatial characteristics, combined with expert knowledge of field conditions.

The main criterion of the Geographic Information System (GIS) basin analysis tool is to identify and fill data voids to ensure more complete representation of hydrologically relevant characteristics in a basin. The results should be improvement in the spatial distribution of inputs to a simulation model. Improvements in forecast accuracy may result from this, but it is difficult to predict this outcome.

BASIN ANALYSIS PROCESS

The forecast hydrologists at NWCC have developed a prototype analysis procedure to locate additional SNOTEL sites. This procedure relies on the use of spatial data layers in the GIS application, ESRI® ArcGIS. This prototype procedure is both objective and subjective. It uses several spatial data layers, in a consistent manner, to aid in defining the hydrologic, climatic, and management characteristics of the basins being studied. These layers may include DEMs, Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 1994, and PRISM Climate Group, 2004) annual precipitation, basin boundary information, land management, land ownership, climate sites, streamflow gage locations, land use, vegetative cover, forest canopy, aspect, slope, soils, water bodies, streams, accessible roads, among others. The procedure is flexible enough that any pertinent data layer can be used.

The objective part of the basin analysis process consists of two parts: (1) using the DEM, PRISM, and vegetation layers as the physical basin characteristics being considered; and (2) using land ownership, land management, and road layers as constraints on where sites can be located. The slope, aspect, and basin boundary layers are initially developed, using standard ArcGIS functions implemented within the GIS Weasel. The GIS Weasel was designed to aid in the preparation of spatial information for input to lumped and distributed parameter hydrologic or other environmental models (Viger and Leavesley, 2007).

The subjective portion of the analysis is based on the snow survey staff's model calibration and field experience. Despite the computer results, observed field conditions are always beneficial as a check to the validity of the GIS analysis.

Portland State University (PSU) is under contract with NWCC to automate the basin analysis process. This effort includes the automatic retrieval of the necessary spatial data layers, replicating the portion of the GIS Weasel that produces the slope, aspect, and Area Of Interest (AOI) layers, providing a graphical user interface (GUI), finding the best sources for the spatial layers, and simplifying and standardizing the process. Upon completion of this effort, NWCC forecast hydrologists will be able to complete this process for an entire basin in one or two hours. At the present time, using the prototype procedure, the process takes between three days and a week to complete, depending on the complexity of the basin. Most of the processing time is in finding, downloading, and reprojection of the necessary data layers. The future incorporation of the basin analysis Graphical User Interface (GUI) will streamline the process significantly.

The first step in the process is to define the DEM that will encompass the AOI. The AOI is the georgraphic area above a selected forecast point that is used for creating the map display and basin analysis. It is important to note here that all GIS layers are projected to USA_Contiguous_Albers_Equal_Area_Conic_USGS_version (as denoted in ArcGIS). The reprojected DEM is then used in the GIS Weasel process, executing standard ArcGIS functions to fill DEM depressions, calculate flow direction and flow accumulation, and delineate the AOI from U.S. Geological Survey (USGS) stream gage coordinates. The AOI, slope and aspect layers are the output from the GIS Weasel process. The completed PSU application will replace the GIS Weasel process up this point in the analysis. The directory structure will be preserved, so that the DEM, AOI, slope, and aspect layers produced can be used to develop basin parameters for the PRMS hydrologic model. A second phase of the PSU contract will be to develop tools within ArcGIS to delineate hydrologic response units (HRUs) for the PRMS hydrologic model and to use the spatial data layers to calculate model parameters. This would effectively eliminate the need to use the GIS Weasel for this operation.

The PRMS model calibration can be positively influenced by using climate sites that are diverse in terms of elevation and aspect. The DEM model overlain by existing and proposed sites is evaluated first to determine if there is a sufficient gradient between sites to develop a robust set of orographic precipitation and temperature parameters. Figure 1 is an example of how the DEM is utilized in the analysis.

Analysis of the DEM shows the relief of the study basin and where climate and streamflow gages are located in relation to each other. Figure 1 represents the watershed above Cache La Poudre River near Fort Collins, Colorado. The Cache La Poudre River is located in the northern portion of the South Platte Basin in Colorado and Wyoming. In this particular example, there are several SNOTEL and snow course sites within the study basin. There are five potential sites that were identified to fill sparse data areas that could be used to develop precipitation and temperature characteristics. During the analysis, all of the climate sites are plotted on the basin area-elevation curve, which is derived from zonal statistics, to show the elevational distribution over the watershed.

From the field site visit, it was determined that the Panhandle site suffered from wind scouring and also exhibited the same hydrologic and climatic characteristics as the existing Deadman Hill site. The Long Draw Reservoir site fills a data void in the southern headwaters of the basin. It has easy access for installation and maintenance, and the local water users were willing to cover the initial start up costs. The Acme Creek, George Creek, and Black Mtn sites were located to provide hydrologic model orographic parameters and lower elevation characteristics. From the field visits, the Black Mtn site was chosen for installation.

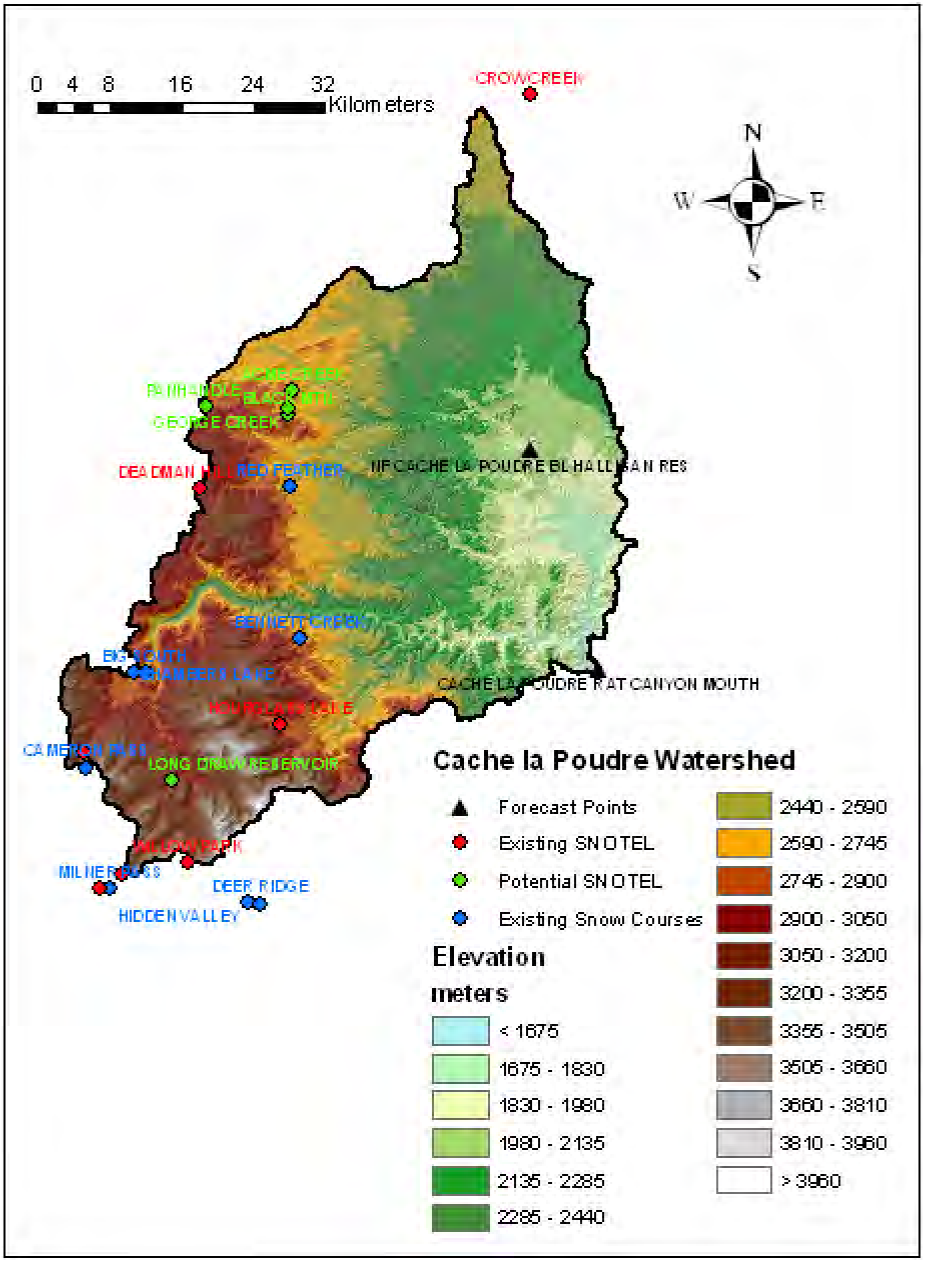

Figure 1 Basin elevational distribution

The northern and eastern portions of the basin appear to be rather data sparse. However, the Crow Creek site, although it is physically outside of the basin, represents the upper portions of the watershed. There are also low elevation National Weather Service (NWS) automated Cooperative Network stations that can be used to further define the basin characteristics. Furthermore, the lower portions of the basin contribute very little, percentagewise, to the normal seasonal runoff.

Next, the PRISM layer is analyzed to determine where most of the runoff at the USGS gage comes from within the basin. In Figure 2, the analysis shows the relationship

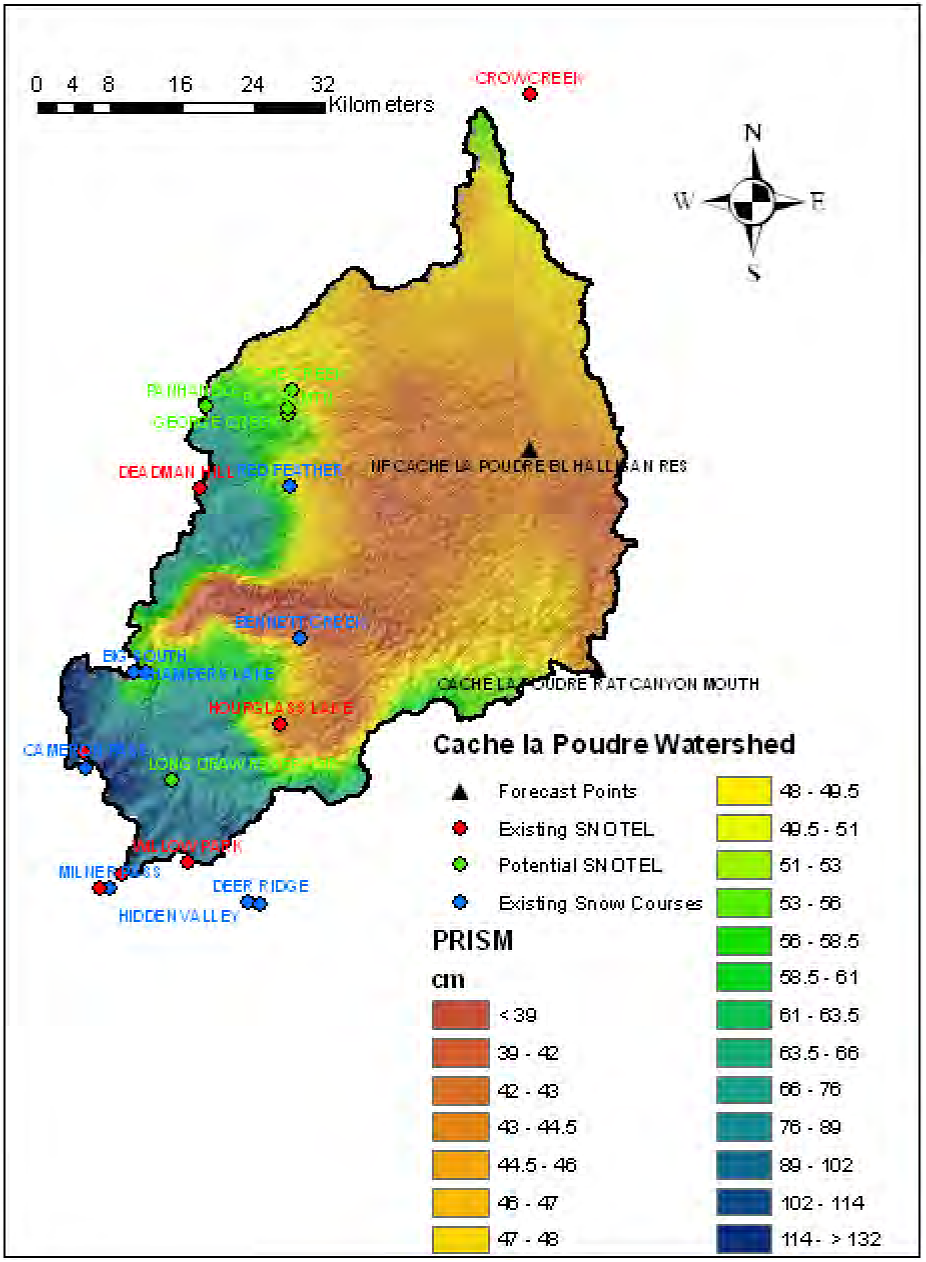

Figure 2 PRISM zonal precipitation analysis

between the existing climate sites (SNOTEL and snow course) and the average annual precipitation. The resolution of the PRISM layer (800 meter) is not the same as the DEM (30 meter). This is an issue with several of the layers. The final application tool will attempt to minimize the visual effects by reconciling the difference in resolution. Regardless, Figure 2 shows quite clearly where the highest precipitation areas of the watershed are located and offers a good indication of the source of the effective runoff.

The basin analysis tool can also be used to develop zonal statistic tables. Graphical representation of these tables indicates which elevation zones receive the most total precipitation through a combination of precipitation amounts and amassed zonal area. Figure 2 illustrates that most of the potential SNOTEL sites are located in a different precipitation zone than most of the existing climate sites. One of the potential sites (Black Mtn) will be installed and used to distribute the precipitation and temperature parameters across the basin.

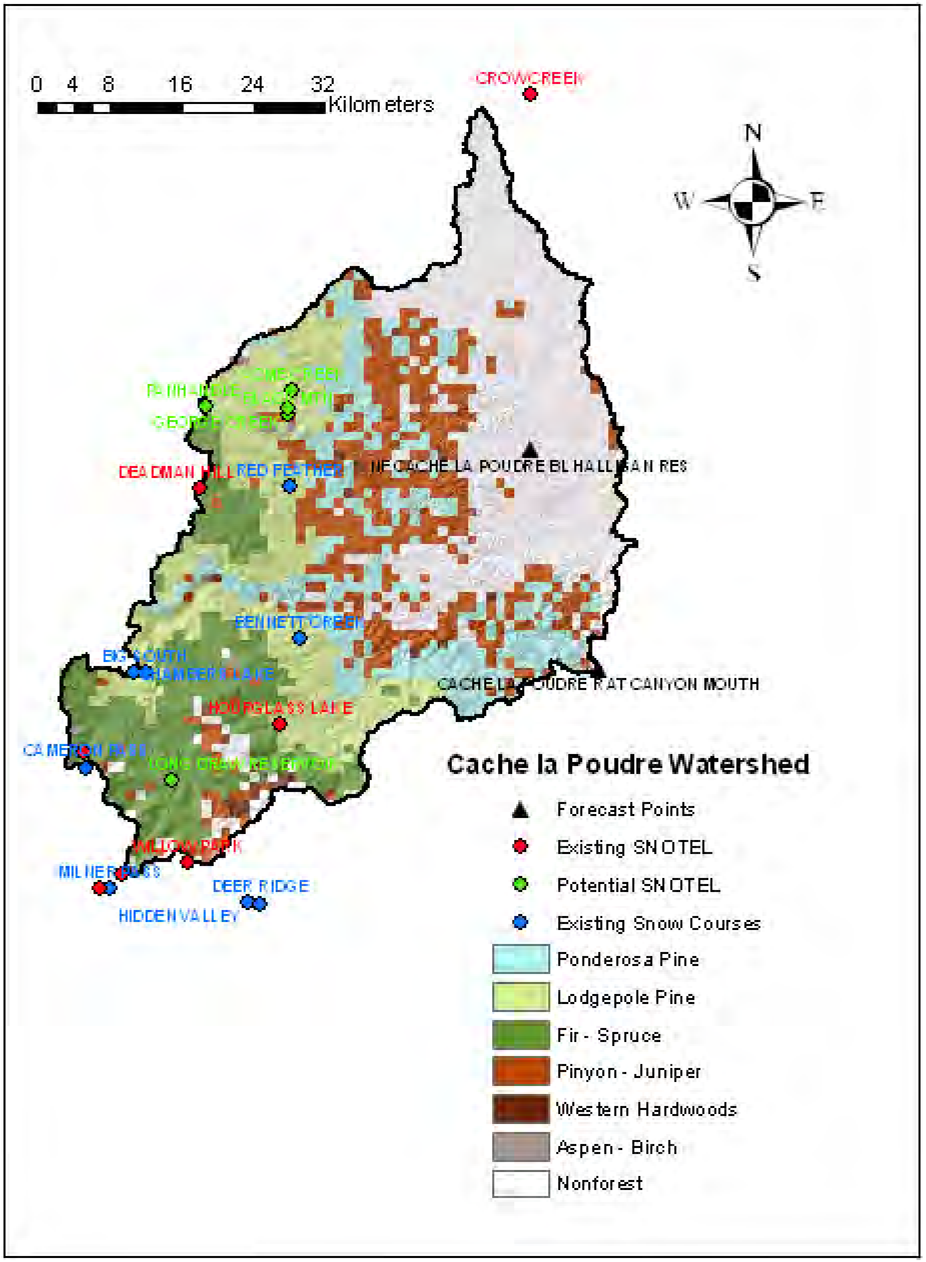

Figure 3 Forest cover types

Figure 3 is an example of the vegetation layers that are used to determine where existing and proposed sites are located in relation to the vegetative cover types and densities. From these layers, rooting depth, potential plant transpiration, and interception characteristics can be developed for use in a hydrologic model.

A major consideration when adding additional SNOTEL sites throughout the West is land management and ownership (Figure 4). NRCS does not typically locate SNOTEL sites on private property. Regardless of how agreeable the landowner may be, any agreement or understanding can be terminated at any time, or the land may be sold to someone that

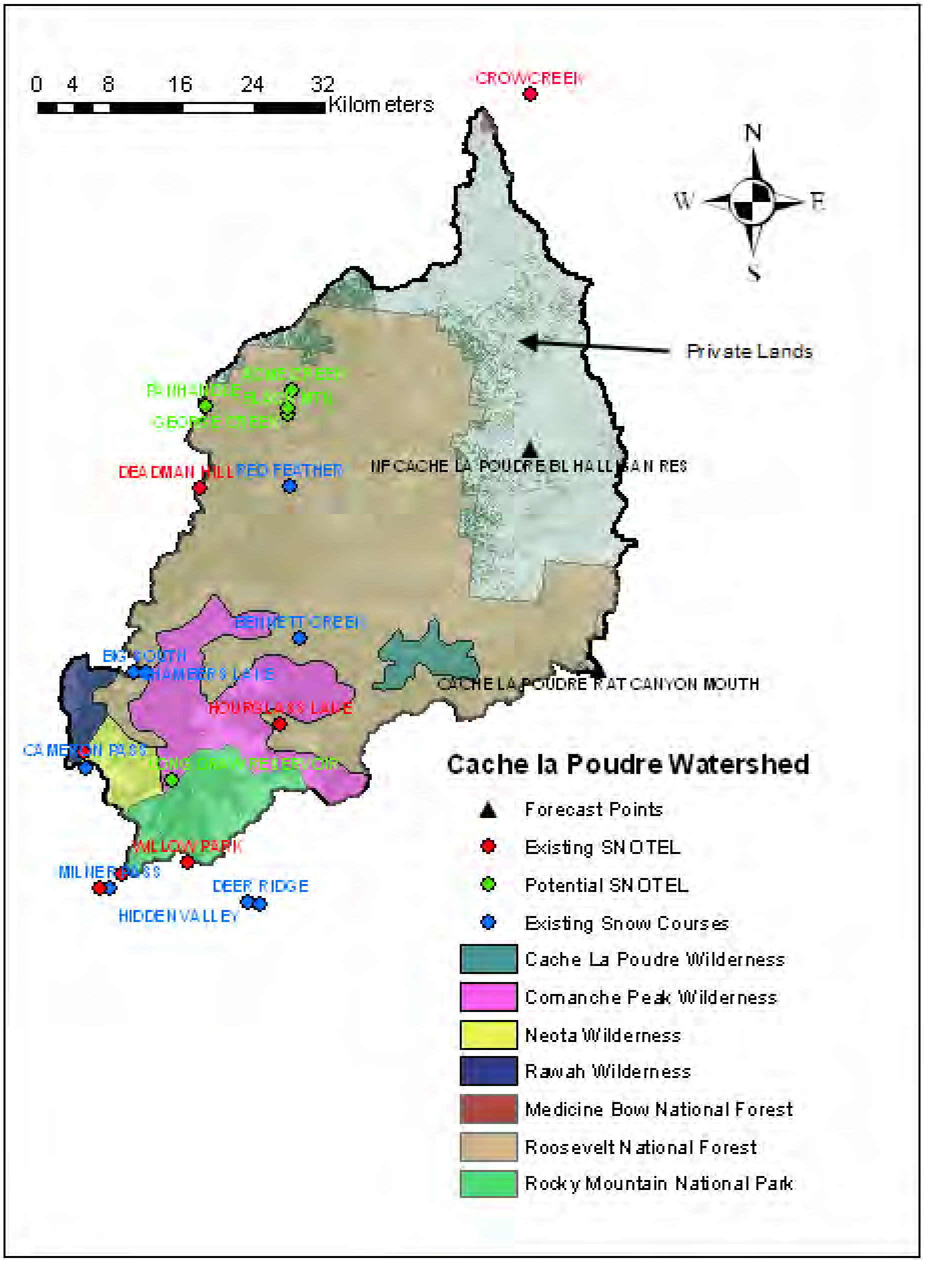

Figure 4 Land ownership/management

does not want the site on their property. Or, as in a recent case in Colorado, the landowner clear cut the forest around a very important site for forecasting, which drastically changed the physical characteristics of the site and rendered its data useless for water supply forecasting for years to come. Some Native American tribes are very agreeable to locating climate sites on their lands. It is preferable to locate sites on public or Tribal lands that offer long-term access and continuity.

The rigorous permitting process makes it very difficult to get permission to construct permanent SNOTEL site installations within wilderness boundaries. Because of this, NRCS Data Collection Offices (DCOs) usually do not pursue this course of action. The type of issues mentioned above make it very important to identify land ownership and management.

Another very important factor to consider in locating a new SNOTEL site is accessibility. Good access is important for installation, maintenance, affordability, and safety reasons. Some of the NRCS SNOTEL site installations are in very remote areas that are at risk from avalanches or are only accessible by helicopter. Sometimes this cannot be avoided because of the necessity of having good data to run the forecast models. Sometimes road closures by the managing agencies or landowners require that a site that previously had easy access using trucks, snowmobiles or all terrain vehicles (ATVs), can now only be accessed and maintained by helicopter, horseback, or on foot.

Accessible road data layers are available from the U.S. Forest Service (USFS) (where most of the SNOTEL sites are located) and sometimes from the Bureau of Land Management (BLM). An example of an accessible road layer is shown in Figure 5. Even though efforts are made to keep these road layers up to date, there is no guarantee that a particular road will be open to travel. The use of the roads must be verified in the field, but the spatial files are the best available and greatly assist when trying to locate new sites.

Based on the GIS layers available, as previously discussed, the hydrologist will select a preferred site or sites that meet the stated criteria (Figure 5). Often, these will be not only specific locations, but also areas that give the DCOs some flexibility in making the final determination of site locations.

One potential outcome of the process, based on available funding for a particular basin, may be to install multiple SNOTEL sites, in order to gain optimal spatial coverage. This would allow for better spatial representation over a diverse area of the watershed being modeled, which would lead to better HRU parameterization and calibration response.

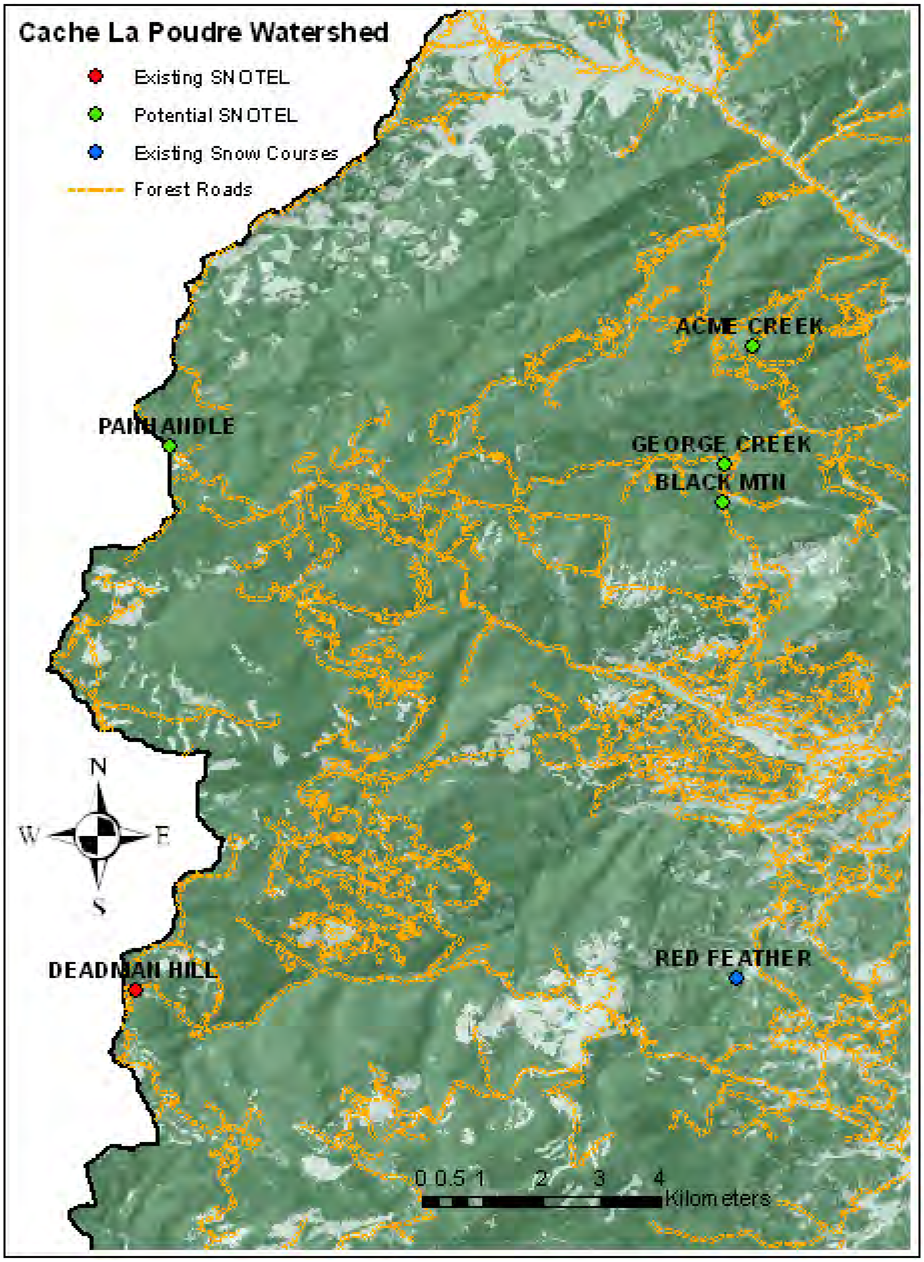

Figure 5 Location of potential sites, based on composite spatial layers

SUMMARY

NRCS DCOs are responsible for installing, maintaining, and collecting data from the remote SNOTEL sites. An analysis, made by a forecast hydrologist can help to ensure that new sites are located to fill obvious data voids and to provide a more complete representation of hydrologic characteristics in a forecast basin. By using the basin analysis process, the hydrologist must determine, with the computer resources available and what limited knowledge he/she might have on the study basin, where additional sites should be located to fill these data voids. This will help to ensure that limited monetary and human resources are spent and used wisely.

NRCS NWCC and PSU are developing an ArcGIS basin analysis tool that will compliment expert field knowledge to aid in the siting and installation of new SNOTEL sites in data sparse areas. Whether the new sites are used as indices in the traditional statistical regression models, or are used to better define HRU parameters for hydrologic models, the goal is a reduction in the forecast modeling error.

The basin analysis tool uses physical characteristics layers (elevation (DEM), average precipitation (PRISM), vegetation, land use, forest cover and soils), with derived layers (slope and aspect), and any other pertinent data layers (land management, roads, etc.) to provide a consistent, systematic format to assess the representativeness of new data site locations. The main criterion for new sites is for the enhancement of the SNOTEL network to provide better parameterization delineation for the PRMS hydrologic model calibrations and operational modeling. Ultimately, the tool will be improved to calculate the model parameters directly.

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