IMPLEMENTATION OF THE SNOW ESTIMATION AND UPDATING SYSTEM (SEUS) IN THE CLEARWATER RIVER BASIN, IDAHO

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ABSTRACT

The Snow Estimation and Updating System (SEUS) was developed by the National Weather Service (NWS) to generate real-time gridded snow water equivalent estimates using ground-based and airborne snow data collected over the western United States. These gridded snow water equivalent estimates incorporate the spatial variability of the snowpack induced by orographic effects in the West. The estimates of snow water equivalent are used for hydrologic forecasting. In previous years, the SEUS has been implemented in portions of the Colorado River Basin and the results used for water supply forecasting.

The 1995 snow season included some enhancements to the way the SEUS methodology was implemented to continue to improve the snow water equivalent estimates generated. Some improved data layers were added including seasonal precipitation layers developed using Precipitation-elevation Regressions on Independent Slopes Model (PRISM). This paper examines the effect of including airborne data on the snow water equivalent estimates. The impact of using satellite areal extent of snow cover to estimate the location of the snow line and its effect on the snow water equivalent is also examined. The NWS is interested in implementing SEUS under a variety of physiographic and hydrologic regimes. The SEUS was implemented in the Clearwater River basin of Idaho where a more maritime climate provides a significant amount of moisture and where the elevations are not as extreme as they are in other portions of the Colorado Basin.

INTRODUCTION

Snow is a very important resource in the western United States, where it can contribute to approximately 75 percent of the annual runoff. Estimating this resource has been the subject of much study and discussion since precipitation measurements and stream flow forecasts have been made. These forecasts are used to manage such diverse interests as water supply, flood control, navigation, agricultural needs and recreation. The National Weather Service provides stream flow forecasts using physically-based, conceptual continuous, lumped-parameter hydrologic models which follow the flow of water through the many hydrologic pathways from the surface of the earth to the stream. Estimating the water content of the snowpack accurately is essential to useful forecasts.

For many of the water management decisions made in the west, the lead time on the forecasts is on the order of weeks, months and seasons. The Extended Streamflow Prediction (ESP) technique is the long-term forecasting component of the NWS River Forecasting System (NWSRFS)(Day, 1985). It uses present day streamflow, soil moisture and snowpack conditions along with historical time series of precipitation and temperature to estimate streamflow weeks or months into the future. The streamflow hydrographs generated by the system can be analyzed based on the likelihood of the precipitation and temperature time series to produce probabilistic forecasts of stream flow variables such as peaks and volumes. However, difficulties in estimating precipitation in the mountains can cause inaccuracies in the estimates of the initial snow water equivalent conditions provided to the models.

Historically, measurements of snow water equivalent have been made in much of the western

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United States. The Natural Resources Conservation Service (NRCS) collects ground-based snow water equivalent at over 2000 SNOTEL and snow course locations. Airborne estimates of snow water equivalent are obtained by the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the NWS using low-flying aircraft to measure natural terrestrial gamma radiation emitted by the soil over 1700 flight lines in the United States and Canada. Background gamma radiation count rates are first obtained under no snow conditions. Then during the snow season over-snow counts rates are obtained, and the attenuation in the counts is used to estimate the snow water equivalent along the flight line (Carroll, et al, 1983). The NOHRSC ingests Advanced Very High Resolution Radiometer (AVHRR) satellite data and Geostationary Operational Environmental Satellite (GOES) data to digitally map areal extent of snow cover over much of the continental United States, Alaska and portions of Canada. This satellite data is classified into areas of snow, no snow and clouds.

To improve forecasting accuracy, the NWS undertook a project several years ago using these ground and airborne snow observation data to develop areal estimates of snow water equivalent. The methodology developed, the Snow Estimation and Updating System (SEUS), involves the interpolation of snow water equivalent data into gridded estimates of snow water equivalent. The SEUS ingests SNOTEL, snow course and flight line data and standardizes the data by subtracting the long term mean and dividing by the standard deviation. The data are interpolated into a gridded field using a distance correlation function developed during the calibration of the basin. Standardized deviates are then converted into snow water equivalent by applying a gridded mean snow water equivalent field and a mean-standard deviation relationship developed as part of the basin calibration. The gridded snow water estimates are summed and averaged for each subarea in a basin, adjusted for any model bias, and used to update the snow water equivalent states of the NWSRFS snow model. For a thorough description of the SEUS methodology, refer to Day(1990) and McManamon et al (1993).

The SEUS has been implemented in the Colorado River basin for the past several years. The NWS is interested in implementing SEUS in a variety of geographic and hydrologic regimes. The Clearwater River basin provides an opportunity to implement SEUS in an area with a maritime climate which is physiographically different from the Colorado River basin. SEUS enhancements for 1995 included the use of satellite areal extent of snow cover data to assist SEUS in determining the location of the snow line.

IMPLEMENTATION

This paper focuses on the Clearwater River basin and its associated tributaries above the stream gage at Spalding, Idaho. At this point, the Clearwater drains an area of nearly 12870 square kilometers (8000 sq. mi.). Much of the area falls within one of several National Forests and more than 80 percent of the basin is forested. Dominant species include ponderosa pine, lodgepole pine and Douglas-fir. The forest density decreases from east to west in the region. The local contributing areas of the Clearwater River above Orofino and Spalding have significant unforested portions within their drainage areas. The Lochsa River rises in the Bitterroot Range and flows south-westward through a narrow river valley. The Selway river rises in the same mountain range south of the Lochsa River and flows northwest to join the Lochsa at Lowell to form the Middle Fork of the Clearwater River. The North Fork of the Clearwater rises in the northern portion of the basin, and flows predominantly westward into the Dworshak Reservoir (Figure 1).

These streams have been modelled within NWSRFS as six separate basins; the North fork of the Clearwater above Canyon Ranger Station, the local contributing area to the Dworshak Reservoir, the Lochsa River, the Selway River, the local contributing area of the Middle

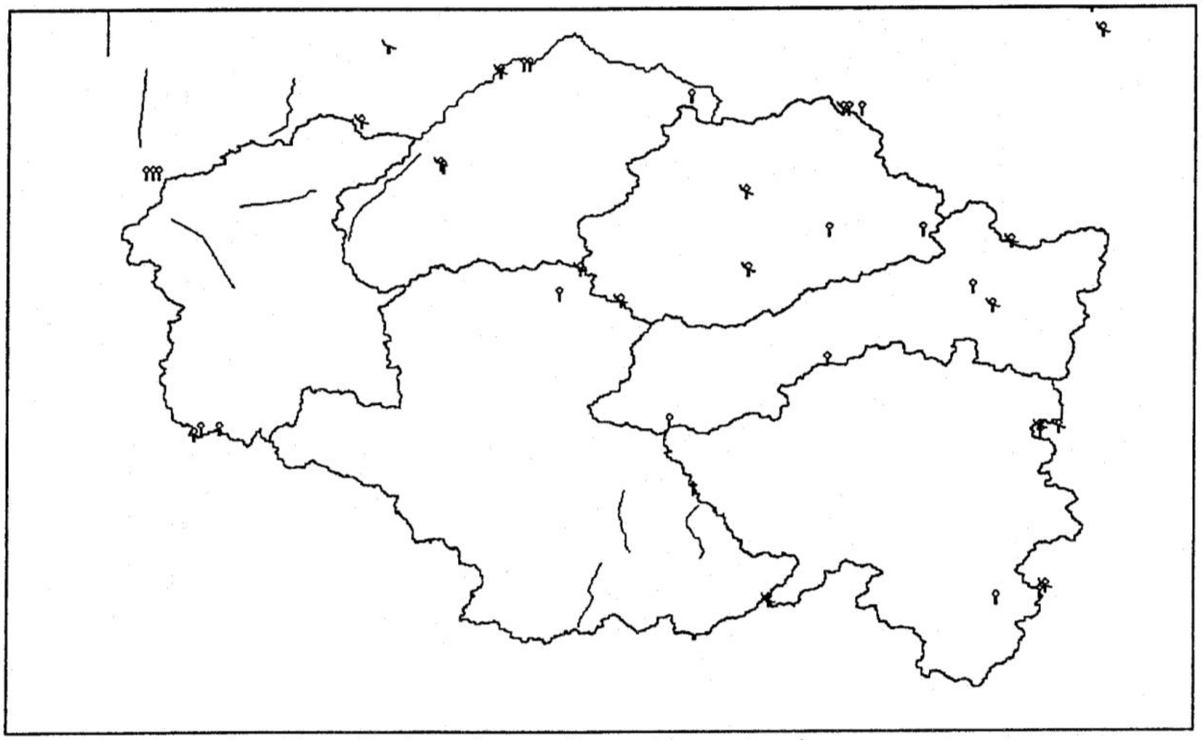

Figure 1. Clearwater River basin and snow observation network.

Fork of the Clearwater River between the confluence of the Lochsa and Selway rivers and the gaging station at Orofino and the local contributing area of the Clearwater River downstream of the other basins but above the gaging station at Spalding. Characteristics of the basins are detailed in Table 1.

Table 1. Basin Characteristics of the Clearwater River Basins.

Basin	Area (sq. km)	Percent Forested	Elevation Range (km)
N. Fork Clearwater River above Canyon Ranger Station	3350	97	615 - 2255
Local contributing area to N. Fork Clearwater above Dworshak Reservoir	1730	90	465 - 2045
Selway River	4965	90	535 - 2630
Lochsa River	3035	93	500 - 2525
Middle Fork Clearwater River above Orofino, ID	6330	78	365 - 2510
Local contributing area Clearwater River above Spalding, ID	3550	41	255 - 1490

SEUS requires a significant amount of historical and near real-time observations as well as several physiographic data layers. Gridded elevation data at a resolution of 30 arc seconds are used to determine slope and aspect. Basin boundaries, gridded forest cover and gridded isohyetal data providing information on the precipitation to be expected during the winter season (October through April in much of the mountainous west) are also necessary. Precipitation-elevation Regressions on Independent Slopes Model (PRISM) (Daly, 1994) generated gridded precipitation data at a scale of .625 arc minutes were resampled into 30 arc seconds using a neighborhood analysis and developing a relationship between the winter precipitation and the corresponding elevation of each neighboring pixel.

The SEUS uses 17 SNOTEL gages in the vicinity of the Clearwater River basin to estimate snow water equivalent. Additionally, there are 14 snow courses in the area, not all of which are collected on a regular basis. The NWS has established six flight lines which fall within three of the Clearwater River basins. During the past three years, airborne measurements have been made at these locations to provide additional data in the area.

The SNOTEL sites located in the area are concentrated in the northern and western portions of the Clearwater drainage area. Two of the stations are between 915 and 1065 meters but the remaining stations are between 1525 and 1980 meters. The snow courses that have been sampled recently are between 1065 and 1705 meters. The flight lines are split into two groups of three lines. One set are near the local contributing area above Spalding and are between 610 and 915 meters. The other set are in the local contributing area above Orofino and are between 1370 and 1980 meters.

CALIBRATION

Although there were several enhancements made to SEUS for 1995, the existing methodology did not require modification prior to implementation in the Clearwater River basin. During the calibration process for any basin, several relationships are developed using snow observation stations falling within the basin's geographic region. The mean - standard deviation relationship is the relationship between the long term mean of a station and the associated standard deviation. This relationship is developed for the first of each month during the snow season. The correlation - distance function illustrates how well any two stations are correlated over time for a specific date as a function of the distance between them. Figures 2 and 3 show the respective relationships for April 1 for the Selway River. An examination of the figures shows that the standard form of each of the equations fits the data fairly well.

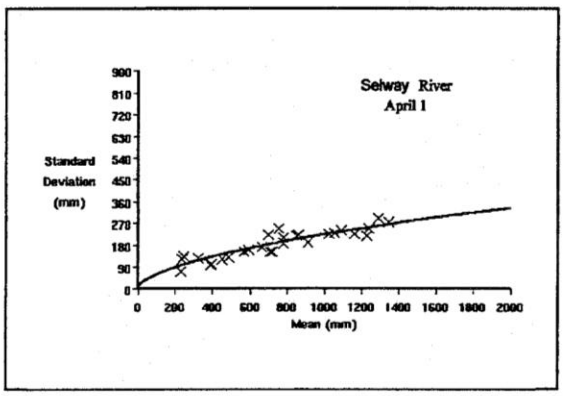

Figure 2. Mean versus standard deviation relationship for the Selway River on April 1.

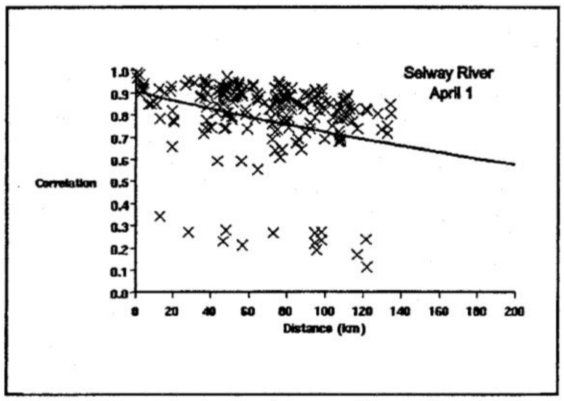

Figure 3. Correlation - distance function for the Selway River on April 1.

The development of mean weekly snow water equivalent maps is another aspect of calibrating any basin within SEUS. Using information from several of the physiographic layers within SEUS and NWSRFS calibrations for each basin, basin mean weekly snow water equivalent maps are developed. One indication of how well these mean snow water equivalent maps represent the physical snow processes is a smooth transition between basins when they are combined to represent the entire Clearwater River basin. Figure 4 illustrates that the six basins provide a smooth transition for the April 1 mean snow water equivalent map developed for the Clearwater River basin without discontinuities at basin boundaries.

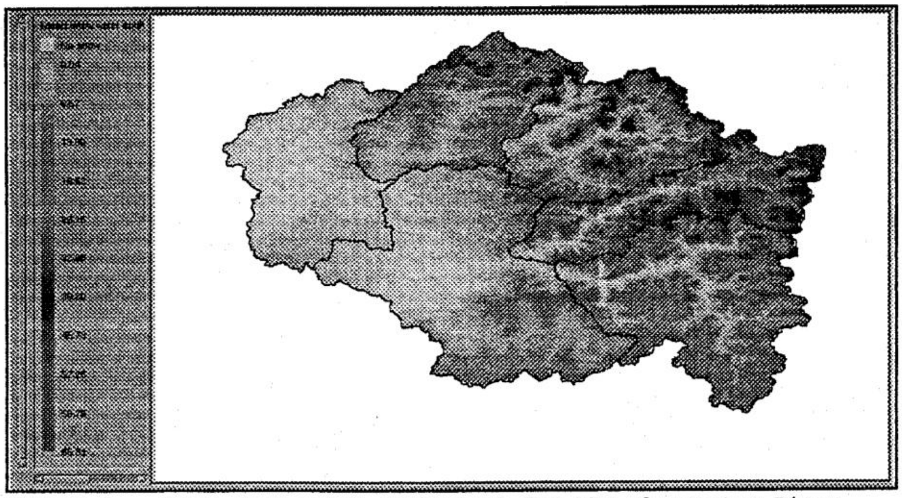

Figure 4. Mean snow water equivalent for the Clearwater River basin on April 1.

WATER YEAR 1995 APPLICATION

During the past snow season, SEUS was run weekly at NOHRSC and monthly at the Northwest River Forecast Center for the Clearwater River basin to create gridded snow water equivalent and percent of average rasters. On several occasions, cloud-free images of the satellite areal extent of snow cover were available and were used to assist SEUS in determining the location of the snow line. Table 2 contains the basin-wide snow water equivalent estimates for February 1, March 1 and April 1. These data suggest that the snow pack was nearly average early in the season, but has decreased to about half of what might be expected by April 1. The lower elevation basins (Clearwater River above Spalding, and the Middle Fork Clearwater River above Orofino) show very low snow water equivalent estimates and the lowest percent of normal of all the basins. The highest basins (North Fork Clearwater above Canyon Ranger Station, the Selway River and the Lochsa River) maintain the highest estimated snow water equivalent and percent of normal. If the

Table 2. Water Year 1995 Estimated Snow Water Equivalent and Percent of Normal.

	February 1		March 1		April 1	
Basin	SWE(mm)	% Normal	SWE(mm)	% Normal	SWE (mm)	% Normal
Clearwater R. above Spalding, ID	75	85	30	20	5	3
N. Fk. Clearwater R. local area into Dworshak Rsvr	315	100	260	60	210	40
N. Fk. Clearwater R. above Canyon Ranger Station	350	95	335	70	290	45
Selway River	300	90	305	70	275	55
Lochsa River	435	95	425	70	400	55
M. Fk. Clearwater R. above Orofino, ID	145	100	105	45	70	25

SNOTEL and snow course station percent of average is examined for April 1, the basin-wide snow water equivalent averages are lower. This difference is caused by the fact that the SNOTEL and snow course network are at fairly high elevations, while the basin-wide averages include significant low elevation information. It appears that only the highest elevations are contributing to the snow water equivalent estimates this year.

As was previously stated, one of the enhancements for 1995 to SEUS was the inclusion of satellite areal extent of snow cover to determine the location of the snow line. Several cloud free shots of the Clearwater River basin were obtained during the year. The effect of the airborne data on the snow estimates derived within the Clearwater River basin was also evaluated. To that end, airborne data were obtained on February 23rd, March 16th and March 30th of this year. Nearly cloud-free satellite images were available for February 25th and April 1, and these two dates are examined in greater detail.

Airborne data have the greatest effect on the areas in close proximity to their location. In the case of the Clearwater drainage, they have the greatest impact on the local contributing area of the Clearwater River above Spalding, Idaho and the local contributing area of the Middle Fork of the Clearwater River above Orofino, Idaho. These basins are significantly lower than the other basins. Additionally, much of the SNOTEL network lies outside the basins and at a significant distance away. Gridded snow water equivalent estimates were made for February 22nd using two different scenarios: with all available SNOTEL, snow course and airborne data, and with just SNOTEL and snow course data. Figure 5 shows the gridded estimates using each set of snow observation data. Figure 6 contains the satellite areal extent of snow cover for a few days later.

The snow water equivalent estimates which include the airborne data more closely match the areal distribution indicated by the satellite data. Using only SNOTEL and snow course information tends to overestimate the gridded snow water equivalent, particularly at lower elevations. In the case of the two lowest basins (Spalding local area and Orofino local area) the overestimation may be caused by two different factors. The available SNOTEL and snow course observations are physically further away from the basin than the airborne data, and they are measured at a much higher elevation. Therefore, the SNOTEL and snow courses may not be as representative of these two basins as may be desired. It is

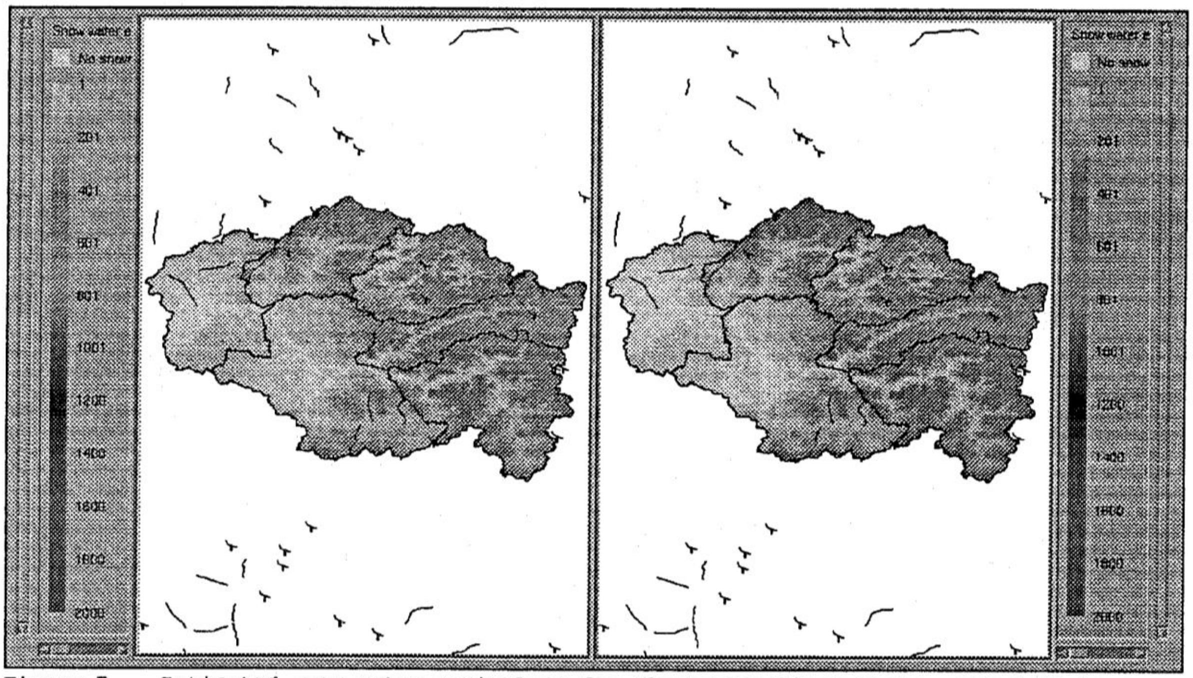

Figure 5. Estimated snow water equivalent for Clearwater River basin. The left image contains the snow water equivalent estimates using only SNOTEL and snow course data. The right image contains the snow water equivalent estimates using SNOTEL, snow course and airborne data.

important to use as much data which is representative of the basin as possible. In this case, the airborne data appears to be more representative than the SNOTEL and snow course data. The satellite areal extent of snow cover information would assist in locating the snow line and could be used to remove overestimated snow water equivalent. Unfortunately, the satellite data is often obscured by clouds, especially in the Pacific Northwest and may not be available. An analysis of all the basins was performed to note the effects of

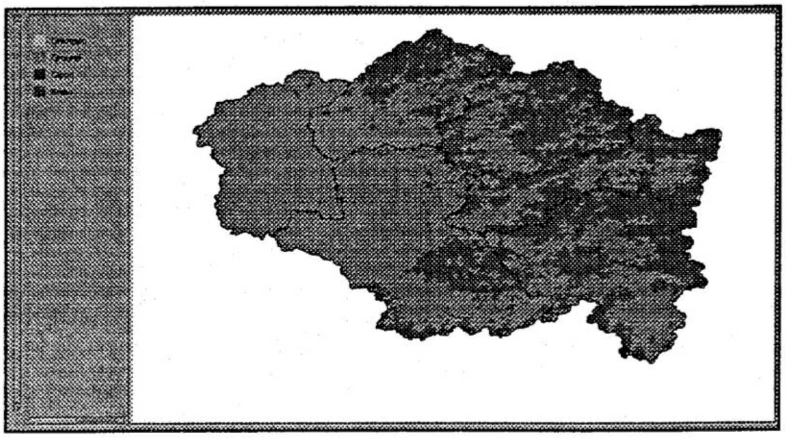

Figure 6. Satellite areal extent of snow cover on February 25, 1995 for Clearwater River.

including airborne data and satellite areal extent of snow cover. Table 3 contains the details of this analysis.

Table 3. February 22, 1995 snow water equivalent estimates.

	With Satellite				Without Satellite			
	SWE (mm)	%Ave.	SWE* (mm)	%Ave.*	SWE (mm)	%Ave.	SWE* (mm)	%Ave.*
Clearwater River above Spalding, ID	0	0	0	0	30	20	55	55
N. Fk. Clearwater R. local area into Dworshak Reservoir	180	30	200	35	300	75	340	90
N. Fk. Clearwater R. above Canyon Ranger Station	300	60	310	60	400	90	415	95
Selway River	230	45	230	45	340	80	340	80
Lochsa River	350	55	360	55	505	90	520	95
Middle Fork Clearwater above Orofino, ID	50	15	55	20	125	60	140	80

*Without airborne data

Examining the information which did not incorporate satellite data, it can be seen that the airborne data has the greatest effect on the basins in which they are located. The data reduce the basin-wide estimate of snow water equivalent in Spalding local area and Orofino local area by a significant percentage of the total estimate. There is also a lesser effect on the local contributing area to the Dworshak Reservoir. There is little if any effect of the airborne data on the remaining basins, which were higher and further away from the location where the airborne data were gathered.

The first four columns of Table 3 indicate the impact of including satellite areal extent of snow cover in the SEUS analysis. The higher basins (both areas on the North Fork Clearwater above Canyon Ranger Station, Selway River, and Lochsa River) show little effect from the satellite data. This early in the snow season, most of these areas are completely snow covered and no snow is removed with the satellite analysis. However, the remaining basins are at a lower elevation and the satellite indicates that portions of the basins are snow free. The satellite information removes all the snow from the local area of Spalding, and much of the snow from the local area above Orofino. However, the actual airborne measurements indicate the existence of measurable snow water equivalent in some locations where the satellite indicates there is no snow.

To further assess the conflicting information from the satellite data and the airborne data, additional data are examined. Airborne data and a cloud free satellite areal extent of snow cover image are available for April 1. The airborne data indicated no measurable snow water equivalent in the local area above Spalding but the local area above Orofino did have measurable snow water equivalent. Gridded snow water equivalent estimates were made for April 1 using two different scenarios: with all available SNOTEL, snow course and airborne data, and with just SNOTEL and snow course data. Figure 7 shows the gridded estimates using each set of snow observation data. Figure 8 contains the satellite areal extent of snow cover for the same day. In this case, the inclusion of flight line data provides slightly higher snow water equivalent estimates for the local contributing area above Orofino where the flight lines are located. The satellite data indicates that the areal distribution of the snow cover does not include some of the area where the airborne data were gathered. The satellite data indicate that much of the basin is snow free even in areas where the airborne measurements indicate over one hundred millimeters of snow water equivalent. In heavily forested areas with a discontinuous snow pack, the satellite processing technique has some difficulties in properly classifying the image.

An examination of Figure 7 indicates that the airborne data has little impact on most of the basins, but it does affect the local contributing area above Orofino. The areas in the vicinity of the flight line locations indicate that including the airborne information more accurately reflects the actual snow water equivalent measurements in the nearby area.

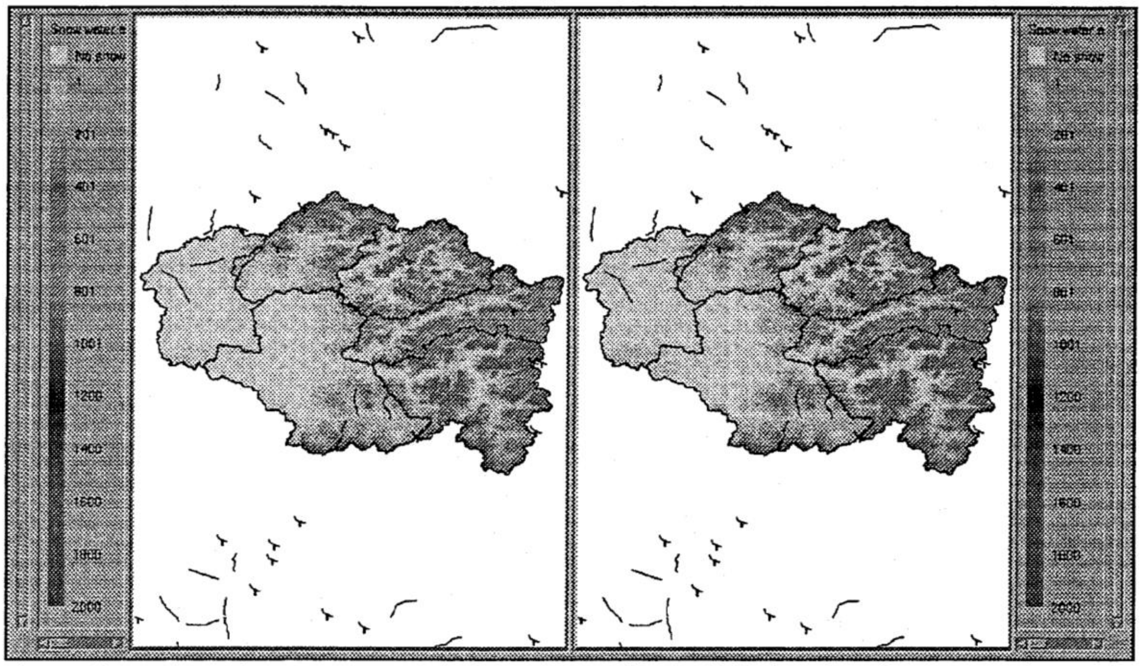

Figure 7. Estimated snow water equivalent for April 1, 1995 for the Clearwater River. The image on the left uses only SNOTEL and snow course data. The image on the right, uses all available SNOTEL, snow course and airborne data.

Figure 8 indicates that much of the snow is retreating from the valleys of the higher elevation basins and the low lying areas of the lower elevation basins.

An analysis of all the basins was performed to note the effects of including airborne data and satellite areal extent of snow cover. Table 3 contains the details of this analysis. The airborne data has less impact on the basin-wide snow water equivalent estimates for April 1 except in the local contributing area above Orofino, where it halves the

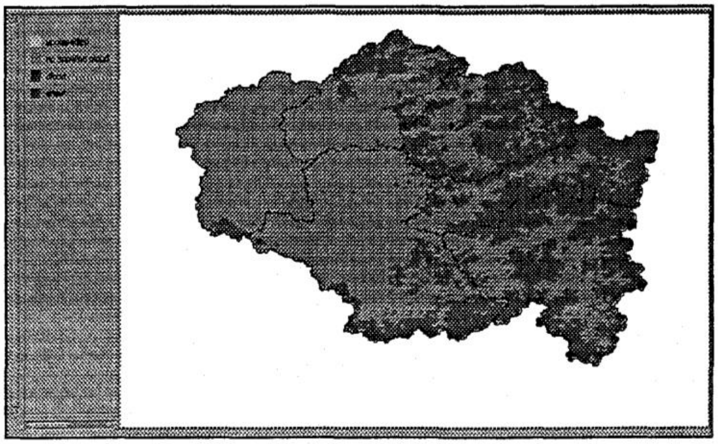

Figure 8. Satellite areal extent of snow cover on April 1, 1995 for the Clearwater River basin.

estimates. The satellite data has a greater effect on April 1 than was seen in the February 22 analysis. The inclusion of these data removes low elevation snow from all the basins.

Table 4. April 1, 1995 Snow water equivalent estimates.

	With Satellite				Without Satellite			
	SWE (mm)	%Ave.	SWE* (mm)	%Ave.*	SWE (mm)	%Ave.	SWE* (mm)	%Ave.*
Clearwater River above Spalding, ID	0	0	0	0	5	3	10	5
N. Fk. Clearwater R. local area into Dworshak Reservoir	120	20	125	20	210	40	230	45
N. Fk. Clearwater R. above Canyon Ranger Station	235	35	260	40	290	45	325	55
Selway River	210	40	220	40	275	55	285	60
Lochsa River	340	45	360	50	400	55	430	60
Middle Fork Clearwater above Orofino, ID	40	10	40	10	70	25	70	25

*Without airborne data

CONCLUSIONS

The SEUS was successfully implemented in the Clearwater River basin. As the Northwest River Forecast Center (NWRFC) calibrates additional basins within NWSRFS, SEUS can be implemented in those basins also. The SEUS was able to provide gridded snow water equivalent estimates for any date during the snow season using all available snow observations. When available, airborne data provided significant information to the snow estimation process, especially in lower elevation basins. Inclusion of satellite areal extent of snow cover may lead to underestimation of the snow water equivalent when the snowpack becomes discontinuous. This effect is especially noticeable in heavily forested areas such as the Clearwater drainage area.

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