Internet of Water

Snow data increase crop yield, optimize hydropower generation, and avoid flood damages

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The Snow Survey and Water Supply Forecasting (SSWSF) program's data are widely used by agricultural communities, government agencies, private businesses, and recreationists to inform day-to day operations and broad decision-making. We compiled numerous case studies documenting the economic value of the SSWSF program to show the benefit-to-cost ratio for different users. We found that 38% of the time the benefits from a single case study exceeded annual program costs.

Organization: data producer and data hub

In the early 1900s academic researchers conducted snow surveys and began developing stream forecasts. As forecasts improved, state agencies and private industries began developing their own snow surveys and forecast methods with wildly varying results. A severe drought in 1934 catalyzed the demand for federal leadership of snow survey activities to develop standardization of data collection and forecasting methods that provides consistent and unbiased information.[1] In 1935, Department of Agriculture (USDA) was authorized to develop a Snow Survey and Water Supply Forecasting (SSWSF) program. Since its inception, the SSWSF program has been a collaborative effort between federal, state, and local agencies to manually collect snow data. Within six years data were collected on 1,000 snow courses.[2] In 1977, the SNOw TELemetry (SNOTEL) data collection network was introduced to provide real-time snowpack and climate data. Today, there are 833 SNOTEL stations and 1,313 manual snow courses within the United States and Canada.[3]

Primary data purpose: Operational and decision-making

The mission of the Snow Survey and Water Supply Forecasting (SSWSF) program is to "provide the most accurate, timely, and useful information possible, in order for water managers and users to make wise and informed decisions about the use of our limited seasonal water supply."[1] The original purpose for these data were to support day-to-day operations and broad decision-making for agricultural communities and reservoir operators (Figure 1). Additional data users quickly emerged including recreationists (led to national broadcasts and widespread demand for snow data), financial institutions, industries, and municipalities. Increasingly, the data are used for research and innovation to improve forecasts and better understand impacts from climate change.

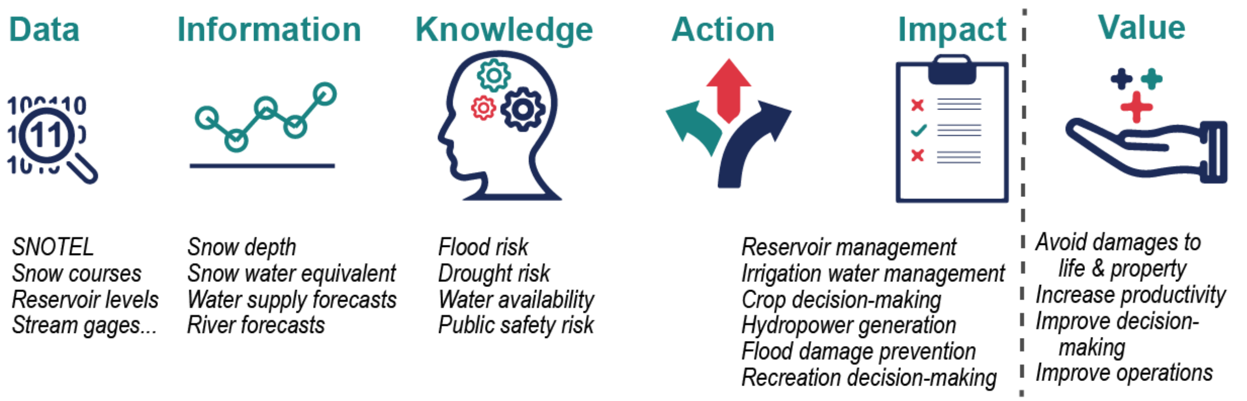

Figure 1: The SSWSF program transforms snow data into information that is actionable.

Benefits of SSWSF snow data

For 84 years the SSWSF program has collected, managed, and shared snow data and water supply forecasts. Snowpack essentially functions as a reservoir, enabling the SSWSF program to estimate the timing and volume of water released (snow generally melts at an average rate of 1-2 inches per day).[4] This is particularly relevant in the western United States, where 70-80% of annual precipitation falls from November to March, and streamflow during the remainder of the year is largely based on the gradual release of snowmelt into streams.[5] SSWSF forecasts enable downstream organizations to make decisions and prepare for the upcoming spring (flood threat) and summer and fall (supply shortages).

There are three categories of forecasts used by decision-makers at different times of the year (Figure 2A). **Volume forecasts** estimate the volume of snow and the amount of water held within the snowpack. Winter recreationists use these forecasts for avalanche warnings, locating competitive sporting events, and so on. Growers use these forecasts in January to make contracting decisions for the types and acreage of crops to plant in the upcoming summer. Power companies use volume forecasts in the winter for cloud-seeding operations and in March and April to estimate hydropower potential and determine if they need to adjust costs and/or create contracts to obtain additional power from other sources. **Peak flow forecasts** estimate the timing and volume of maximum streamflow. Reservoir and hydropower operators use these forecasts in January and March to make storage and release decisions, as well as develop plans to reduce potential flood damages. Whitewater rafters use these forecasts to decide when it is safe to start running the river and they use **low flow forecasts** in the summer months to assess the length of the season and adjust accordingly. Fish managers use low flow forecasts to determine if they need to curtail the fishing season or plant hatchery fish in the spring.[5] Federal and state agencies use snow data to determine whether to close roads, forecast fire weather, study glacier recessions, determine crop insurance needs, etc. Global companies use snow data to assess business decisions such as whether to expand oil and gas operations or develop contracts between food and beverage supply chains.

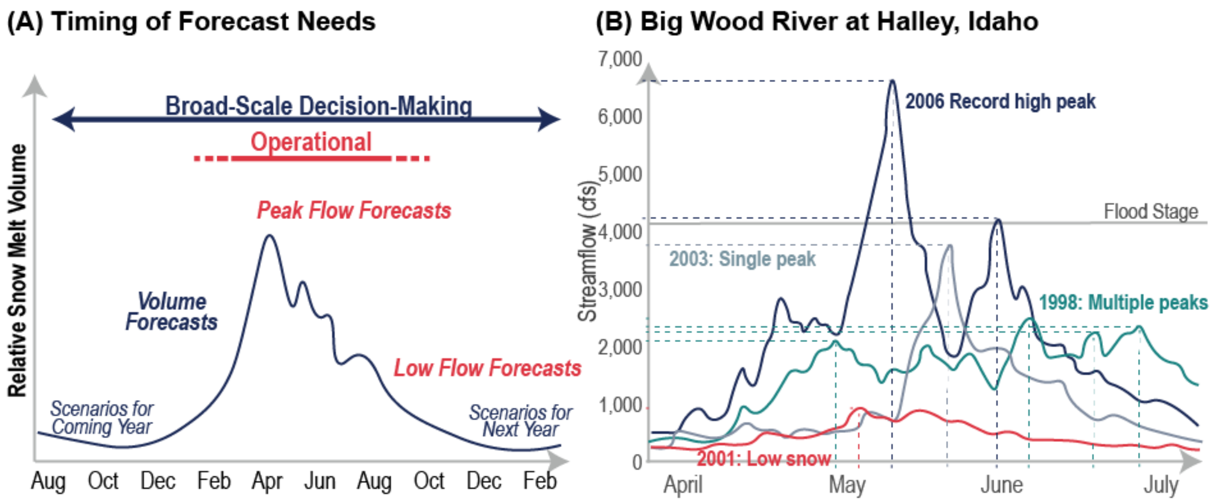

Figure 2. (A) Timing and types of forecasts needed for operational and broad-scale decision-making. (B) Streamflow at a gauge in Halley, Idaho demonstrates the large annual water supply variability that can occur in a snow-dominant stream over the course of the year. Dashed lines indicate the timing and volume of peak streamflow each year. Figures adapted from NRCS (2006).[5]

Critical decisions that require reliable water supply information include:[4]

- Reservoir management and hydropower generation
- Municipal and industrial water supply management
- Irrigation water management
- Crop decisions and crop insurance
- Water rights allocation
- Recreational uses
- Flood damage prevention and drought risk reduction
- Production estimation for commodity future markets
- Protection of endangered species
- Education and research
- Climate change risk assessments for long-term water availability

SWSSF data are widely used. In 2005 over 11 million data reports were downloaded from the NRCS website[6] and more than 16 million in 2006.[5] These forecasts are predicted to become increasingly valuable as changes in climate result in loss of predictability with increased fluctuations in the water cycle and the demand for water increases (Figure 2B).[4,5]

Estimating value

We compiled 21 case studies provided by the NRCS that quantified the economic benefits generated from the Snow Survey and Water Supply Forecasting program data. We converted all case studies to 2019 dollars and compared the economic benefits with the total program cost and the estimated data collection costs in the specified region for each case study.

Costs

The annual budget for the SSWSF program has remained constant at $9 million annually since 2012.[7] These costs do not include those born by partners who also collect data. An individual SNOTEL sensor costs between $25,000 and $35,000 with an additional $3,000 for annual maintenance.[8] The cost varies depending on how many additional sensors are included at a SNOTEL station. All SNOTEL sensors collect air temperature, snow depth, and precipitation, but some collect soil moisture, solar radiation, relative humidity, or wind data. Data collection at snow courses average $3,500 annually and are often collected on a monthly basis.[8] The estimated data collection costs were based on the number of SNOTEL sensors and snow courses within a state or watershed specified by the case study.

Benefits

Prior to the SSWSF program organizations had to make decisions about reservoir operations, crops, and recreational activities without knowing the timing or volume of snowmelt. Today, data and forecasts from the SSWSF program are the basis for many of these decisions. As one person noted after avoiding flood damages from snow melt in 2005, “if we hadn’t had the information there’s no way we could have prepared”.[4] The NRCS has compiled case studies that demonstrate the qualitative and quantitative benefits of SSWSF data to the western economy and society.[8,9]

Estimated benefits from all use cases were converted into 2019 dollars. The value of data from the SSWSF are typically derived from forecasts combining snow, streamflow, reservoir, and weather data (some of which are collected by SNOTEL sensors). The NRCS case studies used different methods to estimate the differences in decisions made when SSWSF data are not available. This allows us to assume that 100% of the economic benefits result from SSWSF data and does not require applying the Business Model Maturity Index method.

The estimated benefit-to-cost ratio was calculated by dividing monetary benefits with the annual program costs ($9 million). Please note that the SSWSF program is collaborative and these estimates do not account for the costs to partners. The case studies were site specific and did not rely on the full data collection network. As such, we also estimated the data collection costs for the case study based on the number of nearby active SNOTEL and snow courses that were in operation during the specified year.[3] The data collection benefit-to-cost ratio divided the benefits by the relevant data collection costs.

Case Studies

The NRCS case studies estimated the monetary benefit experienced by a specific farm, company, or community that used forecasts to make different or better decisions than would have been made otherwise. Case studies on flood protection attributed the avoided costs to early warnings from the SSWSF program that enabled the community to prepare in advance for a flood event. Case studies for agricultural communities estimated the difference in crop revenue made by growers who used SSWSF forecasts to adjust cropping decisions in a dry or wet year than if they had planted as though it was a normal snow year. Case studies for municipal water supply and hydropower generation modeled a loss of efficiency in reservoir operations of 1 to 10% that may occur if SSWSF data and forecasts were not available.

Table 1 provides brief descriptions for each case study. The benefit-to-cost ratio for the full SSWSF program ranged between $0.02 and $91.12 (Figure 3). It is not surprising that a single case study does not cover the costs of the entire program; however, it was surprising that 38% of the case studies created more value than the costs to operate the full SSWSF program. The benefit-to-cost ratio for data collection ranged between $0.13 and $1,185.91 for each case study. Here, 95% of case studies producing greater value than the cost of data collection.

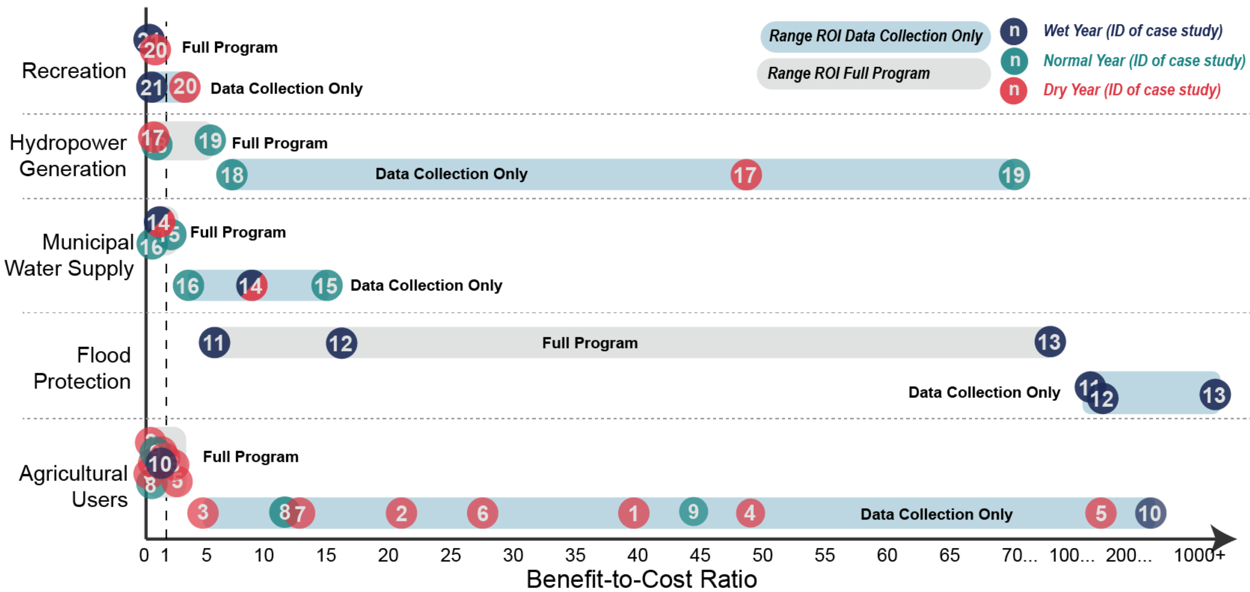

Figure 3: Benefit-to-cost ratio estimated for both the costs of the full SSWSF program (gray bar) and the costs of data collection (blue bar) for the 21 case studies. The case studies are organized by user group and color coded to indicate benefits during dry (red), normal (teal), and wet (navy) years. The number in the circle is the case study identifying number (Table 1).

Value of Snow Data for Agricultural Communities: Low Snowpack

The majority of case studies for low snowpack years focused on the benefits accrued by agricultural communities. Agricultural communities use SSWSF data to make decisions about the types of crops and the number of acres to plant, contracting decisions, and so on. Many of these decisions are made prior to the growing season and are heavily reliant on SSWSF data. The size of the farms in the case studies ranged from 650 to 185,000 acres. The range of benefits generated by increased productivity and improved decision-making during a low snowpack year generated $0.02 to $2.61 in benefits per dollar spent on the SSWSF program. The value of SSWSF data to growers during normal snowpack years were estimated to produce a quarter of the value created during dry years (compare case studies 4 with 8 and 5 with 9). The benefit-to-cost ratio for data collection ranged from $4.73 to $183.47.

Case Study 1: Growers in Elko County, NV
Heavy snows in the foothills took place in March of 1955 were 183% of normal conditions and visually it seemed like a high water supply year. Despite the late snowfall, the SSWSF program predicted that streamflow at Salmon Creek Falls near San Jacinto, NV would only be 60% of normal due to low snow pack at higher elevations in the mountains. The SSWSF forecast led farmers to plan to irrigate smaller acreage than they would have based on visual

evidence alone. This resulted in an estimated $379,000 of avoided losses by this agricultural community ($3.62M in 2019 dollars).

Value of Snow Data for Flood Protection: Large Snowpack

Years with large snowpack can generate significant downstream flooding. The SSWSF forecasts provided advanced warning of downstream flooding that enables communities to implement flood protection measures and mitigate flood damages. The estimated benefit-to-cost was between $5.83 and $91.12 for the full SSWSF program (Table 1: Case Studies 11-13). The benefit-to-cost ratio exceed $150 when applied solely to the snow data collected to inform flood forecasts.

Case Study 13: Flood Protection near Oakley, ID

In January of 1984, SSWSF data indicated that snowpack was 240 percent of normal upstream of Oakley reservoir. Predictions indicated that snowmelt would lead to catastrophic flooding. As a result, the Army Corps of Engineers, National Guard, conservation districts, canal companies, state and local governments, and private organizations worked together to build what ultimately became a 42-mile canal to divert water from Oakley reservoir to the Snake River, avoiding flooding of the town of Oakley, the city of Burley, and surrounding areas. It was estimated that protecting farmland alone amounted to $820M in avoided costs in 2019 dollars (well above the $9M dedicated annually to the SSWSF), not including the value of protecting developed communities.

Value of Snow Data for Hydropower and Municipalities: Normal Snowpack

Hourly and daily SSWSF data are used by hydropower companies to inform cloud-seeding operations in the winter and to make optimal “fill and spill” decisions within reservoir systems to maximize power generation. Here, optimization and integration of operations enabled by SSWSF data lead to increased productivity. Hydropower companies operating multiple reservoirs across river basins have opportunities to move water around within the system based on SSWSF data. While the benefit-to-cost ratio is less than $1 for a single hydropower reservoir, the value accrued by regional hydropower companies in a normal snow year ranged from $0.52 to $5.15 in benefits per dollar spent on the entire SSWSF program (case studies 18 and 19). Similarly, municipal water utilities that transfer water between river basins can receive benefits exceeding the full costs of the SSWFS program by optimizing operational efficiencies. For example, Denver Water Utility had a benefit-to-cost ratio of $0.14 to $1.43 in revenue were saved per dollar spent depending on whether SSWSF data improved operational efficiencies by 1 or 10%, respectively (case studies 15 and 16).

Case Studies 18 and 19: Idaho Power Company

Idaho Power Company is part of a system of 17 hydroelectric power generation facilities in the Snake River plain in Southwestern Idaho. Idaho Power uses SNOTEL data to inform cloud-seeding operations and determine whether to fill a particular reservoir or allow water to run downstream to other reservoirs (spill). SSWSF data are used to make decisions regarding how to move water between reservoirs to take advantage of differences in snowpack across watersheds. SSWSF forecasts also inform long range planning and forward contracting for purchasing and selling power in the wholesale market. The potential revenue lost during a normal water year due to fill and spill errors resulting from not having SSWSF data was estimated at $4.6M (1% loss in accuracy) to $46.4M (10% loss in accuracy).

Final Thoughts

The benefits discussed above went to government agencies (local, state, federal), private organizations (hydropower companies, growers, tourism industry), and individual citizens (recreation). As shown, the benefits accrued in a single case study can exceed the full costs of the SSWSF program even though only a fraction of the data collection network was utilized. The cumulative benefits of the data to all user groups across the western United States undoubtedly far exceed the operational costs of the SSWSF program. The SSWSF program is cooperative with resources invested by other federal, state, local and private entities. The costs to these entities were not considered here. However, the willingness to continue investing in the SSWSF program indicates they value the benefits created by these data.

Table 1: Brief overview of 21 case studies pulled from two papers. SSWSF program costs were set at $9 million annually, reflecting the budget since 2012. Sensor costs were estimated by multiplying the number of SNOTEL sensors by the annual maintenance costs + 1/10th of the cost of the sensor (assumes sensors last for 10 years) and adding the number of snow courses times the annual costs of data collection. The life span of a SNOTEL sensor was arbitrarily selected. All dollars were converted to 2019.

ID	User	State	Year	Year Type	Benefits ($)	N SNOTEL Stations	N Snow Courses	Sensor Costs ($)	Program Benefit-to-Cost	Data Benefit-to-Cost	Notes
1	Agriculture	NV	1955	Dry	3,615,660	0	26	91,000	0.40	39.73	In Elko County, growers visually observed above normal snowfall in the foothills during a below normal year in higher mountains. Water supply forecasts prevented growers from relying on misleading observations of foothills snowfall that would have led to planning for an above normal water year.[9]
2	Agriculture	ID	1960	Dry	2,735,710	12	16	128,000	0.30	21.37	Savings from forecast on 31,000 acres during a drought for an area served by Oakley and Salmon Falls Creek reservoir.[4]
3	Agriculture	UT	2005	Dry	191,588	5	3	40,500	0.02	4.73	Estimated cost of a reservoir spill in a dry year for a single farmer with 650 acres. Assumed use of forecasts along a single river (here, Cache County).[4]
4	Agriculture	ID	2005	Dry	5,089,350	8	16	104,000	0.57	48.94	Estimated value of cropping decisions for 35,000 acres of farmland near Salmon Creek Falls at $145.41/acre due to forecasts in a dry year.[4]
5	Agriculture	ID	2005	Dry	23,483,715	12	16	128,000	2.61	183.47	Estimated value of cropping decisions for 185,000 acres of farmland near Twin Falls at $145.41/acre due to forecasts in a dry year.[4]
6	Agriculture	UT	2006	Dry	19,773,900	87	57	721,500	2.20	27.41	Sevier River Commissioner estimate of avoided losses from making different crop choices because of forecasts.

ID	User	State	Year	Year Type	Benefits ($)	N SNOTEL Stations	N Snow Courses	Sensor Costs ($)	Program Benefit-to-Cost	Data Benefit-to-Cost	Notes
7	Agriculture	UT	2006	Dry	9,797,143	87	57	721,500	1.09	13.58	Sevier River Commissioner conservative estimate of case study 6 in avoided losses due to forecasts.[4]
8	Agriculture	ID	2005	Normal	1,237,950	8	16	104,000	0.14	11.90	Estimated value of cropping decisions for 35,000 acres of farmland near Salmon Creek Falls at $35.37/acre from forecasts during a normal year.[4]
9	Agriculture	ID	2005	Normal	5,712,255	12	16	128,000	0.63	44.63	Estimated value of cropping decisions for 185,000 acres of farmland near Twin Falls at $35.37/acre due to forecasts in a normal year.[4]
10	Agriculture	OR	1946	Wet	8,521,500	0	6	21,000	0.95	405.79	Estimated value of extra crops planted during a wet year in two counties.[9]
11	Flood Protection	MT, ID	1946	Wet	52,440,000	0	96	336,000	5.83	156.07	High snow forecasts led to coordinated effort to shore up flood protection infrastructure and repair dike system with an estimated 17,800 lives protected.[4]
12	Flood Protection	ID	1984	Wet	147,600,000	0	223	780,500	16.40	189.11	Snow data showed more than 300% snowpack, led several agencies to coordinate efforts to strengthen reservoirs and build a 420mile canal system to divert flood waters.[9]
13	Flood Protection	UT	2005	Wet	820,060,000	82	57	691,500	91.12	1185.91	Cost of an earlier flood event pre-dating SNOTEL compared to a similar magnitude event in 2005 that resulted in no flood damages because of advanced preparation from forecasts.[4]
14	Municipal Water Supply	CO	2006	Mixed	7,104,380	85	101	863,500	0.79	8.23	Estimated value of water transferred between the Colorado River reservoir system (more snowpack) and the South Platte River system (less snowpack).[4]

ID	User	State	Year	Year Type	Benefits ($)	N SNOTEL Stations	N Snow Courses	Sensor Costs ($)	Program Benefit-to-Cost	Data Benefit-to-Cost	Notes
15	Municipal Water Supply	CO	2006	Normal	12,827,000	85	101	863,500	1.43	14.85	Estimated value of water lost due to fill and spill errors based on misestimated snow water content (10% error estimate from no forecast data).[4]
16	Municipal Water Supply	CO	2006	Normal	1,282,700	85	101	863,500	0.14	1.49	Estimated value of water lost due to fill and spill errors based on misestimated snow water content (1% error estimate from no forecast data).[4]
17	Power Generation	MT	1955	Dry	1,192,500	0	7	24,500	0.13	48.67	Record low flow forecasts on the South Fork of the Flathead River enabled savings and optimized power generation in an 18 day window.[9]
18	Power Generation	ID	2006	Normal	4,638,548	52	101	665,500	0.52	6.97	Estimated revenue loss in a normal year by not having access to SNOTEL sites (1% error estimate).[4]
19	Power Generation	ID	2006	Normal	46,385,480	52	101	665,500	5.15	69.70	Estimated revenue loss in a normal year by not having access to SNOTEL sites (10% error estimate).[4]
20	Recreation	AZ, CO, UT	2006	Dry	4,739,640	186	181	1,749,500	0.53	2.71	Model assessed avoided losses during a dry year for two organizations using water supply forecasts to guide contracting decisions.[4]
21	Recreation	AZ, CO, UT	2006	Wet	233,680	186	181	1,749,500	0.03	0.13	Model assessed avoided losses during a wet year for two organizations using water supply forecasts to guide contracting decisions.[4]

For more information:

[1] NRCS. 2006. Benefits of the Snow Survey and Water Supply Forecasting Program. Snow Survey Centennial Celebration: 1906-2006.
[2] NRCS. 2008. The History of Snow Survey and Water Supply Forecasting: Interviews with U.S. Department of Agriculture Pioneers.
[3] NRCS. 2019. SNOTEL Interactive Web Map.
[4] NRCS. 2008. A Measure of Snow: Case Studies of the Snow Survey and Water Supply Forecasting Program.
[5] NRCS. 2006. How Snow Survey Data and Products are Used. Snow Survey Centennial Celebration: 1906-2006.
[6] NRCS. 2006. The Snow Survey and Water Supply Forecasting Program. Snow Survey Centennial Celebration: 1906-2006.
[7] USDA. 2019. Budget Summaries from 2012 to 2019.
[8] Domonkos, B., Landers, L. and Wetlaufer, K. 2015. Snowpack Monitoring for Water Supply Forecasting and Drought Planning
[9] NRCS. 2006. Early Snow Survey Program Economics. Snow Survey Centennial Celebration: 1906-2006.

Method Tags: Case Studies

Use Case Tag: water quantity; infrastructure

Organization Tags: government

Benefits Tags: Avoided Costs; Accurate Design and Integrated Operations; Improved Decision-Making; Return on Investment; Increased Productivity