A DETECTOR FOR DETERMINING SNOW WATER CONTENT BASED ON ATTENUATION OF COSMIC RADIATION

by
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ABSTRACT

Water content of the snow pack is measured at approximately 100 sites within the State of California by snow sensors. The sensors detect the water content as a weight exerted on either stainless steel or rubber bladders filled with fluid. The tanks are connected to either a stilling well with a shaft encoder or a pressure transducer. The resulting signal is proportional to the weight of the water in the snow.

These sensors suffer from a variety of problems. They require a large footprint, at least 7.5 square meters to avoid edge effects, with consequent environmental disruption. The tanks and associated plumbing are prone to puncture from both human and animal disturbance. Transport of the bladders poses significant difficulties in wilderness areas where mechanical transport is prohibited. Loss of the sensors for an entire season is not uncommon due to water intrusion into the transducer or leaks in the tanks.

Adding insult to injury, the sensors do not accurately measure the water content under certain conditions. Extensive ice layers in the snow can support part of the pack's weight so that the registered water content is less than actual. Later, after these layers lose some of their structure, or additional snow accumulates to collapse the bridging structure, the sensor readings will reflect actual snow water content.

This paper will describe the development of a detector which measures cosmic radiation and determines the snow water equivalent based on the attenuation of the radiation. The detector has had two seasons of field verification tests at the Central Sierra Snow Laboratory with very promising results.

THE OPPORTUNITY

Throughout the Western US and Canada the majority of surface runoff comes from melting snow. Without the unique configuration of topography, climate and storm track which provides for an abundant snowpack and subsequent runoff, Western urban and agricultural development would be much different from that which has occurred.

The accumulation of snow provides a vast reservoir of water, which is normally gradually released in the Spring and early Summer. If the precipitation where to occur primarily as rain, as in late December 1996 and early January 1997, the reservoir and channel infrastructure that provides both water supply and flood control protection, would require significant enlargement. Fortunately, winter precipitation generally does occur as snow in the higher elevations of the Sierra permitting many beneficial uses for the spring and summer runoff.

The water content of the snow pack provides the best parameter for forecasting the amount of runoff in Spring and Summer. The ability to forecast this runoff allows for optimal utilization of reservoir volumes, provides opportunity to plan agricultural operations, maximizes hydroelectric generation and governs municipal and industrial water allocations. Revenue from agricultural production in the San Joaquin Valley alone is over 10 billion dollars. Fresno County in California, the richest agricultural county in the country, has agricultural revenues of 2 billion. The success of irrigated agriculture in the West is partly due to water management decisions that were guided by water supply forecasts derived from snow survey data.

While measurement of snow water content and water supply forecasting have proven invaluable for assisting in water resources management, the increasing demands on this limited resource dictate the need

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for continued improvements. At its inception, to forecast Lake Tahoe rise, manual snow measurements made near April 1 were sufficient. Over the years, the frequency and locations of manual measurements increased, but not sufficiently to meet the needs of a more complex society. While manual measurements still provide the baseline network within California, a need developed for measurements at a daily time step to provide additional information during high intensity flood producing events, and to allow for more frequent water supply updates following major storms.

As early as 1954 the Corps of Engineers, Sacramento District, had deployed a few remote gauges at State Lakes, Mitchell Meadow and Upper Tyndall Creek in the southern Sierra. These early gauges relied on the known attenuation by the snow pack water of the radiation from a cobalt 60 source. Unfortunately the electronics of that era were insufficiently robust and failed repeatedly.

Ultimately, weight-sensing gauges were developed, consisting of either thin stainless tanks or rubber pillows, which could successfully be installed in remote locations. The sensors detect the water content as a weight exerted on either stainless steel or rubber bladders filled with fluid. The tanks are connected to either a stilling well with a shaft encoder or a pressure transducer. The resulting signal is proportional to the weight of the water in the snow.

These snow sensors avoided the use of a radioactive source, and the attendant difficulties in permitting and deployment. The electronics proved more reliable due to the reduced complexity, but problems remain.

Initially the pillows were filled with ethylene glycol, common automotive antifreeze. This material was found to be toxic and agencies switched to either methanol, propylene glycol or a mix. While these materials do not constitute a hazard some land management agencies have expressed concern over the potential for leaks from the pillows.

Either the stainless tanks or rubber pillows must be of considerable surface area to accurately determine water content. A series of tests found the minimum size to be 7.5 square meters. Transport and installation of the pillows and fluid to remote areas poses considerable logistics problems. Figure 1 depicts a typical pillow installation.

The need for a level site to accommodate the tanks and the preparation required precludes many alpine locations. Snow sensors are therefore frequently installed in meadow environments. Not only are meadows not typical of the watershed but they are often subject to frequent flooding.

The pillows and associated plumbing to connect to the transducers or stilling wells have been difficult to protect from human and animal vandalism. At one site, Paradise Meadow in Yosemite National Park pillows were lost to bear attack four years in a row. Deployment of a "bear net", consisting of a net made of steel cable, has eliminated this problem, but new and interesting problems continue to occur. At Black Cap Basin in the Kings River drainage, two pillows were punctured by an irrational Outward Bound participant who was incensed upon realizing that the soil covered pillows would not provide a good latrine site.

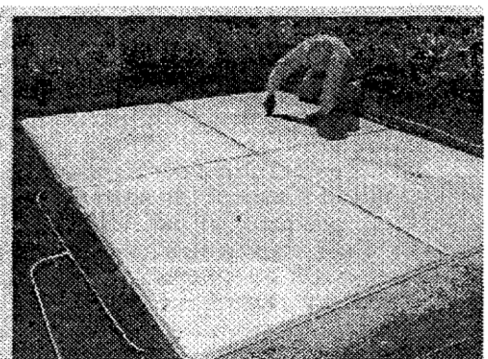

Figure 1

The combination of fluid and electronics has not been a happy marriage. At a site on Kibbie Ridge near Yosemite the buried electronics box burst after the tubing carrying the fluid from the pillows to the transducer melted during a fire and filled the box with methanol.

All of the above problems have been solved by continued improvements in design and installation. Unfortunately, the mechanical properties of the snow present difficulties which can not be surmounted by any sensor scheme based on weighing the snowpack. The snow has varying structural integrity and under certain conditions can bridge over the pillows reducing the apparent weight registering on the pillow. In water year 1997, some basins had a 40 cm layer of consolidated snow form at the base of the pack. The registered water content differed from ground truth by as much as 30 percent. As the season progressed and the snow pack ripened, these differences moderated substantially.

A POTENTIAL SOLUTION

In view of the problems described above, there is considerable interest in developing a technique to determine water content in the snow pack without weighing it. While the pioneering work by the Corps of Engineers with their radioactive source gauges was abandoned, improvements in electronics offered some hope. The National Operational Hydrologic Remote Sensing Center has developed a flyover technique of first measuring the soil background gamma radiation, and then subsequently measuring the same area after snow accumulation to determine water content based on attenuation of the radiation. The soil gamma radiation is less than 3 Mev and is nearly complete attenuated by only 60 cm of water content. This technique is therefore unsuitable to regions, such as California, where 200 cm is not uncommon.

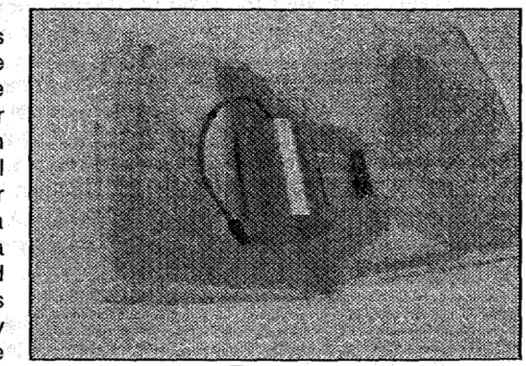

Figure 2

Ken Condreva, a scientist working for Sandia National Laboratory, approached Snow Surveys with an idea to measure the attenuation of high energy cosmic radiation by the snowpack. The gamma ray detectors are scintillation counters approximately 10 cm in diameter and 15 cm long, shown on Figure 2. The detectors effectively measure cosmic radiation up to about 10 Mev. While radiation of higher energy has greater penetration into the snow pack, the 3-10 Mev band offers the best balance of detector cost and particle count rate. Selection of the energy range above 3 Mev filters any local effects from soil radiation. Therefore only cosmic radiation is detected, which must pass through the snowpack to reach the field detector.

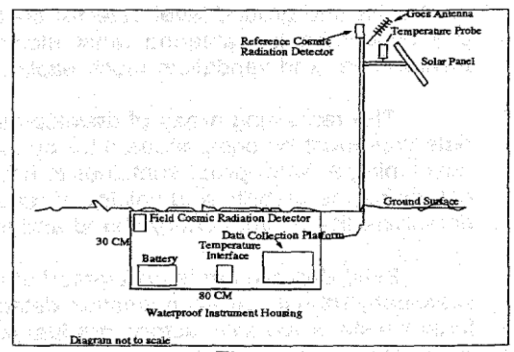

Figure 3

In the initial tests and probable deployment configuration, a detector would be mounted on the top of the antenna mast to provide the reference or background count. A second detector would be mounted at the ground surface. A schematic diagram is shown on Figure 3. A background detector would likely be required at each installation, because localized atmospheric conditions might cause perturbations in the purportedly uniform cosmic radiation flux.

Preliminary tests during the winter of 1995-96 were conducted at the Central Sierra Snow Laboratory, located at Soda Springs near Truckee, California. Analysis shown on Figure 4 shows a very good correlation between tube measurements and water content determined by the detector. Maximum snow water accumulation during the season was only about 90 cm, and there were lingering doubts regarding the frequency of radiation with sufficient energy to penetrate greater depths.

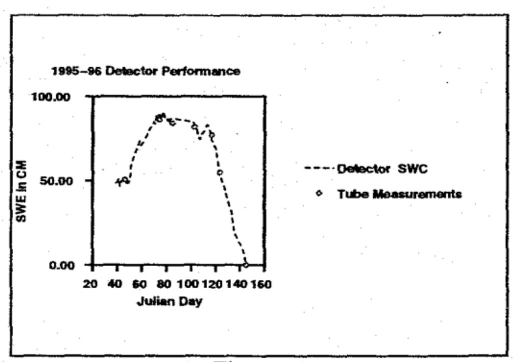

Figure 4

In early autumn tests were conducted with the cooperation of the Scripps Institution of Oceanography and the City of San Diego. The field detector was immersed in fresh water tanks and in San Vicente Reservoir. Various depth regulation problems and amplifier instabilities prevented calculation of a calibration curve. The results did show the ability to discriminate depths at least down to 60 m, certainly sufficient for even California snows. Figure 5 is a typical spectrum from the detectors over a two hour period.

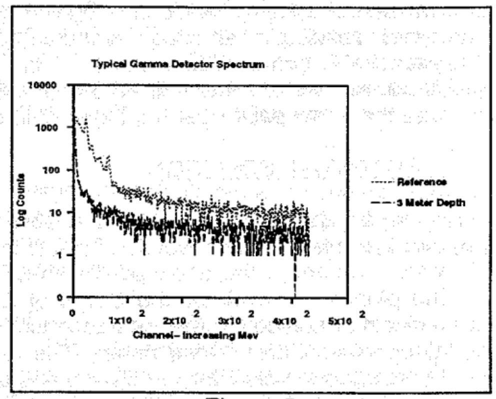

Figure 5

The equipment was reinstalled at the snow lab for the winter of 1996-97. During this season progress was made on determining the minimum time during which an accurate sample could be obtained. Also, work was undertaken to develop the electronic interface between the detectors and a data collection platform.

CONCLUSION

These new detectors offer several advantages over existing technology. First, the water content of the pack is not determined by the weight of the snow water, eliminating all of the problems with edge effects and bridging. Second, the devices could be installed at remote sites with equipment which is sufficiently small and light that transportation difficulties would be minimized. Third, the site disturbance is minimal. Fourth, locations could be selected in areas other than meadow environments. Fifth, the entire package of electronics and ground level detector could be housed in a waterproof container which would only require connections to the antenna mast electronics. This would make installation and protection from the environment and vandalism much easier.

The remaining areas of development do not appear daunting. The effect of temperature on the detectors must be compensated for by the electronic interface. Scripps Institution of Oceanography is developing a water-proof container to house the electronics and detector. Further analysis is needed to determine the stability and validity of readings in an operational setting. Additional work is needed to determine the optimal energy band and measurement duration.

Field deployment is anticipated at two sites during the summer of 1997 if the interface package is sufficiently robust. At each location detectors will be colocated with stainless steel pillows. Should these further tests prove satisfactory, gradual replacement of the snow pillows would occur following the turn of the century.

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