OPERATIONAL SNOW SENSORS

by

ROBERT T. DAVIS
SNOW SURVEY SUPERVISOR
SOIL CONSERVATION SERVICE, SPOKANE, WASH.

Early Days

The art or science of snow surveying and water supply forecasting, as we know it today, is relatively young. The first known record of a snow survey in the United States was made in 1834 by John B. Jervis. In a report (1) he made to the New York Canal Commissioners, Mr. Jervis, Chief Engineer of the Chenango Canal, stated, "Snow on the ground which fell in November and December 1834 on the watershed of Madison Brook (9.37 square miles) amounted to 87,120,000 cubic feet of water." His method for this computation is unknown at present but would seem to be essentially a snow survey and water supply forecast.

The first known snow survey with documented methods (2,3) is found in a letter dated March 7, 1903, from Charles A. Mixer, resident engineer of the Rumford Falls Power Company at Rumford Falls, Maine, on the Androscoggin River, to Dr. H. C. Frankenfield, in charge of the River and Flood Service of the Department of Agriculture. In this letter Mr. Mixer stated, "My usual gaging of the snow on the ground consists of simply getting a correct and full sample of the snow on the ground and then melting it to get the water equivalent. The sample is secured by forcing a cylinder down to the ground, then shoveling down around it and inserting a sheet metal bottom and lifting it out." Mr. Mixer goes on to state, "On my volumtary observer's report for March 1900, there is given my first report of such measurements."

In 1906, across the continent in the high Sierras near Reno, Nevada, a young professor of the classics offered to climb Mt. Rose every month of the year to obtain temperature readings (4). This man was Dr. James E. Church. In the succeeding years, automatic recording instruments were developed and installed at an observatory on the mountain, but the measurement of the snow could not be recorded automatically.

Development of the Manual Sampling Equipment

Because of the snow's great depth, it was not feasible to take an 8-inch snow sample and melt it, as was done in the East. Dr. Church, therefore, designed and built the Mt. Rose snow sampler and scale.

The Mt. Rose snow sampler was the first specialized equipment to measure snow (5). This equipment consisted of a tube of stainless steel 12 feet long. The tube was equipped with a saw-toothed cutter to drill through the ice and had a series of slots cut in the side so that the core of snow could be observed. The scale was the dial type so that the empty tube, when weighed, could be adjusted to read zero. Weighing the tube and snow then gives the weight of the snow alone.

Because of the awkwardness of carrying a 12-foot steel tube into the mountains and also because snow depths greater than 12 feet were encountered, the sampling sets were cut into 30-inch sections joined by threaded couplings.

The next step was to make the equipment lighter and more transportable. The Federal Mt. Rose snow sampler, or Federal snow sampler, was developed to meet this need (6). It was made of duraluminum with a steel snow cutter. The scale was changed to a tubular spring-loaded balance and was graduated to weigh in ounces. The steel cutter was made to cut a core 1.485 inches in diameter and the scale reading was then equivalent to inches of water in the sampled snow cover.

While this deep-snow equipment was being developed by Dr. Church and Mr. George Clyde of Utah, many other types of sampling sets were tested. The "Snow Thief" (7) was made from a 24-gage galvanized iron tube 8 feet long. A smooth, sharp steel cutter was riveted to one end to cut a 2.254-inch core of snow. This was replaced in 1923 by similar equipment but having a toothed cutter. The 8-foot galvanized sampling sets were finally replaced by the Federal snow sampler because of its greater versatility.

In the East, the snow surveyors did not have to measure the great depths of snow encountered in the West but were plagued by ice and dense snow layers. In the early twenties, a set of snow sampling equipment consisted of a length of 4-inch pipe, pail, hammer, ramrod, and platform scales. The iron pipe was driven through the snow with the hammer, then the snow was pushed into the pail with the ramrod and weighed on the scale.

In 1928 a 3-inch steel tube was used instead of the iron pipe. The 12-pound steel tube was a welcome substitute for the 40-pound iron pipe. The steel tube was used until 1946 when it was replaced by a 3-inch aluminum tube with a replaceable steel cutter having a bore of 2.655 inches. This was a further weight reduction of 8 pounds. At the present time, this equipment, termed the Adirondack-type snow sampler is being used.

New Developments

Work is still going on to improve the snow sampling equipment; some of the most recent (that I know of) are the Bowman cutter and tube, the Rosen, and the McCall. The Bowman cutter consists of a long, tapered, steel cutter bit with teeth on the order of a crosscut saw. This is screwed into a plastic tube made up of 30-inch sections similar to the Federal sampler. The cutter is an excellent ice cutter, but the plastic tube may split when sampling deep snows.

The Rosen sampler is made especially for deep snow. It is made out of heavy wall aluminum tubing and had no external couplings, so it is easy to drive. The standard Rosen cutter has eight teeth instead of sixteen. The main trouble with the Rosen is that it does not clear itself of the snow core. The inside diameter is too small in comparison to the cutter diameter. A drop hammer can be used with the Rosen set to penetrate deep snow and heavy ice lenses. The drop hammer will not work effectively on the Federal sampler because of its light construction.

The McCall takes the best features of the Bowman and Rosen and appears to be the best sampler for the deep, dense snowpacks of the West. A person wouldn't want to backpack a McCall very far because it weighs about four and one-half times as much as the Federal sampler.

Nondestructive Sampling

No matter how you look at it, manual sampling of snow is archaic, inefficient, and hard work, but it is reliable--or reasonably so. There must be a better way, one that is nondestructive, reliable, capable of onsite recording as well as suitable for telemetry and relatively inexpensive. A system that will work in a 30-inch snowpack as well as 300 inches. Many systems have been tried and many more dreamed up. I will discuss only those systems that have been tried and worked, even if only on a limited scale, because what does not work in one area might be just the thing for another.

As far as I know the radioactive snow gage utilizing a Geiger-Mueller counter was first tried in California at the Central Sierra Snow Laboratory in 1950 (8). This gage consisted of a radioactive course, usually Cobalt 60, buried in the ground and a G-M counter suspended above the source and above the expected snow depth (fig. 1). A count rate was obtained with zero snow as a base, and as the snow built up the count rate decreased in proportion to the water equivalent. A scintillator was substituted for the G-M tube for greater reliability, and the location of the source and counter was reversed for temperature stability. The limit of this equipment is 50 inches of water equivalent. -Accuracy decreases with snow depth.

A novel twist to this radioactive count method was developed in Montana (9,10). The source was buried at the measurement site, and the scintillator installed in an aircraft. The plane would fly by the site, reading the count emitted and taking photographs at the same time. This way a precise altitude of the plane over the source could be determined. The system works, but it has limitations. Daily readings are not feasible, and inclement weather stops the readings completely. Also, the radioactive source has to be quite strong up to 60 mill curies for a 40- to 48-inch water equivalent, and unattended radioactive material in the woods is a safety and environmental problem.

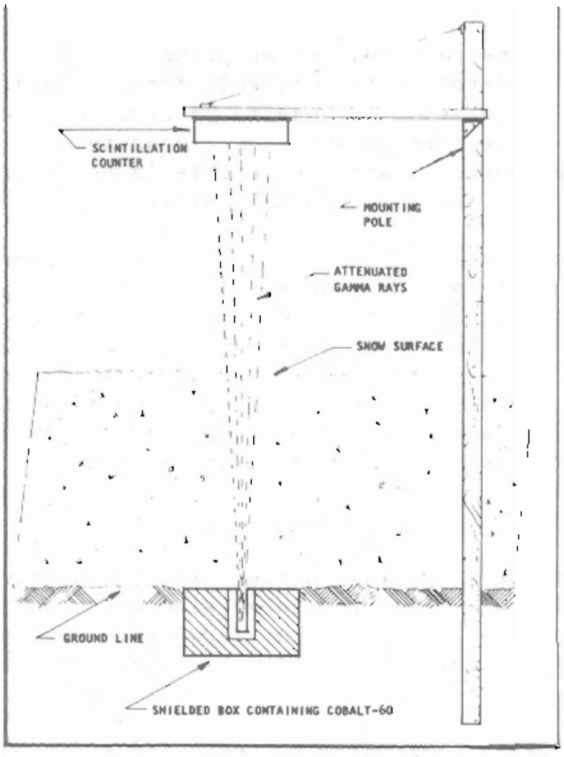


FIG 1

Schematic Drawing of Radioisotope Method of Measuring Water Content of Snow.

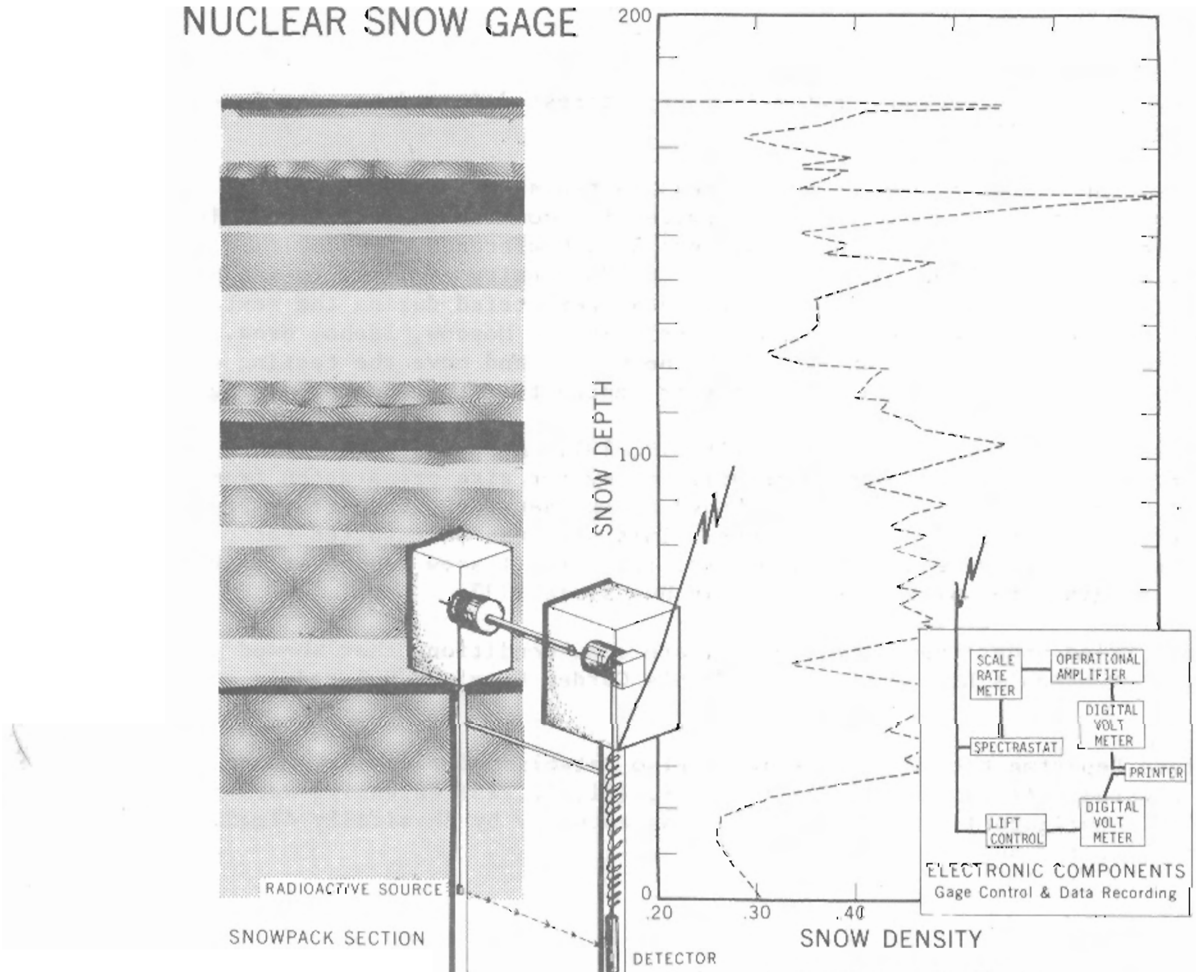


FIG 2

PROFILING THE SNOWPACK

It's done with radioactive isotopes of Cesium 137. A radioactive source is lowered in one tube. A sodium iodide crystal lowered simultaneously in the other tube detects gamma rays pulsing through the snow from the Cesium 137. The number of rays is proportional to snow density, and an index to its character. Development of the gage, which has been patented, has been made possible by research grants from the Atomic Energy Commission.

Another radioactive gage uses the neutron scatter principle (11, 12). This instrument is generally used for soil moisture determination or soil density on compacted fills. As a snow sampler it leaves much to be desired. It has to be carried into the field, is bulky, and requires the snowpack to be cored. Subsequent measurements are generally not available for the same site. The neutron scatter principle is best suited for snow pit studies when used in conjunction with the 500 cc SIPRE sampler.

The most promising of the radioactive gages are the isotopic gages developed by the USFS-AEC (13,14) and Idaho Industrial Instruments (15). The Isotopic profiling snow gage as developed by Dr. Jim Smith, USFS and the AEC, appears to be an excellent instrument to define the snowpack densities down to ½-inch increments (fig. 2), This instrument when coupled to its computer gives a detailed profile of the snowpack by nondestructive means. This enables the researcher to plot water movements through the snow as well as formation and destruction of ice lenses. The instrument is extremely accurate, although at present it is not suited ideally to remote sites. It does require AC power or equivalent and voice grade telephone lines. Several references to this gage are included in the reference list.

The other isotopic gage is quite new. This winter will be the first full year of an operational installation. This gage gives the integrated water equivalent of the snowpack but not the snow depth although you can determine the snow depth to the nearest 30 inches from the readout. Advantages of this unit are that it is completely static and that the data is radio transmissible.

The natural ground radio activity (16) has also been used as a snow sensor. This is only good for very light snowpacks as encountered in the Plains states. However, there are problems with soil moisture, humidity, aircraft elevation, etc.

Snow Pillows

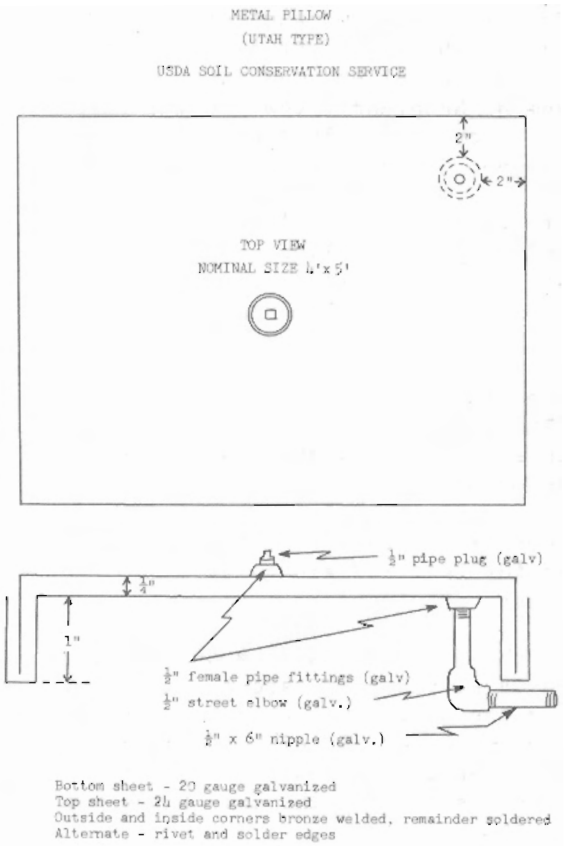
The sensor that the Soil Conservation Service is most interested in and has developed from its beginning is the snow pillow.

The first mention of the use of a snow pillow to measure the snow-water equivalent was made by R. T. Beaumont of the Soil Conservation Service at a committee meeting held in Bozeman, Montana, in 1958, in conjunction with the Western Snow Conference. Following that meeting a contract was made with Dr. Cal Warnick of the University of Idaho to investigate, manufacture, and test snow sensors (17). Several ideas were tried during the next few years, but the main problem was the lack of snow to test in the Moscow, Idaho, area. It was finally decided to discontinue the contract with the U of I and move the testing to Mt. Hood in Oregon. The pillow principle came out of this contract as the most promising.

The Mt. Hood test site was established in 1961 (18, 19, 20). A Special Use Permit was obtained from the Forest Service and some cooperative money for site preparation from Pacific Power and Light Company. This site has continued as the Service's snow study area. A number of manufacturers have supplied test equipment. This site was well suited for its purpose. Lack of snow has never been a problem here, the April 1 snow depths at nearby Phlox Point snow course ranging from 42 inches to 212 inches since 1937.

Ideas developed and tried under these maritime climate snow conditions that showed promise were tried out at Montana's Lick Creek site, Utah's Garden City and Colorado's Rabbit Ears site.

The California State Department of Water Resources also established a remote sensor data test site in the Sierras. At this site, Called Alpha, (21, 22, 23) extensive work has been done with pillow configuration and size as well as accuracy by physically digging the pillows out and weighing the snow (fig. 3).



Bottom sheet - 20 gauge galvanized
Top sheet - 24 gauge galvanized
Outside and inside corners bronze welded, remainder soldered
Alternate - rivet and solder edges

FIG 4

PILLOW CONSTRUCTION DETAIL

FIG 3

SNOW PILLOW DIG OUT - CALIFORNIA ALTA SITE

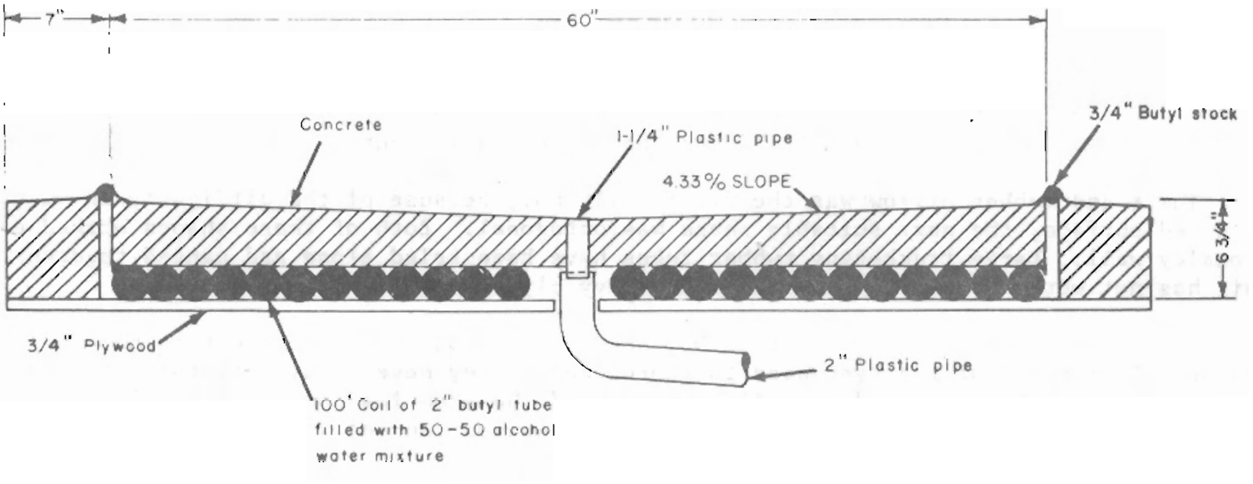


FIG 5 UNIVERSAL PRECIPITATION GAGE - CONSTRUCTION DETAIL

Types of Pillows

Pillows come in all shapes, sizes, and material. The first pillow manufactured for the Moscow tests was made of Butyl* rubber. It was round and about 12 feet in diameter. The manufacturer made about a dozen. These first ones were of excellent quality. Most of them are still in use. The next manufacturer made them of Neoprene*, changed the shape to eight-sided for ease of manufacturing, charged twice as much, and sold a couple of dozen. All failed within a couple of years. Neoprene did not do the job.

Because of the excessive amount of fluid necessary to fill rubber pillows, a metal one was devised (24). These 4- by 5-foot pillows take only about 10 gallons each as compared to the 300 gallons for the 12-foot pillows. This can be a logistics problem at some of our sites. The fluid used has ranged from pure alcohol to equal parts of alcohol and water.

The first all-metal pillows were designed and made in Utah and are logically called the Utah pillow. Several sizes and shapes were tried. These pillows had two major faults: (1) they were not very rigid and (2) the solder had a tendency to crack and leak. The current design, also developed in Utah, is excellent when properly constructed (fig. 4).

One of the main advantages of the metal or tin pillows is the fact that they don't need a level area. A gentle slope, in fact, is preferred for better drainage from the pillow surface. Pillows have been installed on up to 30 percent slopes.

A concrete pillow (25, 26) was designed and built by the Agricultural Research Service (fig. 5). This pillow called the Universal Precipitation Gage, not only catches the snow and weighs it but also records the amount of water leaving the snowpack either from melt or rainfall. It does have one major disadvantage: water can move laterally either off the pillow or onto it from surrounding areas. If the pillow is correctly located, these two factors should balance out. A rubber pillow (27) that does essentially the same thing has been tried, but so far I have not seen any definitive results.

There have been a number of other experimental pillows tried with a varying degree of success: (1) a rubber disc bolted to a concrete platform, (2) rubber and steel, (3) aluminum plate on a plastic base, (4) wooden platforms on rubber bladders, (5) fiberglass pillows, and (6) stainless steel.

The shape of the pillow does not seem to have any bearing on its accuracy, but the size does. The Service has found that the 12-foot diameter pillow is large enough for any snow depths we have encountered and works as well on the light snows. The Soil Conservation Service recommends that the following minimum pillow sizes be followed:

40 sq ft for up to 30 inches snow-water equivalent
60 sq ft for up to 50 inches snow-water equivalent
80 sq ft for up to 75 inches snow-water equivalent
120 sq ft for more than 75 inches snow-water equivalent

The round rubber pillow was the first built but, because of the difficulty in vulcanizing a curved surface, the next suitable shape was octagonal. Both of these shapes worked exceptionally well. Large truck-type rubber tubes have been tried alone and ganged together, but this has not worked even when covered with heavy plywood.

One monster that was tried out at Mt. Hood was a wooden platform resting on four industrial bladders of the type used to store fuel. They never could get this one strong enough to carry the snow load, and if you computed the snow load on a 12- by 12-foot platform with a water equivalent of approximately 100 inches, you can see why. Any attempt to make

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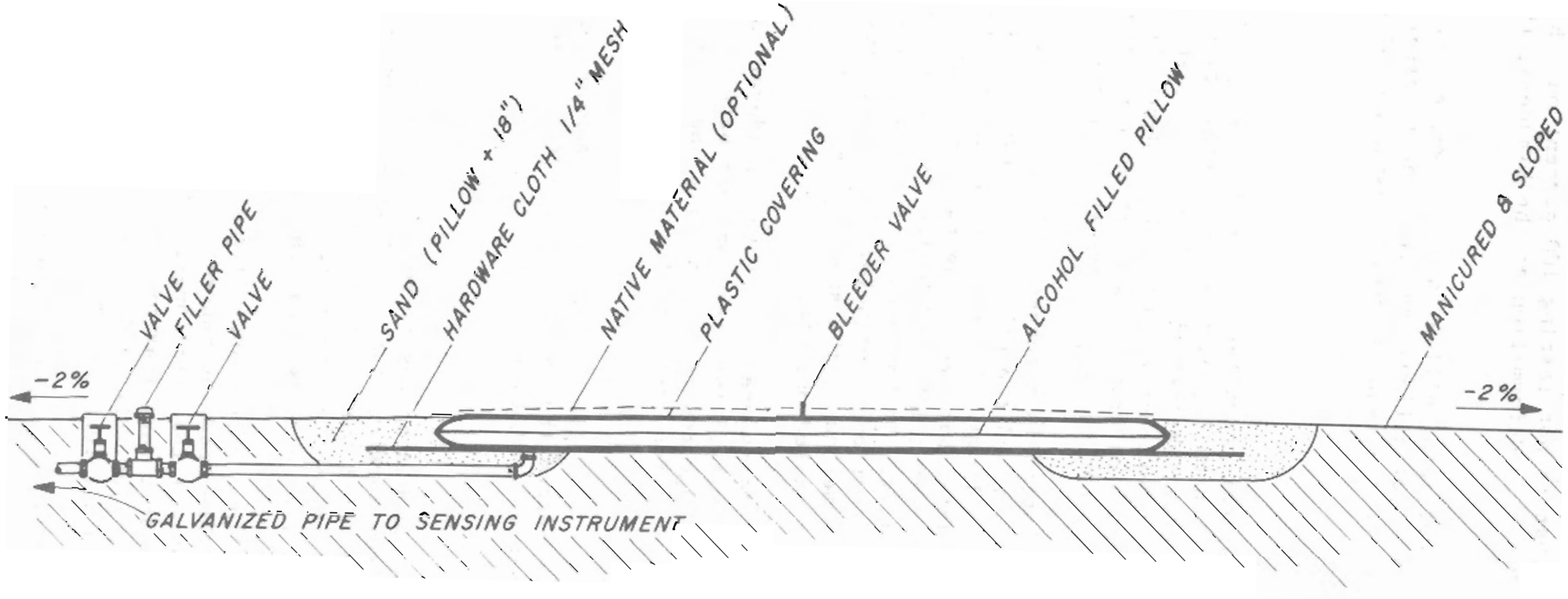
* Trade names are used solely to provide specific information. Mention of a trade name does not constitute a guarantee of the product by the U.S. Department of Agriculture nor does it imply an endorsement by the Department over comparable products that are not named.

FIG 6

CALIFORNIA COOPERATIVE SNOW SURVEYS

RECOMMENDED STANDARD INSTALLATION
SNOW PRESSURE PILLOW



a rigid platform that is not resting 100 percent on a bladder of some kind usually results in failure. Also due to deformation of the bladders, the unit had to be calibrated by loading.

The 4- by 5-foot metal pillows are also subject to controversy. Some say that when two or more 4- by 5-foot pillows are connected together even if they are butted together, you do not get any better results than by using one alone. This question has not yet been settled.

Installation

It does not appear to matter how the pillow is installed, whether on the surface, flush, or buried. Generally, each of the installations reads out equally well. Also, it does not seem to matter whether the pillow is covered. It is my opinion that the proper installation of both metal or rubber pillows should be just below the surrounding surface with a light half-inch covering of sawdust or sand (fig. 6). I believe that an installation of this kind is less noticeable and therefore less susceptibel to vandalism.

If the installation is a rubber pillow, the area has to be leveled and there should be a drainage area all around the pillow--a trench filled with coarse sand. This is also true for the metal pillows. It is advisable to put the pillow on a bed of sand about 2 inches thick to deter burrowing rodents. It is also preferable to restrain the edge of the pillow with something like an aluminum or fiberglass lawn edge. This will keep the pillow from stretching. It has been found at Mt. Hood that any obstruction, like a stump or slope change, either above or below the pillow, has a decided influence on the pillow reading. In the former case, the snow appears to be held off the pillow surface; and in the latter, the snow is pulled onto it.

When all these items are taken into consideration, you can see why the metal pillow is gaining in popularity. The area does not have to be level--just smooth. The metal pillow requires no edge restraints, no deep sand bed for a rodent barrier, and moreover fits the land slope. You just have to keep away from stumps and other obstructions.

With any type of pillow, problems will appear, and I believe the Soil Conservation Service has experienced them all. I will describe several problems and give some ideas on how to prevent some of them.

Problems

All pillows should be tested before you take them into the field. That still may not prevent leaks from forming as the pillows are being transported. Place the pillows on a concrete surface and fill them up to the design level with water. I know of one instance in which they tried to test a rubber pillow with air and put in too much and another in which they put about 4 feet of water head on a metal pillow.

With the pillows filled and a manometer connected, let them stabilize with the air temperature and then read the manometer. Look the pillows over for any wet spots, especially the corners of the metal ones. After a couple of days check them again, also at the same temperature. Any leak present should show up both on the manometer and as moisture on the pillow. Leaks in the metal pillows can be soldered. For the rubber pillows, the manufacturers have their own special patching material.

Usually, new rubber pillows don't leak. If you are going to install a rubber pillow, it is best to cover it top and bottom with 4- by 4-foot hardware cloth. This seems to stop the rodents as well as larger animals. If you use plastic or rubber tubing from the pillow to your readout device, it should be protected also. Copper tubing with flare fittings is preferred for these connections.

Nothing is going to stop an angry or curious bear (fig. 7). I have my rubber pillows in a fenced area where I can take the fence down in the fall and put it back up in the spring. I lost one pillow because I didn't get my fence up in time. I know of another case in which the pillow was covered with plywood and a bear dug the pillow out from under, not once but twice.

Elk or deer can walk across the rubber pillows without doing any damage, but if they hook the pillows with their antlers it is goodbye pillow.

The next greatest problem is man himself. There have been more pillows punctured with snow sampling tubes than with anything else. So don't check the snow depth on top of the pillow. Vandalism has always been a problem, in some places more than in others. It is always best to have the pillow location out of sight. If it can't be seen, it won't be vandalized.

The rubber pillows we now get do not seem to have problems, but in the past it was a different story. All rubber pillows are made of a nylon-rubber fabric that is approximately 1/8 inch thick. Some of this material in the past has been porous to the alcohol we use for fluid. Pin holes have usually shown up after there is a good snowpack. The nylon fibers have also been known to "wick" the alcohol through the rubber from one seam to another. Vulcanized edge joints also have given out. On the metal pillows the corners should be brazed because solder cracks since it has no strength. Again one of the main causes of leaks is the human animal.

The plumbing fittings, whether they are plastic or copper, are subject to leaking and, with the low pressures experienced, sometimes leaks are hard to find. Care must always be exercised when making the installation.

The only way you can tell if a pillow is really doing the job is to dig it out. This has been done at all test areas. The process is simple. You start at least 2 feet out from the edge of the pillow and dig the snow away down to the ground. After you have the trench dug, you start shaving the snow into the pillow edge maintaining a vertical surface. When you get that far, the only thing left to do is to take all of the snow off the pillow and weigh it. As you can imagine though, it takes a lot of digging. Most digouts have been done in 100- to 150-inch snowpacks.

The next best method is to sample the snow in adjacent areas but <u>not on top of the pillow</u>. Admittedly, the sampler has inherent errors (28), but still it is the instrument we have been using in the past for our measurements.

The third way is to make multiple installations. This is what is done at the test sites. We now know the 12-footer is an accurate sampler so we compare the others with this.

Readout and Telemetry

Of the readout devices, the first and easiest to use is the manometer. This is a clear plastic tube fastened vertically beside a scale where the fluid line is read and recorded. Only the condition at the time of reading is available. This should only be considered as an interim method until a radio or onsite recorder is installed. Another way to make onsite readings is to use a water surface popper. This is read down a vertical metal standpipe to which the pillow is connected. A water surface popper is a weighted, cup-like device fastened to the end of a tape. This is dropped down the pipe, and the popping sound indicates the surface of the water, which is read from the tape. This type of measurement device would not be too practical in deep snow or if there was any hint of "snow creep."

The standpipe is the safest way to make onsite recordings but has some definite disadvantages (fig. 8). The standpipe has to extend through the snow depth or be placed in an instrument shelter. The shelter is preferable because the instruments are better protected from the weather. It is also more convenient to get in out of the weather when you are servicing the instruments. The density of the fluid has to be taken into consideration when making float measurements. It has been found that it is advisable to have no more than 10 percent of the fluid in the pillow transfer to the standpipe. In other words you cannot run an 8- or 10-inch recorder float from a single tin pillow.

Both the A-35 Leupold-Stevens gage and the Fischer-Porter punch tape gage have commonly been used for onsite recordings of operational pillows. I understand that the F-Stage recorder has also been used, but this is preferably used when the recorder is unattended for periods up to, but not exceeding, 30 days. The Leupold-Stevens telemark has also been used with pillow standpipes for telemetry but is generally considered too slow for modern communications.

Transducers

There are three general types of transducers in use today: resistance, inductive, and strain gage. The resistance and inductive types are mechanical, the change of pressure being translated through an aneroid barometer-type bellows to a linear movement. The resistance or potentiometer gages that I am familiar with seem to have too much drag and hold up with slight changes of pressure. This in turn requires a shaker to equalize the wiper arm before readout.

The inductive gage appears to be more friction-free and thus more sensitive (fig. 9).

The nonmechanical strain-gage type of transducer seems to be the most foolproof but is the most expensive of the ones I have seen.

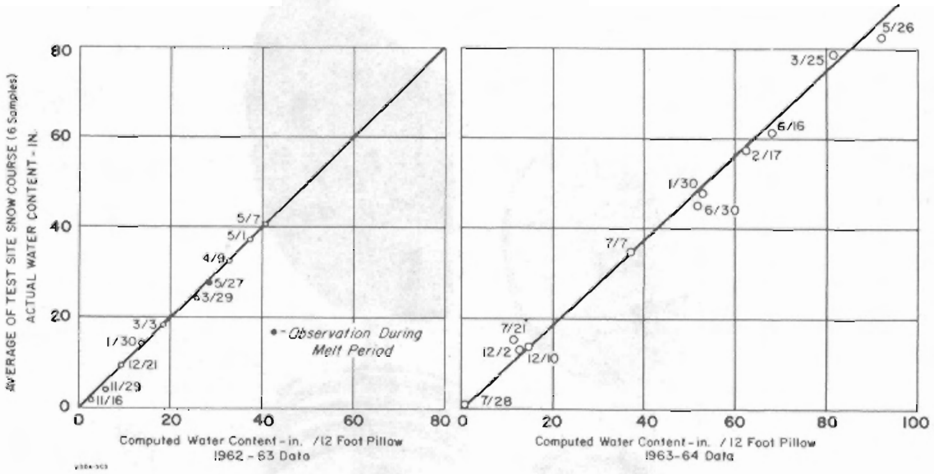
When you are dealing with range of only 0 to 5 p.s.i., your transducer must be sensitive, yet in the adverse environment in which it works, it must be foolproof.

The next step along the chain is telemetry.

Conclusion

I have talked about the growth of snow sampling from the early manual methods to modern nondestructive methods. Each of the modern types, whether radioactive or pillow, has its place. It all depends on what is needed and where it is to be placed. In general, the metal pillows are the best for remote installation: they are more foolproof, are less susceptible to damage, and when connected to a sensitive transducer, are quite accurate.

MT. HOOD TEST SITE



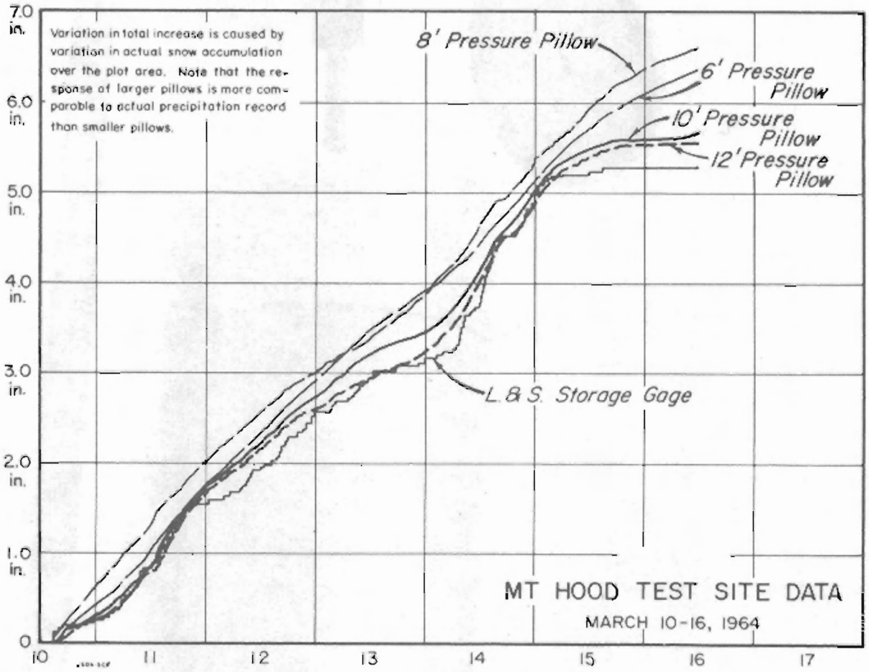


FIG 8 SNOW PILLOW STANDPIPE READOUT

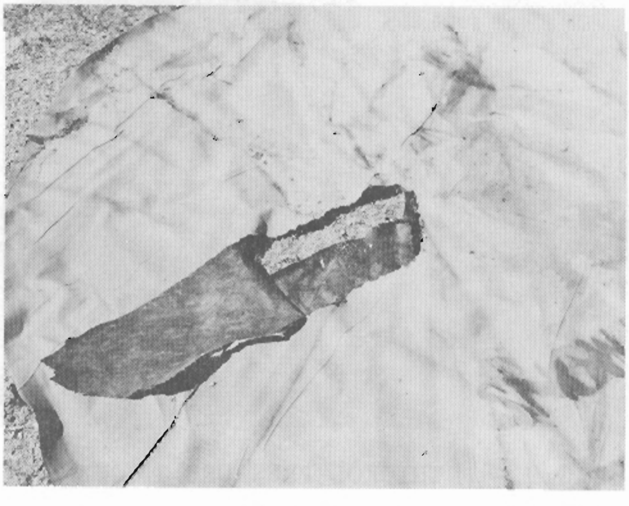


FIG 7 BEAR DAMAGED BUTYL SNOW PILLOW

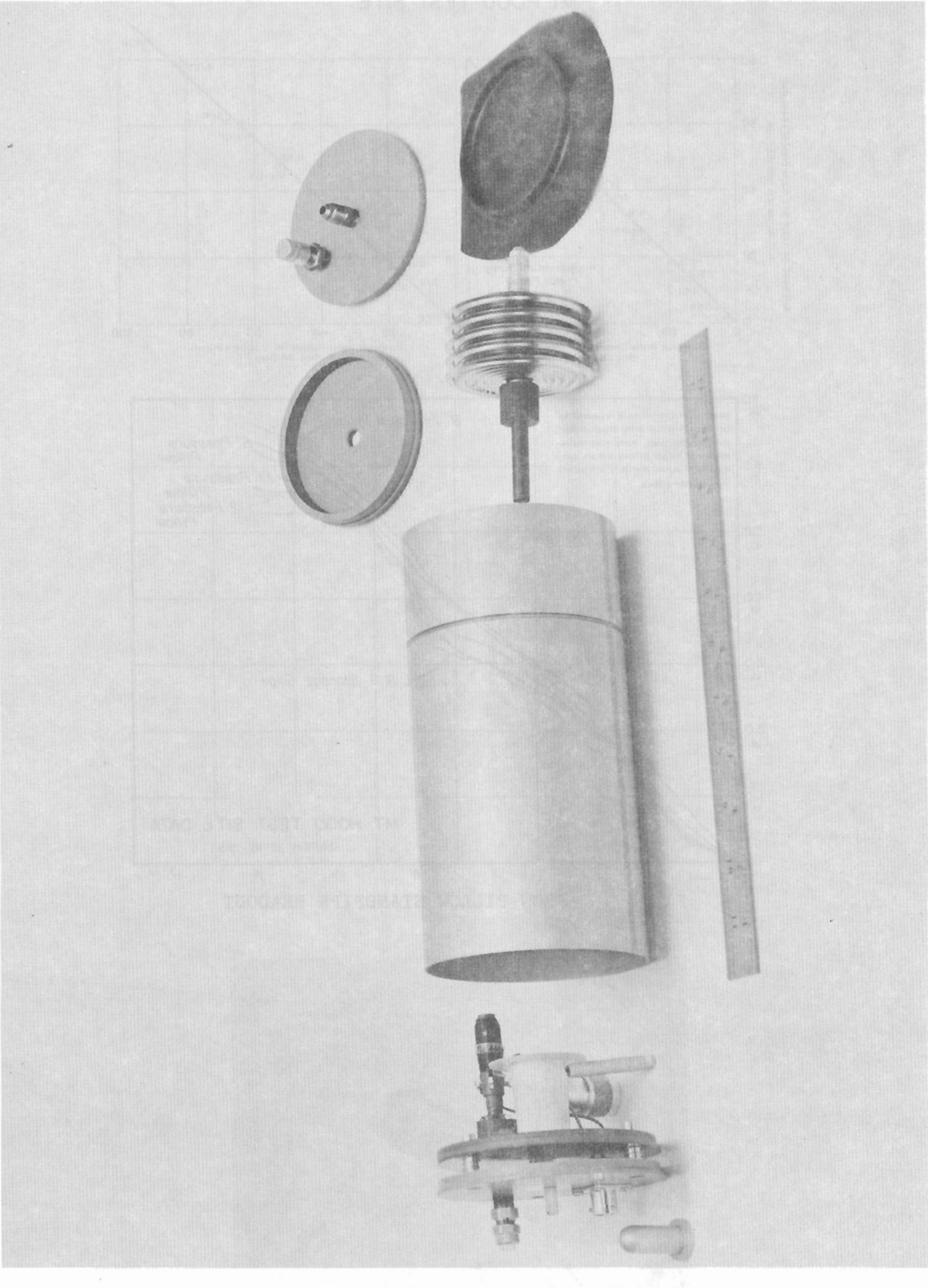


FIG 9 THIOKOL PRESSURE TRANSDUCER

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