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Experience Gained Operating Snow Pillows on a near Real-Time Basis in the Mountainous Areas of Alberta

by

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Introduction

From a water management point of view, the South Saskatchewan River Basin (Figure 1) is probably the most important basin in Alberta. Limitations due to the availability of a reliable water supply are already placing constraints on the development of the industrial and agricultural potential of the basin which covers an area of approximately 111,000 sq. kilometres in Alberta. The water management problems have wider ramifications as an apportionment agreement exists between the Federal Government and the Prairie Provinces which requires Alberta to pass on to Saskatchewan fifty percent of the natural flow originating in the Province.

The South Saskatchewan River Basin is made up of three major sub-basins: the Red Deer, the Bow and the Oldman. All three of these rivers originate in the Eastern Slopes of the Rockies. These mountainous headwater areas have long been recognized as the key to the water supply and flood forecasting in Southern Alberta. However, until recent years, the collection of real-time water related data in the headwaters was extremely difficult due to the remoteness of the area, and the ruggedness of the terrain. For many years, most of the precipitation stations that existed in the area were storage gauges which were visited twice a year and only provided a winter and summer total accumulation of precipitation.

Presented at Workshop on Snow Property Measurement, Lake Louise, Alberta, 1985.
Mention of trade or company names in this paper is solely for the benefit of the reader.

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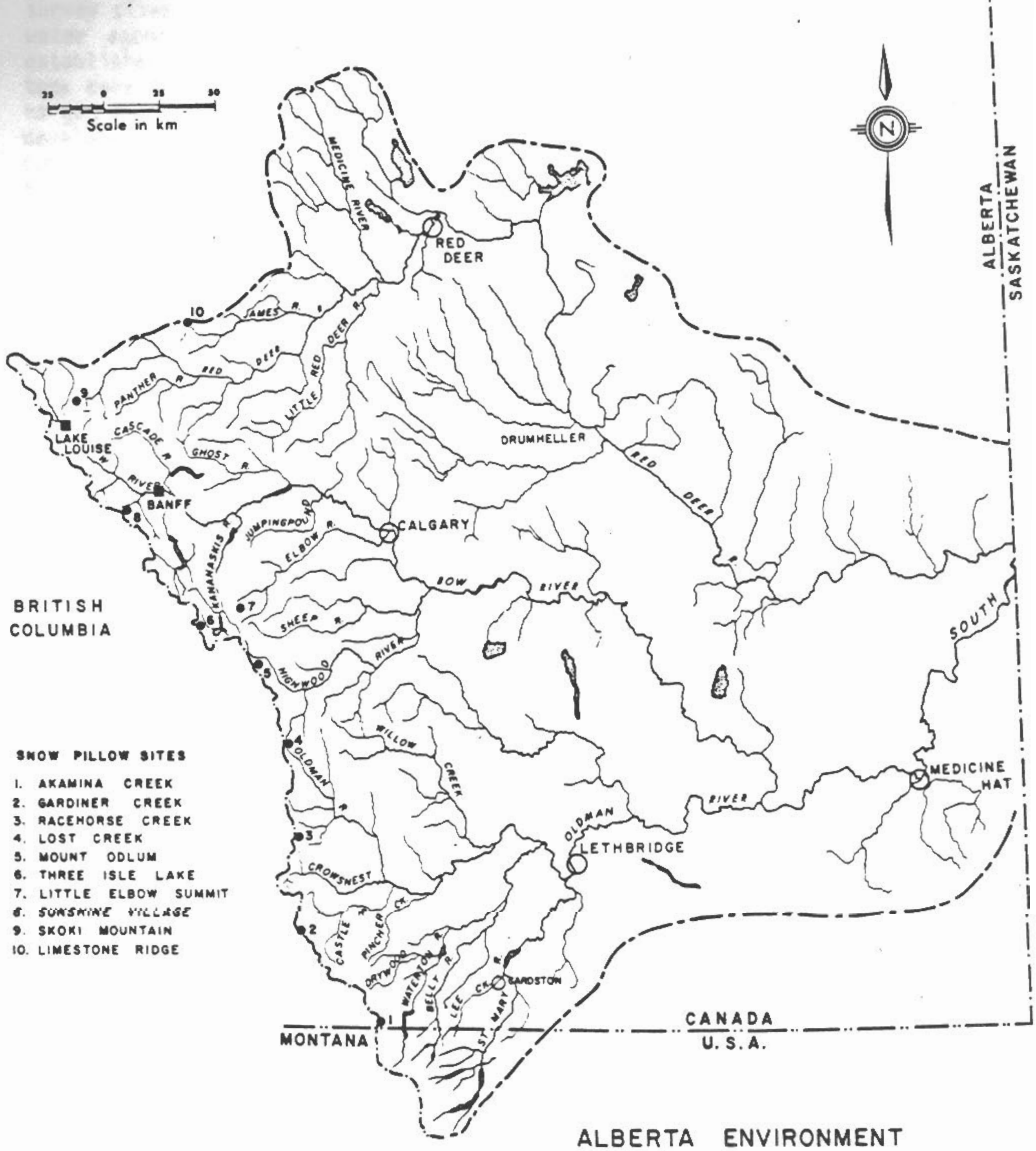

ALBERTA ENVIRONMENT
MOUNTAIN SNOW PILLOW SITES
SOUTH SASKATCHEWAN RIVER BASIN
(ALBERTA)

MARCH, 1985

FIGURE 1

In addition to the precipitation network there were a number of snow survey sites in the mountain parks which were established and run by the water agencies of the Federal Government. Some of these sites were established as far back as the 1930's. In 1978 Alberta Environment took over the mountain snow survey network and added a number of courses to get better coverage with respect to area and range in elevation. The development of data collection platforms (DCPs) and satellite communication in the 1970's provided the means of obtaining data on a near real time basis from virtually any point in the Province. In 1978, the Alberta Environment River Forecast Centre (Graham and Kuhnke, 1978) produced a major proposal to upgrade the precipitation and climate network of the headwaters of the South Saskatchewan Basin. As the main purpose of the new network is to support flood and water supply forecasting needs, all 26 precipitation stations and the 12 climate (multi-parameter) stations are equipped with telemetry capable of transmitting data on a near real-time basis. In the case of the remote mountain sites telemetry could be provided most economically by the use of satellite communications. In 1979 the network upgrading proposal was accepted and work began immediately.

Instrumentation used to monitor snow

For any snow data collection system to be useful for forecasting purposes, the data must be available in near real time. Conventional snow courses are very expensive to operate particularly in remote mountain areas where helicopters are the only means of access. It is not economically feasible to carry out snow surveys more frequently than once per month. Therefore, it was decided to include snow monitoring equipment at ten climate (multi-parameter) sites. The locations of the sites were chosen taking into account exposure and local ground conditions. It was considered important to have an even geographical distribution of stations from north to south throughout the basin. Some of the sites are located along the continental divide with others along the front and middle ranges. The elevation of the sites varies between 1800 and 2300 metres. See table 1 and figure 1 for locations and further details. As of March 1985, eight of the stations were in full operation and the other two are expected to be completed this summer.

Nine of the ten proposed stations were located in the mountains far from telephone lines or observers. After careful study of the communication alternatives it was decided to use the Geostationary Orbital Environmental Satellite (GOES) system . The first data collection platforms (DCPs) using the GOES system were installed in 1980 and have been extremely reliable. In 1981 for example, eight precipitation stations operated for the full twelve months. Of the 209,646 pieces of data expected for the period, 98.7% were received. The missing data included all losses due to failure of sensors, equipment and line losses between Edmonton and Wallops Island, Virginia (Coles and Graham, 1983). The tenth station located at Sunshine Village ski resort near Banff was installed in cooperation with Parks Canada and forms part of their avalanche warning system. This station uses telephone lines to transmit the data from Sunshine Village to Banff.

The data collection platforms are powered by twelve volt batteries, recharged by vertically mounted solar panels. Mounting the panels vertically minimizes the build up of ice and snow and guarantees a power source even during the coldest parts of the year.

Each of the ten climate sites are equipped with sensors to monitor precipitation, temperature, and the water equivalent of snow on an hourly basis. Some of the sites also have wind and humidity sensors (See table 1).

The instrument used to measure melt rate and snow water equivalent is the snow pillow. The pillows used by Alberta Environment are 3 metre diameter hypalon pillows manufactured by the Water Saver Company of Denver (See figure 2). The pillow is filled with approximately 1200 litres of a solution consisting of 50% water and 50% methyl alcohol. The pillow is connected directly to a stilling well by means of 19 mm diameter polyethylene tubing. The level in the 20 cm diameter stilling well varies in direct proportion to the amount of pressure exerted on the pillow by the weight of the snow. The changes in level in the stilling well are monitored continuously by a Leupold & Stevens A71 water level recorder. The readings after adjustment for specific gravity provide a continuous historic record of the snow water equivalent. A Baldwin optical encoder working in parallel with the Stevens recorder translates the hourly readings (measured to the nearest millimetre) into binary coded decimal data (BCD). The data are then transmitted every three hours to Wallops Island, Virginia via the GOES system. The data are retrieved automatically by phone at pre-determined intervals which can be changed as required.

Siting and Installation Problems Associated with Snow Pillows.

Siting is the single most important factor to be considered when installing snow pillows. Because the cost of the hardware and its installation is so high, the site chosen should be close to ideal. The 1985 capital cost of a snow pillow with telemetry and sensors to measure precipitation, temperature, humidity and wind is approximately $25,000.00. The cost of installing the station depends on the difficulty due to the individual site and the amount of helicopter time required. Installation costs in Alberta including wages, expenses and miscellaneous materials have ranged between $10,000.00 and $20,000.00.

General guidelines are available (Farnes, 1978) on locating a single snow pillow in a basin. The snow pillow should be installed in a sheltered area near the mean water-producing elevation of the basin. If the pillow is located too low in the basin the snow on the pillow will be depleted before the peak runoff in the basin occurs. Also the amount of snow accumulated on the pillow will be much less than the average snow water equivalent for the basin. On the other hand if the pillow is located at too high an elevation in the watershed, melt will not occur until after the main runoff has taken place at lower elevations. Several pillows located at various elevations within a sub-basin would be ideal, however, the cost of installing several pillows could not be justified.

TABLE 1

ALBERTA ENVIRONMENT

INVENTORY OF MOUNTAIN SNOW PILLOWS

NAME	BASIN	LOCATION LATITUDE	LONGDITUDE	ELEVATION (metres)	ADDITIONAL SENSORS	YEAR TELEMETRY ESTABLISHED
Akamina Pass	Oldman	49^{o} 01' 40"	114^{o} 03' 10"	1800	P.T.W.H.	1981
Gardiner Creek	Oldman	49^{o} 21' 40"	114^{o} 30' 57"	1920	P.T.W.H.R▼R▲.	1983
Limestone Ridge	Red Deer	51^{o} 53' 19"	115^{o} 23' 04"	1950	P.T.W.H.	1982
Little Elbow Summit	Bow	50^{o} 42' 20"	114^{o} 59' 20"	2120	P. & T.	1979
Lost Creek	Oldman	50^{o} 10' 26"	114^{o} 42' 36"	2130	P.& T.	1985 (Sept)
Racehorse Creek	Oldman	49^{o} 49' 17"	114^{o} 37' 19"	1920	P.& T.	1983
Skoki Mountain	Bow	51^{o} 32' 26"	116^{o} 03' 23"	2040	P.& T.	1981
*Sunshine Village	Bow	51^{o} 04' 43"	115^{o} 46' 48"	2200	P.& T.	1981
Three Isle Lake	Bow	50^{o} 37' 53"	115^{o} 16' 46"	2240	P.T.W.H.	1983
Odlum	Bow	50^{o} 29' 10"	114^{o} 54' 26"	2060	P.T.H.	1985 (Sept)

P - Precipitation
T - Temperature
W - Wind direction & velocity
H - Relative humidity
R▼ - Radiation (Incoming) R▲ Radiation (outgoing)
* Located at Parks Canada Installation

Once the general location of the site has been selected the specific site must be chosen. The State of California (1976) and Cox (1978) provide detailed guidelines on this topic. The main points to be considered are the following:

1. Snow pillows should be located in a clearing in the trees, small enough to minimize drifting. However, the trees should not be so close that they influence the snow accumulation by forming a canopy or cause melt due to long wave radiation.

2. Pillows should be located on level ground to prevent creep and drainage problems, but the pillow should be at a slightly higher elevation than the instrument house (see figure 2).

   Extreme care when installing pillows is imperative. If the pillow is not properly installed, malfunctions will occur and no useful information will be obtained for the season. Once the pillow is covered by snow it is virtually impossible to make repairs to the system.

   The most common problems to be aware of are as follows:

1. Leaks in pipes and fittings: Even the smallest leak can drain the pillow and cause complete loss of record.

2. Puncturing of pillows: The ground beneath the pillow must be flat, and clear of any debris which might puncture the pillow. The base should be covered with a clean material such as sand which can be levelled with ease.

3. Damage to the installation by rodents: Rodents tend to eat the pipe fittings and even the pillow itself. Damage can be minimized by covering the pillow with 6 mm hardware cloth.

4. Air locks in the system: A certain amount of air may be introduced into the system when filling with the methyl alcohol solution. A vacuum pump is used to remove all air from the pillow. Care must also be taken to avoid any air locks between the pillow and the stilling well.

5. Destruction of pillows by wildlife: The sharp hooves of deer, moose or elk can easily puncture the pillow. Sites should be fenced to deter such animals. (Unfortunately fencing is not always effective, as the Little Elbow pillow was punctured earlier this winter). In Montana and British Columbia, where bears are a major problem, pillows are completely covered with a light gauge metal sheeting.

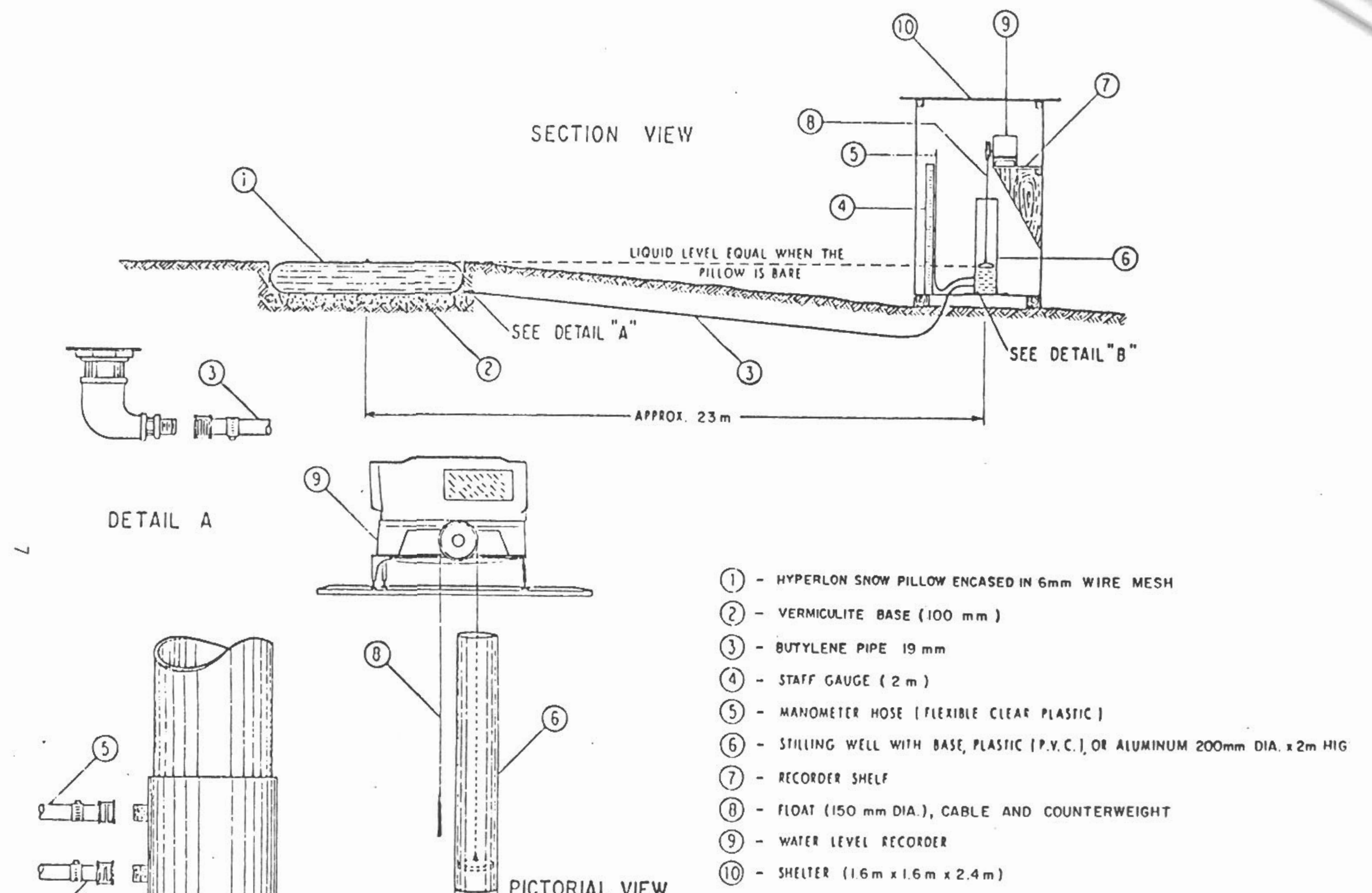

FIGURE 2

SCHEMETIC DIAGRAM - SNOWPILLOW

(NOT TO SCALE)

FROM: KERR (1976)

Operational problems associated with snow pillows

Most problems associated with the operation of snow pillows can be eliminated by the use of proper installation techniques and careful maintenance. However, there are some problems inherent to the system which should be recognized, otherwise serious errors can be made in the interpretation of the data obtained from the pillow.

Bridging of the pillow commonly occurs when precipitation falls as rain or when a melt period is followed by a severe cold spell. The bridge formed by ice layering in the pack prevents the full weight of snow on the pillow from being transmitted to the stilling well and results in an undermeasurement of the snow water equivalent. Checking the accumulation in the precipitation gauge against the snow pillow indicates if such a condition exists. In Alberta, bridging has been found to be a common phenomenon in the shallow plains snow pack, but seldom occurs in the mountains. The condition can sometimes be relieved by walking around the perimeter of the pillow, thereby breaking the "bridge" that has formed.

Several studies (State of California, 1976) have indicated that there is a lag between the time the snow falls, and the time the recorder fully registers the event. Careful comparison with precipitation gauge data in Alberta has revealed that lags do occur after major snow falls, but they have been usually measured in hours rather than days.

Just before melt occurs quite drastic diurnal fluctuations often occur in many snow pillow plots. A sudden drop in pressure is indicated around mid-morning and the trace in the pillow then recovers slowly reaching a maximum around mid-night. The reasons for these diurnal fluctuations are not fully understood. The fluctuations are not solely temperature dependent, but occur only in the early part of the melt season. It appears the fluctuations are due to structural changes that take place in the pack caused by variations in temperature and short wave radiation. It is interesting to note that when melting has relieved the internal stresses, the diurnal fluctuations disappear and the pillow operation returns to normal. Diurnal fluctuations are much more common in shallow snow packs on the plains then they are in the mountains. They are also more prominent on clear sunny days. The problem of interpreting the data when diurnal fluctuations occur is overcome by using a reading at a time when the pillow is stable. The Alberta Environment River Forecast Centre uses the 6:00 a.m. reading as the value for the day.

At higher elevations drifting due to winds is difficult to predict. At Gardiner Creek, the site was selected in the late spring and the station was installed the same summer. It did not appear that wind would be a problem. However, high winds this winter have caused serious drifting and the results from the pillow have been erratic. The policy now is to run a conventional snow course for at least one full winter before deciding on a pillow installation site. In this manner, it should be possible to detect potential problems before committing to a permanent installation.

Comparison of snow water equivalence data collected from snow pillows and standard snow courses

One of the reasons for installing snow pillows is to reduce or eliminate the number of costly visits that have to be made to measure the standard courses, the eventual goal being to eliminate the need for certain snow courses all together. At some snow pillow sites there are adjacent snow courses which have many years of record. Data from these courses are often used as indices in streamflow forecast models. For this reason it is necessary to relate snow course data to that obtained from the snow pillow.

The method used in Alberta to calibrate the pillow to the snow course is a method suggested by the United States Soil Conservation Services (1972). Over a period of at least three years the ratio of snow course to snow pillow reading for concurrent dates is obtained and a mean value calculated. As long as the variation from the mean of the ratios is not more than plus or minus 0.05, the pillow record is considered to duplicate the snow course record. In the Alberta experience, the relationship between the pillow and the courses does not always meet the criteria described above, and it has been necessary to develop a new index based solely on continuous pillow readings. This may be due to the fact that the snow courses (comprising the average of ten separate point measurements) were established before the snow pillow location was determined. It is now standard practice at each site visit to obtain a reading from the old snow course and readings adjacent to the pillow. Figure 3 illustrates the relationship between pillow and snow course readings in 1982/83 at Little Elbow Summit.

Comparison of precipitation data collected by snow pillow sensors and the Fisher Porter precipitation gauges.

It has been well documented (Goodison & McKay, 1972) that the Fischer Porter automatic gauge under catches snow particularly in areas exposed to wind. As mentioned previously the Alberta snow pillow sites are for the most part well sheltered. Generally, the accumulation of precipitation measured in the Fischer Porter gauges and that measured by the pillow compare favourably. The two values are plotted throughout the winter, and any significant deviation from one to the other usually indicates a problem has occurred or that the precipitation is falling as rain.

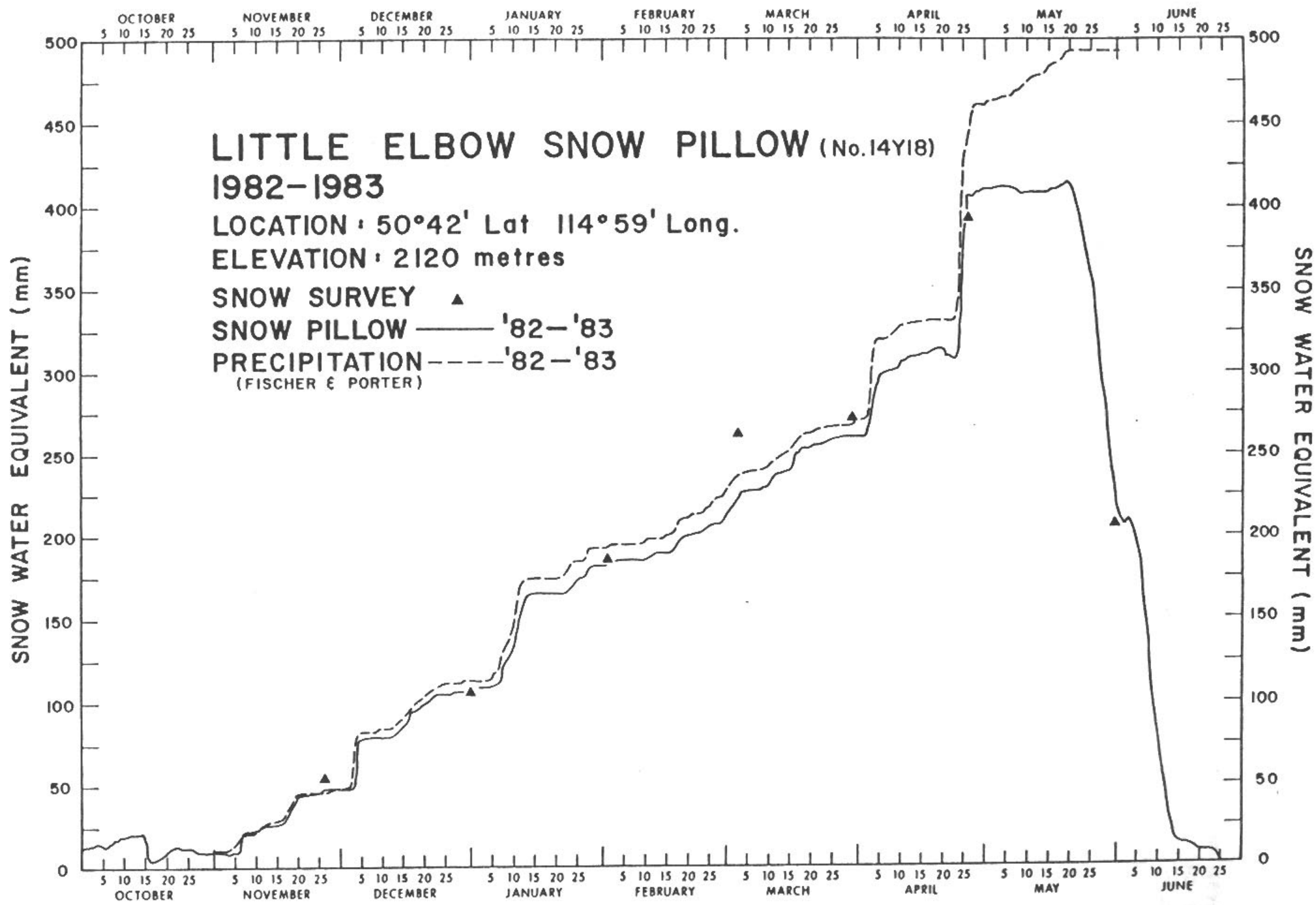
LITTLE ELBOW SNOW PILLOW (No. 14Y18)
1982–1983
LOCATION : 50°42' Lat 114°59' Long.
ELEVATION : 2120 metres
SNOW SURVEY ▲
SNOW PILLOW ——— '82–'83
PRECIPITATION - - - - '82–'83
(FISCHER & PORTER)
SNOW WATER EQUIVALENT (mm)
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
5 10 15 20 25
0
50
100
150
200
250
300
350
400
450
500

FIGURE 3

An example of the type of problem that has been noted on several occasions is "capping" of the Fischer and Porter gauge. When the snow fall is wet and sticky (condition that occurs quite often in Southern Alberta), the snow clings to the side of the gauge eventually forming a cap. The cap prevents any more precipitation from entering the gauge. If the temperature should rise above freezing, the cap falls into the gauge and normal operation resumes. It is only with telemetry, the presence of a snow pillow, and a Fischer Porter gauge that this undercatchment can be quantified. In the standard networks which do not have telemetry this phenomenon can go undetected, as the period between visits is often several months.

Heavy rain on snow often results in a dramatic (although sometimes short lived) drop in pressure (Buer et al, 1984) on the snow pillow. Comparison of the snow pillow data with the Fischer Porter data and temperature often confirms that a rain event had taken place. The form in which precipitation falls, snow or rain, is extremely significant to the forecaster, for rain on snow can cause rapid melt.

The primary purpose of the snow pillow is to measure snow accumulation and melt rates whereas the main reason for the Fischer Porter gauge is to measure summer rainfall. However, the experience gained operating both types of sensors in real time during the winter indicates that inconsistencies in performance is due to specific physical conditions and the operation of the dual system of sensors in the winter is well worth while.

<u>How snow pillow data have been used</u>

1. Snow melt rates during the critical spring and early summer period can be fed directly into runoff simulation models. A modified version of the Streamflow Synthesis and Reservoir Regulation (SSARR) model is used to predict mountain runoff in Alberta. A melt rate index is necessary to simulate snow melt runoff with the model. Melt rates from snow pillows are calculated for individual basins. Studies by Ferner & Wigham (1985) have shown that snow pillows in the Marmot Research Basin provide better melt rate estimates for application to SSARR than indirect methods that use temperature and other parameters.

2. To carry out long range water supply forecasts, the daily accumulation of snow obtained from pillows is input to simulation models which are constantly updated. Snow pillows provide a method to constantly update this information, particularly after major storms.

3. Snow pillows provide a reliable estimate of snow accumulation from the start of the runoff season throughout the active period. If the models are deviating too much from the observed snow available, they can be corrected as needed.

4. For flood forecasting in the spring, data from the pillows are used to detect if precipitation is falling in the form of snow or rain.

5. Snow pillows can be used to estimate the date of the peak flow for specific streams. For example, a straight forward way of predicting peak dates using snow pillow data in the Western U.S. has been described by Farnes, (1984).

In the Western United States (Farnes, 1985) where extensive snow pillow networks have been used for many years, pillows are being used for purposes other than those related to water resources. Snow pillows can be used in the management of parks and wildlife. For example, they can give useful information with respect to back country travel, can be used to tell how much snow is on the ground at higher elevations, and whether the snow conditions are ripe for avalanches. Pillows can also be used to help predict when bears may emerge from hibernation, for a good correlation appears to exist between the start of melt and the beginning of bear movements.

In Montana the pillows are also used to help manage remote mountain highways. From a base camp, managers can determine if they need to plough roads and in what order the work should be done. It is believed that in the future, further applications for snow pillow data will be found.

Conclusions

1. Snow pillows in the mountainous areas of Alberta monitored in near real-time and used in conjunction with other meteorological sensors provide valuable information for streamflow forecasting.

2. The successful operation of snow pillows depend on good installation and maintenance practices. Data from the pillow and other sensors must be inspected and evaluated on a ongoing basis to obtain maximum benefit from the information provided.

3. Since winter precipitation may fall either as snow or rain, it is desirable to run a precipitation and temperature gauge in conjunction with the snow pillow at key sites. Anomalies in the performance of these sensors that may normally go undetected can be found by closely monitoring the data from the two different types of sensors.

4. Snow pillows are not the ideal snow monitoring device for they are expensive to install, and they have inherent weakness in operation which are sometimes difficult and even impossible to overcome. They are also prone to destruction by several forms of wildlife. New devices such as the nuclear snow gauge look promising and their performance should be investigated for the forecasting networks of the future.

5. Melt rates provided from strategically placed snow pillows give an index that when used in the SSARR model results in better forecast estimates than using an index based solely on temperature.

6. There are potential uses for snow pillows that go beyond the water resource management field. Some of these are avalanche prediction, wildlife management, and general park management.

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