SNOW MEASUREMENT ACCURACY IN HIGH DENSITY SNOW COURSE NETWORK IN COLORADO

By

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Introduction

The purpose of the Park Range Atmospheric Water Resources Program is to determine whether natural precipitation can be increased by artificial means. It is a cooperative effort administered by the Department of Interior, Bureau of Reclamation.

At the inception of the program in 1964, the Bureau of Reclamation requested the Snow Survey Unit of the Soil Conservation Service in Colorado to collect snow data in this area. These data would be used as an aid in evaluating the project.

The selected area is located in North Central Colorado, near the town of Steamboat Springs. The area is characterized by relatively high annual precipitation of which a major portion is snow. Ice nuclei process of precipitation formation predominates, and a major portion of the storms are associated with Southwest to Northwest winds over the area. The Park Range lies East of Steamboat and provides orographic effects. The area is an important source of water to the Colorado River, via the Yampa River and its tributaries.

The Project area covers roughly 20 x 24 miles with a primary target zone of 4 x 12 miles, as shown in Map #1. The overall project area ranges in elevation from 6,500 to 10,700 feet. The backbone of the target area lies along the 10,000 foot Continental Divide.

To meet the Bureau's request, twenty-two snow courses were located over the entire area. Eight courses of low elevation were established between 6,500 and 7,600 feet and were located in the valley around Steamboat Springs. Seven courses were established in the middle elevation zone or from 8,000 to 9,600 feet. The remaining seven courses were established at 9,600 feet or higher. The highest snow course of this project is 10,700 feet. There were four snow courses established before the project. These four snow courses were used and are included in the above totals.

The low elevation snow courses consist of three sample points, and are located near an access road that is kept open all winter. The Southern most snow course is 14 miles South of Steamboat, while the Northern most course is 10 miles from Steamboat. At various times throughout the winter melting occurs on these courses. The medium elevation courses have ten sample points, and are usually within or near the target area. These courses are located mostly in aspen forests.

The ridge snow courses were established in October 1964. These courses are on the windward side of the Park Range. They were laid out at regular intervals starting near the summit of Rabbit Ears Pass and running Northward for 14 miles. Six of the ridge courses are within the target zone while three are located to the North.

The terrain has many large open parks, especially at the 10,000 foot elevation. The ridge courses are established in the small parks or on the lee-side of the tree rows in the larger parks. Areas of snow drifting immediately next to the tree rows were avoided. High winds or blizzard conditions are not typical of the area, but many drifts do occur in the areas adjacent to the bands of trees.

To obtain the best measurements possible, the snow courses were corrected as the season progressed. Since the courses were laid out on level terrain, any difference in snow depth was attributed to drifting. A maximum of 10% variation between individual samples on each snow course was determined desirable. During the winter each snow course was checked for this difference. If any given sample had an error of more than the 10% for two consecutive readings, the sample point was dropped or put on the doubtful list. At the end of the

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first winter only nine points on all twenty-two snow courses had been eliminated. During the second season only one additional point was deleted from the network.

Any variation from normal operation was recorded and evaluated. For example, the snow tube and scales were changed during the first winter operation. Comparative readings were made using new and old equipment to check for possible deviations. The readings using old scales and old tube, new scales and new tube, etc., were recorded. For a total of 60 readings there was less than 1% difference, so no adjustment was made in the data. It is interesting to note that the new scales and new tube almost always over-weighed. The cutter on a new tube is thicker at the point than a worn cutter. This seems to be the reason for the over-weighing.3/

Data Analysis

After the completion of the first year's snow surveys, all data was checked for completeness, accuracy, and coverage. The winter of 1964-65 produced about 115% of normal snow cover over most of Colorado. No cloud seeding was done in the project area during this season. At Round Mountain Snow Course the maximum snow measured was 150 inches and contained 69.3 inches of water. This is more snow than ever measured before in Colorado.

Table #1 shows the elevation of the snow courses compared to their maximum water content. It is interesting to note that from the 8,000 foot level up, only one snow course is out of place in elevation-water content relationship. Since the elevations were established with a hand altimeter, they could be slightly in error.

This table also shows the relationship for the 1965-66 winter season. Note that in 1966 the snow pack was only about 58% of 1965, but the elevation vs. water content relationship is exactly the same. We would not expect the snow courses 7,600 feet and below to follow the elevation curve, because of the melt factor, exposure, and low snow. They do, however, follow the same relationship trend as the higher courses.

In order to check for similarity of snow packs by elevation and accuracy of the measurements, we normalized all snow courses to one. Buffalo Pass Snow Course was selected as the standard. This choice was made simply because of its proximity to the middle of the project area.

Table #2 shows an entire season of normalized data comparing Long Lake Snow Course to Buffalo Pass Snow Course. As you can see the average deviation is only 2.4% or 0.59 inches of water. This much error could easily be attributed to the measuring processes. Table #3 shows normalized data for all courses. The maximum deviation in 1966 for the entire network is only 5.3% or 1.06 inches of water. This we feel is an extremely small difference. Correlation coefficients between Buffalo Pass and the other snow courses for the entire 1964-65 winter season were computed. There is high correlation, ranging from an r - .992 for the Little Lake - Buffalo Pass relationship (Little Lake is the farthest snow course to the North), to r - .967 for Patrol Station Snow Course which is in the Southern part of the area.

You can see by this analysis that many snow surveys were made. Approximately 4,000 samples were taken for the 1964-65 season alone.

Conclusions

Several conclusions can be reached from this data review. First, if extreme care is taken when reading snow courses manually, a very high degree of accuracy can be achieved. The selection and training of snow surveyors is most important. Second, the selection of this site for the Atmospheric study was an excellent choice. If future years have the same characteristics as the past, even manual measurements are accurate enough to be used in evaluating additional snowfall due to weather modification. Third, in this area, snow-water content is a function of elevation, Chart #1. Fourth, for water supply forecasting, if adequate back records are available, one snow course, carefully installed and measured, would supply sufficient data to forecast all streams in this entire area. As you can see by Chart #2, the snow pack can be determined for any elevation ranging from 8,000 to 10,700 feet by using any snow course in the area for the index.

TABLE 1

SNOW COURSES BY ELEVATION AND MAXIMUM SNOW WATER CONTENT

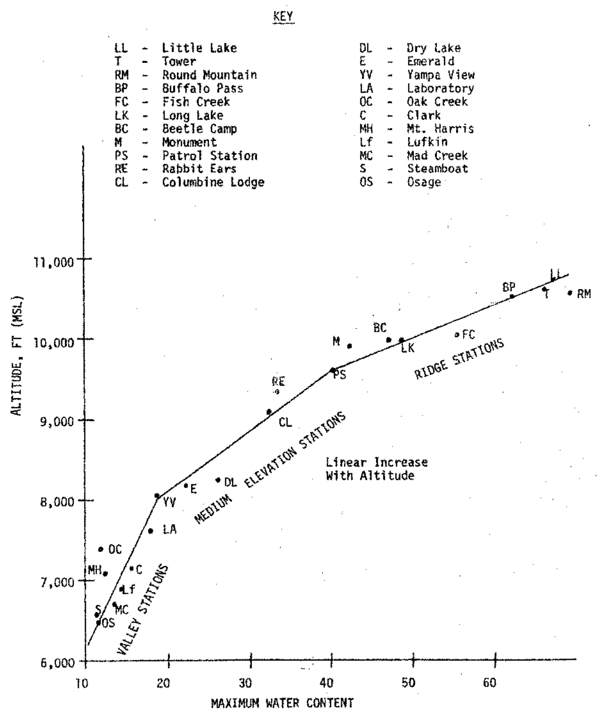
Snow Course	Elevation	Maximum Water Content in inches	
		1965	1966
Little Lake	10,700	67.5	39.1
Tower	10,600	66.4	38.5
Round Mountain	10,540	69.3	39.2
Buffalo Pass	10,500	62.4	34.9
Fish Creek	10,020	55.3	31.4
Long Lake	10,000	48.6	28.2
Beetle Camp	10,000	47.1	28.1
Monument	9,920	42.2	23.8
Patrol Station	9,600	40.2	22.5
Rabbit Ears	9,370	33.2	19.9
Columbine	9,100	32.6	15.9
Dry Lake	8,220	26.1	15.4
Emerald	8,200	22.0	11.2
Yampa View	8,180	18.5	10.9
Laboratory	7,600	18.0	6.8
Oak Creek	7,410	11.5	4.2
School*	7,280	15.2	5.8
Mt. Harris	7,150	12.0	5.8
Lufkin	6,900	14.5	5.5
Mad Creek	6.760	13.3	5.5
Howelsen*	6,690	10.8	4.2
Osage	6,580	11.7	4.0

* These two snow courses were changed to new locations in 1966, so do not correspond.

TABLE 3

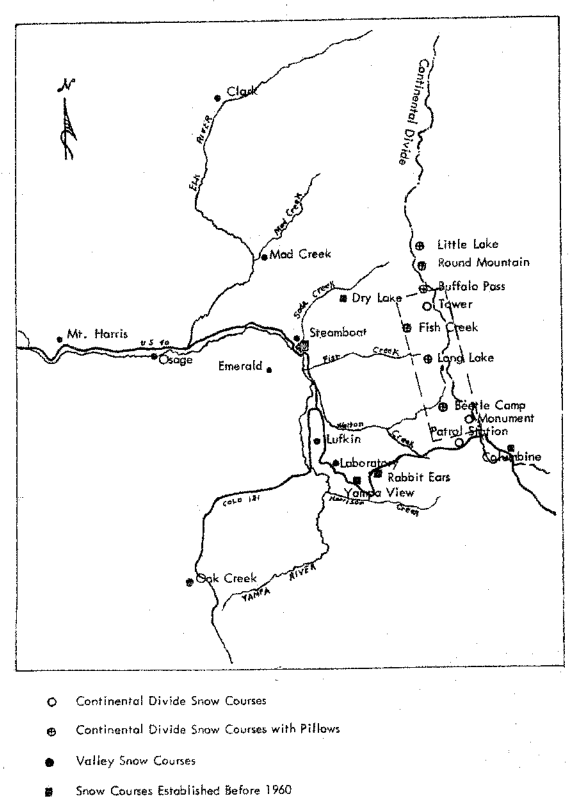
COMPARATIVE DATA FOR STEAMBOAT AREA SNOW COURSES NORMALIZED TO BUFFALO PASS FOR 1966

Snow Course	Average Percent Deviation from Mean	Average Inches of Water Deviation from Mean
Round Mountain	3.0%	0.89"
Little Lake	2.1%	0.63"
Tower	3.3%	0.89"
Fish Creek	3.8%	0.84"
Long Lake	2.4%	0.57"
Beetle Camp	5.3%	1.06"
Monument	3.7%	0.64"
Patrol Station	3.4%	0.54"
Rabbit Ears	3.9%	0.58"
Columbine	1.8%	0.21"
Dry Lake	3.8%	0.38"
Yampa View	1.2%	0.10"
Emerald	1.6%	0.14"
Laboratory	2.6%	0.12"
Lufkin	2.3%	0.11"
School	2.1%	0.09"
Mad Creek	1.5%	0.06"
Howelson	0.5%	0.02"
Mt. Harris	2.2%	0.09"
Oak Creek	0.8%	0.03"
Osage	2.0%	0.05"

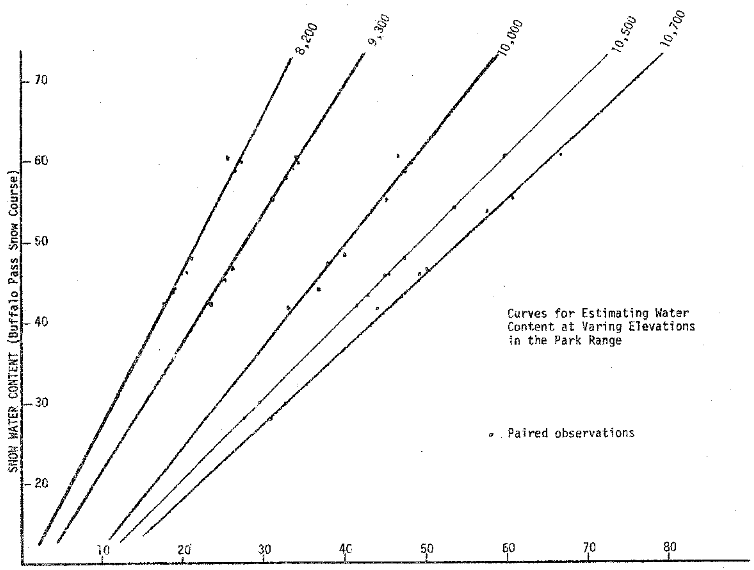


1964-65 SEASONAL MAXIMUM SNOW WATER CONTENT
COMPARED TO SNOW COURSE ELEVATION

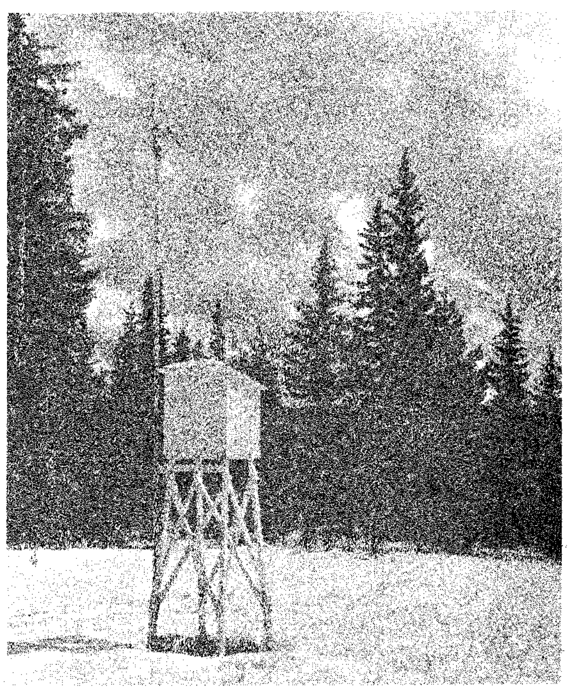
CHART #1



Snow Course Map #1



SNOW WATER IN INCHES
CHART #2



Instrument Shelter on Park Range Project

Date	Long Lake Snow Course Snow Depth	Long Lake Snow Course Water Content	Buffalo Pass Snow Course Water Content	Long Lake in % of Buffalo Pass	Difference from Average %	Water Content Difference from Average
1/5/66	50	16.0	20.3	79	4	0.6
1/14	63	17.5	21.2	83	0	0
1/21	59	19.2	22.1	87	4	0.8
2/2	65	19.8	23.9	83	0	0
2/9	70	21.4	25.3	85	2	0.4
2/16	75	23.3	27.9	84	1	0.2
2/22	78	25.0	29.1	86	3	0.8
3/1	75	24.9	29.4	85	2	0.5
2/8	76	26.0	29.7	85	2	0.5
3/15	72	26.6	31.1	86	3	0.8
3/18	76	26.7	31.4	85	2	0.5
3/23	81	28.1	33.4	84	1	.3
3/30	71	28.2	32.5	87	4	1.1
4/6	64	27.0	32.6	83	0	0
4/14	63	26.4	33.6	79	4	1.1
4/20	64	26.9	34.5	78	5	1.3
4/28	59	27.5	34.9	79	4	1.1
Average		24.1 in.	29.1 in.	83.4%	2.4%	0.59 in.

TABLE #2. NORMALIZING BUFFALO PASS TO LONG LAKE SNOW COURSE
YEAR 1966

Second Phase

The second phase of this project involved the automation of several snow course sites. This provided considerably more data, so that snowfall could be recorded hourly, if desired, and each site could be checked at exactly the same time. It was felt that the snow survey data would be even more accurate if measurements were gathered at exactly the same time.

Snow pressure pillows were used as sensors in 1966. Pressure transducers and on-site recorders completed the installation. A modified A-35 type recorder was used at each site. This recorder automatically up-dated itself each hour.

Six sites were selected for automation. Two pillow sites were outside the primary target area, one nearly on the border and three within the target area.

The exact spot for the pillow was computed from past records of each snow course. Several spots that measured nearest to the snow course average were determined. A ground analysis of the selected spots then determined the exact point for pillow placement. The ground was then leveled, smoothed, and the pillows were installed in a similar manner to the recommendations made from tests at Mt. Hood, Oregon. 4/

It became apparent after one year of automatic operation that pillows provided some much needed data. Some years there was considerable snowfall between April 1 and May 1 which was not recorded. The first 5 or 10 days of April sometimes produced heavy snowfall which was not indicated on the May 1st survey because of melting. In some cases precipitation gages were used to determine this snowfall. With the advent of the snow pillow and continuous recorders, however, this precipitation is automatically recorded in one operation. This should improve forecast accuracy once a pillow network is established.

This increased data also gives advance information on the start of snow melt runoff.

During the winter, numerous problems developed with the equipment. All pillows leaked to some degree. We discovered, by excavating the pillows, that any leak on the upper side of the pillow would lead to erroneous readings. The antifreeze in the pillows, melted pockets in the snow immediately above the smallest hole. As the pressure of additional snow load increased, the pillow expanded into this snow pocket and the same melting, expanding operation started again. Eventually the pillows became so badly deformed that accurate readings were impossible. Ice layers as thick as 3 inches formed at the top of these melted pockets, and caused bridging. It is not known if this bridge was supported by snow beyond the edge of the pillow.

We removed as much as seven feet of snow from some pillows and found them all deformed. Some were flat, some just slightly deformed. If the leaks were small (not enough to change fluid level materially), a plastic film over the entire pillow would help to alleviate this problem. However, pillows that do not leak is the final answer.

Another problem was water proofing the battery and transducer boxes. Although considerable time was devoted to water proofing this equipment, some water was present in the bottom of these boxes. It was apparent that the cases containing the batteries and transducer were subjected to as much as 8 inches of ponded water during the melt period.

All of the problems were analyzed and the equipment adjusted or changed to alleviate them for the 1966-67 season. It is felt that if the pillows work correctly, a very accurate measurement of the snow pack, increment by increment could be made for the entire season.

New pressure pillows in conjunction with permanent housing for our on-site recorder and radio equipment were installed to attain this goal. Five of the ridge snow courses are currently being telemetered to a base station in Steamboat. This information comes in automatically once daily or on demand at closer intervals if desired. The base station is equipped with punch tape, and a visual read out. The punch tape can be processed by a computer.

The manual snow surveys are still made on a regular basis, each ten days or after every major storm. This double measurement technique is used to assure accurate and continuous data. If the automatic system proves reliable, manual readings may be reduced or completely eliminated.

With the automatic pillow network in operation we will have considerably more data at the end of the 1966-67 operation. Snow courses in this network can then be analyzed on a storm by storm basis if need be. One properly placed snow pillow coupled with historical records can give accurate data to be applied to other snow courses, indicating peak snow pack in other areas. Also, the one pillow can tell a forecaster when the melt season starts, and at what rate the melt is taking place.

Each additional snow survey taken in this area confirms that the streamflow forecaster can expand his snow survey data to great distances in this and similar areas.

Although final results of this program will not be known for some time, the side benefits and increased knowledge derived from this project are numerous.

REFERENCES

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4/ Beaumont, R. T.: "Mt. Hood Pressure Pillow Snow Gage". Presented at Western Snow Conference, Colorado Springs, Colorado, April 1965, pp. 29-35.