RIME ICE AND SNOW CAPPING ON HIGH ALTITUDE PRECIPITATION GAGES

By

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SYNOPSIS

This paper presents a resume of research carried on since September, 1954, on rime ice and snow capping of high altitude precipitation gages. The report is primarily for the review of cooperative groups concerned with measuring precipitation and forecasting river runoff. The principal aim of this cooperative study known as Special Research Project 17A has been to obtain basic information on weather conditions that cause accumulation of snow and ice on precipitation gages and the development of counter measures that will provide serviceable records from remote mountain locations. Funds for the project have been made available through the University Special Research Program and cooperative assistance and grants from several federal agencies. Presently the City of Moscow is also cooperating.

A survey has been made of the extent of capping and review made of operational attempts to overcome the problem. Two experimental gages have been placed in operation at Bogus Basin near Boise, Idaho, to obtain information on the problem and the Weather Bureau is furnishing data from a station near the TV transmitter at Deer Point in the mountains above Boise. An experimental gage with a heated orifice that draws energy from batteries has been developed on the campus at Moscow. An additional prototype gage with a heated orifice system has been placed in operation beside a control gage on Moscow Mountain. The latter gage has operated through one winter season. Data are also being accumulated from other high altitude stations where hourly records of temperature and precipitation are available.

Results of the study to date indicate that snow capping is not just a local problem in the Boise River Basin, but in several other areas of the West investigators have experienced capping to some degree. Indications are that this phenomenon occurs during storms where the wind velocity is low, the temperature is near 32°F and the snow adheres to surfaces readily. The heated orifice storage gage performed satisfactorily first with a temperature control for the heating operation and then later with a control system that allows the electrical resistance wire heating system to operate only when there is precipitation falling in the temperature range 20° to 34°F.

Tables, graphs and pictures report the results of the experiments to date.

INTRODUCTION

This study organized as Special Research Project 17A was initiated in September, 1954, as the result of interest expressed by several federal agencies in finding a solution to the problem of rime ice and snow capping on precipitation gages. Contact with hydrologists in several western states indicated that the problem was not strictly local, but involved numerous places where high-altitude precipitation measurements are made. Figure 1 illustrates the problem showing a completely capped Sacramento type storage gage.

The purpose of the study has been to obtain more basic information on the causes and conditions for accumulation of snow and ice on precipitation gages and the development of counter measures that will permit the obtaining of consistent records of precipitation at remote mountain locations. These counter measures are directed toward using existing standards and gages insofar as possible.

PREVIOUS INVESTIGATIONS

No attempt has been made to find the earliest mention of this problem, but significant reports, correspondence and literature pertaining to the problem of snow capping have been studied. The most widely used means of minimizing the capping of gages with snow and ice has been to paint

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the gage flat black which tends, in time, to absorb enough heat from the sun to clear the orifice and walls of the gage. Prolonged snowstorms under certain condition will allow the orifice opening actually to close completely and the gage will thus remain inoperative for long periods of time.

Investigators who mention experience with the problems are: Church (1)(2), working in Nevada for many years; Foto (3), snow ranger with the Forest Service at Stevens Pass, Washington; Goodell (4)(5), working on snowmelt studies at Fraser Experiment Forest in Colorado; Helmers (6), conducting precipitation research at Priest River Experimental Forest in Northern Idaho; Hildebrand (7), of the Corps of Engineers reporting on determination of annual precipitation at the Central Sierra Snow Laboratory in California; McClain (8), also of the Corps of Engineers, reporting on precipitation, evapotranspiration, and runoff at Willamette Basin Snow Laboratory in Oregon; Nelson (9), of the Soil Conservation Service making precipitation and snow survey measurements on the Boise River Basin in Idaho; Veatch (10), of the U. S. Geological Survey at Tacoma, Washington, making measurements in the Cascade Mountains; and Wilson (11), of the U. S. Weather Bureau reporting on winter precipitation observations of the cooperative snow investigations. The consensus was that the accumulations of snow or capping occur when air temperatures are slightly below freezing, when moisture content of the snow crystals favors stickiness and when there is a minimum of wind. Several special cases are reported though, such as blowing snow freezing on the windward side of the gage.

Besides the conventional painting of the gage surfaces and windshields a flat black, various attempts have already been made at heating precipitation gages. Church (12) mentions the use of storage batteries to heat the collar surrounding the gage. Conover (13) of Harvard University, working at the Blue Hill Meteorological Observatory, has developed a heated orifice gage using a nichrome ribbon and an AC power source of 60 watts. Foto (3) likewise has used AC power with a "Wrap-on" heating coil with fixed temperature air thermostat at Stevens Pass in Washington. Allen (14) of the Bureau of Reclamation with others has perfected a heated precipitation gage intake tube for the radio-reporting rain gages of the Central Valley Project, California. This apparatus uses a gas fuel to heat an inert gas carried by copper tubes and works similar to a gravity return vapor heating system. This device is further discussed by Tarble (15) of the Weather Bureau who has pointed out possible weaknesses in the system. Thickstun (16) of the Weather Bureau reports that the instrument division of the agency investigated a heating system for a tipping bucket gage using electric light bulbs controlled by thermostats. This was apparently used to prevent freezing of the precipitation in the catch bucket rather than to prevent capping with snow. Zobel and Reinecke (17) of the University of Gottingen in Germany reported on an extensive study made there on heating recording gages. They presented ideas for electrical heating, chemical heating and heating with gas. From their studies they developed and recommend a heated gage using propane gas. The inner chamber of the recording gage is heated but not the orifice rim. Apparently capping is prevented by heat rising from the inner chamber. Riter (18) in the AGU Report of the Committee on Snow describes briefly the work being done by the Bureau of Reclamation on a standpipe storage gage that is heated with gas and heats the charge as well as the intake tube.

With the exception of the last gage the heating systems have all been provided to work on other than storage gages. The present study by the Engineering Experiment Station has approached the problem for storage gages that will be reliable for use in remote locations throughout the western states.

FACILITIES AND TESTING

Field Stations

In the fall of 1954 a field testing site for the project was selected near the Bogus Basin ski area on the Boise River Basin about 18 miles from Boise, Idaho. This site was selected because it was accessible and yet in the elevation range and region where snow capping might be expected. Two gages were installed there in a protected area where winds were not expected to exceed 15 mph. One of the gages was a standard (8-inch orifice) Sacramento storage gage equipped with a modified Alter windshield. The other gage had a 12-inch diameter orifice and was also equipped with a modified Alter windshield. Figure 2 is a picture of the two gages. These gages have been under observation for three winter seasons now to indicate characteristics of the conditions that cause capping. Observations and work with these gages have been carried out cooperatively with personnel at the ski lodge, the Soil Conservation Service and the Weather Bureau. The 12-inch gage was installed to see if the larger gage would remain free of a complete snow or rime ice cap when the smaller orifice was capped over. A thermograph record has been obtained this winter season (1956-1957) at the Bogus Basin gages.

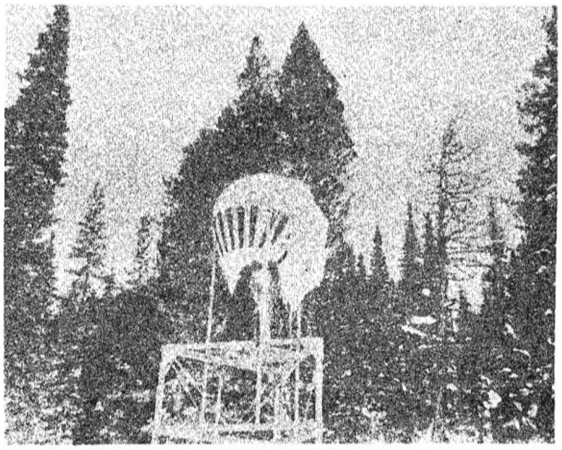

Fig. 1. Snow-capped Sacramento Storage gage - Boise River Basin, Idaho.

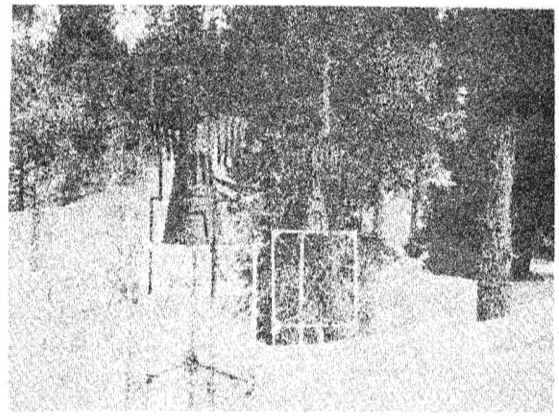

Fig. 2. Field gages at Bogus Basin, Idaho.

Fig. 5. Battery plates of primary cell used to supply electrical energy for heating orifice rim.

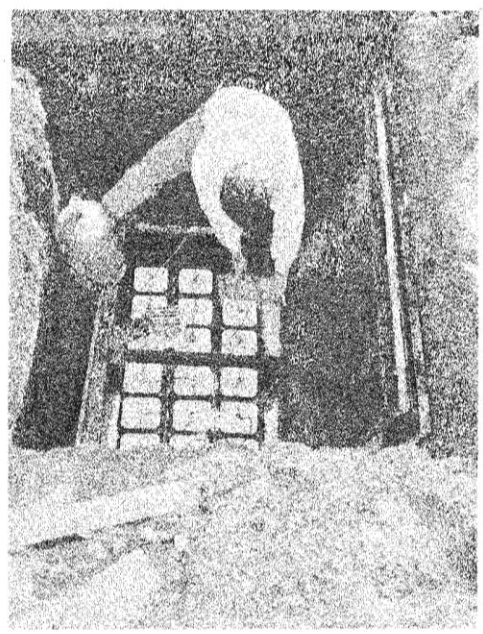

Fig. 6. Wiring the batteries in buried battery box.

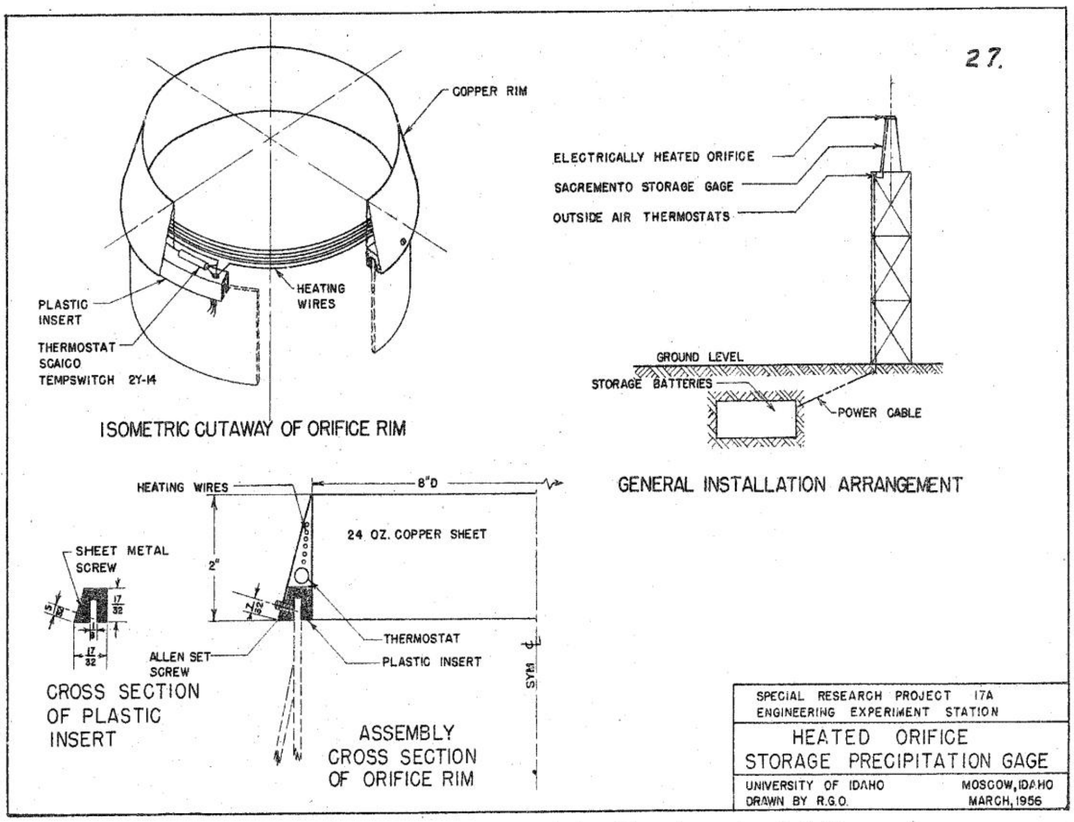

Fig. 3. Details and general arrangement for heated orifice storage precipitation gage.

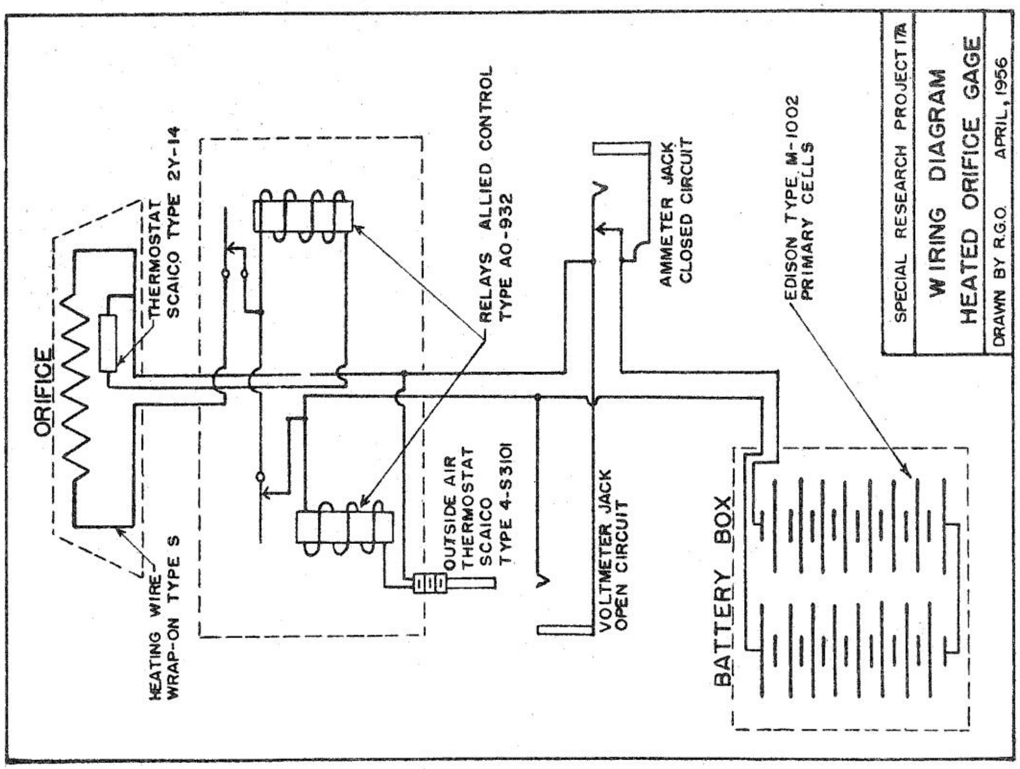

Fig. 4. Wiring diagram for initial design of temperature controlled heated orifice precipitation gage.

In addition to these installations, the Weather Bureau has assisted in the study by placing a recording precipitation gage in operation at Deer Point near the KBOI-TV transmitter. This is near Bogus Basin but about 500 feet higher in elevation and on a windswept exposure. Here records were obtained of the hours of the day that the temperatures were between certain ranges and the hours when snow was falling.

Other regular or special weather stations at high-altitude stations have furnished data for the studies of hours of heating and the power required. Station records used were those from Mullan Pass and Priest River Experiment in northern Idaho and Mt. Baldy near Sun Valley, Idaho.

Prototype Heated Orifice Gages

After submitting a proposal on the feasibility of developing a heated orifice storage gage to representatives of the Bureau of Reclamation, Corps of Engineers, Soil Conservation Service and Weather Bureau, the Station developed an experimental gage that was installed late in 1955 on the campus for preliminary testing. This was a standard Sacramento storage gage fitted with a special collector rim. Figure 3 gives details for this special heated rim and the general arrangement of the installation. The basic design was set up such that electrical energy was drawn from a battery and dissipated in resistance wires fitted inside the hollow orifice rim of the gage. The system was thermostatically controlled so that the outside air thermostat was set to interrupt the circuit when the temperature dropped below 20°F and the thermostat inside the orifice rim was set to interrupt the circuit when temperature on the rim increased to 34°F. The diagram for the electrical circuit is shown in Figure 4. A later revision to the circuit eliminated one of the relays and the circuit is shown in Figure 10.

After an extensive search for batteries and consideration of windchargers as a power source it was decided to test first a battery power source consisting of a group of primary cells manufactured by the Thomas A. Edison Company, Bloomfield, New Jersey. The design voltage was set at 10 volts and capacity rating was anticipated to be about 2000 ampere-hours. This required 32 cells. Figure 5 shows one of the staff pointing out details of the type of plate used in the battery and Figure shows the cells being wired up in the battery box. A water tight box was built to house the batteries. This was placed in a hole at a depth of about 4 feet below the ground surface. Actually during the first winter it was only temporarily covered and was exposed to rather severe temperature changes.

After initial success with the temperature control of the heating cycle, it was recognized that the gage was heating many hours during which there was no real need, because there was no snow falling. A search was then made to find a way to control the heating cycle such that it heated when there was precipitation falling in the temperature range between 20°F to 34°F. A moisture sensing element was proposed that would actuate the heating circuit. This system was not completed until the late summer of 1956 and has now been placed in operation on the gage on the campus and another gage on Moscow Mountain.

The additional heated-orifice gage on Moscow Mountain was installed to get data from an actual installation at a higher elevation where capping was considered to be more a problem. Beside this gage another standard Sacramento gage was installed as a control gage to make comparisons. The gages are located on a saddle at an elevation of about 4200 ft somewhat sheltered from high winds. Both gages are equipped with Shasta windshields and are identical except that one is equipped with the electrically heated orifice. Figure 7 shows these two field gages.

Instrumentation

To obtain information on the performance of the heated-orifice gages, hygro-thermographs were set up adjacent to the experimental gages on the campus and on Moscow Mountain. This was done to obtain records of outside temperatures indicating times when the temperature control should be acting and to obtain continuous records of temperature and humidity so as to indicate the conditions that cause capping. A recording anemometer has been in operation the past winter season (1956-57) near the campus gage to obtain records of wind velocity.

Measurements of power were initially made with ordinary ammeters and voltmeters at periodic times during the time the orifice heating system was in operation. Late in January 1957 two ampere hour meters of the totalizing type were obtained for use on the project. This permits obtaining a continuous record of the ampere hours of energy used. Periodic checks with the voltmeter then permit computation of the watts of power used and the estimated total energy in watt hours. Recently a source was found for obtaining a recording wattmeter of the DC type; this has been ordered and will be used to measure power used in the future.

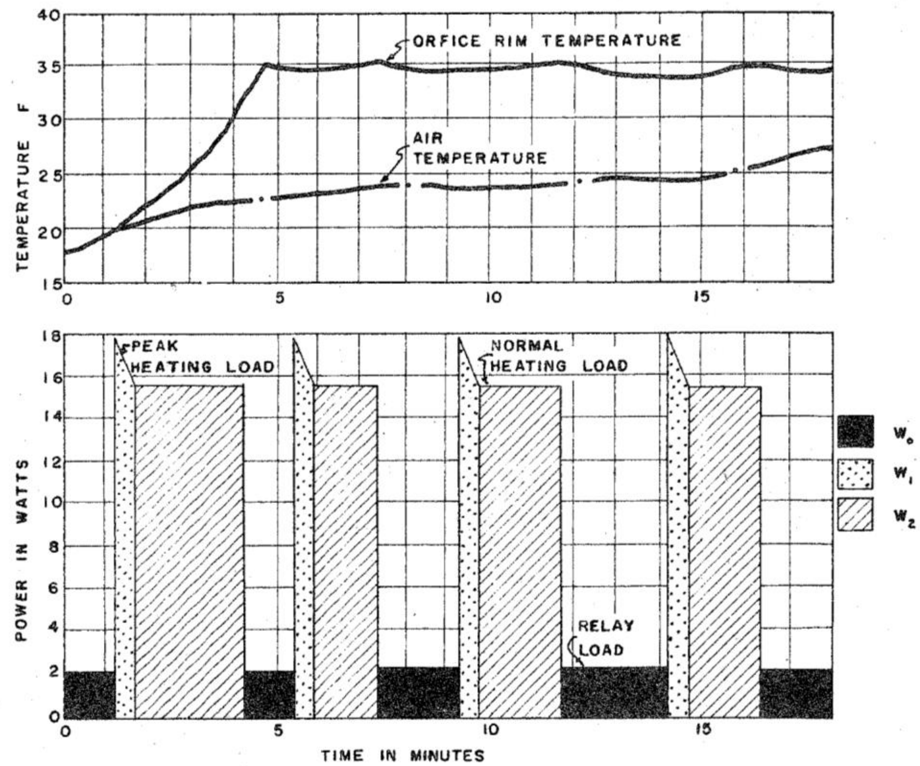

Fig. 8. Graph of typical heating cycle for heated orifice precipitation gage.

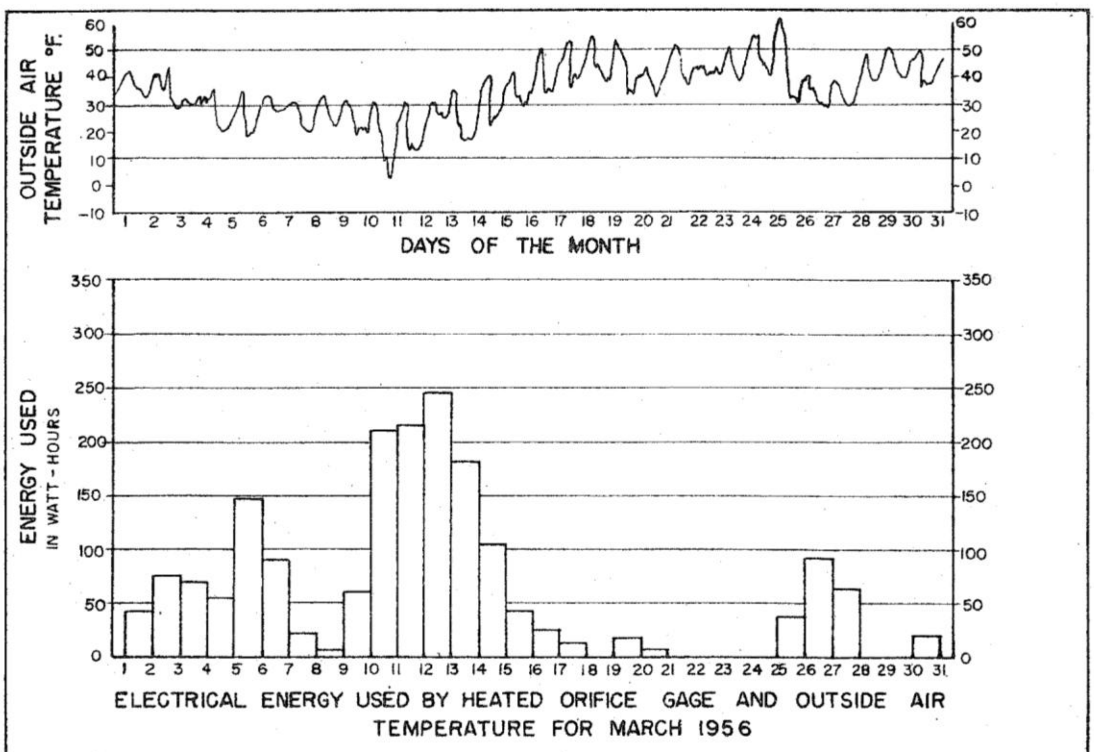

Fig. 9. Graphical plot of electrical energy used by heated orifice in March, 1956.

In April, 1956, a recording rain gage was placed in operation on the campus to obtain a continuous record of when precipitation was falling. This record is being used to analyze the amount of time the heated orifice gage will be functioning.

Recently a recording potentiometer was obtained on loan from the Corps of Engineers and this is being equipped to provide a continuous record of surface temperatures of the gage orifice to study efficiency of the heating cycle under various weather conditions.

RESULTS AND DISCUSSION

The first experimental heated orifice precipitation gage was placed in operation on 4 February 1956 on the campus of the University of Idaho. It was anticipated that the heating might be continuous, but it was soon observed that the heating was cyclic so measurements were made of line current, voltage, air temperature and surface temperature to describe the heating cycle. Figure 8 illustrates the heating cycle prior to the time the one relay was deleted from the circuit and also shows air temperature and gage surface temperature variation through a typical series of cycles of heating. Using the instantaneous voltage and line current during different periods of heating, the power rates for each period were computed; W_0 represents the relay load, W_1 the five second peak load, and W_2 the normal load over the remainder of the cycle. Using these power rates and data on the number of cycles and the total time of operation, a graph of power-used was obtained. Figure 9 illustrates the results for March 1956. Here it can be observed that the energy for heating is considerably influenced by the air temperature.

This past winter (1956-57), the delay of shipment of certain electronic parts, including ampere-hour meters, did not permit the gages with the heated orifices to be operated under measured conditions until late in January, and then only the one on Moscow Mountain was in operation on a continuous basis. This gage had the moisture sensing element included in the circuit. Figure 10 illustrates the circuit used on this present installation and Figure 11 shows the control box that holds the control parts of the circuit. The power used was read on weekly visits to the gage so no day-to-day record of consumption of power was obtained, but a weekly consumption was computed. Table 1 gives the summary for power used at the Moscow Mountain gage.

TABLE 1. Power used by Moscow Mountain heated-orifice precipitation gage

Period covering 1957	Ampere-Hours Used
26 Jan. - 2 Feb.	0.1
2-9 Feb.	1.3
9-16 Feb.	0
16-23 Feb.	4.25
23 Feb. - 2 March	2.35
2-9 March	7.1
9-16 March	2.0
16-23 March	33.3
23-30 March	4.6

In summing up this performance it should be noted that for a 63 day period when voltage averaged about 13 volts the watt hours of energy used by Moscow Mountain gage would total 715 watt hours. The energy used by the prototype gage on the campus during the period 4 February to 30 March 1956 (a 54 day operation) when only temperature control of the circuit was in operation was 4,684 watt hours. This indicates that the new prototype gage with both moisture and temperature control uses about one-eighth as much energy as the gage with just temperature control.

To determine a general trend of heating requirements and to illustrate better the benefits from moisture controlled heating, a study was made of storm and temperature conditions at both Mullan Pass, Idaho, (elevation 6500) and Mt. Baldy, Sun Valley, Idaho (elevation 9000 ft.). Table 2 shows a summary for Mullan Pass by months of the potential hours that heat would be needed under a temperature controlled system and also under a moisture-temperature controlled system. Note this has a 18°-34°F range instead of the 20°-34°F.

TABLE 2. Summary of temperature and precipitation conditions prevailing at Mullan Pass

Period	Hrs. of Temp. between 18°-34°F.	Hrs. of Precipitation in Temp. Range 18°-34°F.
Nov. 1951	192	100
Dec. 1951	329	276
Jan. 1952	296	163
Feb. 1952	416	175
March 1952	544	268
April 1952	279	77
Six Month Total	2056	1059

TABLE 3. Summary of temperature and precipitation data at Mt. Baldy near Sun Valley.

Period	Hrs. of Temp. between 20°-34°F.	Hrs. of Precipitation in Temp. Range 18°-34°F.
Oct. 1954	200	4
Nov. 1954	280	34
Dec. 1954	240	35
Jan. 1955	206	3
Feb. 1955	207	2
March 1955	227	38
April 1955	297	26
Six Month Total	1657	142

The same type of information is shown in Table 3 for Mt. Baldy at Sun Valley. These data present a widely varying amount of time for the required period when a heated orifice gage might need to be in operation. The data at Mullan Pass were taken from half-hour interval reports and include some periods when heavy fog was reported while the data from Mt. Baldy were taken from precipitation gage traces which probably did not include periods when only a trace of snow or snow flurries were prevailing. Other studies of this type are continuing and it is hoped to evaluate upper limits of heating requirements. From these data it appears that 1000 hours of potential heating period might be required. Since cyclic heating prevails during the storm period it would seem reasonable that 500 hours of actual heating may be the upper limit that the gage will be in operation during any one winter season.

Operation During Capping Type Storm.

On 21 February 1956 a storm capable of capping the prototype gage occurred on the campus at Moscow, Idaho. The snowstorm started early in the evening and lasted most of the night with a 10-inch increase in snow depth being measured on the ground. Actually the orifice of the Standard Weather Bureau gage, maintained by the Agronomy Department on the campus, was nearly closed during the storm. The air temperature during the storm was slightly below 32°F resulting in a wet, sticky snow. Figure 12 shows how the heated orifice kept the gage rim free from snow. The following morning the storm ended and the temperature raised above 35°F, but early in the morning an accumulation of four inches of snow was visible in places on the nearly vertical walls of the gage. Wind velocities did not exceed 8 mph. Although Moscow area does not experience this type of storm frequently, it did prove the heated orifice was effective.

Operation During Wind Driven Storm.

Early in March 1956 the gage operated during a snowstorm when the wind velocity averaged 15 to 20 mph. The system was again effective in preventing capping, but snow did tend to build up on the windward side when the thermostat was located on the leeward side of the gage. This was caused by an apparent temperature differential wherein the leeward side was warm enough (above 34°F) and the windward side was near 32°F. The new installations have two thermostats in series to prevent such a condition.

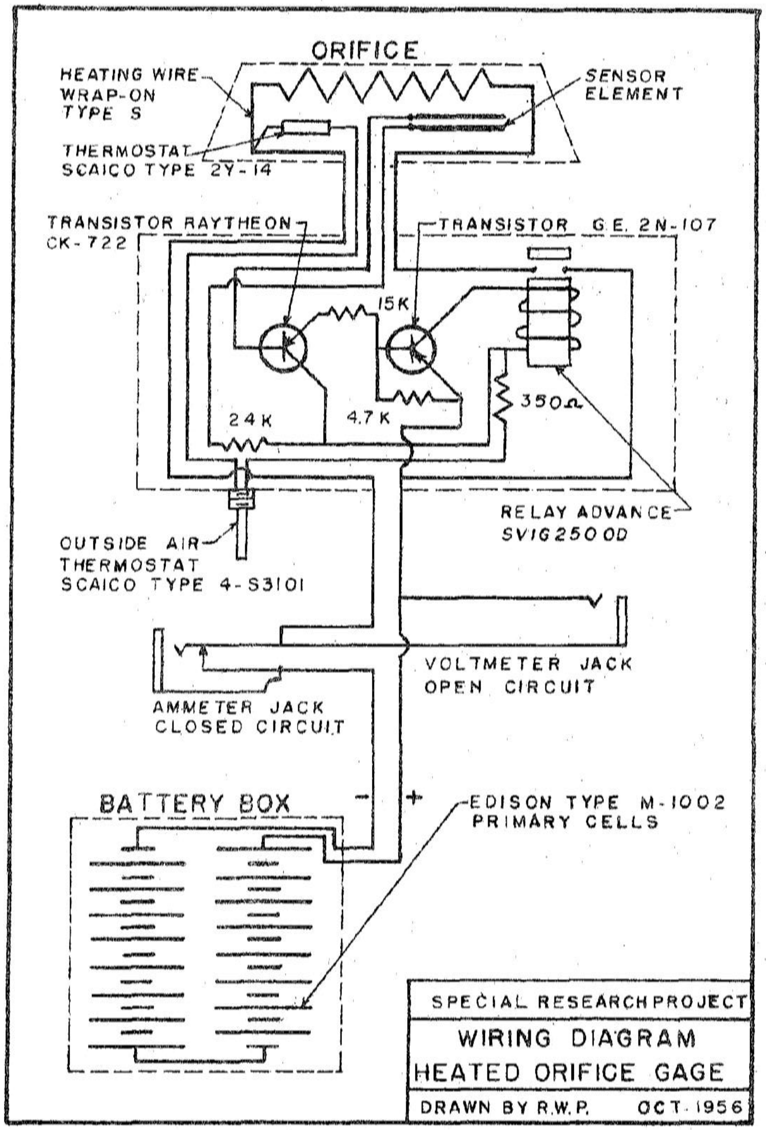

Fig. 10. Wiring diagram of revised heating circuit with moisture control for heated orifice precipitation gage.

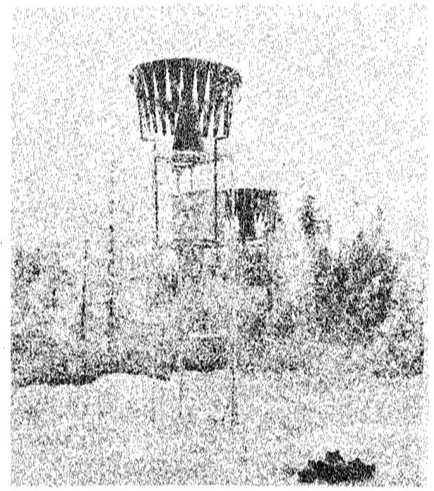

Fig. 7. Experimental gage and control gage on Moscow Mountain, Idaho.

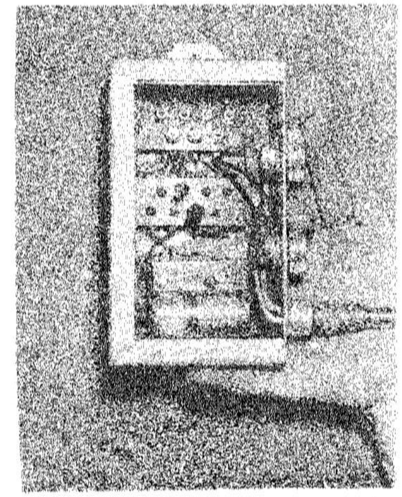

Fig. 11. Control box for heating circuit on heated orifice gage.

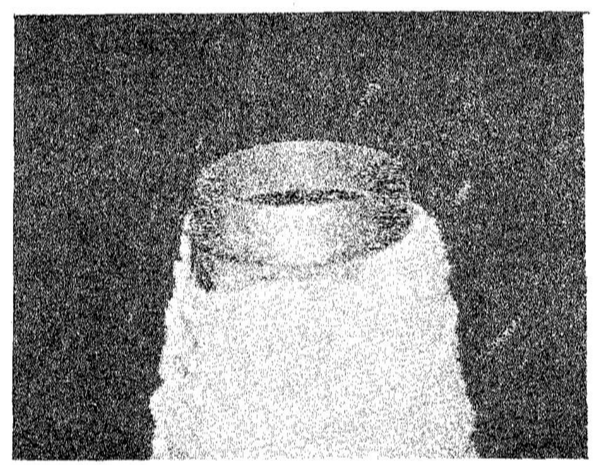

Fig. 12. Photographs showing heated orifice gage in operation during capping storm of 21 February 1956.

COST INFORMATION

An indication of costs for a typical installation of this type would seem important although only experimental models have been built to date.

Table 4 gives a summary of expected costs of a typical installation based on purchases made for the experimental unit and experience gained with installation of the prototype gages.

TABLE 4. Cost estimate for typical heated orifice precipitation gage

Item	Cost
Sacramento Storage Gage with windshield & 15 ft. tower	$ 200.00
Special orifice for gage	30.00
Thermostats, switches, relays, wiring & electronic parts	60.00
Storage box for batteries	60.00
Primary cell batteries (18 cells recommended)	250.00
Installation labor	150.00
	$ 750.00

Because part of the batteries must be replaced when using the primary cells, there will be a cost for battery replacement of $175.00. Actually operation data obtained this year indicated these batteries should last about four years.

Storage batteries of the nickle cadmium type may provide a cheaper energy source if used with a windcharger, but as yet no data are available on performance. Equipment for making tests of such a power system have already been ordered for next year's operation. Annual maintenance costs above the battery replacement should not exceed $50.00.

CONCLUSIONS

From this study and tests made during the past two years on capping of unattended precipitation gages the following conclusions are made:

1. There is a distinct problem of capping of unattended precipitation gages with snow that appears to exist quite generally at high elevations in several states of the Western United States.
2. There is need for additional basic data on weather conditions that cause capping. Data have already been obtained at several locations through the work of this project and instrumentation has been set up to obtain additional detailed information.
3. An experimental storage type precipitation gage using electrical energy supplied from batteries has been developed and placed in operation. First attempts utilized a Sacramento type gage that was thermostatically controlled to heat only between 20°F to 34°F. A second attempt and refinement of the first gage utilized the thermostatically controlled system plus a moisture sensing element that restricts heating to when there is precipitation falling in the temperature range between 20° to 34°F. Operation of this latter unit permits considerable saving in power and after the first season of use appears to be very effective in preventing possible capping of the gage with snow.
4. Cost data on the experimental indicates a typical installation completely installed would cost about $750.00 if the temperature and moisture control system is used.
5. There is definite need for further study of this problem and the needs and recommendations for implementing further study are reported under Recommendations.

RECOMMENDATIONS

For future study on this project the following is recommended:

1. The study of the experimental gage on the campus of the University of Idaho should be continued using the moisture and temperature control system developed during the past year. Work should consider the effect of wind on heating requirements, the changes in surface temperatures on the rim of the gage, and radiation effects. Controlled wind tunnel tests should be attempted to give further data on power requirements under very adverse conditions.
2. The Moscow Mountain experimental gage should be operated again during the winter of 1957-58 and additional instrumentation provided if possible. The cooperation of the City of Moscow

the local Soil Conservation District, and other federal agencies should be sought to keep the work of the project practical and to provide data of actual value. At this site the use of storage batteries and a windcharger should be attempted to find a cheaper source of power.

3. Gages at Bogus Basin should be watched to accumulate more information on the capping phenomenon. Data on temperature and precipitation conditions at other high altitude locations should be sought to evaluate expected heating requirements that might be needed for the gages at various locations throughout the west.

ACKNOWLEDGMENTS

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On the Engineering Experiment Station Staff, C. W. Hathaway and D. M. Oliason assisted with much of the planning and preparation of equipment for the project. D. R. Duncan, V. E. Penton, R. W. Peterson, L. E. Garlinghouse, D. L. Mecham, and R. G. Osborne, engineering students, have assisted in conducting tests and processing data, and have furnished many original ideas. Mrs. Irma Murphy has done the stenographic work and has been most helpful in reviewing and editing this report. All work has been under the direction of Dean Allen S. Janssen as director of the Engineering Experiment Station.

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