# DIURNAL FLUCTUATIONS IN REMOTE PRECIPITATION GAGE READINGS

by

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## INTRODUCTION

The use of telemetered precipitation gage readings available from hundreds of remote sites in the western United States could provide dramatic improvements in the accuracy of streamflow forecasts These improvements could be extremely valuable in conserving limited water supplies during critically dry years, or in minimizing losses with advanced warning when flooding is imminent.

Unfortunately, diurnal fluctuations of more than 3 cm have been observed in some automated, remotely sensed precipitation gage readings when precipitation did not occur. In fact, a statistical analysis of precipitation data fluctuations from 517 remote sites indicated that 60 percent exhibited a temperature dependency (Huber, 1986). Fluctuations from about 40 percent of the sites were greater than that specified in the transducer design criteria. However, the fluctuations can result from several other factors in addition to temperature-related response of the transducer.

Under normal conditions where readings are monitored at only one given time each day, these fluctuations do not cause problems. However, when snowpack conditions on a watershed are such that flooding could occur at any time, water supply managers want forecasters to provide frequent up-to-date estimates of pending streamflow volumes and stages. Under these conditions, if a site was monitored in the morning and then again later the same day, it could appear that 3 cm of precipitation had occurred. Three centimeters of warm rain in less than twelve hours on a ripe snowpack could cause flooding of catastrophic proportions. Therefore, it is extremely important that the forecaster have accurate and reliable data with which to work.

This study describes an attempt to determine the cause of the diurnal fluctuations observed, so that methods of eliminating or reducing the problem can be developed.

## Description of Study Site

In order to study the diurnal fluctuations on a frequent basis, a simulated remote precipitation gage site was installed during the spring of 1986 at the Federal Building grounds in Boise, Idaho. The installation was configured similar to many Soil Conservation Service (SCS) and Bureau of Reclamation (BOR) field sites. It includes an instrument shelter, a 4.27 m high storage precipitation gage, the normal fluid and electrical lines between the gage and the shelter, a Robinson-Halpern[4/] pressure transducer, and a tygon tube manometer in the shelter. In addition, two Druck pressure transducers (one 50.8 cm below the gage and the other 66 cm below the shelter), extra plumbing to house the transducers, temperature sensors at five depths within the gage and at each pressure transducer, and gate valves in the fluid lines were installed as shown in Figure 1. Air temperature and precipitation were also monitored. All of the data were recorded at 15-minute intervals using the BOR data collection platform (DCP) which automatically transmitted the data to receiving equipment in the adjoining Federal Building every three hours.

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[4/] Product names are supplied for reader convenience and in no way constitute endorsement or recommendation for use by the U.S. Department of Agriculture, Agricultural Research Service.

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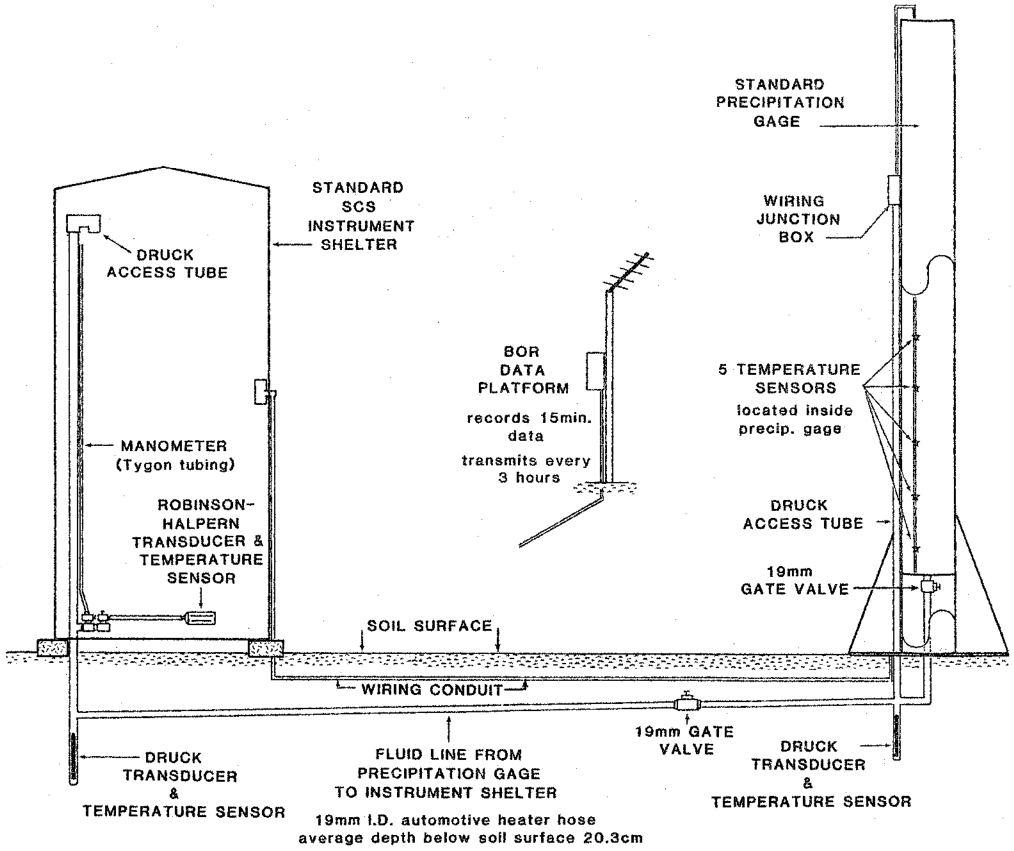

Figure 1. Schematic diagram of the Boise Federal Building simulated remote precipitation gage site showing location of system components and sensors.

Additional measurements were made during visits to the site for use in checking calculations and assumptions used. These included: 1) soil temperature measurements at the base of the gage, near the gate valve in the fluid line, and on the north side of the instrument shelter; 2) hand-held infrared radiometer measurements of the gage surface temperature; 3) measurements of the gage diameter near the time of minimum and maximum air temperature; and 4) the height of the fluid level in the manometer.

## PROCEDURES

At the start of the study, the precipitation gage was charged by SCS personnel using 19 liters of standard 60 percent methyl alcohol-40 percent ethylene glycol mixture. About once a week, variations were imposed on the system by 1) altering the fluid level, concentration, and type; 2) insulating the gage and the soil surface above the fluid and electrical lines; and 3) opening and closing the two gate valves individually. The effects of temperature on the instrumentation and various parts of the system were then observed for a number of different fluid and system configurations under natural climatic conditions encountered during the summer and fall seasons.

Table 1 contains a brief summary of the conditions imposed during each study period, the average variation of air temperature, the average manometer reading change, fluid level in the gage, and the fluid characteristics.

At the end of the study, the two Robinson-Halpern transducers used were tested in a laboratory chamber over a similar range of pressures and temperatures.

Table 1. Conditions imposed on the simulated remote precipitation gage system, during twenty-one periods studied, fluid level and characteristics, observed fluid level changes, and average daily temperature changes.

| Study Periods | Percent Methyl-Glycol in Mixture | Depth of Fluid in Precip. Gage | | System Configuration | Average Daily Change in Manometer Reading (0630-1800 hrs) | Average Daily Change in Air Temp. |
|---|---|---|---|---|---|---|
| 6-8 to 6-11 | 100 | 23 cm | | Open system | No data | 17.2 °C |
| 6-13 to 6-16 | 100 | 23 cm | | Valve at gage base closed | 13.5 mm | 18.3 °C |
| 6-18 to 6-20 | 50 | 50 cm | | Open system | No data | 18.9 °C |
| 6-24 to 6-27 | 50 | 50 cm | | Valve closed[1] | 9.5 mm | 20.4 °C |
| 7-2 to 7-5 | 25 | 90 cm | | Open system | 7.5 mm | 14.6 °C |
| 7-15 to 7-18 | 25 | 90 cm | | Valve closed[1] | No data | 16.7 °C |
| 7-22 to 7-25 | 25 | 90 cm | Precip. gage and soil insulated during this period | Open system | 12.9 mm | 20.7 °C |
| 7-27 to 7-30 | 25 | 90 cm | | Valve closed[1] | No data | 19.2 °C |
| 8-2 to 8-5 | 0 | 89 cm | | Open system | No data | 22.2 °C |
| 8-9 to 8-12 | 0 | 89 cm | | Valve closed[1] | No data | 21.7 °C |
| 8-15 to 8-17 | 0 | 89 cm | | Open system | 5.4 mm | 16.8 °C |
| 8-19 to 8-22 | 0 | 89 cm | Recorder mounted on top of precip. gage | Open system | 6.2 mm | 18.8 °C |
| 8-23 to 8-25 | 0 | 89 cm | | Valve closed[1] | No data | 20.6 °C |
| 8-30 to 9-2 | 0 | 23 cm | | Open system | No data | 17.5 °C |
| 9-3 to 9-6 | 0 | 23 cm | | Valve closed[1] | No data | 21.3 °C |
| 9-13 to 9-16 | 100 | 23 cm | | Open system | No data | 13.1 °C |
| 9-21 to 9-24 | 100 | 23 cm | | Closed off manometer | No data | 18.1 °C |
| 10-8 to 10-11 | 85 | 28 cm | | Valve at gage base closed | No data | 19.2 °C |
| 10-12 to 10-14 | 85 | 28 cm | | Open system | No data | 21.1 °C |
| 10-15 to 10-18 | 85 | 28 cm | | Valve closed[1] | No data | 20.2 °C |
| 10-28 to 10-30 | 85 | 28 cm | Different transducer | Open system | No data | 16.1 °C |

[1] Refers to valve between precipitation gage and instrument shelter.

## ANALYSIS

The diurnal nature of the fluctuations noted at field sites suggested that the problems were temperature related. The various system configurations imposed during the twenty-one study periods were designed to show the effects of temperature on the electronics, the pressure transducers, the system materials, and the fluids used. Plots of the data collected were used to isolate effects on electronics and transducers.

The magnitude of the changes that could be expected due to system and fluid expansion were calculated, to see if the calculated values compared in sign and magnitude with observed data, and to determine if other possible causes could be eliminated.

## Thermal Expansion

The application of heat to solids causes practically all of them to expand. The amount they expand when heated is measured by their coefficient of linear expansion ($\alpha$). This coefficient gives the fraction by which the length ($\ell$) (or width, or thickness) of an object will increase for each degree rise in temperature ($\Delta T$), according to the equation

$$\Delta \ell = \alpha \ell \Delta T.$$

Coefficients of linear expansion for the materials used in this study and the source from which the values were derived are presented in Table 2.

If the length and width and thickness of a solid increase as it is heated, its volume will also increase. The volume coefficient of expansion "$\beta$" of a solid is very closely approximated as

$$\beta = 3\alpha \ .$$

Table 2. Coefficients of linear and volume expansion.

| Material | Coefficient of Linear Expansion |
|---|---|
| Aluminum | $25 \times 10^{-6}/°C$ [1] |
| Plastic pipe | $54 \times 10^{-6}/°C$ [1],[2] |
| Rubber heater hose | $90 \times 10^{-6}/°C$ [1],[3] |
| Tygon tubing | $63 \times 10^{-6}/°C$ [4] |
| | **Coefficient of Volume Expansion** |
| Water | $0.21 \times 10^{-3}/°C$ [5] |
| Methyl alcohol-<br>Ethylene glycol | $0.976 \times 10^{-3}/°C$ [6] |
| All solids | $\beta = 3\alpha$ |

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[1] From Handbook of Chemistry and Physics, C. D. Hodgman, R. C. Weast, and S. M. Selby (eds.), 42nd edition, The Chemical Rubber Publishing Co., Cleveland, OH, 1960, pp. 1558, 2239, 2241-2244, 2245.

[2] Supplier, Pacific Plastics, Inc., "PVC temperature variation," June 1984.

[3] Supplier, Gates Rubber Company.

[4] Supplier, Norton Company, Ohio.

[5] From Physics: Foundations and Frontiers, G. Gamow, and J. M. Cleveland, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1960, p. 150.

[6] Supplier, Chemcentral Corporation, 7050 West 71st Street, Chicago, IL, 1986.

The cavity in a hollow object (tank or flask) expands as though it was a solid block of the same material. Liquids, in general, follow the same law of expansion as that applicable to solids; however, the expansion is a function of volume change rather than length. The change in liquid volume produced by a change in temperature can be written as

$$\Delta V = \beta V \Delta T$$

where V is the original volume, $\Delta V$ is the change in volume, and $\beta$ and $\Delta T$ are as previously defined. Values of the volume coefficient of expansion of the liquids considered in this study are also found in Table 2.

Using the relationships described above, the amount of expansion of the precipitation gage system and the fluids were determined for each of the 21 study periods listed in Table 1. The effect of the system and fluid expansion was then compared to observed changes in the pressure transducer output, and, where possible, fluid elevation in the manometer.

Calculations were made for each portion of the system shown in Figure 1, starting at the precipitation gage on the right-hand side and working through the other portions, with the tygon tubing on the left-hand side being last. The plastic pipe and rubber hose were each divided into four sections for the calculations because of different exposures and plumbing arrangement. For example, the plastic pipe had a below-ground and above-ground section on the gage and the shelter side. By dividing the pipe into sections this way, a more realistic diurnal temperature change could be assigned to each section. The same type of procedure was followed for the rubber hose. However, in this case there was only one above-ground section between the valve at the bottom of the precipitation gage floor and the soil surface. The three below-ground sections were divided by a plastic tee and a gate valve. In the case of the precipitation gage, the tygon tube manometer, and the two standing plastic pipes, a depth was used to calculate volume rather than length of total pipe, tube, or gage.

The temperatures used to determine expansion were those measured at different points in the system and air temperature. The air temperature above the fluid at 107 cm above the precipitation gage floor was used to determine expansion of the aluminum gage and the fluid within. Hand-held infrared radiometer measurements of the gage surface temperature showed that the air temperature above the fluid better approximated the skin temperature variation than did the 15 cm fluid temperature at the center of the gage. Air temperature was used for the above-ground plastic pipe on the north side of the gage. The temperatures at the buried Druck transducers were used for all below-ground sections of pipe and rubber hose. The temperature at the Robinson-Halpern transducer in the instrument shelter was used for the above-ground plastic pipe, the tygon tube manometer, and the above-ground rubber hose under the gage.

## RESULTS

Variations in temperature and pressure transducer output for four selected three-day study periods are shown in Figures 2-5. Analysis of these and similar figures for all twenty-one study periods indicated that the fluctuations did in fact exist (up to 1 cm with only 23 cm depth of fluid in the gage). As previously mentioned, the simulated precipitation gage system included extra valves and transducers designed to assist in isolating the problems. As an illustration, Figures 2 and 3 show that by merely closing the gate valve at the base of the precipitation gage, the response of the pressure transducer shifted from an inverse relationship with temperature to a direct relationship with temperature. Since the fluid, the DCP, and the pressure transducer remained the same, and were subjected to essentially the same diurnal temperature change, some other component or mechanism related to the precipitation gage itself must be responsible for the fluctuation observed. The two Druck transducers were on the same side of the valve as the Robinson-Halpern transducer and exhibited the same shift shown in these figures. These results suggest that the DCP and pressure transducer were not causing the magnitude of fluctuations observed.

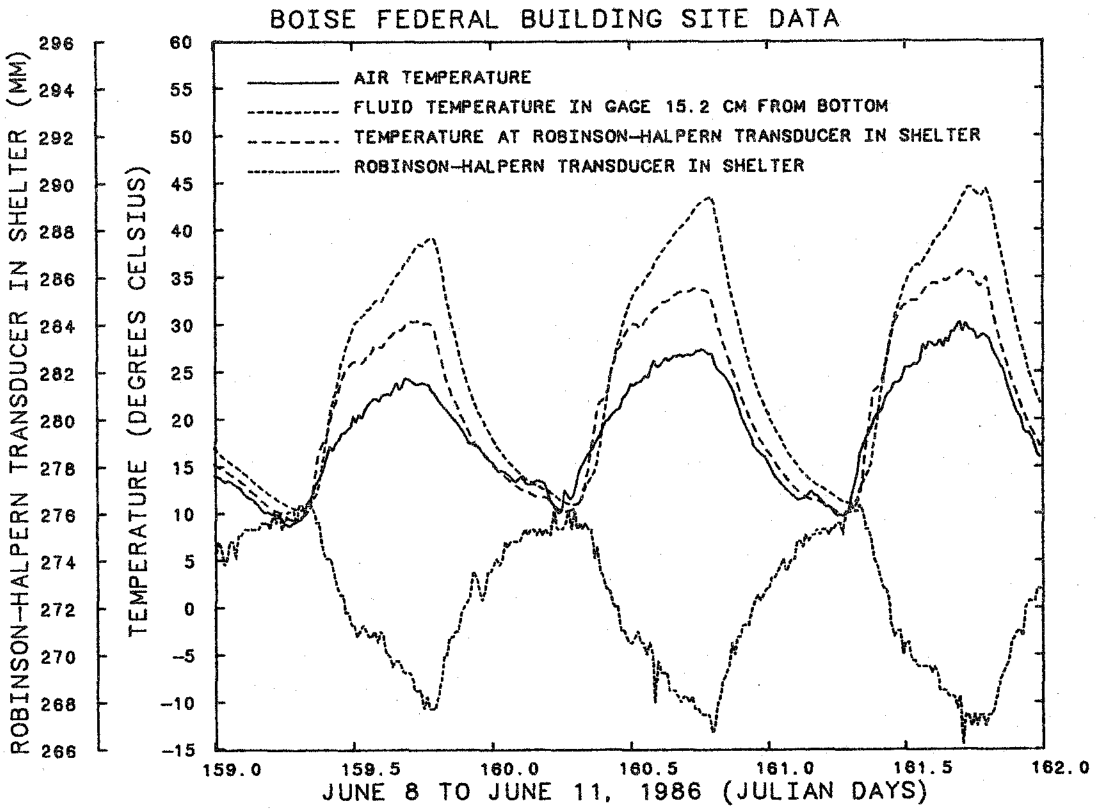

Figure 2. Temperature and pressure transducer records obtained from the simulated remote precipitation gage site, Boise, Idaho. Fluid consists of 100 percent methyl-glycol mixture at a depth of 23 cm. All valves are open.

The influence the diurnal temperature change has on the magnitude of the observed pressure fluctuation can be demonstrated using Figures 2 and 4. Although the air temperature went through a greater diurnal change during the late July period (Fig. 4), the fluid temperature in the gage exhibited a much smaller range. This was due to the effects of a layer of insulation, like that used to insulate water heaters, being placed on the precipitation gage during this period. In this case, with a greater diurnal range in air temperature, the diurnal pressure fluctuation in the gage was only 0.4 cm as compared to the 1 cm range observed for the earlier June period (Fig. 2). These figures and results also demonstrate the influence temperature changes within the fluid and the precipitation gage have on the magnitude of the fluctuations. Since the volume of the gage and the fluid in the gage are up to 100 times greater than the rest of the system, it follows that the greatest influence in modifying the pressure change can be accomplished by changing the gage and fluid characteristics.

The influence fluid characteristics have on the range of the diurnal fluctuations can be demonstrated using Figures 2 and 5. In Figure 2 the fluid is a standard mixture used by SCS of 60 percent methyl alcohol and 40 percent ethylene glycol. In Figure 5 plain tap water was used. In both cases the fluid depth was 23 cm, and both were exposed to essentially the same diurnal temperature range of about 22 °C. The pressure fluctuation was about 1 cm for the methyl-glycol mixture and only about 0.3 cm for the water.

From the above analysis of Figures 2 through 5, it appears that the expansion and contraction of the system (particularly the precipitation gage), and the fluid characteristics relating to temperature changes, are the main factors influencing the range of pressure fluctuations observed. An analysis of the effects of expansion and contraction for the standard (valves open) system are summarized in Table 3. Included in the table are values of the change in pressure head due to expansion of the system, values of pressure change due to temperature effects on the transducers used, total pressure change expected, observed pressure change, and difference between calculated and observed pressure change.

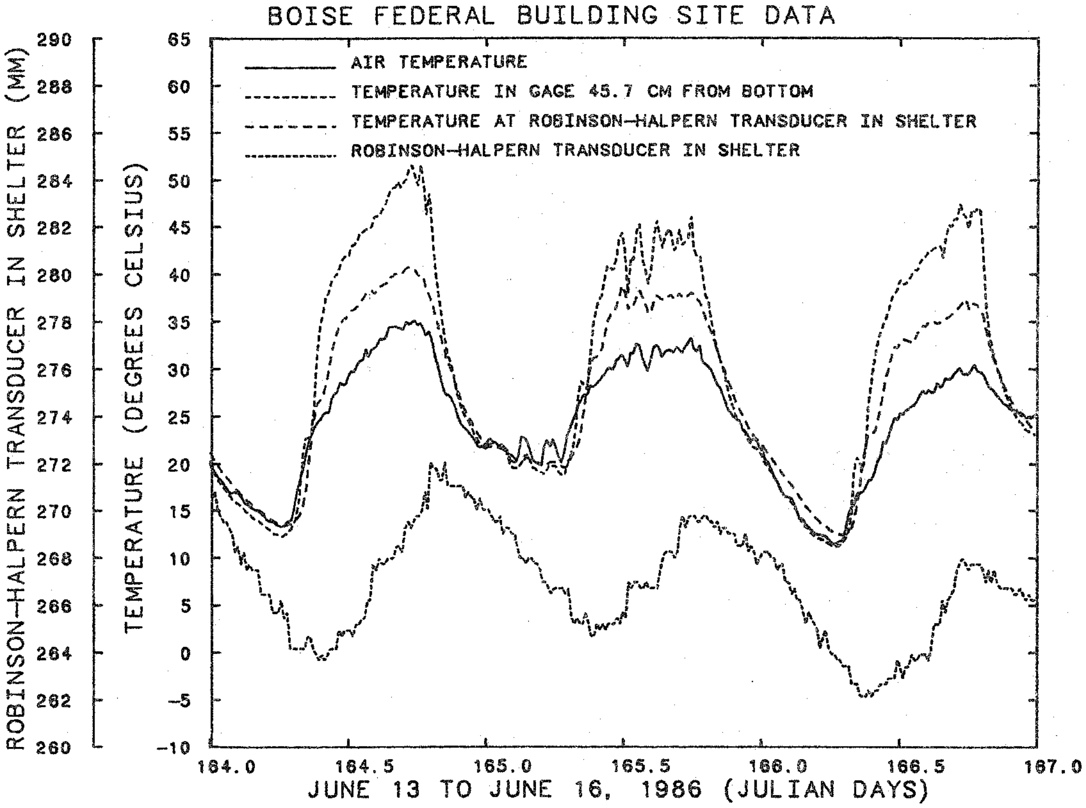

Figure 3. Temperature and pressure transducer records obtained from the simulated remote precipitation gage site, Boise, Idaho. Fluid consists of 100 percent methyl-glycol mixture at a depth of 23 cm. Valve below precipitation gage floor is closed.

The calculations summarized in Table 3 support the findings discussed in reference to Figures 2 through 5, i.e., the fluctuations are due mainly to fluid characteristics and heating of the gage. The computed change in pressure due to expansion of the system is somewhat less when the gage is insulated. For example, the computed change was -0.18 cm on both days 7/23 and 8/3 when the gage was insulated, and -0.23 cm and -0.20 cm on days 7/2 and 8/16 when the gage was not insulated. A greater influence is produced by the amount of methyl-glycol mixture in the fluid. The higher the percentage of methyl-glycol in the mixture, the greater the observed fluctuation and the greater the difference between calculated and observed pressure changes.

The calculated change in manometer reading was similar to observed change (0.97 vs. 0.87 cm and 0.33 vs. 0.40 cm) on two of the three days when readings were available. On the third day, the difference was 0.5 cm (0.76 vs. 1.27 cm). The differences could be caused by selection of an unrepresentative temperature to determine fluid expansion, problems in reading the manometer, impurities in the fluid, or other unexplained problems.

One problem associated with all of these calculations is the variation in time of occurrence of the maximum temperature change that occurs during the diurnal cycle. For example, the fluid and buried transducer maximum and minimum temperatures lag the corresponding air temperatures, thus different parts of the fluid and system are experiencing maximum expansion at different times. The calculations are based on temperature change from the time of minimum air temperature until the time of maximum temperature during the same day for each of the sensors used.

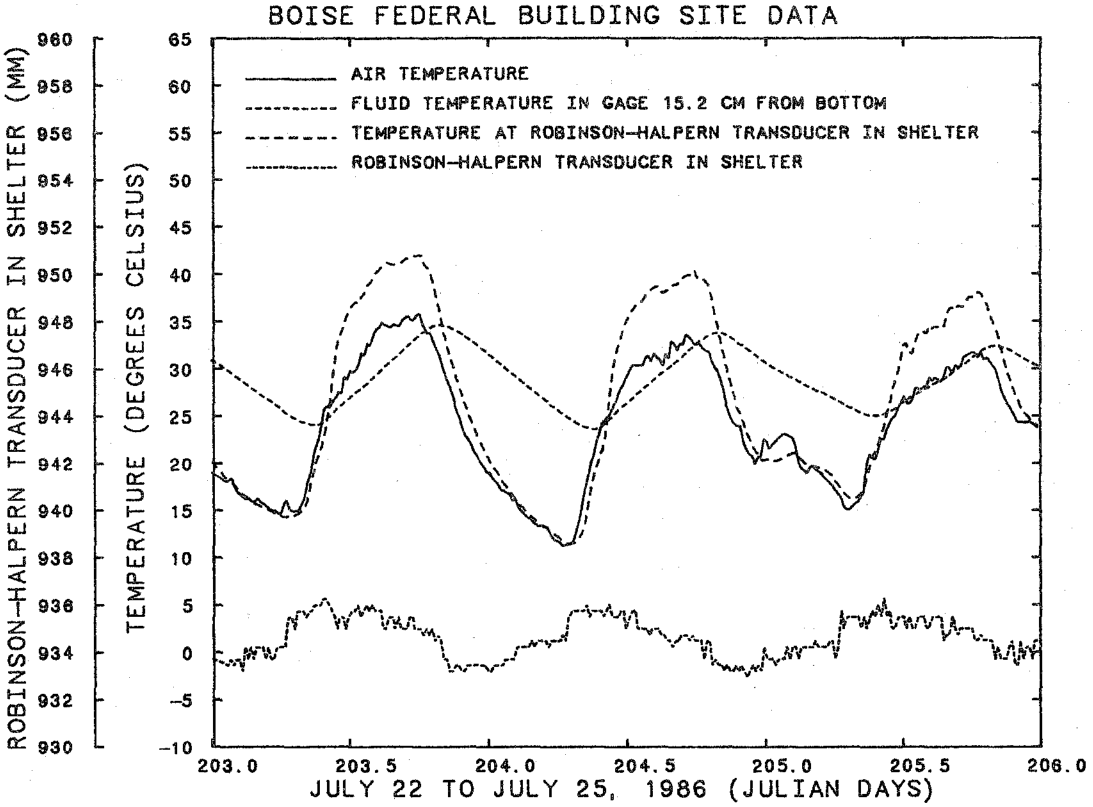

Figure 4. Temperature and pressure transducer records obtained from the simulated remote precipitation gage site, Boise, Idaho. Fluid consists of 75 percent water and 25 percent methyl-glycol mixture at a depth of 90 cm. All valves are open. Precipitation gage and ground surface were insulated.

Manometer readings were taken at approximately 0630 and 1800 hours each day and do not necessarily represent the time of maximum elevation change. Realizing these minor limitations, the calculated and recorded values of both pressure and elevation changes are reasonably close to observed fluctuations during the periods shown. When the fluid is water the fluctuation can be attributed to system expansion and transducer heating. When the fluid is methyl-glycol, there is an additional phenomena taking place which affects the transducer reading, but is as yet unexplained.

From our analysis, it appears that for depths of 90 cm or less the range of the pressure change (cm of $H_2O$) that can be attributed to expansion of the system independent of the fluid may well be within 0.3 cm. Therefore, if pressure changes of more than 0.3 cm are observed, or if the changes are in phase with diurnal temperature changes, the problem may be in the transducer, the fluid characteristics, the DCP, or due to an abnormality in system plumbing.

As a check on the simulated precipitation system and the calculation procedures used, a transducer from an operational field site that demonstrated rather large diurnal fluctuations during the statistical analysis previously mentioned (Huber, 1986) was obtained and installed at the Boise site. This transducer was previously located at an SCS site designated Moores Creek Summit, Idaho. Results obtained at the Boise site using the Moores Creek Summit transducer are shown in the last line of Table 3 for day 302. The calculated and observed pressure fluctuations were not only different in magnitude, but also different in sign. The Moores Creek Summit transducer exhibited an increase in pressure with an increase in temperature, while the original transducer indicated a decrease in pressure with increase in temperature. The magnitude and direction of change are consistent with field results studied (Huber, 1986), and with the laboratory tests that were conducted on the Moores Creek Summit transducer. These results suggest that the simulated precipitation

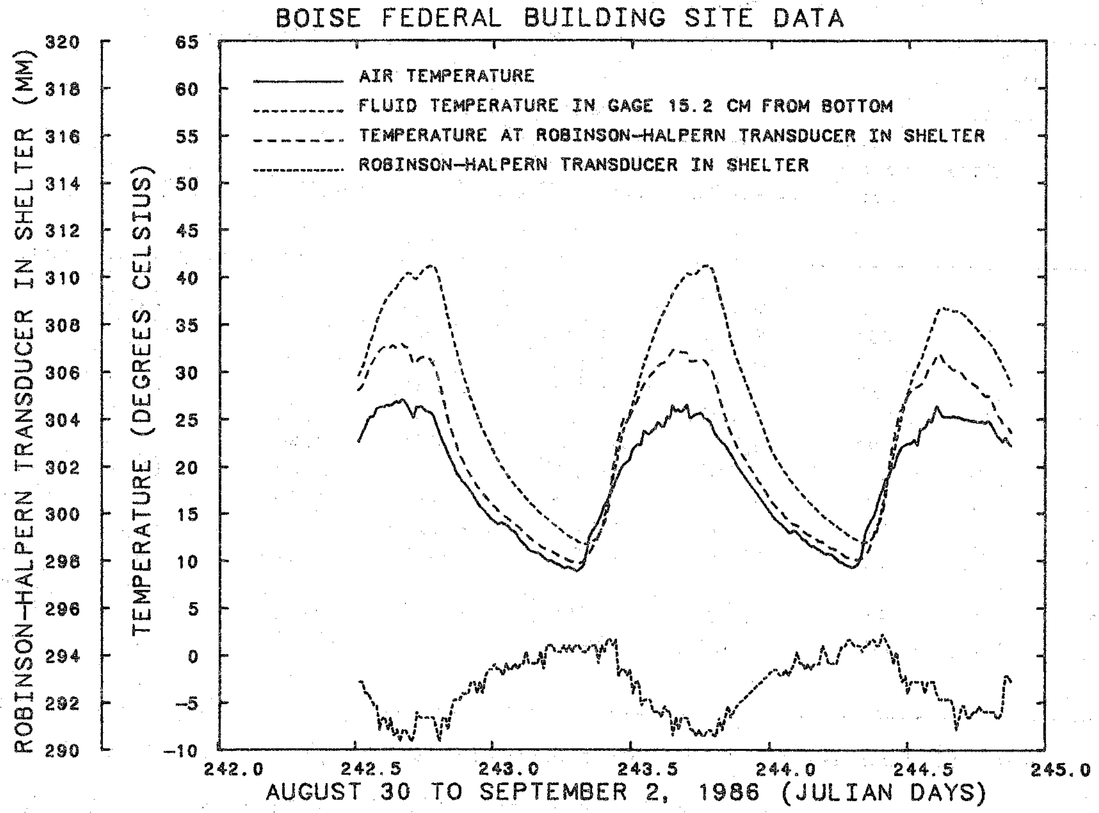

Figure 5. Temperature and pressure transducer records obtained from the simulated remote precipitation gage site, Boise, Idaho. Fluid consists of 100 percent water at a depth of 23 cm. All valves are open.

system does produce results consistent with field conditions, but more observations are needed to determine if the calculations would produce consistent and reasonable results using the Moores Creek Summit transducer. They also indicate that the effects of temperature on the transducer reading for this transducer are greater than the effects of temperature on the fluid and the precipitation gage system.

## CONCLUSIONS

Results obtained from the simulated precipitation system installed in Boise, Idaho indicate that:

1. The effects of temperature on the expansion and contraction of the precipitation gage system independent of the fluid will generally be less than 0.30 cm of $H_2O$ for fluid depths of 90 cm or less, and that most of this fluctuation is due to heating and cooling of the precipitation gage itself. This problem may be partially alleviated by insulating the gage or making it a lighter color.

2. The concentration of methyl alcohol-ethylene glycol affects the magnitude of the observed fluctuation, i.e., the less the concentration, the smaller the observed pressure change. Other anti-freeze solutions may provide the same protection and not produce this type of problem.

3. If the observed diurnal fluctuations are greater than 1.0 cm (for a system originally charged with 19 liters of a standard methyl-glycol mixture and a total depth of less than 90 cm), the problem is most likely a temperature sensitive transducer; however, a malfunctioning DCP and problems in the plumbing could also cause fluctuations of this magnitude and more.

Table 3. Comparison of observed and calculated diurnal pressure changes for a simulated remote precipitation gage system in Boise, Idaho. All valves are open.

| Month & Day | Percent Methyl-Glycol in Mixture | Fluid Depth (cm) | Pressure Change (cm of $H_2O$) Computed [1] | Transducer Correction [2] | Total [3] | Observed [4] | Differences [5] | Remarks |
|---|---|---|---|---|---|---|---|---|
| 6-10 | 100 | 23 | -0.08 | -0.38 | -0.46 | -0.94 | -0.48 | |
| 9-15 | 100 | 23 | -0.05 | -0.28 | -0.33 | -0.76 | -0.43 | |
| 9-23 | 100 | 23 | -0.08 | -0.28 | -0.36 | -0.81 | -0.45 | |
| 10-13 | 85 | 28 | -0.08 | -0.23 | -0.31 | -0.64 | -0.33 | |
| 6-19 | 50 | 50 | -0.13 | -0.25 | -0.38 | -0.76 | -0.38 | |
| 7-2 | 25 | 93 | -0.23 | -0.18 | -0.41 | -0.64 | -0.23 | |
| 7-23 | 25 | 89 | -0.18 | -0.18 | -0.36 | -0.30 | +0.06 | Gage insulated |
| 8-3 | 0 | 89 | -0.18 | -0.13 | -0.31 | -0.20 | +0.11 | Gage insulated |
| 8-16 | 0 | 89 | -0.20 | -0.08 | -0.28 | -0.33 | -0.05 | |
| 8-20 | 0 | 89 | -0.25 | -0.13 | -0.38 | -0.38 | 0 | Recorder on gage |
| 8-31 | 0 | 23 | -0.08 | -0.33 | -0.41 | -0.41 | 0 | |
| 10-29 | 85 | 28 | -0.08 | +3.05 | +2.97 | +1.42 | -1.55 | Moores Creek transducer |

[1] Change in pressure head caused by expansion of the precipitation gage system.

[2] Change in pressure head caused by temperature effects on the transducer as determined from laboratory tests.

[3] Sum of 1/ and 2/.

[4] Change in pressure recorded by DCP.

[5] Difference of 4/ minus 3/.

## ACKNOWLEDGEMENT

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## REFERENCE

Huber, A. L. (1986) SNOTEL water supply forecast and instrumentation development. ARS-SCS Cooperative Study, Annual Progress Report No. 6, December, pp. 30-50.