MEASURING WINTER PRECIPITATION WITH AN ANTIFREEZE-BASED TIPPING BUCKET SYSTEM

by

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ABSTRACT

The objective of this study was to determine if a modified storage gage charged with antifreeze and attached to a tipping bucket recorder would continuously and accurately measure winter precipitation. Precipitation measured in eight tipping bucket/storage gage (TIPSTOR) recorders were compared to measurements from eight paired snow boards, two storage gages and two weighing precipitation gages. The average total accumulation for six TIPSTORs (83.8 mm) was greater than storage gages (75.7 mm) but less than adjusted snow board and weighing precipitation gage measurements (85.6 mm and 89.3 mm, respectively) These results indicate that reasonable accuracy can be expected from the TIPSTOR. The design of the gages and the results of field tests are presented.

INTRODUCTION

Measuring continuous accumulation of winter precipitation is difficult in mountain environments where precipitation occurs as snow or mixed rain and snow. Snow pillows measure Snow Water Equivalent (SWE) on a continuous basis; however, snow pillows only measure the SWE of the snow pack and not total precipitation which includes rain and mixed rain and snow. Snow pillows with a continuous chart recorder cost, at a minimum, $4000.

Storage gages measure yearly accumulation of precipitation in the form of rain and snow, while tipping buckets measure only rain. Storage gages accumulate snow because they are partially filled (charged) with a biodegradable antifreeze solution of 50 percent Propylene Glycol and 50 percent Ethanol and topped with transformer or mineral oil to prevent evaporation. The antifreeze allows snow to melt and accumulate in the gages without freezing. Storage gages are read periodically, providing an inconsistent record of individual storm accumulations, however, they do provide reliable data on total accumulation. It is expensive to modify them for continuous measurements. Data loggers with pressure transducers cost $2000 - $3000.

A tipping bucket measures rain on a continuous basis when used in conjunction with an electronic recorder but does not accurately measure snow. Tipping buckets are used as a standard precipitation measuring device on hundreds of weather stations scattered across the Western United States. Identification of specific snow and mixed rain and snow events are important in the spring when streamflow and stream sediment production are high. Current budget constraints dictate that more economical methods be explored to utilize tipping buckets in measuring snow and mixed rain and snow events.

The TIPSTOR (tipping bucket/storage gage) test was initiated to determine if precipitation overflow from a modified storage gage, charged with antifreeze and transformer oil, could be economically constructed and used with a tipping bucket to measure winter precipitation. There are 600 to 800 Bureau of Land Management remote area weather stations (RAWS) and approximately 200 Forest Service weather stations operating in the western United States that use tipping buckets for precipitation measurements. The majority of these stations monitor fire weather data, but they could also be used to obtain year-round precipitation data if an economical method of modifying tipping buckets to handle snow events could be developed. These additional weather data would help resource managers, water supply forecasters and climatologists.

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MATERIALS AND METHODS

Research Site

The TIPSTOR study site was located near the Forestry Sciences Laboratory on the Montana State University campus in Bozeman, Montana. Eight TIPSTOR gages were installed on a 2 X 4 grid pattern (5 m between TIPSTOR gages) along with eight snow boards that were paired with each TIPSTOR (Figure 1). Other instruments located within the 2 X 4 grid were two storage gages with external manometers, two weighing precipitation gages, and a snow depth stake. The orifice heights varied from 170 to 175 cm above the ground for all instruments except the snow boards. Inside orifice diameters were 194 mm for the TIPSTORs, storage gages, and weighing precipitation gages.

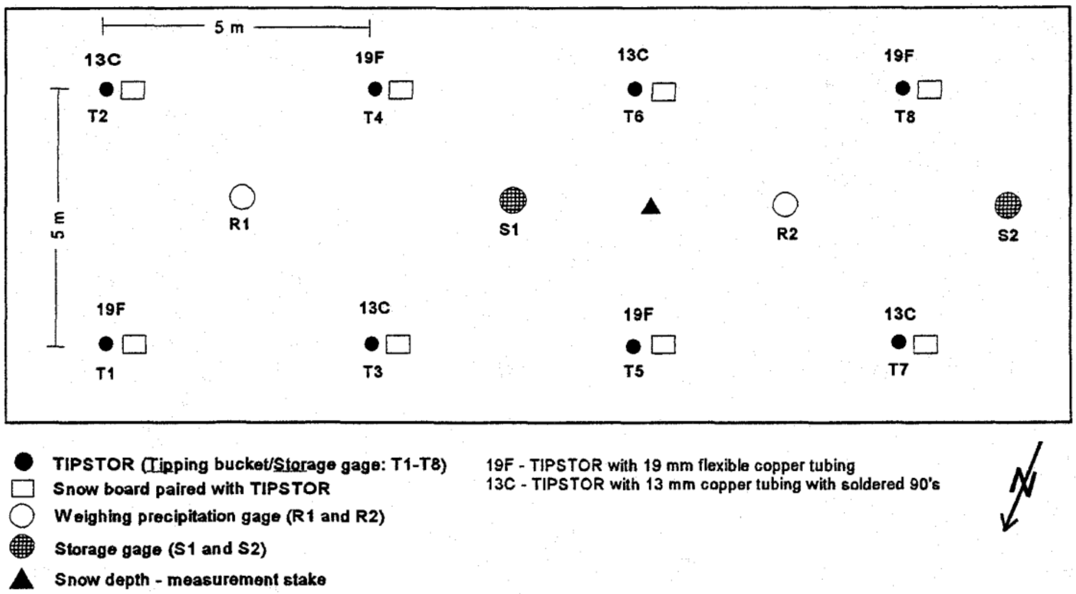

Figure 1. Diagram of study layout showing locations of the two TIPSTOR overflow pipe designs, eight snow boards, two storage gages, two weighing precipitation gages, and snow depth stake.

TIPSTOR Design

The modified storage gage for the TIPSTOR was constructed from PVC irrigation pipe (100 PSI) 150 cm long, 6 mm thick, and 194 mm inside diameter (Figure 2). The top edge of the pipe was beveled on a 45° angle to the outside so the sharp edge was on the inside of the pipe. A hole was drilled in the center of a 6 mm thick, high-pressure end-cap (125 lb) and threaded to accept a 13 mm fitting (Figure 2). A gooseneck-shaped overflow pipe was attached to the close nipple.

Two designs were used for the overflow pipe (flexible copper and copper tubing), and two methods were used to attach them to fittings through the end-caps (pipe reducer fitting and pipe to plastic fitting). A 19 mm diameter flexible copper tube (water supply line) was bent to form a gooseneck-shaped loop and the end fitting cut off. The inlet to the pipe was lower than the inside of the pipe near the top of the crook (Figure 2). The flexible tube was then attached to the close nipple with a 13 to 19 mm reducer.

The second design was constructed from 13 mm diameter copper tubing (not rigid copper pipe). Copper tubing was used instead of rigid copper pipe because of its malleable properties. A gooseneck shape was formed by soldering two 90° elbows and a short piece of copper tubing between the elbows (Figure 2). The copper tubing was attached to a 13 mm pipe-to-plastic fitting threaded through the end-cap with a 7 cm long (13 mm inside diameter) flexible plastic tubing. Hose clamps were used on each side of the union to seal the plastic tubing to the bottom of the copper tubing and to the pipe-to-plastic fitting.

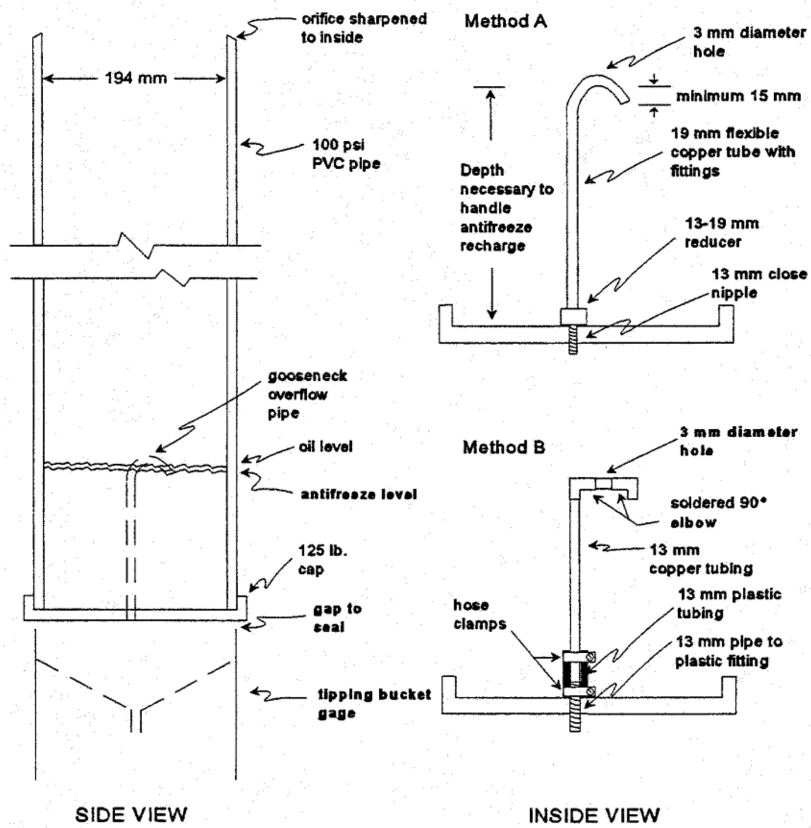

Figure 2. Diagram of TIPSTOR showing storage gage components, including overflow pipe test designs. (A - 19 mm flex tube; B - 13 mm copper tubing)

The total height of the overflow pipe, including fittings is determined by the amount of antifreeze needed for specific climatic areas (McGurk, 1992). The distance from the cap to the overflow crook was 25 cm for this study. The gooseneck design on the overflow pipe prevents the loss of transformer oil through the overflow pipe but allows overflow of the mixed antifreeze and precipitation solution. A 3 mm diameter hole was drilled or cut with a hacksaw at the highest part of the crook to prevent siphoning during precipitation events.

The end-cap with the overflow pipe was then glued to the bottom of the storage gage pipe. The completed storage gage was mounted on the tipping bucket and duct tape used to seal the small gap between the two TIPSTOR components. Three steel fence posts were used to support and vertically align both TIPSTOR components.

One-half of the antifreeze solution (50% Propylene Glycol and 50% Ethanol) was poured into the TIPSTOR and then the transformer oil (450 ml for a 15 mm depth) was added. The remaining antifreeze was added until it flowed through the overflow pipe and the tipping bucket responded. The specific gravity was 0.94 for the antifreeze solution.

<u>Measurements</u>

The tipping bucket component of each TIPSTOR was connected to an electronic recorder (OMNIDATA$_{TM}$[3] Easylogger). The storage gage mounted on the tipping bucket had an inside orifice diameter of 19.4 cm and an area of 295 cm^2 compared to the tipping bucket with an inside orifice diameter of 20.0 mm and an area of 314 cm^2. Thus, a factor of 1.064 was used to divide measurements from the tipping buckets since each tip on the tipping bucket represents 1.064 times the actual precipitation increment. ~~The tipping bucket measurements were also adjusted for specific gravity of the antifreeze solution (1.064 ÷ 0.94 or 1.132 times each tip)~~.

One snow sample was taken from each of the eight snow boards immediately following a snow event. Snow samples were collected with a 101 mm diameter sharpened clear plastic tube (area = 80 sq. cm) with attached depth scale. Snow depth was measured to the nearest millimeter and recorded. A 127 mm x 178 mm thin aluminum plate was inserted between the snow tube and snow board to keep the snow sample from falling out of the sampling tube. The snow was placed in containers of known tare weights in grams. The containers were weighted on an electronic balance scale to the nearest gram; weights were recorded and snow weight calculated by subtracting the tare weight from the filled weight of the container. The weight of the snow sample was multiplied by 0.1253 to convert snow weight to snow water equivalent (SWE) to the nearest 0.1 mm. Snow density for each sample was calculated by dividing the SWE by the sample depth. The average depth, SWE, and density were computed for each snow event. Snow boards were cleared of snow after each measurement and replaced on the snow surface. Rain increments from the weighing precipitation gages were added to snow board measurements to account for total site precipitation.

The fluid level in the external manometer on the two storage gages was recorded to the nearest millimeter and multiplied by 0.94 to correct for the specific gravity of the antifreeze (McGurk, 1992). Charts for the two weighing precipitation gages were changed weekly and precipitation increments were measured and recorded. Daily and hourly storm increments were measured in inches on charts, converted to the nearest 0.25 mm, and recorded along with associated dates and times. The weighing precipitation gages were calibrated before the test and had less than 1 percent error between actual and recorded weight.

Tests started on January 4, 1996 and continued through early April 1996. Accumulated and individual storm precipitation was measured and compared among all gages. The storage gages and weighing precipitation gages were used to quantify the total precipitation occurring on site. Antifreeze and transformer oil were added to the weighing precipitation gages and storage gages at the start of the tests. Snow board measurements were used as the total precipitation from an individual snow event. Incremental precipitation from rain and mixed rain and snow events were recorded in the weighing precipitation gages and were added to snow board readings to adjust snow board readings to reflect total accumulation.

Temperatures varied from a low of -34 °C to a high of 25°C during this study. Drifting snow caused high variability in snow board readings in 10 percent of the snow events. Two of the TIPSTOR gages (6 and 8) developed electronic problems and were eliminated from the comparisons.

RESULTS AND DISCUSSION

Nearly 65 percent of all precipitation events were snow and about 35 percent were mixed rain and snow events during this study. Snow provided 72 percent of the accumulated total precipitation while rain and rain mixed with snow events contributed the remainder.

The average accumulated precipitation determined from the TIPSTORs was 111, 98 and 94 percent of the average catch of the storage gages, adjusted snow board readings, and weighing precipitation gages, respectively (Table 1). The close total accumulation readings between the TIPSTORs and storage gages were expected since the gages are of similar design. Individual TIPSTOR values ranged from 75.3 mm to 88.2 mm total accumulated precipitation even though the gages were in close proximity. Variation in total accumulation of precipitation among gages at a site is common in weather instrument studies (Goodison and Metcalfe, 1982). It appears that TIPSTOR gages can provide a reasonable estimate of the total winter precipitation, since no precipitation gage accurately measures snow. Studies by Farnes (1980) found that annual catch in storage gages is about 11 percent less than the total precipitation catch calculated using both snow pillows and storage gage measurements.

The accumulated precipitation of the storage gages was 15 percent less than the TIPSTORs with the 13 mm overflow pipes (Table 2). The TIPSTORs with 19 mm overflow pipes recorded 7 percent more precipitation than the storage gages and 8 percent less than the 13 mm overflow design. Since all gages are of the same dimension, it is unclear why the precipitation differences occurred, unless they are related to the size of the overflow tube or among-gage variation in precipitation. Wind creates the greatest error in precipitation measurements and could account for some of the variability between gages on this study (Helliwell and Green, 1974; Wilson, 1954)

Table 1. Accumulated precipitation measured by individual TIPSTORs weighing and storage gage and snow boards plus rain increments for Bozeman test site January 4 - April 8, 1996. Snow board values are adjusted to include rain events.

TIPSTOR	Precip.	Snow board	Precip.	Storage gage	Precip.	Weighing gage	Precip.
	mm		mm		mm		mm
TIP1	78.7	SB1	85.6	ST1	79.9	R1	94.3
TIP2	85.0	SB2	88.3	ST2	71.4	R2	84.3
TIP3	87.3	SB3	84.1	Avg	**75.7**	Avg	**89.3**
TIP4	75.3	SB4	84.3	SD	6.0	SD	7.1
TIP5	88.2	SB5	81.3				
TIP7	88.2	SB6	88.3				
		SB7	83.6				
		SB8	89.3				
Avg	**83.8**	Avg	**85.6**				
SD	5.5	SD	2.8				

Table 2. Accumulated precipitation measured by TIPSTORs with 19 and 13 mm overflow pipes and by storage gages for the period January 4 - April 8, 1996.

19 mm	13 mm	Storage gage
(mm)	(mm)	(mm)
78.7	85.0	79.9
75.3	87.3	71.4
88.2	88.2	
Avg. 80.7	Avg. 86.8	Avg. 75.7
SD 6.7	SD 1.7	SD 6.0
*+7	*+15	

* The percent difference from storage gage values.

Hourly TIPSTOR readings showed small increments of precipitation continuing to flow through the tipping buckets for up to four hours as the fluid level stabilized following the end of a snow or rain event. After four hours, the fluid level stabilized at the same elevation as the overflow pipe. An overflow lag continued for up to a few days during some snow events. The data and visual observations suggest that during snow events, snow accumulates on the top of the overflow pipe for a period of time before melting. Fluid in the TIPSTOR would not flow through the overflow pipe until melt occurred or until snow was incorporated into the antifreeze solution. It is possible that an internal snow cap was formed by build up of snow on the overflow pipe. The lag could also be the result of cold temperatures decreasing viscosity of the oil, thus causing snow to sit on top of the oil for a short time before assimilating into the antifreeze.

It appears that accumulated winter precipitation can be measured with reliable accuracy by using the economical TIPSTOR concept at existing remote weather stations that have a tipping bucket system for precipitation measurements. Accumulation adjustments should be made to TIPSTOR values to account for the 11 percent under measurement associated with storage gages (Farnes, 1980). The TIPSTOR system permits continuous measurement of precipitation and eliminates the need for regular site visits. Occasional site visits are still recommended to ensure that all components of the TIPSTOR are functioning properly. Total cost of TIPSTOR materials is $50-60, with an assembly time of 2-3 hours. Cost of the recharge, transformer oil, and tipping bucket was not included as it would be similar in cost to that required for an existing weather station with tipping bucket and storage gage.

The TIPSTOR does not appear to be accurate for hourly precipitation measurements because of the 4-hour lag in precipitation overflow. However, daily and total yearly precipitation measurements, which include lag periods, are comparable to those from other types of gages that use antifreeze solutions.

RECOMMENDATIONS

There was an 8 percent difference in precipitation catch between the 19 mm and 13 mm overflow pipe designs. It is recommended that the 13 mm copper tubing be used since it catches the largest amount of precipitation (Table 2). The 13 mm copper tubing is readily attached to the pipe-to-plastic fitting with plastic tubing and hose clamps. The copper tubing can be adjusted to the proper height for any given average annual precipitation amount. The smaller diameter overflow pipe reduces the exposed area above the fluid for snow to build up on which reduces the chance of internal capping.

The inlet pipe should be bent so that it lies along the edge of the south side of the storage container rather than in the center to minimize snow capping (Figure 3). Radiant heat from the sun will help melt any internal snow on the overflow pipe or in the gage. Painting the storage gage a dark color, such as brown or black, will also encourage radiant heating in the gage. This design should reduce any significant internal snow capping.

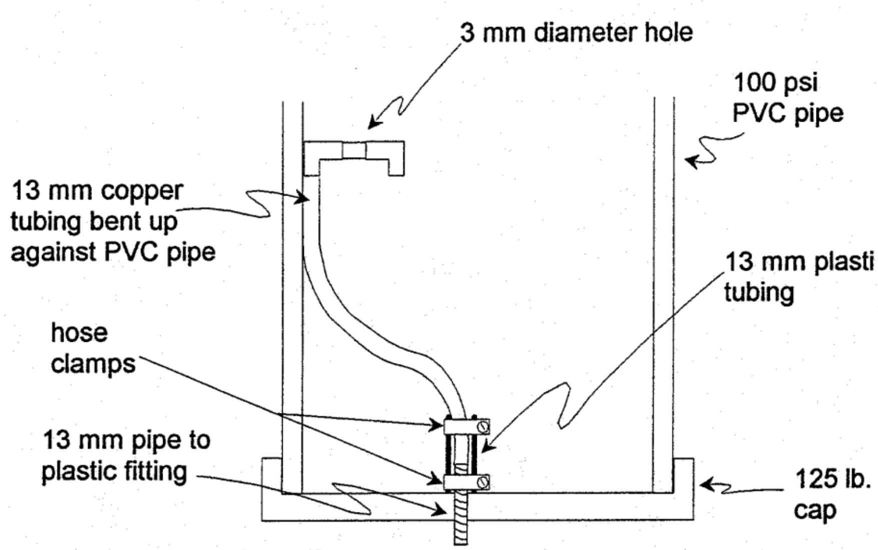

Figure 3. Diagram of recommended design for an overflow pipe on a TIPSTOR.

The TIPSTOR unit can remain in place during the summer months and be recharged in early fall (October 1) like other precipitation storage gages unless hourly data is needed. This would avoid dismantling the gage in the spring and reassembling it in the fall. The joint between the tipping bucket and storage gage should be sealed with a rubber sleeve and large hose clamps rather than duct tape. Rebar or other suitable rigid materials can be used to connect the storage gage to the tipping bucket when steel posts cannot be used. Wind shields for existing gages can be installed on the TIPSTOR orifice.

It is imperative that the orifice of the TIPSTOR be above maximum snow depth for the area and the length of the TIPSTOR storage container and height of the inlet pipe be adequate to hold the recommended quantity of antifreeze solution (McGurk, 1992).

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