DESIGN AND INSTALLATION OF A TIPPING BUCKET SNOW LYSIMETER

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ABSTRACT: Snow lysimeters can be used to measure melt water movement in seasonal snowpacks. They are based on the same principles as soil lysimeters, in that they are designed to measure the movement of liquid water through a porous matrix. Lysimeters serve several useful research purposes with significant potential applied uses. They may be used to measure ripening processes within the snowpack, melt water production rates, and travel time though the snow pack. This information may also be useful operationally to avalanche forecasters and water managers. Periodic chemical sampling allows concentrations to be combined with volume to calculate mass flux and preferential elution of chemical species. Melt collectors may be placed at chosen heights within the snowpack, or may be placed at the snow/soil interface. The lysimeters described in this paper were placed at the bottom of the snowpack, on the soil surface. Although the design and installation of the lysimeter are relatively simple, we have learned a great deal about both the apparatus and process with more than a decade of experience. We describe the design and installation of a tested snowmelt lysimeter used in a variety of snowpack and climatic environments, including Fraser Experimental Forest near Fraser, Colorado, USA, and Boise State University's Bogus Basin Snow Study Site, near Boise, Idaho, USA.

KEYWORDS: snowmelt, melt water, wet snow

1. INTRODUCTION

Snow lysimeters can be used to measure melt water movement in seasonal snowpacks. They are based on the same principles as soil lysimeters, in that they are designed to measure the movement of liquid water (timing and volume) through a porous matrix. They may be used to measure ripening processes within the snowpack, melt water production rates, and travel time though the snow pack. By controlling the contributing area, lateral movement of melt water in the snowpack may be studied. This information may also be useful operationally to avalanche forecasters and water managers. Periodic chemical sampling allows concentrations to be combined with volume to calculate mass flux. Melt collectors may be placed at chosen heights within the snowpack, or may be placed at the snow/soil interface. The lysimeters described in this paper were placed at the bottom of the snowpack, on the ground surface. Although the design and installation of the lysimeter is relatively simple, we have learned a great deal about both the apparatus and the application. We have written this paper with hopes of saving others the difficulty and expense of climbing the learning curve.

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2. BACKGROUND

Snow lysimeters have been used for many years in a variety of configurations. They may be simple (e.g. Jones et al. 1976), or complex in design (e.g. Greenan and Anderson, 1984). Many applications have a single collection pan, while some have a collection field or array of multiple pans (Kattelmann, 1989). Pan size is dependent on application and may range from less than a square meter to many square meters (Kattelmann, 1989).

3. DESIGN

The snow lysimeter consists of four primary components: 1) tipping bucket, 2) support frame, 3) collection pan, and 4) plumbing assembly. Data loggers and protective structures are also necessary elements of the system, but vary widely depending on application and installation and are, therefore, only briefly mentioned below.

3.1 *Tipping Bucket*

The tipping bucket mechanism consists of a double catchment bucket system held between two plates that allows continuous filling and dumping of melt water flow (Fig. 1). A funnel on top of the apparatus collects the flow and directs it into the empty side of the bucket. When one side of the bucket fills to a critical volume, the weight of the collected fluid causes the mechanism to tip away from the center of the funnel dumping its contents, and the other side of the bucket mechanism begins to fill. As the bucket tips, the magnetic reed switch temporarily closes. The process repeats while the event logger records the time stamp of the switch closure. Water from the spilling bucket simply falls to the enclosure floor and is routed out of the structure via a subterranean drain.

The buckets are of adequate size to handle maximum snowmelt rates in a variety of snow climates, but must also be sized for the collection pan. We have found that the bucket size we use (approximately 0.5 L) is well suited to most snowmelt application in maritime and continental snow regimes. The buckets can be adjusted to a desired tip volume between 250 and 600 cc. We adjust the assembly to have an approximate tipping volume of 500 cc. Initial calibration and adjustment should be made in an indoor laboratory before installing in the field. Carefully check the actual tipping volume once final installation is completed.

Raising or lowering the stop bar adjusts the tipping bucket volume. Adjusting the stop bar on the opposite side of the bucket in question controls the volume. Raise or lower the stop bar on side B to control the tipping volume on side A (Fig. 1). Loosen the nuts on the stop bar support rods and move to desired location. If the calibration volume is not correct, repeat adjustments and measure volume again.

It is very difficult to get an exact volume (e.g. 500 cc). For most applications, this does not matter as discharge will be integrated over time and the single-tip volume is irrelevant as volumes accumulate (liters/hour or liters/day). It is however, important to know the volume that is accumulated for each tip, and it is important to know how many tips occur.

Tipping volume can be measured for calibration by two simple methods. Both of these methods should allow one to determine the tipping volume with an error of plus or minus 5 cc. Take 5 to 10 measurements for each side and use the mean value. This calibration should be performed twice a year – once near the beginning of the melt season and again at the end of flow. If it is suspected that the assembly has moved for any reason, check the calibration. It is a good idea to mark both buckets with an A and B, or 1 and 2, to keep track of which is which.

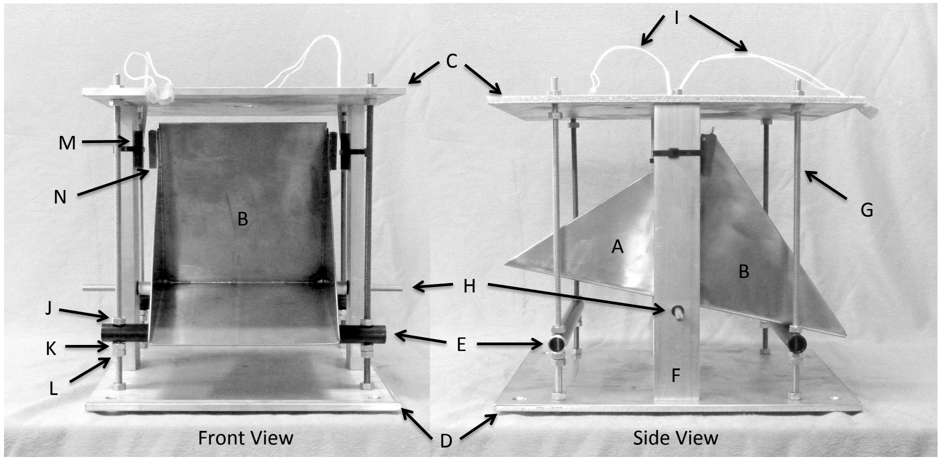
Method 1 – Volume
Make sure the assembly is level. Use a graduated cylinder to pour the bulk of the known volume into the bucket, and then add additional volume with a 50 cc or 60 cc syringe capable of accurately measuring small volumes. For example, to calibrate to a 500 cc tipping volume, fill the bucket with 450 cc of water from the graduated cylinder, and then slowly add another portion with the syringe, carefully noting the actual volume necessary to create the tip. Adjust the stop bar height if necessary to change the tipping volume.

Method 2 – Weight
Carefully collect the bucket discharge in a Ziploc bag when it tips and weigh the bag (remove the tare weight of the Ziploc). One cubic centimeter of water weighs one gram so calibration is straightforward.

3.2 *Support Frame*

The tipping bucket assembly needs to be mounted in a secure location without the possibility of movement, vibration, or loss of leveling. There are many different configurations and structures that can be used for mounting the tipping bucket assembly in place. Fig. 2 shows one possible design.

The most important aspect of the support frame is that it should be as stable as possible. Neither vertical nor horizontal displacement is acceptable as both may compromise measurements. Driving metal stakes or rods into the ground is a good method, coupled with a firmly attached structure on which to mount the bucket assembly. Attempt to drive stakes or rods to a point below the freezing depth in the soil. The structure can be a well-fabricated wooden or welded metal frame. The support frame should shed water. Note that the frame itself does not need to be level. Final leveling is done by fine-tuning the tipping bucket assembly using the mounting or leveling studs (detailed below).



A. Tipping bucket – side A
B. Tipping bucket – side B
C. Top plate
D. Bottom plate
E. Stop bars
F. Support arm
G. Support rods
H. Bucket axel
I. Wires to event logger
J. Top lock nut
K. Stop bar adjusting nut
L. Bottom locking nut
M. Reed switch
N. Magnet

Fig. 1: Tipping bucket assembly – front and side view, without funnel assembly.

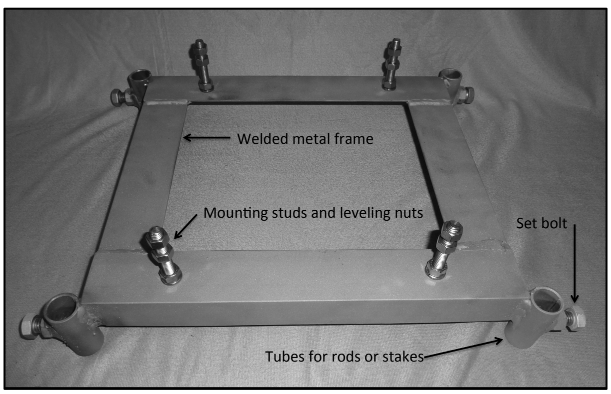


Fig. 2: Support frame for tipping bucket assembly.

One design is shown in Fig. 2. To mount this unit, place it on the flat ground surface, place the metal rods in the rod tubes, pound each one in as far as needed or possible. Slide the frame up the rods to the desired height and fix in place with the set bolts. Check for level and readjust if necessary. Mount the tipping bucket assembly on the support frame using mounting studs in the corners of the frame. Stainless steel bolts with fully threaded shanks work well for this purpose.

Keeping the unit level is probably one of the easiest and most important parts of collecting quality data. Bull's eye levels are inexpensive, accurate, and perfect for this application. Place a bubble level on the top close to one of the vertical support arms, as this is likely to be the most level portion of the unit. Minor deformation may occur in the top plate closer to the ends and corners so these areas may not be level. It is suggested that the level is checked at least twice a year to see if mounting settlement or any other disturbance causes problems in the orientation. Check and adjust if necessary. It is worth leaving a bubble level on each unit all the time as a quick, regular check can be performed with each visit to the site.

3.3 <u>Collection Pan</u>

Collection pans should be located in a place that represents the conditions of interest (slope, aspect, land cover, etc.), not in an altered environment that changes the local snowfall, accumulation, or energy balance at the snow or ground surface. Poor placement near fences, concrete walls, and even meteorological stations may compromise the snow lysimeter.

Collection pans for snow lysimeters may be made out of a variety of materials. Stainless steel works well, but is cost prohibitive for large pans. Plastic is another option, but sun leads to deterioration that compromises the pan over time and cost is still significant. Our preferred design has a hard frame, with a soft bottom. It consists of three 2” x 6” x 12’ boards on edge connected at the ends to form a triangle (Fig. 3). This gives a pan surface area of 5.7 m^2. Pan size and shape are dependent to some degree on the application. However, larger pan sizes integrate the surface melt response over a larger area and increase the likelihood of actual melt water catch at the base of the snowpack. Triangular shapes are simple, structurally robust, and guarantee delivery of melt water to a point where the collection bucket is located with little or no need for ground modification.

Fig. 3: Assembled frame for collection pan. Drain assembly, not yet installed and 4” elbow (upside down).

Experience has shown that small collection pans may not collect any melt water at all due to lateral movement of water in the snowpack. At the same time, an excessively large collection pan may overwhelm the tipping bucket measurement system, large pan areas are difficult to manage and are expensive. The 5.7 m^2 pan has proven to be a good size in the continental subalpine snowpack environment. Some researchers have used fields of small collection pans to answer questions of spatial variability of flow (e.g. Niwot Ridge LTER). In such multiple pan fields, adjacency of the collection pans increases the probability of catch, but reduces the sample area.

The triangle is oriented with one vertex at the downslope end so that the melt water collects at the lowest point. A bucket is buried in the ground below the downslope vertex and plumbed to the tipping bucket shed. Strong tarp and polyethylene plastic sheeting are laid in the collection pan area and over the edges. Excess is trimmed and the edges are stapled in place along the top of the frame. Dimensions can be adjusted to fit individual applications and needs. If the installation is located on flat ground, the ground surface can be contoured to funnel melt drainage to the collection bucket. Practically, it makes sense to make the low point at the vertex closest to the tipping bucket, but it could be located anywhere as long as all drainage is toward the collection bucket.

3.4 Plumbing

The collection bucket concentrates pan discharge into the transfer pipes that route melt water flow to the tipping bucket. We have used pickle barrels, paint buckets and architectural drainage collectors (Fig. 3). All have worked equally well. Pickle buckets are the least expensive, but they require more effort to couple to the transfer pipe. The architectural drain is the most expensive option, but it is the most straight forward to attach to the transfer pipe.

We have found that 4” diameter, schedule 40 pipe works best for a variety of reasons. It has adequate strength to resist puncture or crushing after burial. Large diameter pipe (4”) resists blockage due to freezing because even if some freezing occurs, it is not adequate to block all flow. Continued flow tends to melt out the residual ice from a freezing event. Small diameter pipes freeze more easily than larger diameters and are difficult to clear once blocked by ice. Small diameter pipes also tend to get blocked by pine needles, rodents, and other debris while large diameter pipe will likely clear all of these problems. Two heat tapes are buried with the transfer pipe. Wrap the tail end of tapes around the collection bucket and then along the length of the transfer pipe. Hold the tapes in place with duct tape before burial. Heat tape plug ends are extended into the tipping bucked shed where they can be accessed with line power from a generator when needed.

No direct connection is made between the transfer pipe and the tipping bucket. Rather, the end of the transfer pipe is connected to a 45^o elbow to direct the flow into the tipping bucket collection funnel. Leaving this connection open helps keep the transfer pipe from freezing since cold air drains easily into the warmer shed. The open connection also allows sending objects up the pipe to remove clogging should that occur. Pipes should be buried at least to a depth below the annual frost line if possible.

At the onset of melt the heat tape should be plugged in for a short period of time to ensure that residual ice in the pipes melts and runs out before snow melt accesses the collection pan. If line power is available, the heat tape can be put on a timer and run for 30 minutes or so, three times a day, during the cold part of the melt season. Experience will dictate the necessary amount of intervention to keep the system thawed and productive.

3.5 Data Loggers and Event Counters

Reed switches may be directly connected to event loggers or data loggers. Spade connectors make for easy installation and allow removal of the logger without the need for rewiring the entire unit. Two reed switches are attached to each assembly because the switches appear to be the most likely point of failure in the system. Two loggers are needed as well, but redundant data can be used for quality control and will help ensure no loss of data.

3.6 Protective Structure

Many different protective structures may be used to keep the tipping bucket system warm and working properly. They range from small temporary boxes to elaborate buried overseas shipping containers. We use plywood or chip board with a 2"x4" internal frame, and a tin-covered, sloped roof to shed snow. Insulating the shed with foam board will reduce freezing problems and make heating more efficient. We do not insulate our shacks because melt season is relatively warm and we heat the shacks with small electric area heaters hooked to line power. We have used propane with a small wick lamp in remote locations to keep the units from freezing.

Make sure that the shed will cover the entire hole. Leave room for a propane or electric heater on the shoulder of the hole so that the heater will not be flooded under any condition, including a clogged drain. Set the shed over the hole. If the slope is significant, pin the shed in place with rebar stakes. Hang the loggers on the shed wall where they will stay dry regardless of conditions in the shed. Hang the heat tape tails on the wall too so they are readily available when needed. Minor landscaping upslope from the shed may be necessary to route overland flow away from the shed and tipping bucket hole. Flush the system with a few full buckets of water poured into the collection pan to remove any dirt or debris from the system.

An adequate drain is one of the most important elements in the whole system. If the system does not drain faster than the incoming melt water, the bucket assembly will flood and cease to work. The drain should be at least 4" diameter pipe and should be screened with a coarse mesh at the intake so it does not clog.

4. INSTALLATION

Choose the site based on desired data collection parameters. Identify the collection pan location based on scientific needs and choose the tipping bucket location based on pragmatic considerations. Choose the location based on good drainage geometry from the collection pan, substrate considerations (rocks, etc.) and trees. Sloping locations make installation easier because gravity drives the plumbing system. Fig. 4 provides a schematic of the system.

Clear the collection pan location of debris, shrubs, rocks and other irregularities that will complicate flow or compromise the tarp. If there are sharp object that cannot be removed, cover them with inner tubes, carpet remnants, or some other protective material.

Lay out the collection pan sideboard in a triangular shape with the downhill vertex over the location chosen for the collection bucket (Fig. 3). Attach the three boards together using galvanized strapping or other bracket material. Remove the triangular frame and dig a hole of adequate depth and width to hold the collection bucket and provide space for the plumbing that connects the transfer pipe.

Dig a deep, wide hole for the tipping bucket apparatus. The hole should be deep enough to allow the transfer pipe to come into the hole at a height above the top of the tipping bucket. Remember that the transfer pipe will be buried deep to keep from freezing. Dig the collection bucket hole and tipping bucket holed before digging the trench for the transfer pipe. That way, if problems are encountered with either of these locations, they can be relocated so as not to have to re-dig the trench as well. Once the two critical holes are excavated, dig the transfer pipe trench between the collection pan and the tipping bucket location. Dig the drainage trench downslope from the tipping bucket.

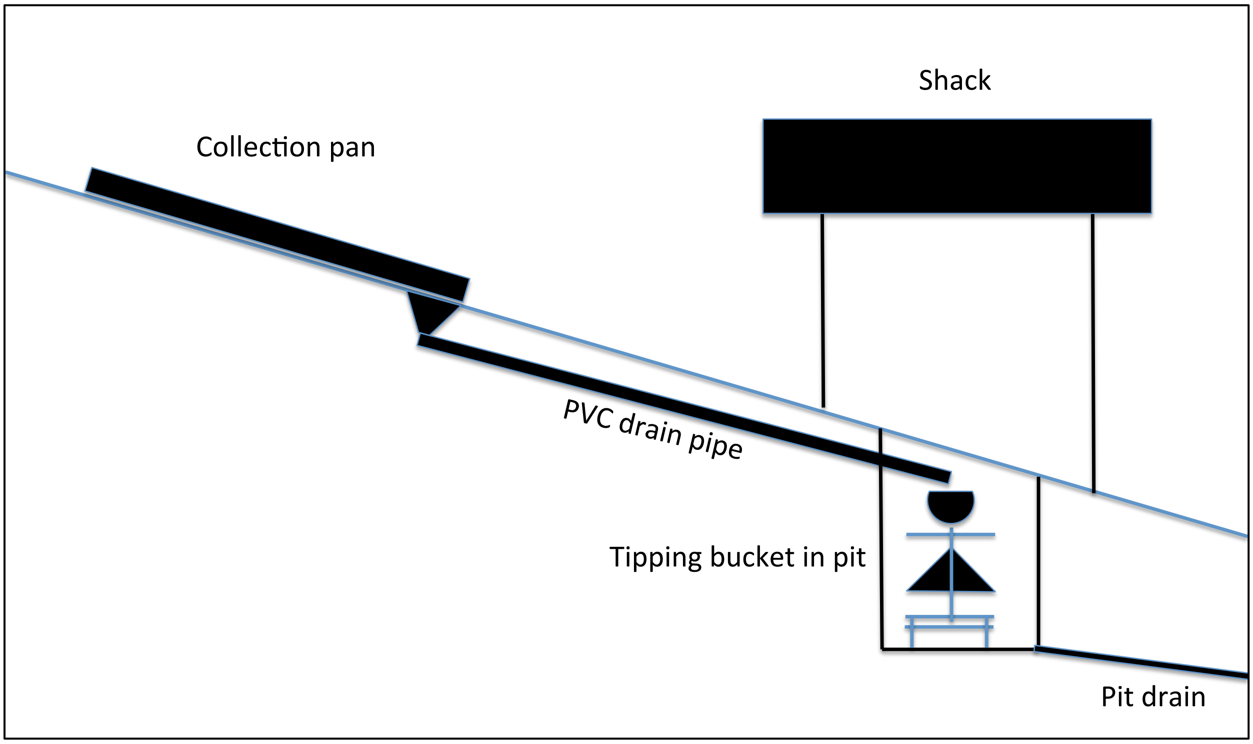


Fig.4. Basic layout of lysimeter system (not drawn to scale).

Lay the 4” pipe in the trenches and cut to correct lengths. Glue the 90° elbow and attach the collection bucket to the transfer pipe. Make sure that the pipe is well supported along the length of the trench. Carefully lift the pipe and bucket structure out of the trench. Tape the heat tape to the pipe and bucket and lower the plumbing system back into the ground. Carefully bury the plumbing by backfilling the excavated material.

Lay the triangular collection pan frame over the collection bucket, locating the bucket just inside the edge of the triangle at the downslope end of the lowest vertex. If the slope is significant, stake the frame in place with rebar or other metal stakes. Lay any padding or ground covering material in place. Place the first tarp over the collection pan, being sure to have adequate overlap on all sides. Stretch a layer of plastic sheeting over the entire collection area, followed by a second tarp. The upper tarp should be a light color (silver or tan) to emulate the surrounding undisturbed substrate albedo. A dark tarp will absorb solar radiation as the snow cover becomes shallow and will cause an unrealistically rapid final melt out on the pan surface. Push the material down flat along the interior edges of the collection frame and cut the excess away on the outside of the frame.

If the area is windy, leave extra material and cover it with dirt or other heavy material (Fig. 5). Staple the top edge and outside of the frame to hold the plastic and tarp in place. Use the staples liberally, but do not staple in the collection area. Use staples that are at least 3/8” long, preferably ½”, tapping in fully with a hammer, if necessary. Cut an X shape in the tarp over the collection bucket. Fold the flaps of the X into the bucket and leave as is. Place the screen over the bucket hole. The upper end of the system is now operationally ready.

Sun deteriorates the tarp and compromises the waterproof integrity of the collection pan through the summer months when there is no snow cover protecting the pan surface. This problem can be minimized by placing Masonite or some other opaque material over the pan when snow free. We choose to leave the pans uncovered as they also make excellent large-area rain gauges during the summer months and will record snowfall/snowmelt events in the fall as winter gets underway. To combat the deterioration problem, we periodically lay a new tarp over the collection pan and staple it in place as described for the original installation. We do not remove the old material as it provides added cushion and protection to the new tarp being installed.

Figure 5. Lower apex of collection pan. A new tarp has just been added and small logs are placed along the sides of the collector to help hold the tarp in place until snowfall. Expanded metal screen keeps rodents and debris out of the drain assembly.

Lay the tipping bucket support frame in place near the outflow end of the transfer pipe. Place the tipping bucket in the correct position on the frame. Check the location for height and location in relation to the collection pan drain pipe. Leave extra height because the support frame will be lifted off of the pit floor into final position. If more excavation is needed for correct positioning, do it now. Once the frame is located correctly, remove the tipping bucket apparatus and place the four legs in the frame. Rotate around the each of the four stakes, tapping all in bit by bit. When the stakes are relatively solid, use a larger hammer and pound the stakes in until they are firm and well below the frost line. Slide the frame up the four legs to the correct height and lock in place with the bolts. Check for level and adjust. Place the tipping bucket apparatus on the support frame and bolt in place. Check the level again and adjust as necessary. Cut the drain pipe to the correct length and glue the 45^{o} elbow in the correct position to direct flow into the tipping bucket funnel. Place the drain in the drain trench and backfill.

Finally, mark the vertices of the collection pan. Use T posts, PVC poles, or some other robust vertical marker that will not fall down in wind or snow cover. This will allows measurement of snow depth or snow water equivalence (SWE) around the lysimeter without disturbing the snow over the collection pan. This measurement is useful in determining the contributing area for flow to the lysimeter, which is seldom exactly the same as the pan area due to lateral movement of water within the snowpack. A brightly colored ribbon or cord between the poles will help remind people not to walk, ski or otherwise trespass across the collection pan hidden beneath the snow surface.

5. MAINTENANCE

The tipping bucket design presented here should require very little maintenance. Annual cleaning is a good idea, particularly if the collection pan supplying melt water collects and transfers dirt, vegetative matter, or other debris. A toothbrush and warm, soapy water are adequate. Do not use solvents. Make sure the bucket unit moves freely. Balance it in the center, then be sure that very little pressure will cause a tip in either direction. Make sure there is nothing sticky or adhesive accumulating between the bucket bottom and the stop bar.

The reed switch (Figure 1, M) is the most likely point of mechanical failure, although these too should last for many years. Two reed switches are mounted on each tipping bucket assembly to reduce the chances of data loss. Experience has shown that redundancy is a good idea due to occasional data logger failure, rather than tipping bucket or switch failure. If the switches need to be replaced, they can be found at local hardware stores or electrical shops. Cut the zip tie, peel the old switch off, clean the surface, and apply a new sticky back to mount the replacement. Make sure both the magnet and the reed portion of the switch are aligned properly. Replace the zip tie as an added precaution. Be sure that the switch is oriented with the wires pointing downward.

Freezing may destroy the bucket assembly. In particular, if significant water is allowed to freeze *in situ* in the buckets, the welded seam that seals the center wall divider into the bucket assembly may be compromised. Every attempt should be made to *not* allow water to freeze in the buckets.

6. DATA PROCESSING

Examine time series data plots carefully. Rapid melt rate with a 5 m^2 collection pan will fill a 500 cc bucket in approximately 40 seconds. If the data show double tips, (tips very close together in time), it is necessary to filter the data to get rid of the second of the two time stamps that represent false tips. A simple filtering algorithm that examines at the differences in the time stamps will allow proper removal of the bogus data. Set the threshold to 30 seconds or less, based on observations of maximum tip rates at the site. Any repeat tips (events) that occur under the threshold time are bogus and should removed. Fluctuation or vibration of the reed when the magnet passes by the reed switch causes this problem. We have not found an inexpensive switch that alleviates this problem completely. It is important to beware of the issue and correct for it.

7. CONCLUSIONS

This basic design has been used for 12 seasons at the Fraser Experimental Forest in Colorado and for several years at the Boise State University field study site in Idaho with great success. During that period, many of the small problems have been worked out and the improvements are incorporated in the design and reflected in this document. The design has proven to be robust under a variety of harsh conditions. Data have been used to track melt water movement through the snowpack, quantify melt production volume and rates, and quantify the timing of potential strength changes within the snowpack. Snow lysimeters are a valuable tool for basic research including melt water movement, snowpack energy balance, and snow chemistry. Snow lysimeters have a number of valuable forecasting applications including wet snow avalanches, runoff timing and volume, and ground water recharge.

REFERENCES

Greenan, H., and E. Anderson, 1984. A snowmelt lysimeter for research applications. *Proceedings of the 41st Eastern Snow Conference,* Washington, DC, 212-216.

Jones, M., P. Ffolliott, and D. Thorud , 1976: Lysimeter snowmelt in Arizona Ponderosa Pine Forests. Hydrology and Water Resources in Arizona and the Southwest, Arizona-Nevada Academy of Sciences, 177-179.

Kattelmann, R. 1989: Spatial variability of snow-pack outflow at a site, Sierra Nevada, U.S.A. *Annals of Glaciology*, 13, 124-128.