A SNOWMELT LYSIMETER FOR RESEARCH APPLICATIONS

Hugh J. Greenan[1] and Eric A. Anderson[2]

Hydrologic Research Laboratory
U.S. National Weather Service, NOAA
Silver Spring, MD 20910

ABSTRACT

Energy balance and water transmission studies of snow require accurate measurements of snow cover outflow. Direct measurement of the outflow is difficult because melt or rainwater moves horizontally as well as vertically as it passes through the snow. Two lysimeters, approximately 3 meters in diameter, were constructed at the NOAA Snow Research Station near Danville, Vermont, in 1972. The lysimeters use a heat ring to melt a slot that separates the snow above the collector from the surrounding snow cover. The resultant data have been extremely valuable for research studies though some practical problems have limited data collection during some years.

INTRODUCTION

Snowmelt studies, especially those involving the use of the energy budget approach, require accurate measurements of the primary variable that is being computed, i.e., snowmelt. Actual snowmelt volumes, occurring at the surface and also within the snow cover due to shortwave radiation penetration, are extremely difficult if not impossible to measure directly. Thus, the normal approach has been to measure the change in the water-equivalent of the snow or the amount of water leaving the snow cover.

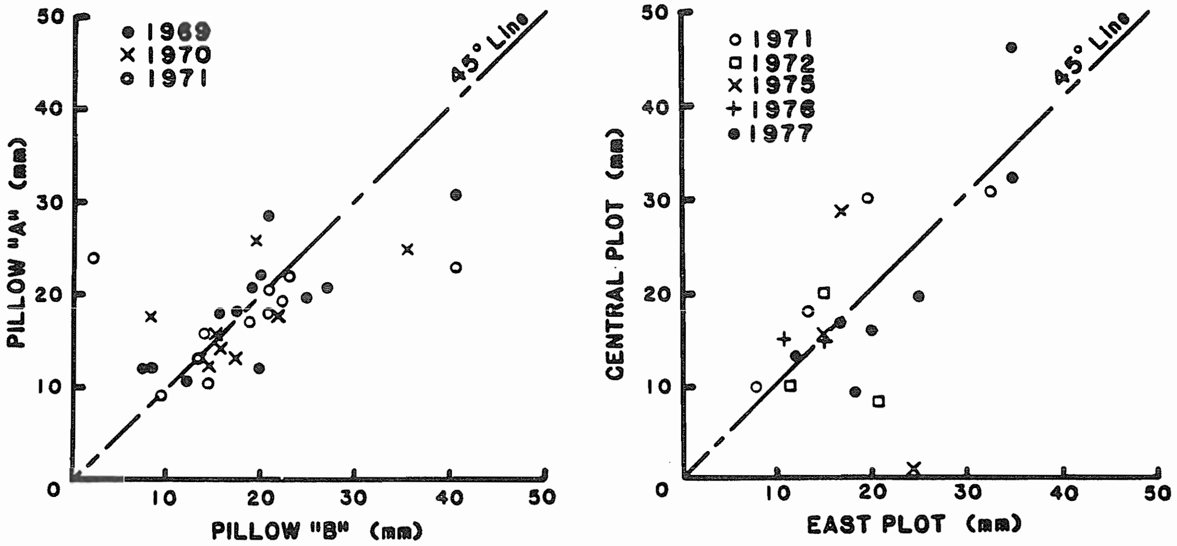
Comparisons of computed and measured water-equivalent over some number of days or weeks is adequate in many snowmelt studies to verify that the procedure being used to compute melt produces unbiased results. However, using the differences between subsequent measurements of total water-equivalent is not a reliable method when one is interested in studying snowmelt over time intervals of a day or less. Since the change in water-equivalent over short time intervals is relatively small in most cases when compared to the total water-equivalent of the snow cover, the total must be measured very accurately to get an accurate measurement of the difference. Whether any current instrumentation can measure the total water-equivalent accurately enough to get good difference measurements is unclear, but it is clear, as illustrated by the scatter shown in Figure 1, that measurements made by snow tubes and snow pillows aren't nearly accurate enough.

The use of snowmelt lysimeters to measure the outflow from the bottom of the snow cover is the most common method used when one is trying to obtain accurate measurements of short period changes in the water equivalent of the snow cover. The main problem in measuring snow cover outflow with lysimeters has been that the area of the outflow

---

[1] Meteorological Technician, Snow Research Station, Danville, Vermont
[2] Research Hydrologist, Hydrologic Research Laboratory

Proceedings of the Eastern Snow Conference, 41st Annual Meeting, Washington, D.C., June 7-8, 1984.



la: Adjacent snow pillows

Ib: Adjacent snow course plots

Figure 1. Comparison of daily change in water-equivalent from snow pillows and snow courses at the NOAA Snow Research Station.

measurement may not be the same as the area that the melt or rainwater is coming from. This is because water moves horizontally, as well as vertically, when passing through the snow, especially when ice layers are present.

There have been a number of approaches used in the design of snowmelt lysimeters, especially in the methods used to separate the water produced directly above the lysimeter from water moving through the surrounding snow. In some cases there was no attempt to separate the snow above the lysimeter from the surrounding snow cover (Cox, 1971; Obled, 1973). In the case of Obled's measurements it was noted that the total lysimeter outflow didn't agree with water balance computations and the relationships between the two were not the same from year to year or even linear within a given year. During the Snow Investigations (Corps of Engineers, 1956) a 56 m^2 lysimeter was used as part of the energy budget studies of snowmelt at the Central Sierra Snow Laboratory. After noting significant differences between lysimeter outflow and water balance computations during the previous year, a 5 cm slot was cut just inside the lysimeter walls prior to the 1954 measurements (Hildebrand and Pagenhart, 1953 and 1955). Excellent results were obtained during the 1954 melt period. Others have used artificial barriers, such as styrofoam boards (Pysklywec et al., 1968), polyethylene sheets (Haupt, 1969), and in the most monumental effort to-date, large aluminum cylinders which can be mechanically adjusted to accommodate varying snow depths (Thompson et al., 1975), to separate the lysimeters from the surrounding snow.

The NOAA-ARS Snow Research Station was established near Danville, Vermont, in 1967 to study snow metaphorism and melt (Johnson and Anderson, 1968; Anderson et al., 1977). In 1972, two lysimeters, approximately 3 meters in diameter, were constructed at the research station. The most unique feature of these lysimeters is the use of a heat ring to melt a narrow slot to separate the snow above the lysimeter from the surrounding snow cover. This paper describes the construction of these lysimeters and their operation, including problems encountered, as well as presents some results.

CONSTRUCTION

Two lysimeters were constructed so that intercomparisons could be made and so that if operating difficulties occurred with one lysimeter, data could still be obtained with the other. Figure 2 is a diagram of the measurement site at the snow research station showing the location of the lysimeters and the recording house where the outflow is measured. Figure 3 shows a construction diagram for the lysimeters. Commercial power is available at the snow station, which is essential for the high wattage heat tapes used to melt the slot around the lysimeters.

Uprights -- The initial construction step consisted of setting 4 uprights (4 cm diameter aluminum pipes) for each lysimeter to serve as guides for the heat ring. These vertical pipes which extend 2 m above ground and are imbedded 0.75 m into concrete, serve as guides for the heat ring during ascent and descent. The uprights also serve to define the circumference of the lysimeter. The tops were capped to prevent precipitation from filling the pipes. The upright vertical pipes are made of aluminum, partly to minimize suncupping of the snow around the pipe.

Heat Rings -- The heat rings were fabricated to conform to the inside circumference of a circle defined by the 4 uprights. Aluminum hollow tubing (1.5 cm OD X 0.4 cm wall, 3.6 m lengths) used for the ring was bent into shape to form a 3 m diameter circle with some overlap. In assembling the sections of tubing, the joints consist of 1 "Tee" and 2 couplings. The heat tapes (1600 watts total) were inserted through each side of the "Tee"

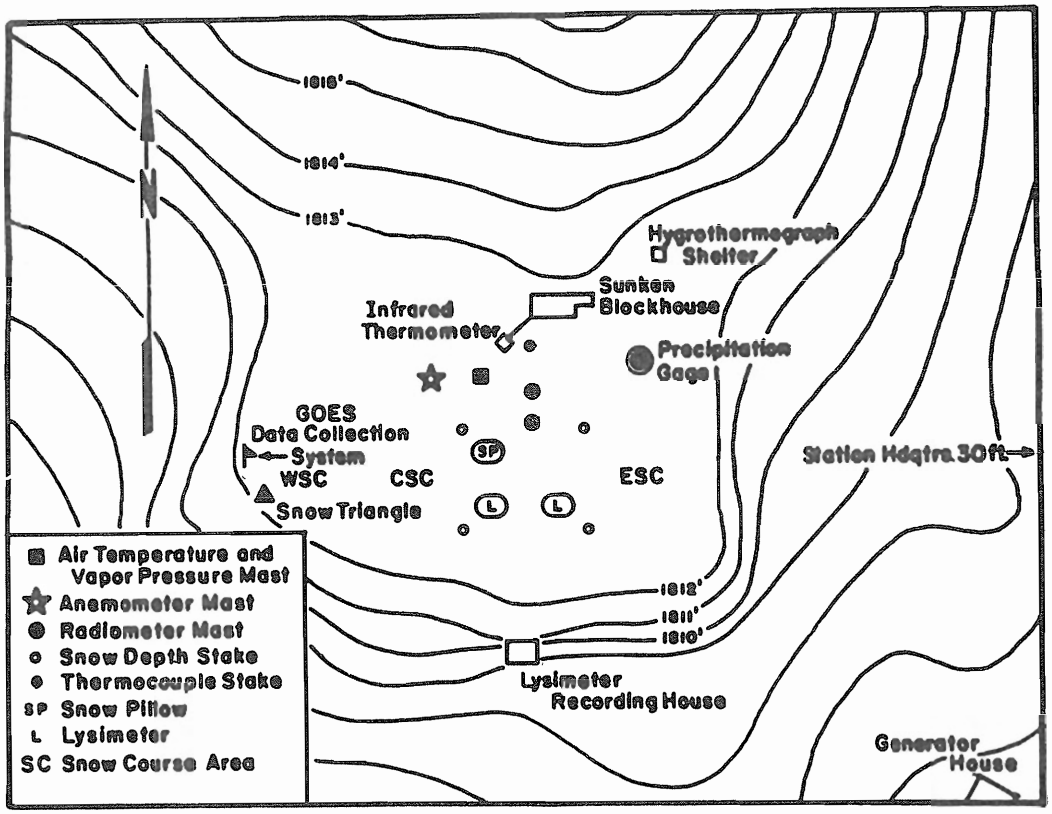


Figure 2. Site diagram of the NOAA Research Station.

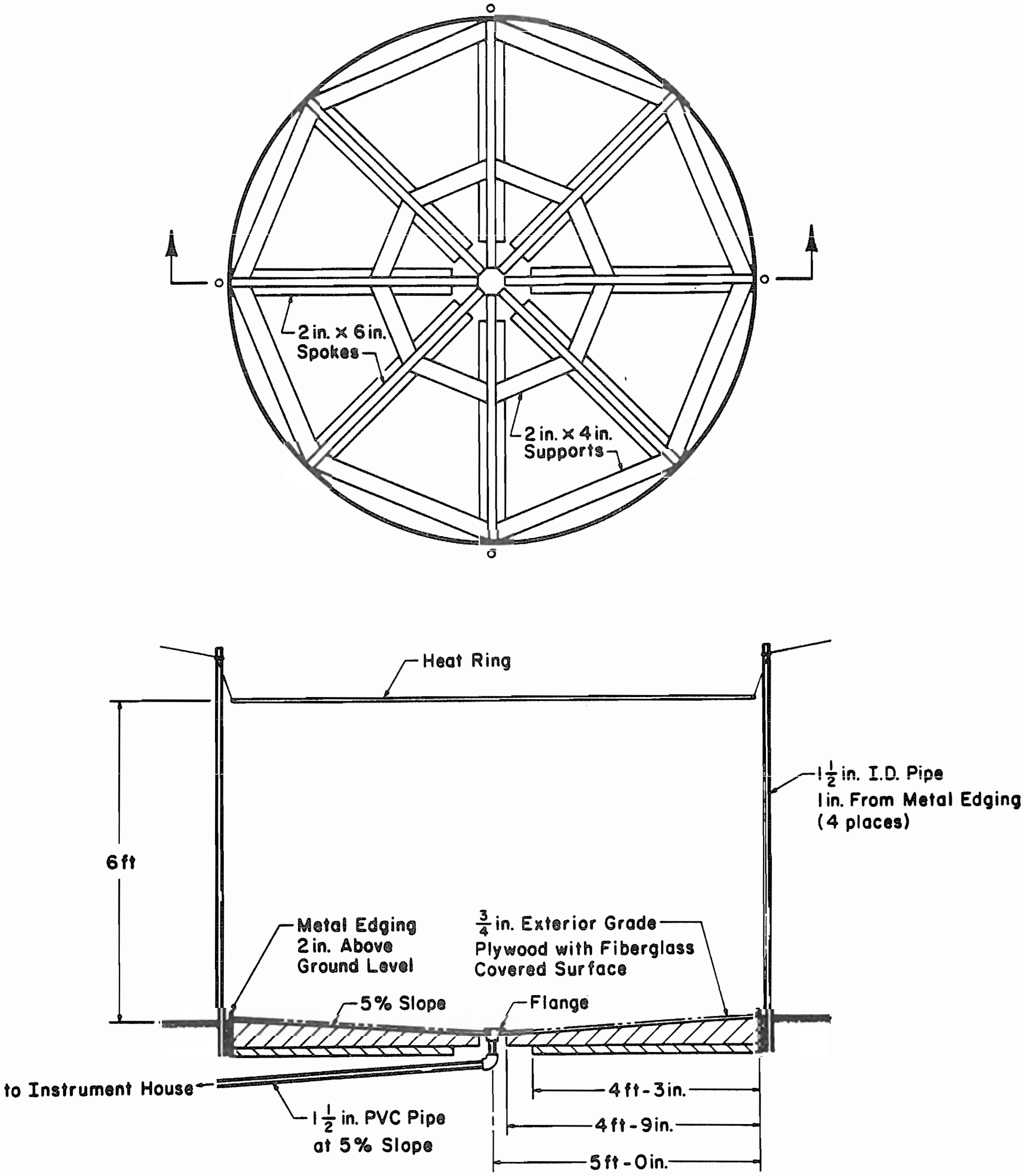


Figure 3. Construction diagram for the lysimeters.

and then snaked through both arcs of the hollow tubing. The terminus of the heat tapes were located at the end of each tube section. These ends were then potted with waterproof sealant and capped. The ends overlay each other approximately 0.75 m and are joined together by stainless steel hose clamps using small aluminum block spacers at the overlap; preventing metal-to-metal contact of the heat ring tubing to preclude forming a hot junction (heat spot). The 220VAC power cable access to the heat tape was potted and sealed to provide a good moisture seal.

Lysimeters -- The frames for the lysimeters were made with 2 X 6's, each piece being submersed in creosote for at least 24 hours. The framework could be likened to the spokes of a wheel. The frame was laid flat and sloped 2 X 6's were spiked to each frame member so that the lysimeter would have a 5% slope to the center. The inner and outer ends of the wheel spokes were braced by spiking 2 X 4's to the inside and outside frame members. Eight of these spoke members center on the hub which is a 4 inch (10 cm) standard floor flange. The lysimeter surface was fabricated by cutting 3/4 inch (2 cm) exterior grade plywood into wedge or pie shapes. These pieces were also individually treated with creosote and fastened to the wheel frame with caulking at each joint and nailed to the framing. Finishing was made by priming the surface, then applying two coats of white epoxy paint. This finish sufficed for two seasons, but had to be repainted each year thereafter. During the summer of 1978, a modification was made by applying a high grade formica surface with special adhesive. Completion of the lysimeter surface was accomplished by applying a metal rim around the perimeter. This rim was fabricated by cutting strips of aluminum roofing flashing (20 cm wide, 3.6 m lengths). The rim extends 5 cm above ground level to prevent lateral inflow at the soil surface.

Discharge Lines and Outflow Measurement -- On the underside of the floor flange a 1 1/2 inch (4 cm) PVC pipe was installed that runs about 13 m, at a 5% slope, to the lysimeter house. The discharge line was laid in a trench below the frost line. The trench was backfilled with sawdust to prevent heaving and/or freezing. The discharge line empties into a 1 ft^3 nalgene tank (28 liters) which serves as a reservoir. Attached to the nalgene tank is a specially built tipping bucket assembly to measure the snow cover outflow (each tip is about .001 inches or .025 mm). The reservoir is heated to prevent freezing. A heat tape is also installed in the discharge line so that if ice blocks the line, it can be reopened.

220VAC Power Access -- The 220VAC power access pole (5 cm diameter, 2 m high) has a dual all-weather receptacle box mounted about 1.5 m above ground level. For safety purposes the main disconnect is located in the block-house, with twin 50 ampere breakers. The power access cable runs from this pole to the heat ring "Tee" and is supported by a stainless steel aircraft cable.

Winch -- The winch used to raise and lower the heat ring consists of a winch pole (5 cm diameter, 2 m height) and a hand-operated winch drum. Fastened to the drum are 10 stainless steel aircraft cable lines, 5 going to each lysimeter. Four of these lines are routed to each heat ring through a series of "eye" bolts. The fifth line has the same routing and is attached to the power access cable and ties in at the heat ring "Tee". During heat application the winch is disengaged, lowering the heat ring in the snow surface. As heat is applied a slot about 1.7 cm wide is melted through the snow and the heat ring gradually descends downward by gravity through the snowpack to the ground snow interface. The heat ring works well. A sharp, clear slot melts evenly, except at the power cable connection and the end overlaps. These somewhat larger dimensioned parts of the apparatus can cause the heat ring to occasionally hang up on an ice layer within the snow cover. This is alleviated by raising the heat ring slightly and then lowering it again. Gravity then forces the heat ring past the obstruction. When the channel slot is melted all the way to the ground, the power is disconnected, the winch is engaged and the heat ring is mechanically raised back up through the snow to a position about 1.8 m above ground level.

OPERATION OF THE LYSIMETERS

The use of the heat rings to melt the slot around the lysimeters is kept to a minimum. The slot is only melted during the winter if a rain-on-snow event or melt period is anticipated. The heat ring is also used prior to the beginning of the main spring melt period to insure that the snow above the lysimeter is separated from the rest of the snow cover. The heat ring may also be used to reopen the slot if a significant snowfall occurs during the spring melt period, though some fresh snow covering the top of the slot is beneficial since it retards solar radiation from entering and enlarging the slot. As the melt season progresses, the slot becomes wider at the top. Typically the width of the slot is about 5 cm halfway through the melt season and becomes about 10 cm wide when only about 15 cm of snow depth remains.

The snow cover outflow, as measured by the special tipping bucket assembly, is recorded hourly. A signal is generated from a 12 VDC magnetic reed switch when each tip occurs. The signal pulses to a solid state decade counter relay system which keeps track of the number of tips each hour. The tipping bucket assembly is calibrated before and after each snow season. The calibration is determined by passing a known volume of water through the system at varied flow rates.

Operational problems, primarily caused by various types of icing conditions, have resulted in periods of missing or unreliable data during some winters. Some of the problems that have occurred are:

- Icing can occur at the drain orifice or in the discharge line, blocking the outflow. Icing can also occur in the reservoirs and/or the tipping assemblies. These conditions are alleviated by controlled heat application at the proper points. When the drain line is reopened, the backed up outflow is suddenly released. Sometimes the accumulated total can be measured. In other cases, the discharge causes the reservoirs to overflow, resulting in missing data periods.

- The magnetic reed switch can become defective due to icing. The switch can be replaced without affecting the calibration of the tipping assembly.

- An ice layer can form at the snow-soil interface. Normally this is not a problem because the 5 cm high metal lip around the lysimeters prevents overland flow from entering. However, in 1974 an ice layer exceeding 5 cm depth formed at the base of the snow cover allowing overland flow to enter the lysimeters. As much as 425 mm of water passed through the lysimeters in one day during March and April of 1974. No good data were obtained during that year.

Except for 1974, at least one of the lysimeters has provided good data each winter since they were installed. Since 1976 both lysimeters have provided data in all years except 1983 when only the west lysimeter was operating properly.

RESULTS

The lysimeter data have been used to verify the results of snow cover energy and mass balance models (Anderson, 1976) and in studies of water transmission through snow (Colbeck and Anderson, 1982). In this paper results are presented to show the accuracy of the lysimeter data.

Figure 4 shows a comparison between daily outflow measurements from the two lysimeters during periods when both were operating properly. As can be seen, the amount of scatter is much less than in Figure 1. Some of the most widely divergent points at the low end of the scale occurred at the beginning of the melt season when discharge starts from one lysimeter several hours before the other. The most widely divergent points at the upper end of the scale all occurred near the end of the 1982 melt season. The two points (48,59) and (42,38) occurred on successive days when multiple ice layers caused a heavy burst of rain late in the day to move through the lysimeters at different rates. The east lysimeter peaked just before midnight on April 17th while the west lysimeter didn't peak

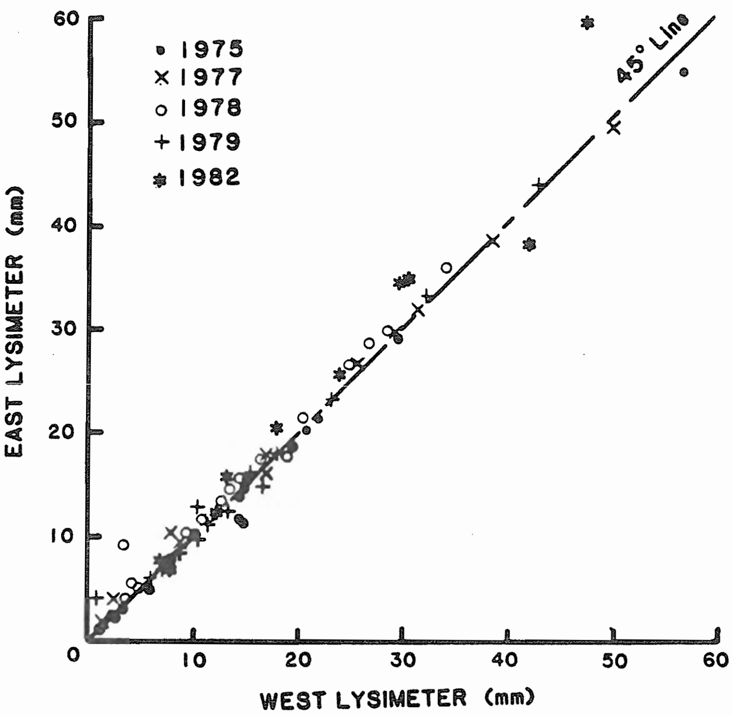


Figure 4. Comparison of daily outflows from adjacent lysimeters.

until 4 a.m. on the 18th. In addition, the west lysimeter appeared to be measuring about 10 percent low at the end of the 1982 melt season. This was not due to a calibration shift as the fall and spring calibrations were the same. The exact cause of these apparent low measurements is unknown.

Table 1 contains a water balance summary for each melt season when the lysimeters were functioning properly. Some of the reasons for non-zero residuals are:

- uncertainty in the initial water-equivalent estimates which are based on snow tube measurements (the standard error of the snow tube measurements is estimated to be about 10 to 15 mm)
- precipitation gage catch deficiencies or snowfall being blown off the somewhat elevated measurement site.
- evaporation or condensation during the melt season.
- uncertainty in the lysimeter outflow measurements (the apparent low measurements by the west lysimeter at the end of the 1982 melt season are reflected in the high negative residual).

Figure 5 shows a typical comparison of hourly outflow values from the two lysimeters during snowmelt and rain-on-snow periods. The response of both lysimeters is almost identical nearly all of the time.

Table 1. Water Balance Summary for lysimeters over the spring melt period (units are mm).

Year	Melt Period	Initial W.E.	Precip.	Available Water	Outflow East	Outflow West	Residual East	Residual West
1973	3/11 - 4/17	187	145	332	347		+15	
1975	4/11 - 5/5	236	35	271	275	277	+4	+6
1976	3/18 - 4/10	267	79	346		363		+17
1977	3/9 - 4/12	239	100	339	329	305	-10	-34
1978	4/10 - 5/7	273	47	320	336	309	+16	-11
1979	3/3 - 4/21	230	170	400		408		+8
1980	3/24 - 4/10	79	52	131	127	121	-4	-10
1981	3/24 - 3/31	55	21	76	80	75	+4	-1
1982	3/10 - 4/26	248	170	418	397	335	-21	-83
1983	3/16 - 4/27	114	185	299		317		+18
1984	3/16 - 4/18	203	116	319		263		-56

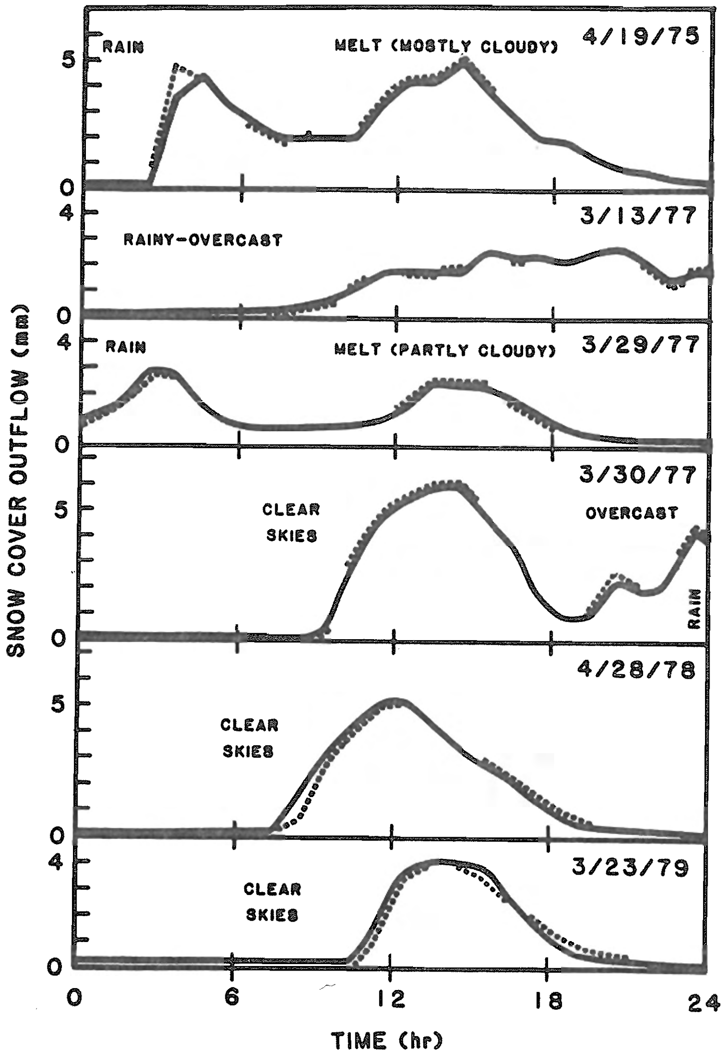


Figure 5. Comparison of hourly outflow values under various conditions as measured by the east (—) and west (----) lysimeters.

SUMMARY

The lysimeters have proven to be a very valuable addition to the snowmelt studies being conducted at the NOAA Snow Research Station. The lysimeters have provided high quality data on short period outflow volumes that were critically needed to verify point energy and mass balance models. The use of the heat ring has provided a means of ensuring that the contributing area is known with minimal interference to the heat transfer mechanisms. Operational problems, primarily due to icing, have resulted in some missing data periods, but experience gained in the early years of operation have kept the missing data periods to a minimum in the later years. The high wattage needed to melt a slot around lysimeters of this size and practical problems involved in operating the winch assembly restrict the use of this type of lysimeter to a staffed research facility.

ACKNOWLEDGMENTS

The original suggestion for the use of a heat ring was made by Max Kohler, then Director of the Hydrologic Research Laboratory. Dr. Charles Hoffeditz designed and fabricated the special tipping bucket assembly used to measure the snow cover outflow. The manuscript and figures were prepared by Mildred Larson, Stephen Ambrose and Lianne Iseley.

REFERENCES

Anderson, Eric A., 1976: "A Point Energy and Mass Balance Model of a Snow Cover," NOAA Technical Report NWS 19, U.S. Dept. of Commerce, Silver Spring, MD, 150 pp.

Anderson, Eric A., Whipkey, Ronald Z., Greenan, Hugh J., and Machell, Carl T., 1977: "NOAA-ARS Cooperative Snow Research Project -- Watershed Hydro-Climatology and Data for Water Years 1960-1974," U.S. Dept. of Commerce, Silver Spring, MD, 304 pp.

Colbeck, S.C., and Anderson, Eric A., 1982: "The Permeability of a Melting Snow Cover." Water Resources Research, Vol. 18, No. 4, pp. 904-908.

Corps of Engineers, 1956: Snow Hydrology, Summary Report of the Snow Investigations, North Pacific Division (available as PB-151660), Portland, OR, 437 pp.

Cox, L.M., 1971: "Field Performance of the Universal Surface Precipitation Gage," Proceedings of the Western Snow Conference, pp. 84-88.

Haupt, Harold F., 1969: "A Simple Snowmelt Lysimeter," Water Resources Research, Vol. 5, No. 3, pp. 714-718.

Hildebrand, C.E., and Pagenhart, T.H., 1953: "Lysimeter Studies of Clearweather Snowmelt at an Unforested Site," Snow Investigations, Research Note 17, Corps of Engineers, North Pacific Division, Portland, OR, 24 pp.

Hildebrand, C. E., and Pagenhart, T.H., 1955: "Lysimelt Studies of Snowmelt," Snow Investigations, Research Note 25, Corps of Engineers, North Pacific Division, Portland, OR, 41 pp.

Johnson, Martin L., and Anderson, Eric, 1968: "The Cooperative Snow Hydrology Project -- ESSA Weather Bureau and ARS Sleepers River Watershed," "Proceedings of the Eastern Snow Conference, pp. 13-23.

Obled, Charles, 1973: "Modeles Mathemathiques de la Fusion Nivale Etude des Risques D'Avalanches," Laboratories de Mecanique des Fluides, Institut National Polytechnique de Grenoble, Grenoble, France, 47 pp. (English translation: "Mathematical Models of Snowmelt Study of Avalanche Risks," Translated for NOAA, available on loan from Language Services Division, F43, National Marine Fisheries Service, NOAA, Washington, D.C., 20235, 73 pp.)

Pysklywec, D.W., Davar, K.S., and Bray, D.I., 1968: "Snowmelt at an Index Plot," Water Resources Research, Vol. 4, No. 5, pp. 937-946.

Thompson, K., DeVries, J., and Amorocho, J., 1975: "Snowmelt Lysimeter," Proceedings of the Western Snow Conference, pp. 35-40.