DESIGN, INSTRUMENTATION AND OPERATION OF A SNOWMELT RUNOFF PLOT

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INTRODUCTION

One of the environmental concerns of long range transport and deposition is the accumulation of pollution in the snowpack over the winter season and the sudden concentrated release of these pollutants into streams and lakes during melt events. This problem is of particular concern in Canada where vast areas of seasonal snow cover produce 30-40% of the annual runoff during the spring melt period. The potential acidic shock is increased because it has been found that 50 to 80 percent of the pollutants contained in the snowpack are released in the first 30 percent of the melt water (Johannessen and Henriksen, 1978). The resulting low pH levels in the streams and lakes are fatal to eggs and fry of some fish species. In Canada, a large number of lakes in Ontario and Québec no longer support sport fishing, but a direct link to the acidic shock problem has not yet been made.

Concern over this snowmelt acidic shock problem has led to the development of a climatological water budget/chemistry model (Wilson and Barrie, 1981) which was applied to eastern Canada to determine snowmelt characteristics, snowpack acidity and impact zones where acidic shock potential is high. Using temperature and precipitation data from climate stations and mean pollutant deposition data from the CANSAP and APN monitoring networks, the model provided a first estimate of the areas and periods of maximum acidic shock potential in eastern Canada.

The Hydrometeorology Division of the Atmospheric Environment Service, under the auspices of the AES Long Range Transport of Air Pollutants (LRTAP) Program, has initiated a two part project. The first is aimed at refining the snowmelt shock potential model for application to specific basins and providing time series of the snowmelt, snowpack and meltwater chemistry. The second objective is to design and implement a field study to collect the required meteorological information, as well as data on melt rate, snowpack and meltwater chemistry to verify the model results. This paper provides an overview of the design and instrumentation of the test site and of the approach used for assessing snowmelt and snowpack chemistry.

SNOWMELT PLOT

Kattelmann (1984) reports that various types of snowmelt lysimeters have been used to develop and evaluate procedures for estimating snowmelt volume and timing, evaporation, water transmission and storage, and the mass balance of snowpacks. Since outflow volume was the principal quantity of interest in this study, an enclosed ground-based lysimeter was proposed. Due to the inherent problems of constructing such a device on the Canadian Shield, a design combining the most practical features used by Price (1984) at Chalk River, Ontario and by Goodison (1977) at Cold Creek, Ontario, was employed.

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Generally, a snowmelt lysimeter consists of a collector, a flow-measuring device and a conduit linking the two. The collector consisted of an area approximately 3m by 3m enclosed by vertical walls of wolmanized wood about 50 cm in height and 2 cm thick. A barrier of 3 cm thick styrofoam was added to the inside of the walls to minimize absorption of solar radiation and subsequent reradiation to the snow. The area was lined with 4 mil plastic sheeting to prevent infiltration. The collector was situated on a 4° slope and drained naturally through a hole created on the down slope side of the plot and into a conduit of PVC drain pipe.

The one metre long conduit ran underground to the snowmelt plot recording well. The well consisted of a trench approximately .5m wide x 1m long x 1m deep into which a plywood box, with a lid for easy access, was placed. Two standard tipping buckets joined by a 13 mm pipe provided the measuring system for determining melt rates. All melt water emptied into the first tipping bucket, the primary measuring system; any excess runoff which occurred during extreme flows, or if the orifice of the primary receiver became plugged, flowed into the second bucket. A filter screen was used to keep dirt out of the receivers. The orifice of each receiver had a special nozzle inserted which controlled the maximum flow to about 1,000 tips per hour. This rate still resulted in a small undermeasurement by the tipping bucket system, as is characteristic of this type of measuring system. A correction curve which is dependent on the rate of runoff was developed.

An electric heat band was used to prevent water from freezing in either the tipping bucket orifices or in the one metre conduit. As the snow accumulated, covering and insulating the recording well, excess heat escaped through the conduit and out of the plot creating a "chimney" effect. This resulted in the formation of a cavity in the snowpack at the lower end of the plot and a substantial ice layer on the plastic on the ground. This method of heating will be re-designed before next season to minimize, and hopefully, eliminate this effect.

During heavy runoff events (e.g. rain on snow), water backed-up in the relatively shallow recording well, flooding the tipping bucket mechanisms. A submersible sump pump was installed in the well to alleviate this problem; however, this problem still resulted in some loss of data.

On November 23, 1983 the standard raingauge at the Dorset climate site recorded 5.1 mm of rain. There was no snow on the ground or the plot at the time. The large capacity (750 mm) alter-shielded Belfort recording precipitation gauge measured 5.8 mm of precipitation; the runoff plot, corrected for undercatch, recorded 5.2 mm.

METEOROLOGICAL SENSORS

Meteorological observations (see Table 1) were collected not only to provide input data for the model, but also to permit real-time monitoring and forecasting of melt events. To achieve this, a Campbell Scientific CR21 Synergetics data collection platform (DCP) was installed to provide an efficient, compact and easily programmed means of collecting and transmitting data via satellite. This system provided hourly meteorological, snowpack and melt runoff data which could be accessed via the National Environmental Satellite, Data and Information Service (NESDIS) system in Suitland, Maryland. In conjunction with this real-time system, a second CR21 data logger was used to log ancillary data, such as that from the snowpack temperature profile at 0, 10, 20, 40 and 60 cm above ground. All data were stored on site on cassette tapes.

The DCP and data logging equipment were housed in a Coleman Dura-Bond insulated container. Due to the inherent problems with cassette tape recorders at low temperatures, a Cata-Dyne propane mini-heater system was used to control the temperature in the instrument enclosure. An insulated exterior shelter (80 x 80 x 122 cm) was used to hold two forty pound propane tanks, pressure regulator, mini-heater, thermostat and the power supply. From here, a heat conductor pipe and thermostat sensing bulb ran into the instrument enclosure attached to the lower side of the exterior housing. The temperature inside the instrument enclosure could then be thermostatically controlled as heat was transferred from the heater to the conducting pipe. The heater operated from early November to mid-April on the two forty pound propane tanks with the thermostat set to 7°C. Even when the ambient air temperature was as low as -40°C, the system maintained the instrument enclosure temperature 15° to 20°C warmer. Few data were lost because of cassette tape malfunction related to low temperatures.

SNOW CHEMISTRY

Snowpack and melt water samples were taken at various times during the winter season. Chemical analysis of these samples was performed at the Ontario Ministry of Environment (OME) Dorset laboratory for the following elements: pH, alkalinity, conductivity, NO_3 and NH_4. As well, samples were analyzed for calcium, magnesium, sodium, potassium, fluoride, chloride, sulphate, silicates and dissolved organic carbon at the OME Toronto laboratory.

Meltwater samples were collected manually in 500 ml plastic sample jars as the water flowed out of the conduit, before entering the tipping bucket. Preliminary analysis of the meltwater showed pH values ranging from 3.53 to 5.35. The lowest pH was measured during the initial melt in February rising slowly as melt progressed in March.

Snowpack data collected included depth, density, temperature profile, structure and snow core chemistry (based on horizontal and vertical samples). Density samples were taken using the new ESC 30 snow sampler. The OME sampler (plastic tube, no cutter) was used to obtain snow samples for chemical analysis. Snow cores from both samplers were analysed to assess if a standard hydrological type snow sampler, like the ESC-30, could be used to obtain accurate snowpack chemistry samples. Results for pH are shown in Table 2. In most cases, the ESC 30 samples had a higher pH, although nitrates and sulphates are virtually identical for cores from both samplers. Procedures followed in obtaining all samples for chemical analysis are described in Ontario Ministry of Environment (1981).

Snowpack chemistry samples were generally obtained by taking several vertical samples, depending on the snow depth, and combining them in order to obtain enough water volume for analysis. Concern over point variability between individual samples as a result of small scale variations or sampling procedures resulted in this procedure being looked at more closely. In a test, the pH of ten individual samples were compared to that obtained by the bulk sample method. The bulk method produced a pH value of 4.24 whereas individual samples varied from 4.29 to 4.35.

To assist in the subsequent interpretation of the chemistry of the snowpack and melt water, snowpack structure was recorded at various times throughout the winter season. In general during the 1983-84 season, the snowpack was uniform with no significant ice layers or wind crusts being formed. Red dye used during a mid-February melt proved to be a useful indicator for tracing melt zones and the vertical and lateral movement of water within the snowpack.

SUMMARY

The first winter of operation at the Dorset site provided valuable information on procedures and techniques developed for use in this study, as well as initial data for testing the snowmelt model. The snowmelt plot generally worked well, but the heating cable produced more heat than was required to keep the tipping mechanisms and receptors free of ice, ultimately interfering with the natural melt on the plot. An alternative method of heating is recommended. The snowcover on the plot was representative of an open area. A similar installation in the bush would provide useful data on melt rates in the forested areas.

The DCP and data loggers worked well. Real-time access provided an effective means for scheduling field sampling and permitted initial data screening, processing and model testing. Automatic sampling of meltwater for chemical analysis does not seem possible at this time.

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REFERENCES

GOODISON, B.E., 1977: Snowfall and snow cover in southern Ontario: Principles and techniques of assessment, Ph.D. thesis. Univ. of Toronto, Toronto, Ont., Canada, 403pp.

JOHANNESSEN, M. and A. HENRIKSEN, 1978: Chemistry of Snow Meltwater: Changes in Concentration During Melting. Water Resour. Res., Vol. 14, No.4, 1978, 615-619.

KATTLELMANN, R.C., 1984: Snowmelt Lysimeters: Design and Use. Proc. Western Snow Conference, 52nd annual meeting, Sun Valley, Idaho, April 17-19, 1984, 68-79.

PRICE, A.G., 1984: Snowmelt Estimation in a Decidouss Forest. Univ. of Toronto, unpublished manuscript.

WILSON, E.E. and L.A. BARRIE, 1981: Climatological study of acidic snowmelt shock potential for eastern Canada. Proc. Eastern Snow Conference, 28th annual meeting, June 4-5, 1981, 23-32.

ONTARIO MINISTRY OF ENVIRONMENT, 1981: Outlines of Analytical Methods. Ont. Min. Envir., Laboratory Services Branch. 246p.

TABLE 1

Instrumentation - Snowmelt Acidic Shock Project

Parameter	Sensor	Sensor Output	Output Time Interval	Data Collection Mode Real-time (DCP)[1]	On-site (cassette tape)
Met. Radiation	CSIRO	KJ/m^2	hourly total	X	X
Solar Radiation	Kipp	KJ/m^2	hourly total		X
Wind Speed	Gill 3 cup	MS-1	hourly average	X	X
Air temp.	CS 201[2]	°C	hourly average	X	X
Humidity	CS 201	%	hourly average	X	X
Snow temp.(profile)	CS 101[3]	°C	sample every 3 hours		X
Snow temp.(plot)	CS 101	°C	hourly average	X	X
Precipitation	Belfort(750mm)	mm	hourly sample	X	X
Rainfall	Tipping Bucket (AES)	mm	hourly total	X	X
Runoff	Tipping Bucket (AES)	mm	hourly total	X (primary)	X (overflow)
Shelter temp.	CS 101	°C	average every 3 hours	X	X
Battery voltage	CR 21[4]	Volts	sample every 3 hours	X	X

1. **DCP - Data Collection Platform**

2. **CS201 - Campbell Scientific temperature/humidity sensor**
   (Phys - Chemical Research Model PCRC-11 RH sensor and a Fenwall UUT-51J1 thermistor)

3. **CS101 - Campbell Scientific temperature sensor** (Fenwall UUT-51J1 thermistor)

4. **CR21 - Campbell Scientific data logger** internal volt meter.

TABLE 2

Snowpack Data - Dorset, Ont. 1983-84

Date	Depth (cm)	Density (Kgm-3)	pH MOE Sampler	pH ESC Sampler	Profile
08/12/83	22.0	N/A			NO
12/12/83	29.0	200*	4.86	5.60	NO
15/12/83	26.0	250			NO
19/12/83	34.5	170			NO
03/01/84	55.5	250			NO
05/01/84	53.0	230*	4.45	4.84	YES
11/01/84	57.0	260			NO
19/01/84	69.0	200*	4.32	4.54	YES
23/01/84	62.0	260			NO
30/01/84	72.0	280			NO
06/02/84	70.0	N/A	4.24	4.29	YES
08/02/84	68.0	280			NO
11/02/84	64.0	270*			YES
13/02/84	56.5	320			NO
14/02/84	42.0	315*	N/A	4.59	NO
15/02/84	36.0	400			NO
20/02/84	25.0	450			NO
24/02/84	21.5	480			NO
29/02/84	27.5	380			NO
07/03/84	28.0	360	4.98	N/A	NO
14/03/84	31.0	400			NO
16/03/84	29.0	375*	5.16	5.52	NO
22/03/84	22.0	480			NO
28/03/84	11.5	430			NO
04/04/84	PATCHY SNOW - NO SAMPLE				

*SAMPLES TAKEN USING ESC30 SAMPLER
ALL OTHER SAMPLES TAKEN USING OME SAMPLER