Statewide Cooperative Snow Survey for Maine

M. LOISELLE

Maine Geological Survey
State House Station 22
Augusta, Maine 04333, U.S.A.

G. KEEZER

U.S. Geological Survey
26 Ganneston Drive
Augusta, Maine 04333, U.S.A.

Introduction

Estimates of water content in Maine's late winter and early spring snowpack provide valuable information to a number of Federal and State agencies and to private companies concerned with the management of Maine's surface water resources. This paper provides a brief history of the snow-survey program in Maine, describes the present statewide cooperative program, and provides some examples of the use of a geographic information system (GIS) for the analysis of snowpack data.

Annual snow surveys through 1987

Estimates of the water content of the snow cover have been made at selected sites in Maine for more than 70 years. Information on snow depth and equivalent water content has been collected by a number of operators of hydroelectric power plants and by the U.S. Geological Survey (USGS) in cooperation with the Maine Public Utilities Commission. In 1941, the USGS began a systematic annual compilation of all independently collected snow survey data and the preparation of an annual map showing lines of equal water content on March 1.

In 1972, Hayes compiled a summary map of snowpack data in Maine based on these systematic compilations for the period 1941 through 1965 (Hayes, 1972). This publication remains the only statewide data on the average water content and average density of the snowpack. In addition, the map shows the average date of the maximum water content of the snow in Maine, and the publication discusses how average density and water content of the snowpack varies over time.

Budget cuts at the Federal and State levels in the 1970s and early 1980s resulted in a significant reduction in the scope of the snowpack data collected by the USGS. Snow cover was not measured at many sites in the southern and central sections of the State. Annual maps of water content were prepared as before, but with reduced coverage over large areas of the State. It is likely that reductions in the snow survey program would have continued but for the flood of April, 1987.

The combination of warm temperatures in March (which produced a "ripe" snowpack near or at capacity with respect to water content), the saturated condition of the soils, and an intense low-pressure system that generated near-record amounts of precipitation in Maine's central highlands produced major flooding on many of Maine's rivers (Fontaine, 1987; Fontaine and Maloney, 1987). Damage from the flooding was estimated to ex-

ceed $100 million (Hasbrouck, 1987), and 14 of Maine's 16 counties were declared Federal disaster areas (Federal Emergency Management Agency, 1987).

Present statewide cooperative snow survey

As a result of the April 1987 flooding, increased State and Federal funding was appropriated to upgrade the USGS streamflow-gaging network, expand the annual snow survey network to reestablish statewide coverage, and provide for efficient communication of the results of the snow survey to concerned agencies and private companies.

The present snow survey program (1990) involves international, Federal, and State agencies and private companies (fig.1). These agencies include the St. John River Basin Cooperative Snow Survey, the USGS, the National Weather Service, the Maine Geological Survey and Maine Forest Service, hydroelectric power companies, and paper companies. The private power companies and paper companies collect snow cover data primarily in the headwater regions of Androscoggin, Kennebec, and Penobscot Rivers, and in the Sebago Lake watershed. Data for the St. John River Basin comes from a variety of sources through the St. John River Basin Commission. Data for the remaining part of the State (southern and midcoastal sections, the central highlands, and eastern Maine) are collected by the USGS and by the Maine Geological Survey and Maine Forest Service (which are in the Maine Department of Conservation).

Approximately 217 snow courses have been established in Maine and in adjacent parts of New Hampshire, New Brunswick and Quebec by the agencies listed above. Many of the sites Maine and New Hampshire are the same as those monitored by the USGS and others prior to the 1970s. In addition, new courses have been established to fill in areas on Hayes' 1972 map which was based on limited data, and to replace courses that were lost because of development. Present (1990) staffing levels allow data to be collected for 60 percent or more of these sites on or about February 1, March 1, March 15, and every 2 weeks from mid-March until the snow cover is completely melted (usually late April).

The program is coordinated by the USGS state office in Augusta, where the data are assembled and interpreted. The February 1 and March 1 survey dates are used primarily to train new observers, test communication channels, and coordinate with National Weather Service research efforts. Data from the March 15 survey are used to compile a map of snow cover water content and estimate the "ripeness" (or density) of the snowpack.

The data (in the form of contour maps of equivalent water content in the snow cover) are used primarily to help forecast the potential for floods on Maine's major rivers, estimate inflow to storage reservoirs, and plan long-term flow management. The Maine River Flow Advisory Committee, consisting of Federal, State, and private officials, meets in mid-March to evaluate the current streamflow and reservoir-storage conditions in the major river basins. After reviewing the available information, the Committee issues a press release that summarizes current statewide hydrologic conditions and reminds public officials and citizens that flooding can occur at any time if significant rainfall occurs over a short period. This press release is used by State and local officials in their emergency-response and flood-mitigation planning efforts.

Geographic information system analysis of snow survey data

Rapidly changing weather conditions can alter the condition of the snowpack substantially in in a very short time. Thus, the rapid analysis of snowpack data can increase the usefulness of the snow survey in forecasting snowmelt runoff and river stages. Use of a surface modeling software package to analyze snow survey data quickly and consistently is currently being explored.

The software package being used is the Triangulated Irregular Network (TIN) module of Environmental Research Systems Institute Arc-Info geographic information system (GIS) software. (Note: The use of specific trade names does not constitute endorsement by the U.S. Geological Survey.) On the basis of geographic coordinates and equivalent water contents measured on or about March 15 at sites in Maine and at adjacent locations in New Hampshire, New Brunswick, and Quebec, the software package constructs a three-dimensional surface

model composed of irregular triangles. Each vertex of a triangle represents a snow course with a measurement; the elevation of the vertex above the base datum represents the measured equivalent water content. Within any triangle defined by three measurement sites, the equivalent water content is computed by linear interpolation between the measured values at the vertices. Without any modification, the TIN software can produce three-dimensional perspective views of the snowpack water content.

A contouring package produces a smoothed contour map of equivalent water content from the TIN surface model. Any contour interval for the map may be selected, but using too small an interval produces a map with numerous small closed contours that represent individual snow courses, making interpretation of the final map difficult. Given the disparate sources of data and estimated accuracy of the snowpack-density measurements (and, therefore, the equivalent water content), a contour interval of 2 inches of equivalent water was selected (fig. 2).

Without refinement, the TIN-generated contour map cannot include orographic/topographic effects that can be incorporated into a hand-contoured map. Hayes (1972) discusses the difficulty in estimating snowpack water content at high elevations from his map. In addition, the data used to construct the map must be carefully screened prior to entry to remove questionable values. A comparison of contour maps produced by hand contouring and by the TIN surface model shows substantially more generalization in the hand-contoured map because of an informal averaging process that occurred while the hand contoured map was being produced. In this respect, TIN-generated contour map will produce more consistent and objective maps than hand-contouring methods. Also, once the snow course locations have been initially digitized, a finished contour map can be produced in less than an hour after the data are obtained from observers.

Quantitative estimates of total snowpack water content

GIS tools also can be used to make quantitative estimates of water content within a drainage basin or subbasin (such as a drainage area above a storage reservoir). These calculations take advantage of the inherent capability of GIS software to compute the area of an enclosed polygon.

After constructing an equivalent water-content contour map, the outline of the drainage basin (or subasin) is digitized and transformed into the same coordinate system as the water-content contour map. This basin outline is then combined with the contour map by a "clipping" function provided with the Arc-Info software; the resulting map "clips" the isopachs of equivalent water content at the basin boundaries, forming closed polygons bounded by the drainage-basin boundaries. The area of each closed contour is multiplied by the equivalent water content represented by the contour and summed to give the volume of water in the snowpack in the basin. These calculated volumes are useful both in forecasting flood potential and in flow management and water-resources planning.

Calculations in the Penobscot River basin based on the traditional and TIN-generated contour maps of snowpack for mid-March 1990 yielded storage volumes of 100 billion cubic feet and 106 billion cubic feet of equivalent water respectively. The 6 percent difference between these volumes probably is not significant given the errors in measurement and uncertainties in contouring the data. These volumes correspond to a basinwide average water content equivalent to 5.2 inches of precipitation.

Summary

Major flooding on Maine's rivers in April, 1987, generated renewed interest in obtaining accurate late-winter and early spring estimates of snowpack water content and condition. The present Statewide snow survey is a cooperative effort between international, Federal, and State agencies and private companies, coordinated by the USGS. Annual maps of equivalent water content in the snowpack on March 15 are reviewed by the State's River Flow Advisory Committee and are used by a number of agencies for forecasting flood potential, estimating inflow to storage reservoirs, and planning long-term flow management.

GIS has significant potential in the quantitative analysis of snow-survey data. In addition to providing a tool for the rapid preparation of objective and consistent contour maps on the basis of measured water contents, GIS tools can also be used to make quantitative estimates of total water content in the snowpack within a drainage basin or subbasin.

References

Federal Emergency Management Agency, 1987, Interagency hazard mitigation report: Federal Emergency Management Agency, Region I Hazard Mitigation Team, FEMA-788-DR-Maine, 29 p.

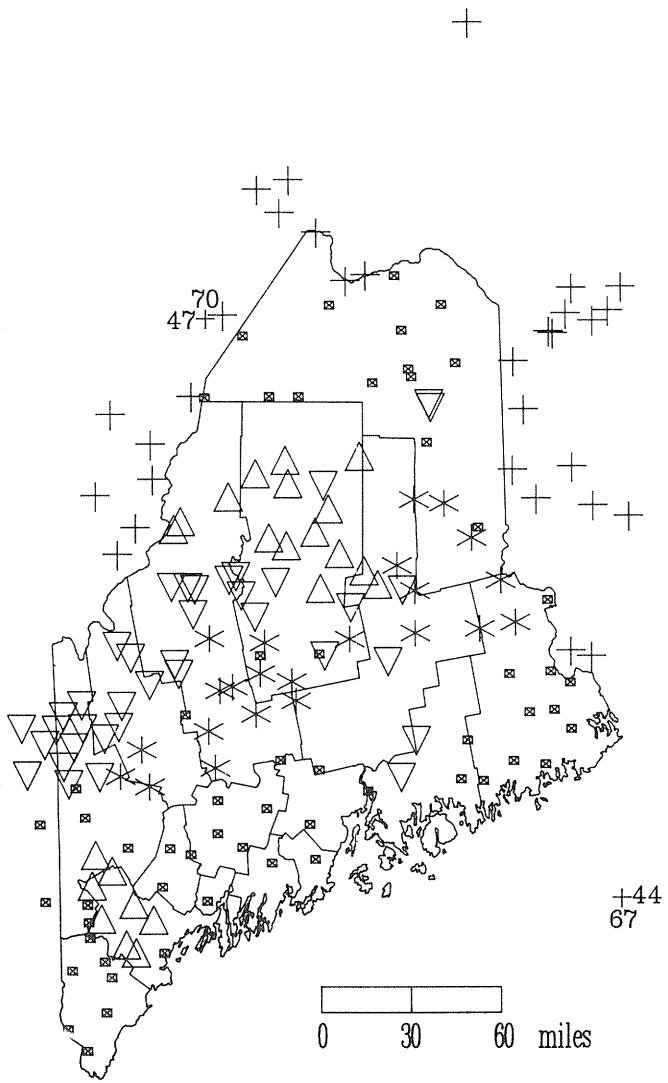
Fontaine, R.A., 1987, Flood of 1987 in Maine, Massachusetts, and New Hampshire: U.S. Geological Survey Open-File Report 87-460, 35 p.

Fontaine, R.A., and Maloney, T. J., 1987, Flood of April 1987 in Maine: U.S. Geological Survey, National Water Summary 1987 - Water Supply and Use: Selected Events: Water Supply Paper 2350, p. 41- 44

Hasbrouck, S., 1987, The flood of April 1987: University of Maine Land and Water Resources Center Natural Resources Highlight Special Report, 12 p.

Hayes, G.S., 1972, Average water content of snowpack in Maine: U.S. Geological Survey Hydrologic Investigations Atlas HA-452, 1 sheet, scale 1:1,000,000

Figure 1. Snowpack-measurement locations and source agencies



Explanation

- U.S. Geological Survey and National Weather Service
- St. John River Basin Cooperative Snow Survey (New Brunswick Electric Power Commission and Ministere de l'Environment du Quebec)
- Maine Geological Survey and Maine Forest Service
- Hydroelectric power companies (Union Water Power Company, Kennebec Water Power Company, Bangor Hydroelectric Company, and Maine Public Service Company)
- Paper companies (Great Northern Paper Company and S.D. Warren Company)

Figure 2. Comparison of hand-generated and TIN-generated snowpack contour maps. Contours based on measurements made on or about March 15, 1990.