COST-BENEFIT ANALYSIS OF AIRBORNE GAMMA RADIATION SNOW WATER EQUIVALENT DATA USED IN SNOWMELT FLOOD FORECASTING

by

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INTRODUCTION

From February 10 to 14, 1985, a significant snowfall contributed to a total accumulation of 6.5 to 9.0 cm of snow water equivalent over large portions of Indiana, Michigan, and Ohio. Soil moisture near the surface over the region was at (or above) field holding capacity. On February 15, 16, and 17, the National Weather Service made airborne snow water equivalent measurements over 92 flight lines covering 52,000 square km in northern Indiana, southern Michigan, and northwestern Ohio. On February 19, the Indianapolis WSFO issued a statement warning of the potential for severe flooding in northern Indiana. On February 25 at 1:15 PM, the Weather Service issued a crest forecast of 2.90 meters above flood stage for the Maumee River at Anthony Boulevard in Fort Wayne. Thirty-four hours and forty-eight minutes later (34 hrs : 48 min) on February 27 at 12:03 AM, the Maumee River at Anthony Boulevard in Fort Wayne crested at 2.91 meters above flood stage.

The paper briefly discusses (1) the technique used to make airborne snow water equivalent measurements using natural terrestrial gamma radiation, (2) the errors associated with airborne measurements made over agricultural areas, and (3) an estimate of the marginal and total costs to conduct the February 1985 airborne snow survey over Indiana, Michigan, and Ohio.

Additionally, an estimate of the 1982 flood costs and the subsequent flood protection plans implemented later are discussed. An estimate of the 1985 flood costs is given with and without the implementation of the 1982 flood protection plan and the 1985 airborne snow survey. The various costs associated with the airborne snow survey conducted over the three state region are summarized and contrasted with the benefits obtained as a result of the flood forecast for the city of Fort Wayne.

AIRBORNE GAMMA RADIATION SNOW MEASUREMENT TECHNIQUE

The Office of Hydrology of the National Weather Service has developed and maintains an operational Airborne Gamma Radiation Snow Survey Program serving the northern portion of the country from Maine to Montana (Peck, et al., 1980). The airborne snow water equivalent data are used by the National Weather Service River Forecast Centers and Weather Service Forecast Offices when issuing spring flood outlooks, water supply forecasts, and river and flood forecasts for the region. The technique uses the attenuation of natural terrestrial gamma radiation by the mass of the snow cover to make airborne snow water equivalent measurements with a Root Mean Square error of 0.8 cm snow water equivalent over agricultural environments and with an error of 2.0 cm over forested areas (Carroll, et al., 1985). There are currently over 1,000 flight lines in the operational network covering 16 states and 5 Canadian provinces. Each flight line is typically 16 km long and 300 m wide covering an area of approximately 5 sq km. Consequently, each airborne snow water equivalent measurement is a mean areal measure integrated over the 5 sq km area of the flight line.

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The physics and calibration of the airborne gamma radiation spectrometer were developed under contract by EG&G, Inc. in Las Vegas and have been described by Fritzsche (1982). A procedure to make airborne soil moisture measurements for the upper 20 cm was developed by Carroll (1981). Results of recent airborne snow water equivalent and soil moisture measurements made in agricultural environments have been reported by Jones and Carroll (1983) and Carroll et al. (1983). Details of the system hardware and radiation spectral data collection and analysis procedures have been described by Fritzsche (1982) and others and will not be discussed here.

Airborne snow water equivalent measurements are made using the relationship given in equation (1).

$$SWE = \frac{1}{A} \left[\ln \frac{Co}{C} - \ln \left(\frac{100 + 1.11\,M}{100 + 1.11\,Mo} \right) \right] \ g\ cm^{-2} \quad (1)$$

where:

C and Co = Uncollided terrestrial gamma count rates over snow and bare ground,

M and Mo = Percent soil moisture over snow and bare ground,

A = Radiation attenuation coefficient in water, cm2/g

Extraneous radiation is contributed to the spectra by the Compton tails associated with the peaks of higher energy, the cosmic radiation component, the airborne and fuel, the pilots, and the detection system itself. The raw radiation count rates for various photopeaks must be "stripped" of the extraneous sources to give the pure, uncollided radiation count rates (Fritzsche, 1982). Airmass between the airborne sensors and the terrestrial radiation source also attenuates the radiation signal. Consequently, air temperature, air pressure, and radar altitude are recorded continuously to calculate and compensate for the intervening airmass. After the appropriate photopeaks have been stripped of extraneous radiation, they are normalized to a standard airmass of 17 g/cm2.

Airborne Measurement Error and Simulation

The principal sources of error in airborne snow water equivalent calculation using the relationship given in equation (1) are: (1) errors in the normalized count rates (C,Co), (2) errors in the estimate of mean areal soil moisture over the flight line (M,Mo), and (3) errors in the radiation attenuation coefficient (A) derived from calibration data.

Vogel, et al. (1985) simulated the principle sources of error for airborne measurements made over forested watersheds with as much as 60 cm of snow water equivalent. The results indicate that airborne snow water equivalent measurements can be made in forest environments with 60 cm of water equivalent with an error of approximately 12 percent. The simulated results agree closely with the empirical errors derived from ground snow survey data collected in a forest environment with 48 cm of snow water equivalent (Carroll and Vose, 1984). In addition, the simulation technique can be used to assess the effect of the principle sources of error on airborne measurements made over agricultural environments with 2.0 to 15.0 cm of snow water equivalent. The results indicate that the error of the airborne snow measurement is, in part, a function of snow water equivalent and ranges from 4 to 10 percent. Again, the errors derived from the simulation agree closely with the errors derived using airborne and ground-based snow survey data collected over an agricultural environment (Carroll, et el., 1983). The simulation procedure and assumptions are described in detail by Vogel.

AIRBORNE SURVEY COSTS

Table 1 gives the assumptions and the relevant cost data required to calculate the cost of the 1985 Fort Wayne airborne snow survey. The costs are calculated on a per flight line and per flight line km basis. The marginal costs are those direct costs required to conduct the survey while the total costs include the marginal costs and the indirect costs.

Table 7

FLOOD DAMAGE SAVINGS BASED ON IMPROVEMENT TYPE

Improvement type	Case 1	Case 2	Case 3
18 Month Work Plan	80% $19.2	85% $20.4	90% $21.6
Flood ALERT system	10% $2.4	10% $2.4	7% $1.7
Airborne Snow Survey	10% $2.4	5% $1.2	3% $0.7

Note: $ in millions

The $7,700 cost of the February 1985 Fort Wayne airborne snow survey was substantially less than the projected flood damage prevented as a result of the early warnings and flood forecasts based on the airborne snow water equivalent data. Additionally, the cost savings attributed to the airborne snow water equivalent data are in keeping with the costs associated with an over or under estimate crest forecast generated using inaccurate or biased snow water equivalent data.

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REFERENCES

Carroll, T. R. (1981) Airborne soil moisture measurements using natural terrestrial gamma radiation. Soil Science. 132(5):358-366.

Carroll, T. R. and G. D. Vose (1984) Airborne snow water equivalent measurements over a forested environment using terrestrial gamma radiation. Proceedings of the Eastern Snow Conference, New Carrolton, Maryland, 6-8 June 1984. pp.19.

Carroll, T. R., J. E. Glynn, and B. E. Goodison (1983) A comparison of U.S. and Canadian airborne snow water equivalent measurements. Proceedings of the Western Snow Conference, Vancouver, Washington, 19-21 April 1983.

Fort Wayne - Allen County flood protection plan, April 1982. (prepared by and available through the city of Fort Wayne) pp. 166.

Fritzsche, A. E. (1982) The National Weather Service gamma snow system physics and calibration. Publication No. NWS-8201, EG&G, Inc., Las Vegas, NV, pp.37.

Jones, W. K. and T. R. Carroll (1983) Error analysis of airborne gamma radiation soil moisture measurements. Agricultural Meteorology 28: 19-30.

Peck, E. L., T. R. Carroll, and S. C. Van Demark (1980) Operational aerial snow surveying in the United States. Hydrological Sciences Bulletin 25(1):51-62.

Shipe, A. P., E. C. Yess, and R. D. Marshall (1985) Performance of flood ALERT system at Ft. Wayne, Indiana, February 1985. Proceedings of the Sixth Conference on Hydrometeorology, American Meteorological Society, Indianapolis, IN. 1985 October 29 - November 1. p.190-192.

U.S. Army Corps of Engineers (Detroit District) (1984) Fort Wayne and vicinity, Indiana flood control study - Reconnaissance Report, June 1984, pp. misc.

U.S. Department of Commerce - Weather Bureau. (1964) Frequency of maximum water equivalent of March snow cover in North Central United States. Technical Paper No. 50, Washington, D.C., pp. 24.