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A WATERSHED INFORMATION SYSTEM[1]

by

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INTRODUCTION

The simulation of snowmelt runoff from high mountain and wind-swept watersheds has presented the modeler with a number of serious problems which tend to limit the reliability of his results. Problems facing the modeler include (1) a lack of basic data to drive the model including precipitation inputs and solar radiation or air temperatures for snowmelt simulation, (2) a lack of information on the spatial and temporal variation of the climatic driving variables, the hydrologic operating parameters, and the resulting hydrologic processes, and (3) a general difficulty in taking advantage of late season data to modify or update the simulation run.

General approaches to these problems have included use of index snow courses or climatic stations to develop statistical relationships, development of lumped simulation models which assume uniform input and snowmelt processes over the watershed, and assumption of uniform temperature and precipitation change rates with elevation.

Imagery from Landsat and lower resolution environmental satellites have been used by others for updating snow cover simulation. The snow covered area within a watershed is first found from manual or machine aided interpretation of satellite imagery. Areal snow cover is then directly input to the simulation model (Dillard and Orwig, 1979) or used in estimating the water equivalent of snowpack (Shafer and Leaf, 1979).

This paper presents a watershed information system which includes a basic data framework of digital terrain overlays, a water balance simulation model which utilizes a spatial data format to drive the snowmelt simulation and a lateral flow model which routes snowmelt through the soil profile to the nearest channel.

In addition to a snowmelt hydrograph, the information system generates a series of snow cover and snowpack-water content maps. These can be compared to Landsat imagery or other snow cover data (snow course measurements, aerial photography) to provide an update capability to the simulation. The update capability has the potential for simulating snowmelt runoff where snow is relocated due to wind action.

SYSTEM DESCRIPTION

The watershed information system consists of a series of computer programs or modules designed to sequentially accomplish the various tasks and options of the system. These tasks include: (1) creation of digital terrain overlays from spatial watershed data; (2) automatic generation of parameter decks for model operation; (3) simulation of snow accumulation and melt; (4) simulation of spring snowmelt hydrographs; (5) classification of snow cover on Landsat imagery; and (6) simulation update using remotely sensed and/or conventional snow-cover information.

Creation of Watershed Overlays

Spatial simulation of watershed hydrology requires a basic framework of digital map data. This is obtained by digitizing existing maps or imagery. In this application maps are divided into square grid-cells 5.76 ha. in size. This corresponds to a 1x1 cm square on a USGS 1:24,000 quadrangle. Each grid cell is assigned an X-Y coordinate identification. Map data digitized includes topography (slope, aspect, elevation), vegetation

[1]Presented at the 48th Western Snow Conference, Laramie, Wyoming, 15-17 April 1980.

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(type, density) and soils (type). If soils characteristics are known additional overlays (field capacity, wilting point, soil moisture content) can be generated from the soils type overlay. Digital map data can be displayed in a gray-mapped form for visual interpretation (Figure 1).

Creation of Parameter Deck for Model Operation

Parameter decks for operating simulation models of snow processes (and hydrograph generation) are created automatically from watershed information in overlays. In order to reduce simulation time grid cells similar with respect to aspect, slope and vegetation type were lumped together to form larger hydrologic response units (HRU's). Soil water parameters within HRU's and elevation are calculated as the mean of individual grid-cell values (Table 1).

The information given in Table 1 is used in generating the parameter deck for operating a water balance model WATBAL. The computer program that generates the parameter deck has built-in calibration options for fast model calibration and options for the simulation of the effects of timber harvesting.

Spatial Simulation of Snow Processes

The snow process simulation model, WATBAL, is a modified version of a model developed by Leaf and Brink, 1973. WATBAL simulates watershed response to climatic input on a daily time step. Required driving variables are the daily maximum and minimum air temperatures and precipitation.

Linkage between WATBAL and other subprograms is established by a permanent file with the daily observed and simulated parameters for each HRU. All simulated parameters (snow-water equivalent, snow temperature and soil moisture deficit) can also be displayed in gray-mapped form for any date between April 1 and July 31 (Figures 2 and 3). Line printer generated gray maps are scaled to overlay a watershed base map at approximate scale of 1:75,000.

Hydrograph Generation from Spatially Distributed Input

WATBAL does not simulate stream hydrographs. No routing is performed and soil water in excess of field capacity is assumed to run off instantly.

In order to compare a simulated hydrograph with the observed hydrograph a lateral flow model was developed to route water from simulated snowmelt and input in the form of rain through soil and groundwater storages to the channel system. The model-based on variable source area concepts- simulates overland flow and baseflow contributions to the snowmelt hydrograph as well as the dominant lateral flow component. Lateral flow and deep seepage is simulated within variable length slope segments (compartments).

Classification of Snow in Landsat Imagery

A snow classifier for classifying the fractional snow-covered area within Landsat pixels was developed. Before classification, the Landsat imagery is preprocessed in order to eliminate image distortion, convert data to the base grid cell format and overlay data on north-oriented overlays with watershed information. Accurate image registration is ensured by automatic registration of the Landsat scene with a synthetic image of Landsat Band 5 calculated from topographic and vegetation information in watershed overlays, spectral characteristics of vegetation classes and solar position (Figure 4).

The snow classifier relies on change detection between a synthetic snow-free image and a real Landsat Band 5 image. Fractional snow cover is classified according to the radiance difference between the two images (Figures 5 and 6).

Since the synthetic image is created from models of topography and vegetation, the radiance difference is assumed due to snow cover only. Before final classification the radiance difference is normalized for the effects of topography, image acquisition data and moderate canopy density.

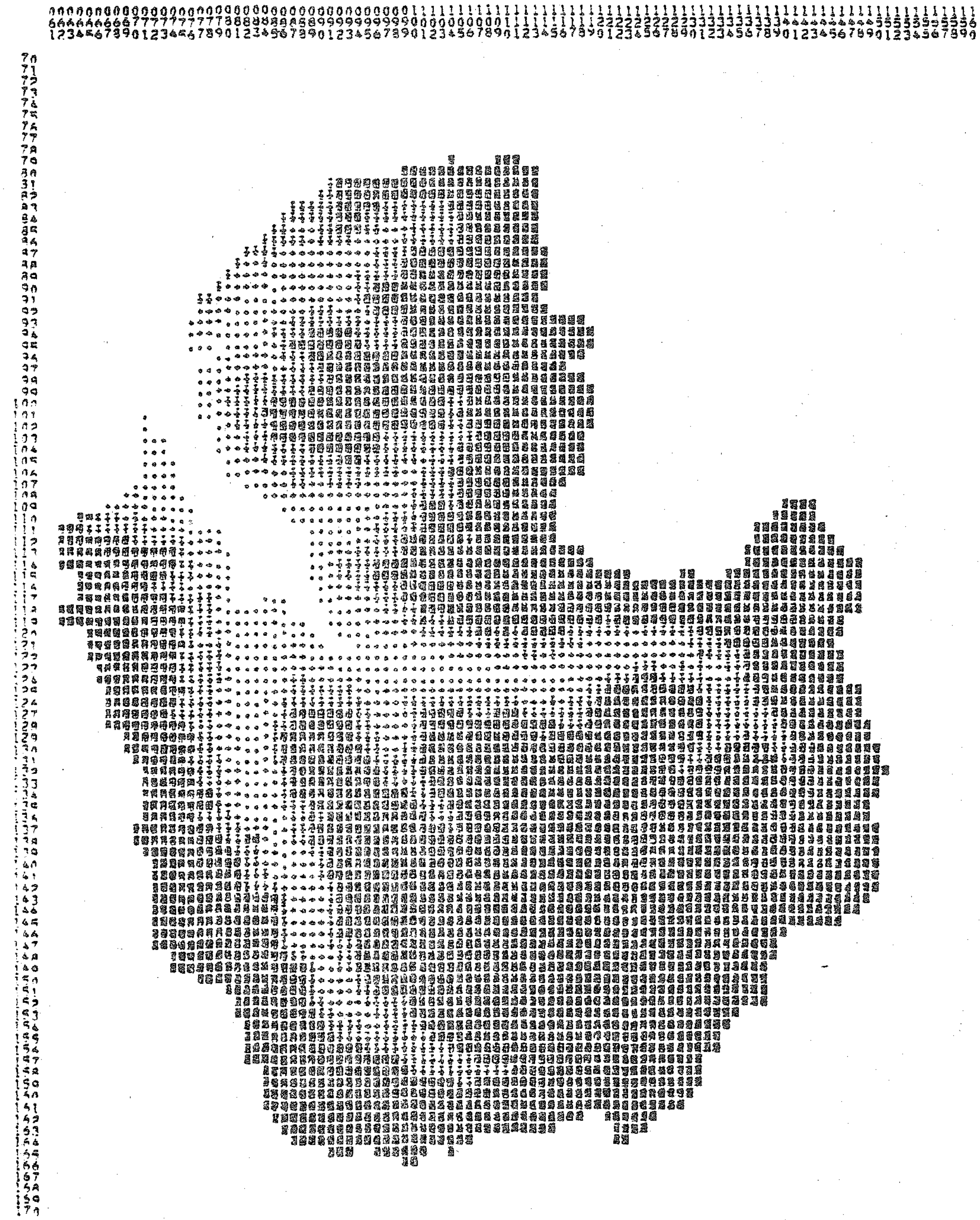

Figure 1. Gray Map Showing the Distribution of Elevations Within the Williams Fork Watershed (Range 8,500 to 12,500).

Table 1. Output from Program EXTRACT Showing Defined Hydrologic Response Units and Parameters Calculated for Units

Watershed Parameters for Watershed(s) 300
Summary for Elevation Zone 7500-13500 feet

Sub-Class	Aspect	Slope	Veg. Type	Veg. Dens.	Field Cap.	Soil Moist. Level	Wilt. Point	Fract. Area	Mean Elev.
011	0	1	1	0	4.6	0.0	1.5	.016	11571
014	0	1	4	75	4.6	0.0	1.5	.007	9516
015	0	1	5	39	5.1	0.0	1.5	.013	10742
021	0	2	1	0	4.6	0.0	1.5	.031	11429
024	0	2	4	75	4.6	0.0	1.5	.003	10787
025	0	2	5	38	5.1	0.0	1.6	.029	10841
031	0	3	1	0	4.6	0.0	1.5	.016	11389
035	0	3	5	40	5.1	0.0	1.6	.006	10857
041	0	4	1	0	4.6	0.0	1.5	.002	11140
111	1	1	1	0	4.6	0.0	1.5	.047	11500
114	1	1	4	75	4.6	0.0	1.5	.017	10310
115	1	1	5	56	5.3	0.0	1.7	.011	10923
121	1	2	1	0	4.6	0.0	1.5	.050	11242
124	1	2	4	73	4.6	0.0	1.5	.035	10231
125	1	2	5	54	5.3	0.0	1.7	.025	10718
131	1	3	1	0	4.6	0.0	1.5	.021	11356
134	1	3	4	64	4.6	0.0	1.5	.012	10167
135	1	3	5	60	5.3	0.0	1.7	.003	10220
141	1	4	1	0	4.6	0.0	1.5	.003	11330
144	1	4	4	75	4.6	0.0	1.5	.003	10065
211	2	1	1	0	4.6	0.0	1.5	.015	11519
214	2	1	4	73	4.6	0.0	1.5	.009	9963
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711	7	1	1	0	4.6	0.0	1.6	.012	11865
714	7	1	4	75	4.6	0.0	1.6	.007	9671
715	7	1	5	22	4.8	0.0	1.6	.008	10837
721	7	2	1	0	4.6	0.0	1.6	.036	11555
724	7	2	4	75	4.6	0.0	1.5	.005	10099
725	7	2	5	31	5.0	0.0	1.6	.016	10795
731	7	3	1	0	4.6	0.0	1.5	.028	11581
734	7	3	4	75	4.6	0.0	1.5	.004	10622
735	7	3	5	35	4.7	0.0	1.5	.010	10211
741	7	4	1	0	4.6	0.0	1.5	.007	11575
751	7	5	1	0	4.6	0.0	1.5	.001	11800

Total number of cells = 1216
Number of Hydrologic Subunits = 85
Sum of Fractional Areas = 1.000

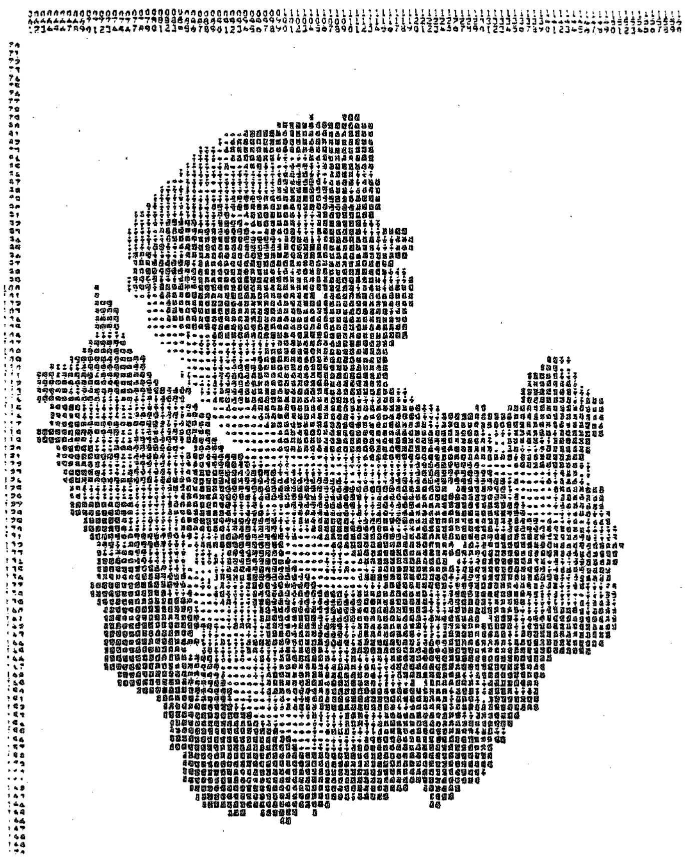

Figure 2. Simulated Snowpack Water Equivalent, Williams Fork Watershed, June 1, 1971. (Range from less than 0.1 to more than 21 inches.)

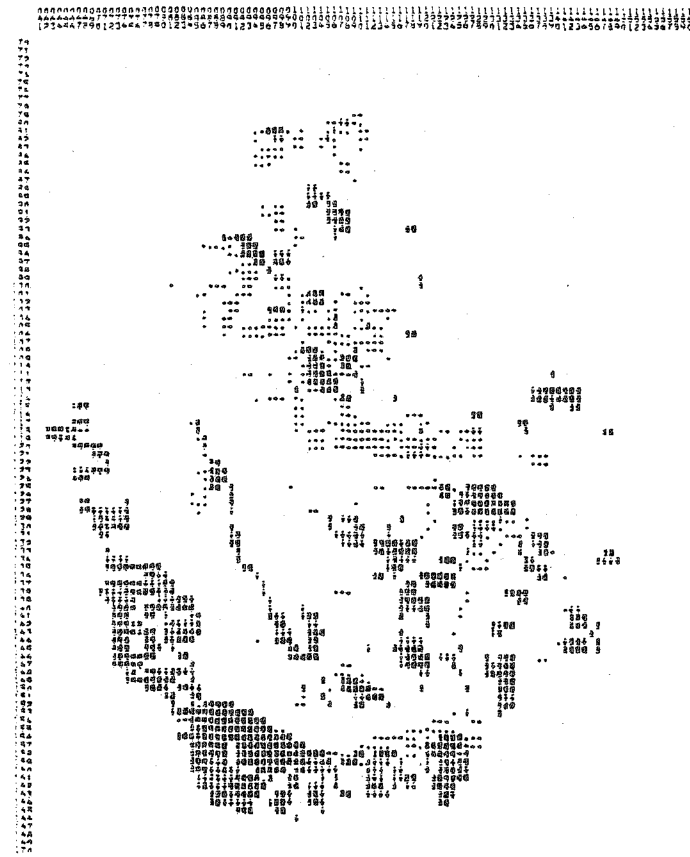

Figure 3. Simulated Snowpack Water Equivalent Williams Fork Watershed, July 1, 1971. (Range from less than 0.1 to more than 21 inches.)

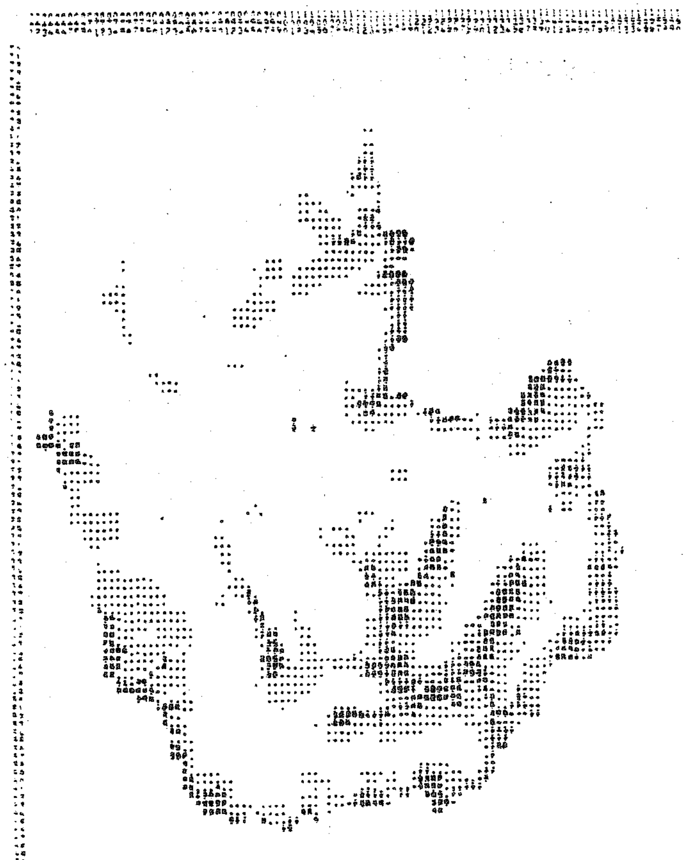

Figure 4. Synthetic Landsat Band 5 Radiance Calculated for July 15, 1976. (Eight classes ranging from 0 to 320.)

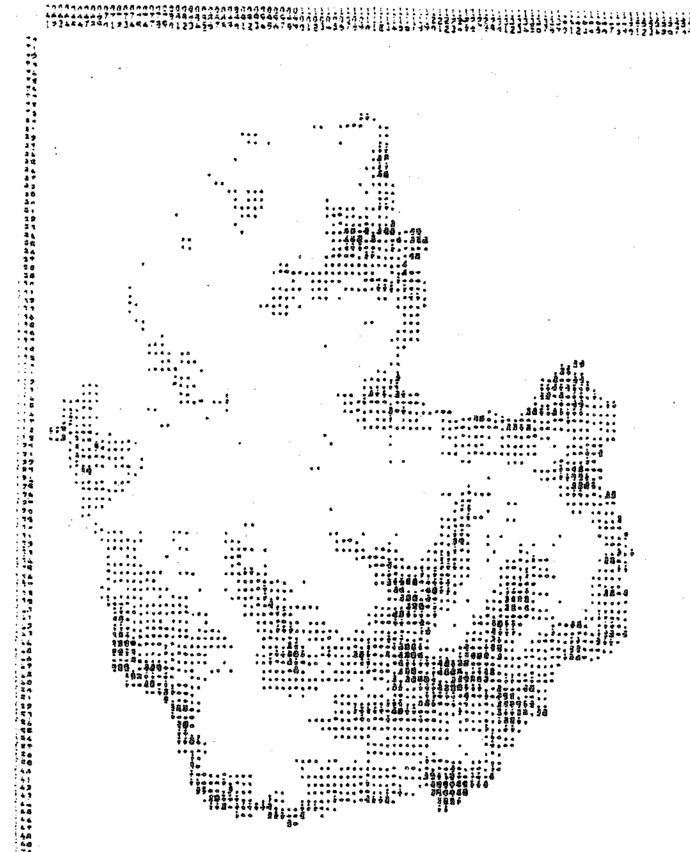

Figure 5. Landsat Band 5 Radiance, Williams Fork Watershed. Date of Overpass July 3, 1976. (Eight classes ranging from 0 to 320.)

Figure 6. Classified Fractional Snow Cover in Landsat Band 5, Williams Fork Watershed, July 3, 1976. (Six classes ranging from less than 20% to greater than 79%.)

Simulation Update Using Snow-Course Measurements

Simulated relationships between elevation, aspect and snow-water content for a given date were used in relating snow-course measurements to areal distribution of snow-water content (Figures 7 and 8). It is seen that the effect of aspect on snow depth is less pronounced on April 1 (Figure 7) than it is on May 1 (Figure 8).

Measurements from four snow courses within or near the study area[1] were combined to form an index of observed water content. Factors relating calculated snow indices and the curves of water content (Figures 7 and 8) are used for predicting the water content at any point in the watershed from an index of snow course measurements.

The predicted water content is used in updating the simulated water content on the date of the snow course measurements. Figures 9 and 10 show the effect of updating a simulation of wateryear 1971, with snow course data on May 1.

Simulation Update Using Classified Landsat Imagery

Snow in Landsat imagery was first classified into percentage snow cover classes as previously described. Relationships between fractional snow cover and water content of snowpack had to be assumed (Figure 11), because suitable Landsat images were not available during the middle of the snowmelt season. Furthermore, the functional relationship between snow cover and water content is likely to vary with topography, time of year and past history of snowpack.

For the update runs included here a particular snow cover/snow depth curve from the family of curves shown in Figure 11 was selected by comparing gray-maps of the classified Landsat image and the simulated water content. During the later snowmelt season the selection can be further improved by considering the effect of recent storms on snow depth.

After a snow cover/snow depth curve has been selected update is performed as previously discussed. Tables 2 gives the comparative results from using snow course measurements and Landsat imagery for simulation update.

Table 2. Comparative Results from Using Snow Cover Measurements and Classified Landsat Imagery for Simulation Update. Date of Update: May 1, 1976.

		Simulated Runoff (Inches)
1.	No update (or recalibration)	13.93
2.	Update with index of snow course measurements	13.67
3.	Update with Landsat Imagery using Curve 2 in Figure 8	13.15
4.	Update with Landsat Imagery Using Curve 3 in Figure 8	12.79
5.	Recorded runoff for wateryear 1976	13.11 inches

SUMMARY

The spatially distributed approach to the simulation of snow processes offers possibilities of direct simulation update on pixel basis if periodical remotely sensed (or other form of) snowpack information is available in overlay form or as point measurements.

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[1]Upper half of the Williams Fork Watershed, Williams Fork is a tributary to the Colorado River at Parshall, Colorado.

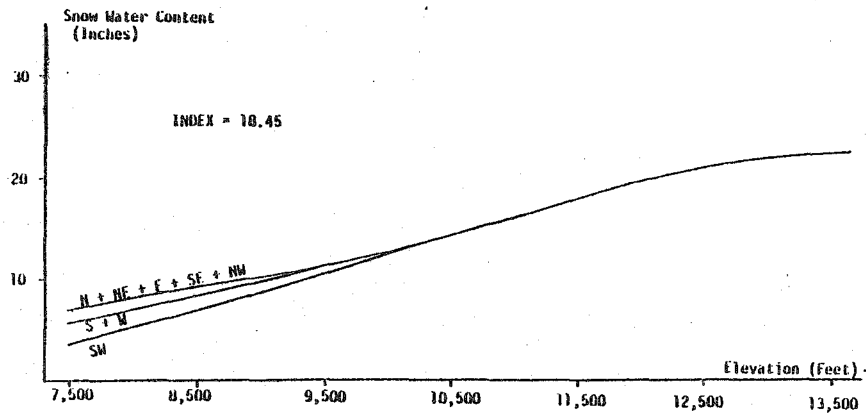

Figure 7. Simulated Snow Water Contents by Aspect and Elevation, April 1, 1971. Snow Cover Index = 18.45.

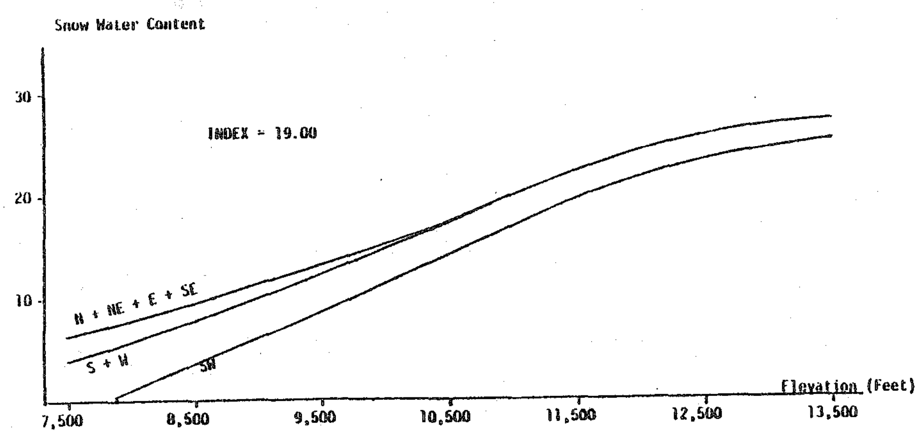

Figure 8. Simulated Snow Water Contents by Aspect and Elevation, May 1, 1971. Snow Cover Index = 19.00.

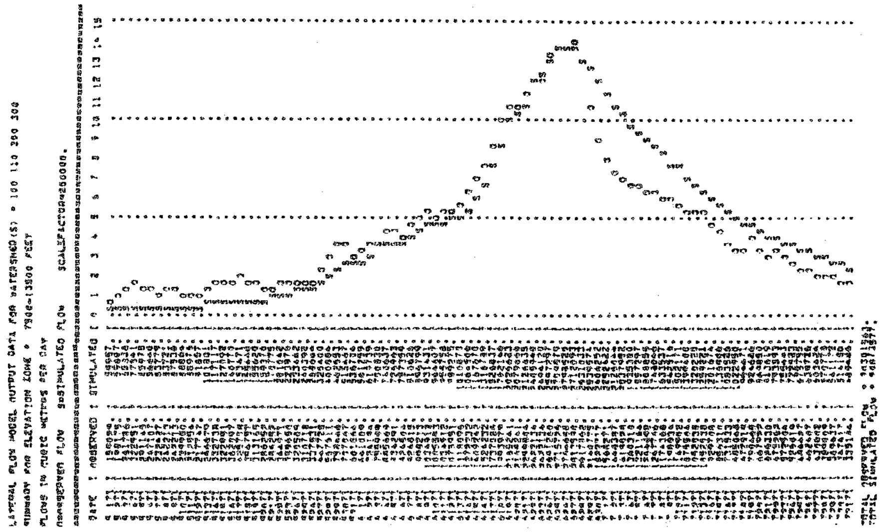

Figure 9. Observed and Simulated Hydrographs, Williams Fork Watershed, Spring 1971.

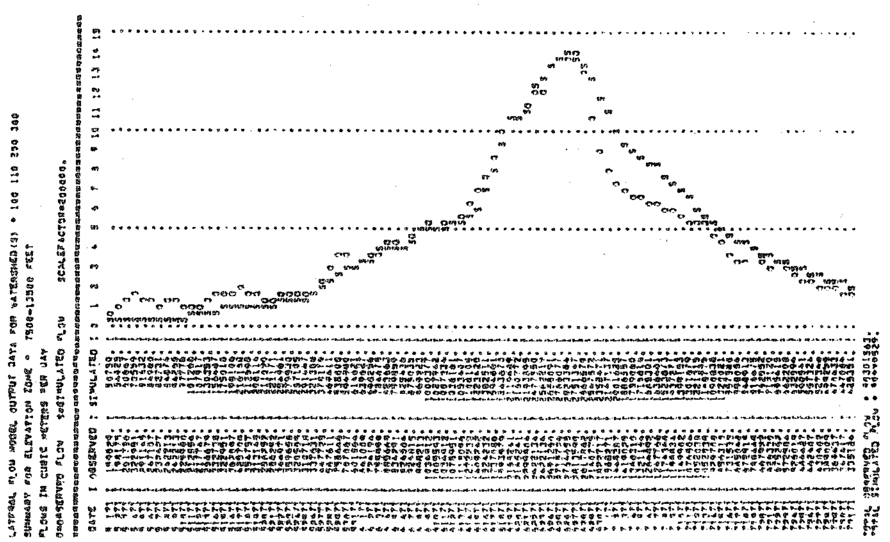

Figure 10. Observed and Simulated Hydrographs, Williams Fork Watershed. Simulated Updated on May 1, 1971.

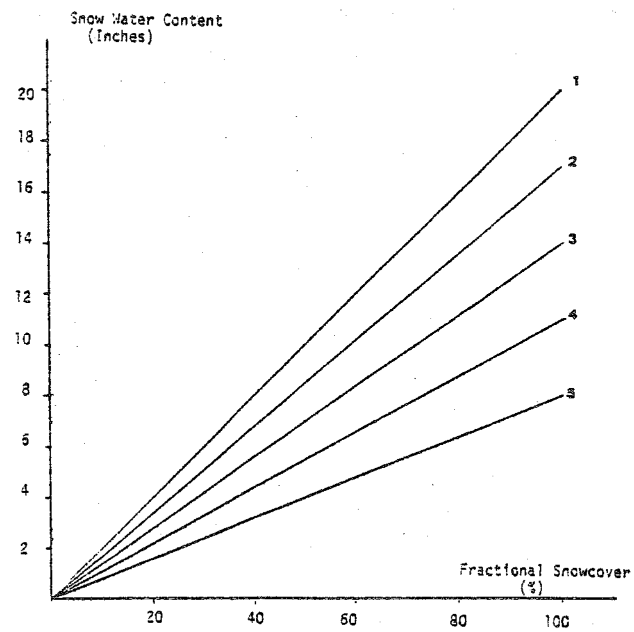

Figure 11. Assumed Relationships Between Fractional Snow Cover Within Landsat Pixels and Snow Water Content.

Snow water content measurements obtained in April during the late snow accumulation phase and Landsat imagery acquired during the later part of the snow-melt season have the greatest potential for improving the prediction of spring runoff from high mountain watersheds.

Besides Landsat imagery, lower resolution imagery from environmental satellites that provide repeated coverage of large areas on a daily basis can be used for simulation update. The lower resolution satellites have the greatest potential for monitoring snowpack in prairie environments.

A potential application is the incorporation of snow transport models for improved simulation of alpine and prairie conditions using the same data base (watershed overlays). The incorporation of wind transport models would reduce the importance of performing simulation update with statellite imagery by accounting for snow relocation.

ACKNOWLEDGMENT

The work upon which this report is based was supported (in part) by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized by the Water Resources Research Act of 1964, and pursuant to Grant Agreement No.(s) 14-34-0001-7145.

REFERENCES

Dillard, John P. and Charles E. Orwig. Use of Satellite Data in Runoff Forecasting in the Heavily Forested, Cloud-Covered Pacific Northwest. Presented at Final Workshop on the Operational Applications of Satellite Snowcover Observations. April 16-17, 1979, Sparks, Nevada.

Leaf, Charles F. and Glen E. Brink. Hydrologic Simulation Model of Colorado Subalpine Forest. USDA Forest Service. Research Paper, RM-107. May 1973. 23 pp.

Shafer, B. A. and C. F. Leaf, Landsat Derived Snowcover as an Input Variable for Snowmelt Runoff Forecasting in South Central, Colorado. Presented at Final Workshop on the Operational Applications of Satellite Snowcover Observations. April 16-17, 1979, Sparks, Nevada.