COMPUTATION OF A SNOWPACK-LOSS COMPONENT FOR A WATER-BUDGET MODEL FOR THE SAN JUAN AQUIFER BASIN IN NEW MEXICO AND COLORADO

by

Scott D. Waltemeyer and John M. Kernodle

INTRODUCTION

A Regional Aquifer-System Analysis (RASA) National Program was initiated in 1978 to appraise the nation's ground-water systems. The San Juan aquifer basin RASA, which is largely in northwestern New Mexico and also parts of Arizona, Utah, and Colorado was conducted as part of the National Program. The present work was done to provide estimates of potential ground-water recharge for the San Juan aquifer basin RASA. Techniques for estimating water yields of basins using water budget, regression, and ground-water flow models have been applied to a part of the San Juan aquifer basin in New Mexico and Colorado. Similar techniques were applied to the Rio Grande basin north of Embudo, New Mexico (Hearne and Dewey, 1988). Previous studies in the area have used a constant rate of sublimation in snowpack-loss calculations. This paper presents a method used to determine snowpack loss as a function of altitude for use in a water-budget model.

The conceptual water-budget model utilizes long-term averages of precipitation, streamflow, and snowpack losses in the water budget to represent average conditions. Geographical Information System (GIS) technology provided the capability to determine basin and climatic characteristics of the study area that are required for the model. Precipitation averages are based on the mean annual winter precipitation (October through April) for the period 1931-60 (U.S. Weather Bureau, no date). Streamflow averages are based on the mean annual discharge for selected basins. Snowpack losses result mostly from sublimation, evaporation, soil infiltration and evapotranspiration (ET). Snowpack loss, as a function of altitude, is determined by subtracting the average April 1 water content of the snow from the average precipitation. The potential recharge rate is estimated by subtracting the streamflow and snowpack loss from the precipitation in a basin.

WATER-BUDGET MODEL USING GEOGRAPHICAL INFORMATION SYSTEMS

The water-budget components consisting of precipitation, streamflow and snowpack loss are utilized in a GIS to determine direct recharge to 272 surface-water basins. Basin and climatic characteristics are evaluated for the San Juan Mountains, Sangre de Cristo Mountains and the northwestern plateau to select the appropriate streamflow characteristic for each of the 272 basins. The following conceptual water-budget model is applied to the basins:

$$R = \bar{P}w - Q - S, \tag{1}$$

where R = potential recharge to the ground-water basin, in ft^3/s (cubic feet per second);
$\bar{P}w$ = average basin mean annual winter precipitation, in ft^3/s;
Q = mean annual discharge from the drainage basin, in ft^3/s; and
S = average snowpack loss from the drainage basin, in ft^3/s.

The water-budget model is developed by determining average basin mean annual winter precipitation, mean annual discharge and average basin snowpack loss. All components for the water-budget model are expressed as a rate. For example, the winter precipitation in inches is expressed in feet per year and subsequently converted to ft^3/s.

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Precipitation Component

The mean annual winter precipitation for each of the 272 basins is used to define the total annual winter precipitation for each basin. The lines of equal mean annual winter precipitation (U.S. Weather Bureau, no date, a and b) and drainage areas of the San Juan Basin study area are digitized and stored in a computer as GIS spatial coverages. The two coverages are superimposed into a single coverage to determine average basin mean annual winter precipitation. A GIS of the basin winter precipitation is distributed throughout the year in inches per year and expressed in ft^3/s for each drainage area.

Streamflow Component

The streamflow component is determined from regression models based on streamflow and basin and climatic characteristics of three physiographic regions in and adjacent to the study area. The basins are diverse in terms of streamflow and therefore separate streamflow regression equations are developed for three categories of average basin altitude and precipitation. Independent variables are evaluated at the 5-percent level of statistical significance for inclusion in the regression model. The regression equation (eq.2) for the basins in the San Juan Mountains is based on 9 streamflow-gaging stations, (eq.3) the Sangre de Cristo Mountains is based on 15 stations, and (eq.4) the northwestern plateau on 8 stations. The regression equations and the average standard error of estimate (S.E.) for each are:

$$Q_{SJM} = 1.03 \times 10^{-1} \; Da^{0.87} \; \bar{P}w^{\,0.99} \;, \; S.E. = 18 \text{ percent} \qquad (2)$$

$$Q_{SCM} = 7.24 \times 10^{-5} \; Da^{0.97} \; \bar{P}w^{\,3.67} \;, \; S.E. = 24 \text{ percent} \qquad (3)$$

$$Q_{NP} = 1.18 \times 10^{-4} \; Da^{1.10} \; \bar{P}w^{\,3.25} \;, \; S.E. = 106 \text{ percent} \qquad (4)$$

where Q = mean annual discharge, in ft^3/s;
Da = drainage area, in square miles; and
$\bar{P}w$ = average basin mean annual winter precipitation, in inches.

Altitude coverage, from the Digital Elevation Model (DEM) of the U.S. Geological Survey, is used to determine average basin altitude in the study area for selection of the appropriate streamflow regression equation. Equation 2 is applied to basins in the San Juan Mountains having an average altitude greater than 7,500 feet and mean annual winter precipitation greater than 12 inches. Equation 3 is applied to basins in other mountainous areas in the San Juan Basin having an average altitude less than 7,500 feet and precipitation greater than 12 inches. Equation 4 is applied to basins in the northwestern plateau having an average altitude less than 7,500 feet and precipitation less than 12 inches.

Snowpack-Loss Component

The snowpack-loss component is determined from the difference between average basin mean annual winter precipitation and the remaining water content in the snowpack on or about April 1. The average basin mean annual winter precipitation for nine basins of the San Juan Mountains streamflow regression model is related to average basin altitude as shown in figure 1. The average basin altitude for the nine basins ranged from 8,640 to 11,300 feet and the average basin mean annual winter precipitation ranged from 17.61 to 30.97 inches. The regression equation to determine the average basin mean annual winter precipitation is:

$$\bar{P}w = 2.70 \times 10^{-8} \bar{A}_b^{2.24}, \text{ S.E.} = 10 \text{ percent} \quad (5)$$

where $\bar{P}w$ = average basin mean annual winter precipitation, in inches; and
$\bar{A}_b$ = average basin altitude, in feet above sea level.

The April 1 snowpack water content is determined from a relation of snowpack water content with altitude. The relation is developed from April 1 water content for the period (1961 to 1985) based on U.S. Soil Conservation Service data from 19 selected snow courses in the San Juan Mountains. The site altitude ranged from 8,600 to 11,000 feet and the average April 1 water content for the 19 snow courses ranged from 7.5 to 32.6 inches. The regression equation is:

$$WC = 1.45 \times 10^{-15} A^{4.03}, \text{ S.E.} = 32 \text{ percent} \quad (6)$$

where WC = average April 1 water content, in inches; and
A = site altitude, in feet above sea level.

The snowpack-loss component is determined from the difference between average basin mean annual winter precipitation (equation 5) and average April 1 water content (equation 6) for selected altitudes. This component is expressed in percentages of average basin mean annual winter precipitation. The average basin altitude of the 272 basins is then used to determine the percentage of mean annual winter precipitation lost. The snowpack loss, or the percentage of winter precipitation, that is lost to all sources is shown in the following equation:

$$S = ((\bar{P}w - WC)/\bar{P}w) \times 100 \quad (7)$$

where S = snowpack loss, in percent;
$\bar{P}w$ = average basin mean annual winter precipitation, in inches; and
WC = average April 1 water content, in inches.

The following snowpack-loss classification is developed from equation 7 for arbitrary altitude ranges.

Altitude range (feet)		Snowpack loss (percent)
--	<7,500	59
7,500	8,000	51
8,000	8,500	44
8,500	9,000	38
9,000	9,500	32
9,500	10,000	27

The snowpack-loss component has large variations with altitude. For example, from 7,500 to 10,000 feet in altitude snowpack losses are 59 to 27 percent, respectively. Therefore, this component may differ substantially from other applications using a constant rate. For comparison, using a altitude of 8,800 feet, a snowpack loss of 36 percent of the mean annual winter precipitation is determined from equation 7. Whereas, sublimation loss of 0.011 inch per day, or a value of 13 percent snowpack loss, was determined for a site of 8,800 feet in Utah by Croft and Monninger (1953) and applied by Hearne and Dewey (1988) in the Rio Grande Basin. The snowpack-loss component determined by equation 7 included all losses, rather than sublimation only, as applied by Hearne and Dewey (1988). Hearne and Dewey (1988) reported sublimation loss is known to vary with altitude; however, because no relation was available, a constant rate was used.

AQUIFER BASIN POTENTIAL RECHARGE

Interpretation of precipitation and ET data in the study area provides the basis of potential recharge during the winter period. The annual ET cycle has been estimated by Tuan and others (1973) for typical locations in the aquifer basin. Their results show that the average monthly precipitation and average monthly potential ET estimates for these locations have approximately the same annual distribution throughout the region (fig. 2). During the November through March period, evapotranspiration (ET) losses are considered to be small. During the April through October period, ET exceeds precipitation availability and all precipitation is assumed lost to ET. The estimated potential ET and precipitation usually converge in the annual distribution about November and March each year. This surplus precipitation (November through March) is available for ground-water recharge, streamflow, and snowpack losses. The mean annual winter precipitation (October through April), however, is used to represent this period.

The water-budget model for the entire 19,400-square-mile region resulted in the following mean values: P = 8,600 ft^3/s, Q = 2,310 ft^3/s, S = 4,840 ft^3/s, and R = 2,010 ft^3/s. The potential recharge rate of 2,010 ft^3/s is equivalent to 1.41 inches per year over the entire aquifer basin. The potential recharge rate, expressed as a percentage of average basin mean annual winter precipitation for the aquifer basin, can thus be summarized in general by this equation:

$$R = 0.486\ \bar{P}w^{0.76} \qquad (8)$$

where R = potential recharge, in ft^3/s and:
$\bar{P}w$ = average basin mean annual winter precipitation, in ft^3/s.

Spatial distribution of the potential recharge rates for the 272 basins used in the analysis in the San Juan aquifer basin is compiled into a GIS coverage. The GIS coverage of recharge rates will be subdivided into areas based on surficial geology. These coverages will be used to estimate the rate of potential recharge to the surface area of these various formations for application in ground-water model simulations.

SUMMARY

A snowpack-loss component as a function of altitude is used in a water-budget model for estimating potential recharge to the San Juan aquifer basin. The precipitation component of the model uses average basin mean annual winter precipitation. The precipitation for the period of May through September is excluded and considered lost to evapotranspiration. The streamflow component is derived by regression relations based on drainage area and mean annual winter precipitation for three physiographic regions. The snowpack-loss component is derived by defining the relation of peak snowpack water content to total precipitation for a given altitude. A generalized potential recharge relation is determined for 272 basins using average basin mean annual winter precipitation and recharge. Snowpack loss range from 27 to 57 percent for altitudes of 10,000 to 7,500 feet, respectively. This relation can be applied to estimate recharge in other study areas of similar physiography.

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_____[n.d.b], Normal October-April precipitation 1931-1960, New Mexico: U.S. Department of Commerce map, scale 1:500,000, 1 sheet.

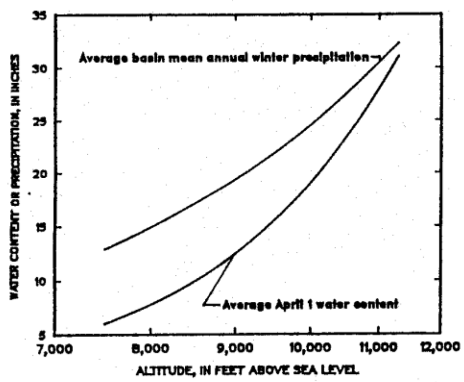

Figure 1. Relation between mean annual winter precipitation and average basin altitude, and average April 1 water content and site altitude for selected snow courses in the San Juan Mountains, New Mexico and Colorado.

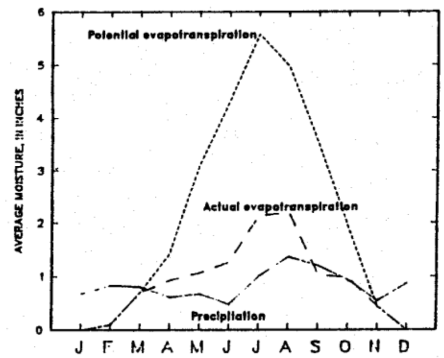

Figure 2. Average monthly precipitation, actual and potential evapotranspiration for Aztec Ruins, New Mexico.(Modified from Tuan and others, 1973)