USING GIS TO ESTABLISH RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES AND SNOWDEPTH IN GREEN LAKES VALLEY, COLORADO, FOR USE IN SWE ESTIMATIONS AND FORECASTING

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ABSTRACT

Geographic Information Systems (GIS) may be useful in forecasting the quantity of water stored in alpine snowpacks because relationships may be established between environmental characteristics and seasonal snowdepth patterns for watersheds of interest. A snow survey performed in May of 1997 for the 224-ha Green Lake 4 Watershed of the Colorado Front Range involved intensive sampling (n = 194) of snowdepth and snow density measurements around the basin. These field data, in conjunction with snow covered area, DEM and landcover data from the Niwot Ridge LTER Spatial Database, were used to investigate 1) the relationship of snowdepth to landcover, 2) the relationship of snowdepth to slope, and 3) the relationship of snowdepth to aspect.

INTRODUCTION

Estimating the amount of water stored in alpine basins in the Western U.S. is of critical importance for water resource allocations. Environmental factors determining the distribution of snow in a given basin include elements such as elevation, aspect, slope, and vegetative cover (Pomeroy and Gray, 1995).

Geographic Information Systems (GIS) may be useful in forecasting the quantity of water stored in alpine snowpacks by establishing spatial relationships between environmental characteristics and seasonal snowdepth patterns for watersheds of interest. Interpolation of snowdepth point data yields a continuous snowdepth surface, which then can be analyzed with respect to landcover type, slope, and aspect to determine the predictive qualities of these environmental characteristics. In addition, better knowledge of snow distribution patterns is needed to improve our understanding of runoff generation in the alpine, and the relative importance of landcover types, slopes, and aspect to snowdepth. Furthermore, little is known about hydrologic processes in alpine basins; therefore, computing continuous snowdepth surfaces can be useful for application as weighting coverages for spatially-distributed stream runoff models, which are easily constructed in a grid-based GIS.

SITE

The Green Lake 4 watershed is a 224-ha basin ranging in elevation from 3575-m to about 4000-m and is situated in the Colorado Front Range of the Rocky Mountains. The area is characterized by a mountain continental climate, annually receiving about 1000-mm of precipitation (Williams *et al.*, 1996), 80% of which is in the form of snow (Caine, 1995). The watershed is part of the Boulder County, Colorado, municipal water supply and has been closed to the public for about 65 years.

The Green Lake 4 watershed is typical of alpine basins with steep cliffs, talus slopes, and limited soil cover. Bare rock makes up about 29% of the basin area, talus slopes make up about 33% of the basin area, and soils make up about 29% of the basin area. The 8-ha Arikaree cirque glacier lies at about 3800-m just below the Continental Divide.

METHODS

As part of the Niwot Ridge Long Term Ecological Research (LTER) Program a snow survey was performed May 12-15, 1997 for the Green Lake 4 watershed wherein 194 snowdepth measurements were made in a semi-regular grid. In addition, snow density measurements were made at seven snowpits located in and near the watershed. Landcover data and a 10-m Digital Elevation Model were obtained from the Green Lakes Valley Spatial Database. The landcover data were refined with a delineation of talus fields, which were digitized from aerial photographs.

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The Spatial Analyst extension of ESRI's ArcView GIS was used to delineate the watershed, and calculate slope and aspect. In addition, Avenue script was written to perform Kriging interpolation of the snowdepth point data. The mean, standard deviation, and total snow volume relative to each environmental characteristic were also calculated using Spatial Analyst. Snow volumes were converted to Snow Water Equivalent (SWE) using the average snow density measured during the snow survey (404 kg/m3).

The relationship of snowdepth to various environmental attributes was investigated. Landcover classifications were amalgamated into vegetated, bare rock, talus, glacier, and lake areas. Slope was categorized such that slopes greater than or equal to 40° were considered high slope, and less than 40° were considered low slope. Aspect was also reclassified such that north facing slopes included areas facing north, northeast, northwest, and west, and south facing slopes included areas facing south, southwest, southeast, and east.

RESULTS

The semi-variogram plotted for the data points suggests that an Exponential Kriging model best described the variability in this area. Local interpolation methods such as inverse distance weighting techniques did not appear to reflect the larger basin patterns. The Kriging surface fit to the snowdepth data points shows largest snowdepths at the Arikaree glacier and the smallest snowdepths on the eastern end of the basin.

Exponential Kriging of snowdepth in the Green Lake 4 watershed yielded a total snow volume of 5,889,300-m^3. Using snow density to convert to SWE, this translated to about 2,379,300-m^3 of water. A water balance is shown in TABLE 1 using the calculated SWE, summer rain, and GL4 seasonal outflow to calculate the residual available for evapotranspiration (ET).

TABLE 1: Water Balance

(In) Total Snow SWE:	2,379,300 m^3
(In) Total Summer Rain:	+ 392,400 m^3
(Out) Outflow from GL4:	- 2,389,750 m^3
(Out) Evapotranspiration:	381,946 m^3 (1.3%)

(Note: Much of the water evaporated from the seasonal snowpack during the winter months, therefore, ET value calculated below does not represent total ET for the water year, but simply for the snowmelt season. This balance also does not reflect change in storage.)

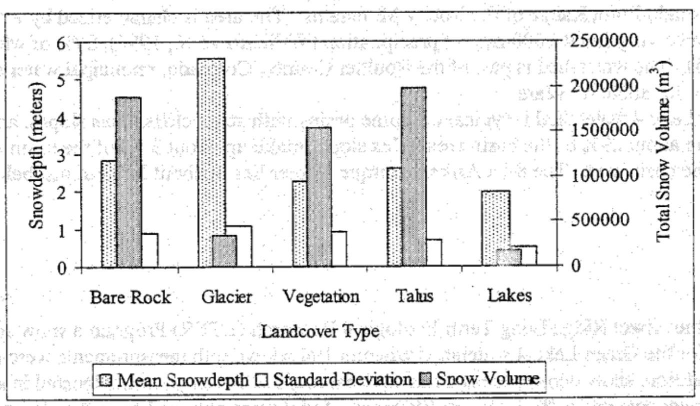

FIGURE 1: The relationship between snowdepth, snow volume, and landcover.

The distribution of snow was found to be uneven in the Green Lakes 4 watershed. The relationship of snowdepth and landcover types shown in FIGURE 1 shows that although the glacier has the highest mean snowdepth, it stores the least amount of snow volume. Although Talus areas are generally thought to have slopes too steep to support deeper snows, Talus areas showed the second largest mean snowdepths. Lakes showed the smallest mean snowdepth. The relationship between slope and snowdepth was unexpected. Higher slope areas showed a higher mean snowdepth, although a higher standard deviation was also calculated (FIGURE 2). This reinforces the idea that talus, which characterizes most of the high slope areas, has a greater ability to accumulate snow because of its smaller scale geometry. However, fewer samples were available from the high slope areas owing to the difficulty of measuring in these areas, and sample bias may exist.

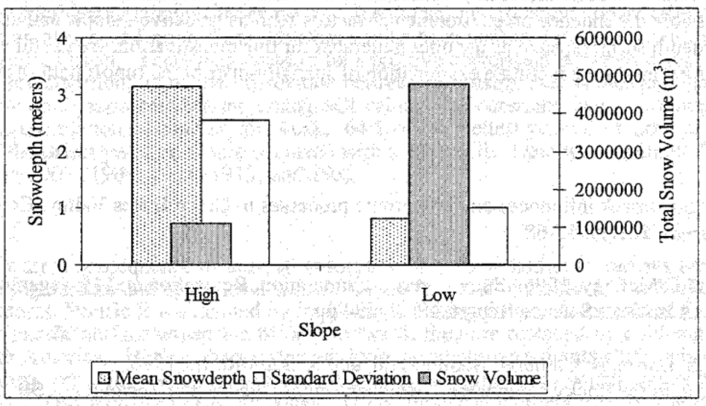

FIGURE 2: The relationship between snowdepth, snow volume, and slope.

FIGURE 3 shows the relationship of snowdepth with aspect. Not surprisingly, south facing slopes have a lower mean snowdepth; however total snow volume is largest for these slopes because they make up the most basin area.

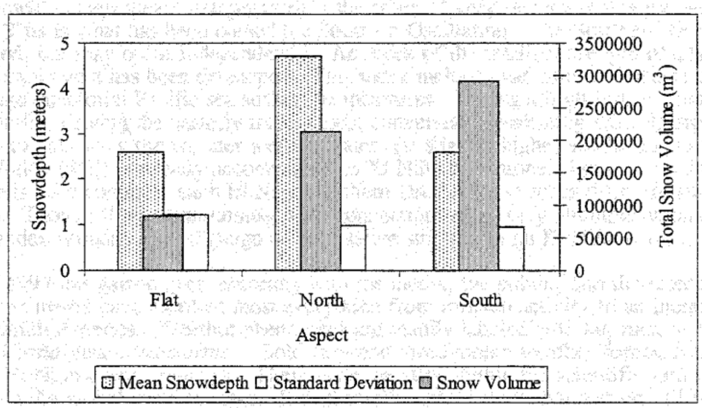

FIGURE 3: The relationship between snowdepth, snow volume, and aspect.

SUMMARY

Additional years of data are needed to establish a temporal trend of snowdepth patterns and environmental variables. This investigation shows highest mean snowdepths associated with the glacier area, higher slopes, and north facing slopes. However, the greatest total snow volumes were recorded for talus areas, low slopes, and south facing slopes. The fact that talus can support significant amounts of snowcover despite its slope is also interesting from the standpoint of hydrologic flowpaths. Talus areas are not yet well understood with respect to their influence on runoff generation dynamics; nevertheless these data suggest that they could be the origin for much of the snowmelt in this alpine basin.

The mass balance shows little water available for evapotranspiration for the 1997 summer season. However, much of the evaporation from the snowpack occurs during the winter season. In addition, the previous season was a high water year and much water remained in storage, which may have been available for ET (Caine, 1997, personal communication).

Spatial analysis of snowdepth patterns in Green Lakes Valley needs to be augmented with future snow survey data so that the usefulness of environmental characteristics for SWE forecasting can be determined. In the meantime, this research has been useful in demonstrating the variability of snow distribution in Green Lakes Valley, and its possible dependence on environmental factors such as landcover, slope, and aspect. Lastly, interpolated snowdepth surfaces, such as the ones generated for this investigation, are useful as weighting grids for hydrologic models because they facilitate examination of spatially-distributed runoff patterns in this alpine basin.

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