Application of a Snow Model for Yellowstone National Park

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This document contains a description and instructions for the Yellowstone Snow Model.

Introduction

Yellowstone National Park (YNP) managers have increasing needs for a landscape level method to predict snow accumulations in YNP during winter. Snow pack may influence stream runoff, plant phenology and plant production during the subsequent growing season (Merrill et al. 1994, Coughenour and Singer 1996b). Snow packs may influence the habitats that ungulates feed in, their abilities to travel, their migration timing, their vulnerability to predators and their energetic expenditures during winter (Brunnel et al 1999, Huggard 1993, Hobbs 1989, Geese and Grothe 1995, Farnes et al. 1999, Cheville et al 1999.) Snowpacks may determine which areas elk or wolves may occupy during winter (Briggs 1995). Snow affects ungulate foraging, and this effect has been included in spatially explicit calculations of elk carrying capacity (Coughenour 1994,1996). Bison leaving the park create management problems, and snow cover in conjunction with population size could be used to predict when bison migrations from the park occur (Cheville et al. 1998). A 5-year multidisciplinary project on bison ecology and brucellosis in Yellowstone coordinated by Pete Gogan is nearing completion, and snow cover effects on bison distributions are being incorporated into a model of bison carrying capacity and emmigration (M. Coughenour, ms. in prep.) More recently, the reintroduction of wolves into YNP in 1995 has generated the scientific need to determine past and present snow packs in order to differentiate sort out any potential effects of wolves on ungulate distributions from effects due to variations in snow cover.

Snow hydrologists have been generating snowfall isopleth maps for many years by manually combining their knowledge of the impact of topography on precipitation, topographic maps, and with point-based weather station and snow depth data. Running et al. (1987) used a simple ratio of data on an isopleth map to the long term base station average to compute precipitation at any given site from base station values, but the outputs were not mapped. Methods for generating maps from point data for precipitation, snowfall, and snow depth have been developed during the last decade or so. In addition to SAVANNA (Coughenour 1991), more specialized models included MT-CLIM (Hungerford 1989), ANUSPLIN (Hutchinson 1989, 1995), and PRISM (Daley et al 1994).

Coughenour (1994,1996) combined GIS and snow depth data to generate bi-weekly snow depth maps for the purpose of estimating elk carrying capacity on Yellowstone's northern range. The idea of developing a GIS-based snow model for Yellowstone's northern range has also been a goal of Phil Farnes (Snowcap Hydrology, Bozeman, MT.) for a number of years (Farnes and Romme 1993, Farnes 1996, Biggs 1995). Although snow features such as crusting density and depth hoar can influence ungulates, Farnes has argued that snow water equivalent (SWE) is the single best measure that incorporates most other snow pack features and can be used to predict ungulate responses (Farnes et al. 1999). Farnes et al. (2000) state, “It has been proposed that GIS be used to determine monthly SWE maps for the northern range for the previous 50 years using SWE values and algorithms generated for the report”.

The purpose of this effort was to respond to that recommendation and to develop the GIS-based component of an operational snow model that could be used to predict SWE at any location on the northern range on any day. Thus SWE can be predicted for the visual or radiotelemetry generated locations of ungulates, or locations of wolves. Our study team makes this GIS model available for park staff and for the other researchers currently evaluating the factors that determine ungulate distributions.

Snow Model Background

A data model consists of a highly integrated combination of a data set, and a model which uses the data to generate useful information. In this case, point data for snow water equivalents are used by a model to generate maps of snow water equivalents across a region. As such, the data and the model are both equally important.

The model is based on an algorithm to spatially interpolate point data, while correcting for effects of elevation. For each time period (eg. month), a regression is performed of precipitation against elevation. In some periods, the regression is not significant and is not used. Another key feature of the algorithm is that the values on the resultant map are guaranteed to match the observed values at each weather station.This algorithm was first developed by Michael Coughenour as part of a spatially explicit ecosystem model called SAVANNA (Coughenour 1992, 1993). The same algorithm was used in a Landscape Carrying Capacity Model (LCCM) for elk on Yellowstone’s northern elk winter range (Coughenour 1994, Coughenour and Singer 1996). The first application of the LCCM to Yellowstone was presented at a research conference held in Yellowstone in 1991 (Coughenour 1994). In this application, GRASS GIS maps for elevation and vegetation were read into the LCCM to calculate snow depth maps, available forage for elk, and elk carrying capacity on a biweekly basis throughout the winter. The model produced output files that were read into the GRASS GIS, to produce maps of snow depth and elk carrying capacity. Snow maps were presented at the 1991 conference.

At about the same time, Phil Farnes was conducting studies of snow distributions on the Yellowstone northern elk winter range (Farnes and Romme 1993, Farnes 1994, 1996). He quantified the ways that slope, aspect, and tree cover affect snow pack, as compared to measurements made on a standard level, treeless sample site. He also developed ways to integrate data from numerous snow water sample sites into a unified data base, and ways to use snow water equivalent to calculate an index of winter severity that combines stress effects of cold temperature and heavy snow on elk.

The idea of combining the Coughenour model with the Farnes data into a stand-alone computer program was the outcome of initial research on bison and elk carrying capacity by the two researchers in Grand Teton National Park (GTNP). The GTNP carrying capacity project was conceived in 1996 by Robert Schiller and Francis Singer. On that project, Coughenour conducted SAVANNA modeling studies and Farnes collected snow data 1996-1998. In 1996 the stand-alone snow model was created by combining the earlier elevation-based model with slope/aspect and tree cover empirical correction factors developed by Farnes. The computer program was called "PPTMAP". The snow data set assembled by Farnes could then be readily translated into maps of snow water equivalents in GTNP. The snow data model was delivered to GTNP by Coughenour and Farnes in 1999, at the same time Farnes delivered his unique data set (Farnes et al. 1999). Subsequently, a new phase of GTNP carrying capacity research was initiated by Tom Hobbs, F. Singer, G. Wockner, and L. Ziegenfuss.

In 2000, Gary Wockner, Tom Hobbs, and Francis Singer (CSU) obtained version 2 of PPTMAP from Coughenour for a new phase of the GTNP project (Hobbs et al. 2001). Working with Farnes and Coughenour, Wockner obtained data to run it, worked through several software bugs, tested it, and then used it in a carrying capacity model for the Jackson elk herd. Wockner developed and added a novel approach for handling the orographic snow shadow effect east of the Teton Range. In addition, Linda Zeigenfuss used the model to predict snow water equivalents (SWE) for elk on the same days as overhead flights on the Jackson elk herd. Model outputs can be seen at http://www.nrel.colostate.edu/projects/teton/.

PPTMAP2 was applied and parameterized in the Fall of 2001 to Yellowstone National Park by Wockner, again using data provided by Farnes, and again for Linda Zeigenfuss for the same purpose in Yellowstone. Funds for the YNP snow modeling work were obtained by Francis Singer. This report is an output of that project.

Coughenour had independently been applying the model to Yellowstone as part of his work on Yellowstone bison and elk carrying (the YNP bison project, P. Gogan PI, USGS funding). Concurrent to the Wockner efforts, the model was applied the model to YNP based on the earlier Farnes data set and additional SNOTEL and climate station data. The model was provided to other researchers on the bison project.

Other researchers working at YNP expressed interest in obtaining the model. Therefore, the model was made available on a website through Colorado State University's Natural Resource Ecology Lab: http://www.nrel.colostate.edu/projects/yellowstone/

M. Coughenour continues to maintain and update the model. The version posted on the web site remains at version 2. However, the current (3/05) version is 3, with SNOTEL data thru 12/04 and climate station data through 8/04. Users are encouraged to contact mikec@nrel.colostate.edu for information on the most recent release.

Model Description
The model creates interpolated snow maps (SWE) of a one-day measurement for the entire Yellowstone study area. Several data sources drive the model:

1. digital elevation map – dem.asc
2. slope map – slope.asc
3. aspect map – aspect.asc
4. vegetation map – snow_veg.asc
5. snow site data – snowsites.dat, which contains the locations and elevations of the 28 snow measurement sites
6. snow measurement data -- yellsnow_data.dat, which contains the measured daily SWE dating from October 1, 1981 through September 30, 1999.

Using the data provided by Farnes measured at 28 YNP snow sites, this model creates a snapshot map of SWE on the study area. Specifically, using the DEM and the snow data, an initial grid is created using interpolation and regression. This grid is then readjusted for the effect of slope, aspect, and vegetation cover. Using slope and aspect, the more the cell tilts toward the sun, the more it is melted off; conversely, the more it is tilted away from the sun, the more snow accumulates. Using the vegetation data, less snow accumulates under conifers. The bigger the trees and the denser the stand, the less snow accumulation. The algorithmns expressing how these files are used are presented in Farnes et al, 2000.

All of these files are included in the zipped packet.

Instructions for Using the Model

1. **<u>Open the file "pptmap.dat".</u>**

The model is in the folder "Snow Model". The model reads an input file "pptmap.dat" which contains input parameters. It is best to open ".dat" files with 'notepad' rather than a word processing program. When the file is opened, it will contain the following parameter options:

```
1            /mapin GIS format  1-ARC ASCII
1            /mapout GIS format 1-ARC ASCII
1            /1-correct for slope-aspect and veg.cover with hard-coded routine sitefact.f, 0-do not
'dem.asc'              /elevation map
'slope.asc'            /slope map
'aspect.asc'           /aspect map
'snow_veg.asc'         /cover map
2                      /base station file format  1-monthly, 2-daily
'snowsites.dat'        /base station info file
'yellsnow_data.dat'  /merged weather or snow data file
1                     /method - 1-inverse distance weighting, 2-Farnes eqn, 3-equiv Farnes eqn
1              /power to use in inverse distance weighting 2-squared distance, 1-linear distance wt
1              /1-take average over a period, 2-take sum
0.20           /max fraction of missing values for a station to be included in regression on elev
```

```
3               /nregmin - minimum N for using a regression equation
0.1             /rsqmin - minimum R-square for using the regression equation
0.              /slpmin - minimum slope for using the regression equation1
1997,1997                   /first and last years (water) to use
0,0,0,0,0,0,0,0,0,0,1,0     /flagged months to use
15,15                       /first and last days of month to use
0,0                         /first and last julian dates to use
```

2. **<u>Change three input parameters.</u>**

The only options that need to be changed to make the model work on a specific day are the three lines -- "first and last years to use", "flagged months to use", and "first and last days of month to use". Only one year, one month, and one day will be flagged at a time. In the above example, a map is created for November 15, 1997. Always use the same year and day before and after the comma in the options. Flag the month with a "1" as in the example above. As another example, if we were to run the model on January 6, 1996, the three lines would read:

```
1996,1996                   /first and last years (water) to use
1,0,0,0,0,0,0,0,0,0,0,0     /flagged months to use
6,6                       /first and last days of month to use
```

Ignore the option for julian dates.

Because the data in "yellsnow_data .dat" is organized by water year, the input in "pptmap.dat" must be in water year. The first day of the 1997 water year is October 1, 1996; the last day is September 30, 1997. To run the model on October 1, 1996, which is water-year 1997, the above file would read:

```
1997,1997                   /first and last years (water) to use
0,0,0,0,0,0,0,0,0,1,0,0     /flagged months to use
1,1                       /first and last days of month to use
```

3. **<u>Save the file</u>**

After changing theses three parameter lines, **save the file**.

4. **<u>Double-click on the application file "pptmap.exe".</u>**

To run the model, simply 'double-click' on the application file "pptmap.exe". The program will open a 'DOS' window and begin running through the rows of data. There are 1299 rows of data. On Wockner's machine (750 Mhz, 400 MB RAM), it takes about 30 seconds to run. When it is done running, press "return" and the window will close.

5. **<u>Import the output into a GIS</u>**

The output map is the file "outmap.asc". It is an Arc ASCII file with a header identical to the input files. We have been importing the file into Arcview, which converts it into an

Arc grid. Then we change the legend and quickly scan the map to make sure the model has worked correctly. Since all input files have 100 meter cells, the outmap will also have 100 meter cells. The input/output is in UTM Zone 12, NAD 83, which is the same as used by YNP for the data that is downloadable from their website. Mike Coughenour recommends smoothing the outmap twice with a 5x5 filter before analyzing or using the results. If you have trouble importing the ASCII files into Arcview, make sure you don't have spaces in the name given to the main folder in which the model is unzipped.

Measurable SWE is rarely present before November 1st, and usually is gone by June 15th at all sites. The site at Gardiner rarely registers any SWE. In the depth of winter, SWE predictions can be as high as 75 inches at the highest elevations in the park.

Several files are created along with the output map. They include:
Baseinfo.out = contains observed versus predicted values at the snow station locations.
Datesinc.out = contains the date of the output.
Debug.out = if there are problems they will appear here. Otherwise will say "doneread".
Info.out = for this model, there will be warnings that base stations are outside the domain. These can be ignored.
Regress.out = contains the predicted values at base stations, the R^2, slope, and intercept of the regression equation.
Basesy.vec = the X/Y locations of the base stations.

Unless the output map looks incorrect, all of the above files can be ignored. We have run the model for various dates in the YNP system and the output always looks correct. Additionally, R^2 and slopes are always adequate. In the Teton system, we had trouble due to an anomalous snow shadow east of the Teton Range. In the Yellowstone system, no large anomalies exist, and the model runs smoothly with respect to its input.

Additional Information
Additional files (not used in the model) are in the folder "Images and Shapefiles". The file Snowsites.jpg is an image of the entire study area including YNP boundaries, Northern Range boundaries, lakes, and snow station locations and names. We have also included shapefiles of these four GIS layers:
Yell_study.shp = Shapefile polygon of the Yellowstone study area
Yell_bound.shp = Shapefile polygon of YNP boundary
North.shp = Shapefile polygon of the Northern Range Boundary
Snowsites.shp = Shapefile points of the snow station locations

The file 1997_Ysnow.gif is an animated snow map of the 1997 water year. It begins in November 1996 and runs through June 1997. Images appear every week throughout the year. The snow-year 1997 was the heaviest on record in the 1981-1999 database. The files should play in a web browser.

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