Effect of Soil Depth on Soil Moisture in the Variable Infiltration Capacity Model

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INTRODUCTION

The Variable Infiltration Capacity (VIC) model (Liang et al., 1994, 1996) was developed as a water and energy balance model. It is a semi-distributed macroscale hydrologic model that has been used to study climate change, water resources management, and land-atmosphere interactions. Some key features are representation of vegetation heterogeneity, multiple soil layers with variable infiltration, and non-linear baseflow.

OBJECTIVE

There are five major components to the VIC model; land cover and soil, snow, meteorology, frozen soil, and flow routing. The objective of this project is to explore the land cover and soil component of the model and to investigate the effect of soil depth on soil moisture. VIC can be run with as many soil layers as desired, but typically three are specified: a top thin layer, an upper soil layer, and a lower layer. VIC assumes surface runoff is generated when infiltration capacity from the top two soil layers is exceeded (Gao et al., in review). The model uses the following equation to evaluate soil moisture in the top two soil layers:

$$\frac{\partial \theta_i}{\partial t} \cdot z_i = I - E - K(\theta)\Big|_{-Z_I} + D(\theta)\frac{\partial \theta}{\partial z}\Big|_{-Z_I} \quad \text{(i=1,2)} \qquad \textit{Mahrt and Pan, 1984}$$

I is the difference between the precipiation and direct runoff, Q_d, calculated as:

$$Q_d = \begin{cases} P - z_2 \cdot (\theta_S - \theta_2) + z_2 \cdot \theta_S \cdot (1 - \frac{i_0 + P}{i_m})^{1+b_i}, & P + i_0 \le i_m \\ P - z_2 \cdot (\theta_S - \theta_2), & P + i_0 \ge i_m \end{cases}$$

Where: $i = i_m(1-(1-A)^{1/b_i})$ and $i_m = (1+b_i)\cdot\theta_S\cdot|z|$ *Zhao et al., 1980*

A is the fraction of area for which the infiltration capacity is less than *i.*

The following equation is used for soil moisture for the lower soil layer and uses the water balance equation, which includes diffusion between the layers.

$$\frac{\partial \theta_3}{\partial t} \cdot (z_3 - z_2) = K(\theta)\Big|_{-Z_2} + D(\theta)\frac{\partial \theta}{\partial z}\Big|_{-Z_2} - E - Q_b \qquad \textit{Mahrt and Pan, 1984}$$

E is the evapotranspiration term and is zero when bare soil. When roots reach the lower soil layer, *E* needs to be considered.

The above equations indicate that depth of the layer is an important consideration in the calculation of soil moisture. In the sample datasets, depths are considered as fixed across the dataset. Typically, depths for the layers from the surface down are set as 0.1 m, 0.3 m, and 1.0 m. This project was an attempt to determine if the depth of soil layers as they vary spatially across the dataset really does need to be considered when working with the Variable Infiltration Capacity Model.

METHODS

There are several steps in getting the VIC model to run including acquiring basic data, processing it so that it can be appropriately ingested into the model, and setting up the parameter files. Data acquisition begins with the selection of a basin. Basin 1704020705 was arbitrarily selected using the National Hydrogaphy Dataset. A DEM of the area was created from National Elevation Dataset 30m data. Precipitation, maximum, and minimum temperature data for the month of May of 2011 was downloaded from the PRISM climate group web application. All datasets were converted to raster grids, resampled to $1/8^{th}$ of a degree, and transformed to WGS 84 to be properly read by the model. Several ArcGIS tools from ArcGIS Desktop and Workstation were used to manipulate the spatial data to a consistent extent, cell resolution, and spatial reference. These tools included but weren't limited to: clip, merge, clean, project, append, resample, polygon to raster, raster to ascii, etc. The majority of tools were executed in Workstation as it was easier to type the command with the appropriate parameters rather than chase down a GUI tool and click to select inputs and outputs. The complete steps for preparing the model input files on the VIC website were followed (http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Documentation/Inputs.shtml).

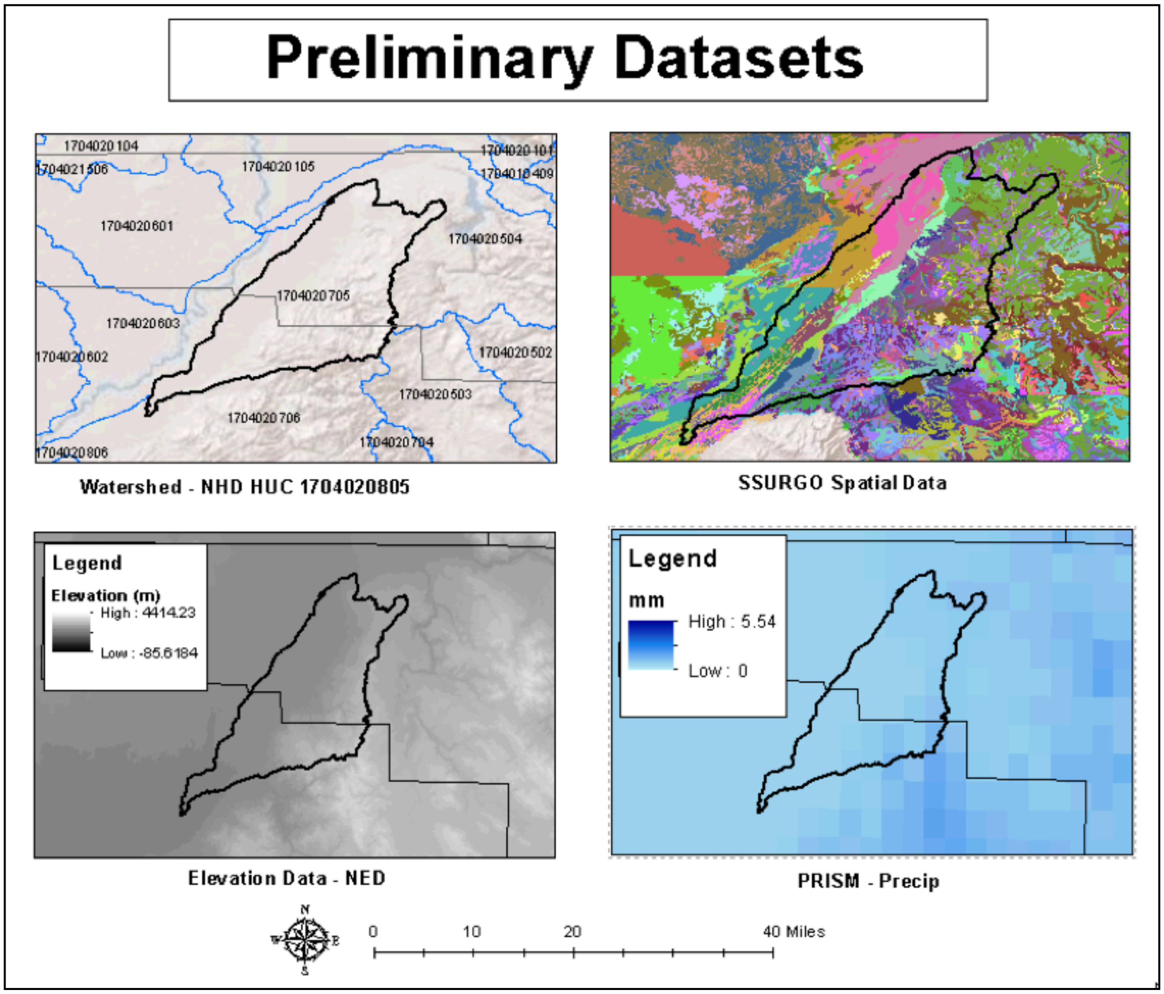

Figure 1. Base Layers

SSURGO datasets for Bonneville and Bingham county survey areas were downloaded from the NRCS Soil Data Mart web application, an additional template database was downloaded and a query to pull out horizon depths for each of the three layers by soil type. A table of soil type and layer depth was created and joined to the spatial dataset.

RESULTS

The resulting soil depths are shown in Table 1 of Appendix A. Average depth for Layer 1 is 0.22 m, 0.68 m for Layer 2, and 1.08 for Layer 3. The standard deviation for each is 0.134 m, 0.448 m, and 0.457 m, respectively.

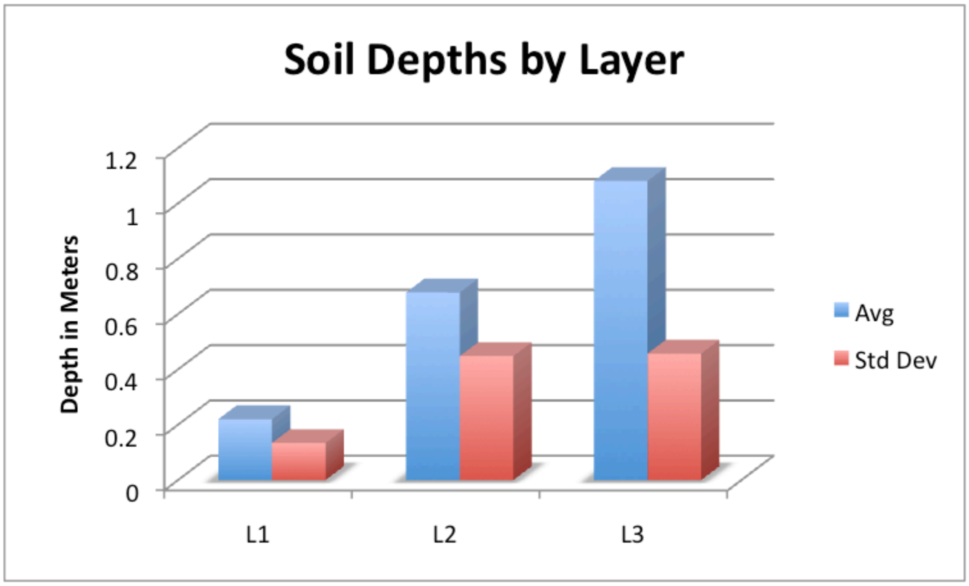

Figure 2. Soil Depth Statistics

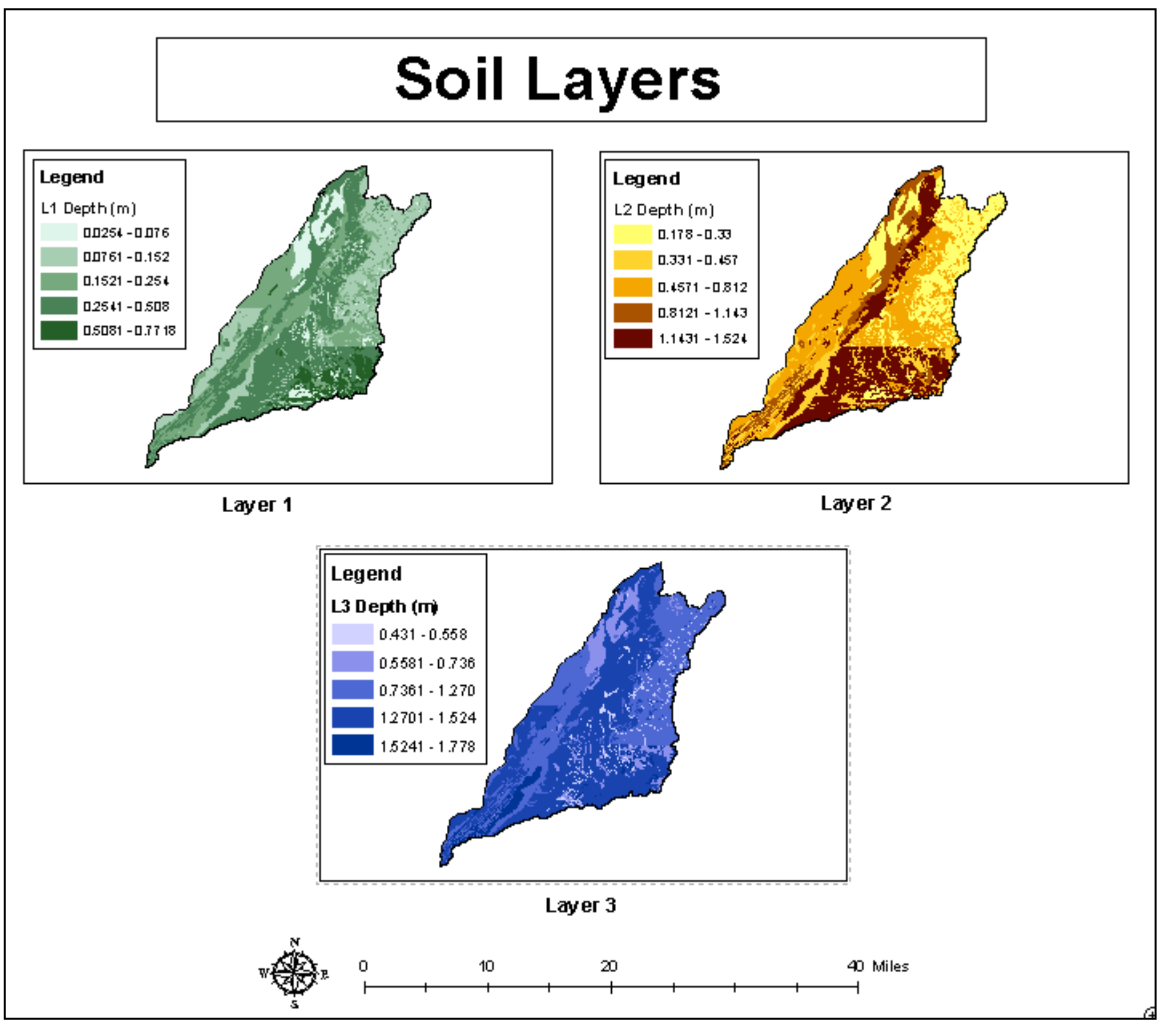

Figure 3. Soil Layer Variability

DISCUSSION

This project began with the ambition of being able to compare model runs of spatially static versus spatially variable soil depths. I was able to finish model parameterization and run it for the spatially static soil depths, but ran into a problem in generating the parameterization file for the spatially varied soil depths. Based on the statistics presented above, and considering the formulas discussed in the objectives section, I would expect differing results in model output for soil moisture.

CONCLUSIONS

In retrospect, I believe the scope of this work may have been slightly too much. The generation of the model inputs, calculation of soil layer depths from the SSURGO dataset, and troubleshooting parameterizing the spatially varied soil dataset took significant time.

Once the parameter file is properly configured and results can be produced, it would be interesting to address two questions, are thin layers (3 inches or less, for example) an appropriate consideration, and how to handle discrepencies between similar soil types

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APPENDIX A.

Table 1. Result of soil depth query for each layer and soil type.

Type	L1	L2	L3
Alpon	0.0254	0.3302	1.1684
Ammon	0.127	0.381	1.016
Araveton	0.1778	1.3208	1.6764
Aquic Cryoborlia	0.1778	1.3462	1.524
Typic Cryaquolls	0.1778	1.3462	1.524
Araveton	0.1778	0.3048	0.5334
Badgerton variant	0.3302	0.508	0.8128
Bannock A	0.1524	0.8128	1.524
Bannock	0.0508	0.1778	0.3302
Blackfoot	0.2032	0.4572	0.635
Bock A	0.254	0.381	1.1938
Bock	0.1016	0.254	0.6096
Bondranch	0.0762	0.4064	0.6604
Declo	0.1778	0.254	1.524
Dranyon a	0.508	1.7018	1.7018
Dranyon	0.0508	0.1524	0.5588
Gilispie	0.1524	0.4064	0.6604
Enochville	0.3302	1.3462	1.524
Fingal	0.2032	0.5588	1.524
Firth	0.3048	1.016	1.524
Fulmer	0.2794	1.5748	1.5748
Harston	0.254	0.508	0.635
Hayeston	0.2286	0.762	1.524
Heiseton A	0.2032	0.9652	1.143
Heiseton	0.2032	0.3556	0.7366
Hobacker	0.1016	0.4064	0.5588
Hymas	0.1778	0.4572	0.7112
Judkins	0.0508	0.1016	0.254
Kimama	0.2794	0.762	1.524
Knull	0.127	0.254	0.8128
LaJara	0.3048	1.524	1.524
Lanark A	0.3556	1.0414	1.524
Lanark	0.127	0.254	0.635
Malm A	0.0762	0.4572	0.8636
Malm	0.1778	0.4572	0.6096
Marsh	0.5588	1.524	1.524
Matheson	0.0762	0.381	1.1684
Mike	0.254	0.4572	0.7112
Newdale	0.3302	1.524	1.524
Nielsen A	0.1524	0.4826	0.7366
Nielsen	0.1524	0.254	0.4572
Outlet	0.4064	0.9144	1.8288
Packham A	0.1524	0.6096	1.524
Packham	0.1016	0.2032	0.381
Paesl A	0.2286	0.4318	0.6858

Paesl	0.127	0.254	0.4318
Pancheri A	0.127	0.6604	1.524
Pancheri	0.1524	0.254	0.4318
Paniogue	0.2286	0.7874	1.27
Paul	0.127	0.3302	1.143
Paulson	0.1524	0.4318	0.9398
Pavohroo	0.0254	0.4572	1.143
Polatis A	0.0762	0.1778	0.7112
Polatis	0.1524	0.2286	0.5588
Portneuf	0.3556	1.4732	1.7272
Portino	0.127	0.254	0.7366
Potell	0.1524	0.254	0.508
Presto	0.2032	0.7112	1.524
Rexburg	0.3048	0.635	1.524
Ricrest	0.2286	0.5842	1.524
Rin	0.1778	0.7112	0.9144
Ririe	0.2032	0.381	0.7366
Robin A	0.762	1.524	1.524
Robin	0.254	0.4572	0.635
Sasser	0.3556	0.9652	1.524
Sessions	0.381	1.524	1.524
Sheege	0.1524	0.4318	0.6858
Spaa	0.1778	0.4572	0.7112
Stan A	0.4064	0.7366	1.27
Stan	0.3302	0.6604	0.8636
Swanner A	0.3556	0.4572	0.7112
Swanner	0.3556	0.4572	0.7112
Tetonia A	0.4572	0.6604	1.524
Tetonia	0.2032	0.381	0.5588
Tenno	0.127	0.381	0.4318
Terrace escarpments	0.127	1.524	1.524
Thornock	0.0762	0.1524	0.381
Torriorthents	0.1524	1.27	1.524
Turnerville	0.5842	1.2192	1.8288
Wapello	0.2032	0.7366	1.778
Wahtigup	0.2286	0.7112	1.143
Wardboro	0.0508	0.2794	1.524
Waycup	0.2032	0.4064	1.27
Weeding	0.508	1.143	1.524
Wolverine	0.1524	1.524	1.524
Xeric Torrifluvents	0.254	1.524	1.524