Development of a Statewide Erosion Vulnerability Screening Tool for Oregon

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Abstract

The Oregon Department of Agriculture (ODA) is responsible for implementation of the State's water quality protection programs on agricultural lands. In cooperation with Central Washington University (CWU) and Oregon State University (OSU), the department developed a statewide Geographic Information System (GIS) procedure using ArcInfo that can be used to examine basin-scale soil erosion potential.

Our objective was to develop a tool that would allow evaluation of relative vulnerability of soils to erosion across all water quality planning basins in Oregon. The output should then allow water quality protection efforts to be focused (e.g., planning, conservation dollars, and monitoring).

The goals of this paper are to 1) illustrate the methodology and applicability of our chosen methodology, 2) describe a cooperative project between a state agency and

two universities, and 3) to show a model by which small-scale, computationally intensive work can be completed at a relatively low cost.

Project Description:

The Natural Resources Conservation Service (NRCS) uses the Revised Universal Soil Loss Equation (RUSLE) extensively to predict soil loss from cropland. In a general sense, the RUSLE may be divided into environmental variables and land management variables. Considering only the environmental variables does not allow absolute estimation of erosion, however, it does allow an evaluation of basin-scale potential for soil erosion. As an example, the soil erosion potential is evaluated within a selected basin to rank areas in terms of their relative vulnerability. This information can be used in a variety of ways, including: selection of stream monitoring locations for sediment or sediment-adsorbed pollutants, land-use planning as it relates to earth disturbing activities (e.g., tillage, construction sites, etc.), estimation of best management practice efficiencies required to prevent excess sediment loading of streams, identification of target areas for conservation dollars or research, and qualitative comparison with Total Maximum Daily Load (TMDL) allocations (i.e., does the TMDL seem to be consistent with our understanding of erosion vulnerability?). Use of the data should be limited to analysis of trends in upland erosion potential across drainage basins unless further validation of the results presented in this paper show that the method may be used for calculation of sediment loads resulting from upland erosional processes.

The new GIS procedure accounts for the influence of soil, rainfall, and topography by combining the associated RUSLE factors. Soil erodibility was extracted from K-factor values in SSURGO and STATSGO GIS coverages (provided by the NRCS). Preliminary R-factor maps (2001), representing rainfall influence, were provided by the Oregon Climate Service (OCS). The LS-factor maps were generated at CWU from 30m USGS Digital Elevation Model (DEM) data. The LS-factor accounts for both slope steepness and slope length.

Both the Oregon Department of Agriculture and Central Washington University are ESRI product users – all work was completed using either ArcInfo GRID or ArcGIS 8.2.

RUSLE

The Revised Universal Soil Loss Equation (RUSLE)) (Renard *et al*., 1997) has been selected as the governing equation for the ODA GIS-Based Erosion Screening Tool. Inspection of the variables of RUSLE indicates that the equation may be broken two parts: 1) the environmental variables, and 2) the management variables.

The environmental variables include the R, LS, and K factors. The R factor incorporates the rainfall dependency of erosion. The LS factor considers both slope angle and slope length. The K factor incorporates those aspects of a soil that contribute to its relative susceptibility to erosion.

The management variables are the C and P factors. The C factor relates to vegetation and method of cultivation. In agricultural regions, this would be the crops grown; outside agricultural regions it relates to a combination of vegetation cover and

ground debris. The P factor allows accounting for implementation of erosion control practices in agricultural lands.

It should be readily apparent from the above descriptions of the variables that the environmental variables are relatively constant over the timescale of tens of years (at a minimum), while the management variables may change over the course of a year or less. For this reason, it is difficult to obtain current and accurate management variable coverage.

On the other hand, if the environmental variable data layers are available, or reasonable estimates of the values may be made, compilation of the data layers in the "usual way" (i.e., multiplication of the values as in RUSLE) may allow interpretation of basin wide trends in soil erosion vulnerability.

Alternatives to the RUSLE

There exist a host of alternatives to the RUSLE approach. These include fuzzy logic, multi-criteria evaluation of various environmental variables (other than RUSLE), and learning algorithms. While all of these approaches represent reasonable approaches for analyzing this type of spatial data, development of each could be accurately characterized as research since the resulting relationship between the variables would need to be validated. By using the RUSLE, we already have a certain amount of validation and acceptance of the relationship as being consistent with the physical system (at least for agricultural lands). Also, the RUSLE-type approach

(including USLE, MUSLE, etc.) is currently being used in Oregon for watershed modeling of sediment loads.

Required Data

The data layers required for an environmental vulnerability screening tool for erosion include the R, LS, and K factor maps. K factor maps are currently available as part of the NRCS SSURGO (approximately 1:24,000 scale) and STATSGO soil survey data sets (approximately 1:250,000 scale). Where SSURGO data was available, it was used; elsewhere, STATSGO data was used to fill the gaps. Prior to use in the RUSLE equation, the K factor data were rasterized to 30m. New R factor maps (at a 4km grid scale), completed by Oregon Climate Service (OCS) for the western U.S., are currently being reviewed by EPA and NRCS. The data used would, therefore, be considered draft.

This leaves LS factor maps as the remaining item needed for creation of a composite map for the state of Oregon. The existing data layers that are closest to an LS layer are LS values available in soil surveys. These yield a range of values and some method of choosing a discrete value must be utilized for computational purposes.

Alternatively, LS factor values can be calculated from DEMs [Hickey *et al*., 1994; Van Remortel *et al*., 2001]. DEMs are currently available in 30 meter and 10 meter resolutions for the State of Oregon. The 30 meter resolution data corresponds to roughly 1:24000 scale, and is, therefore, compatible with the highest resolution soils (K) data. As some of the K data and all the R factor data are at considerably lower

resolutions, the 30 meter DEM was considered to be acceptable for this calculation. In addition, the LS calculation is very computer intensive. Therefore, using the 10 meter data would involve approximately a nine-fold increase in computer time. As it turned out, approximately 1800 hours of computer time (spread over eleven computers) were required to process the entire State at 30m resolution. When complete, the eleven LS grids were merged into a single LS factor grid that encompassed the state of Oregon.

The compilation of the environmental variables from RUSLE is a combined RKLS layer. This was done using ArcGIS Spatial analysis with the output resolution set to 30m and the extent set to the state of Oregon. Calculation times were trivial. The results are in numbers that have no real units. This relationship between the factors was developed to satisfy the empirical relationship of the factors to observed erosion (as documented by USLE research). For this reason, it is likely that the results may only be used in two ways. First, the data may allow qualitative comparison of environmental vulnerability to erosion across a basin (either through assignment of relative magnitude or percentile of land area). Second, the data may be used as input to a RUSLE calculation if the required C and P factors can be obtained.

LS-Factor Layer

The LS-factor layer was calculated using an ArcInfo AML using the method of Van Remortel *et al*. (2001) (visit http://www.yogibob.com/slope/slope.html for more information). The calculations were conducted on 30 meter DEM data. Since the calculation is very computationally intensive and as one of the code's authors, Dr.

Robert Hickey is affiliated with Central Washington University (CWU), CWU was contracted to create the LS coverage.

To manage the computational load, the state was divided into eleven watersheds. Each watershed was then run on a different computer in CWU's GIS lab (http://www.cwu.edu/~gis/) during Christmas break, 2001. Depending on the size of the watershed, the LS factor calculations finished in 68 to 312 hours. The PCs were 1 GHZ PIII's with 256mb RAM and 30 GB harddrives. Without the availability of the lab, it would have taken a single dedicated PC approximately 75 days to finish the calculations. It is worth noting that newer code is available that cuts LS processing times by a factor of around 30.

QA/QC and Preliminary Results

Since the computer code is relatively new and has only recently been published in the peer-reviewed literature (Hickey *et al*., 1994; Van Remortel *et al*., 2001), the method of calculation was reviewed for reasonableness of the assumptions. This review was conducted by GIS modelers at Oregon State University (OSU) and by ODA geomorphologists, hydrogeologists, and GIS specialists. The review indicated that assumptions appeared reasonable, though sub-grid effects (i.e., changes in slope that occur on a less than 30 meter length scale) may result in more frequent deposition of sediment (i.e., shorter slope lengths). When considering that the goal of the tool is to identify basin scale trends, the effect of sub-grid effects is thought to be relatively small or at least uniform across the basin (since the same assumptions hold everywhere). This implies that the results of the calculation should only be used in a comparative

sense, and not to calculate sediment loads unless further validation or correction of the data occurs.

In addition to the above algorithm review, an extra level of quality assurance was accomplished by performing a more detailed review of a single basin where erosion is understood relatively well. The Umatilla water quality planning basin was chosen because there is a sediment total maximum daily load (TMDL) in place and NRCS highly erodible land (HEL) determinations are available in an electronic format. The Umatilla basin location is provided in Figure 1. Its area is 6607 square kilometers, representing about 2.4% of the state of Oregon. Figures 2, 3, and 4 respectively show the K, LS, and RKLS data layers that resulted from the screening tool output.

The DEQ TMDL modeler that completed the TMDL assessment reviewed the data for consistency with his experience. Initial review indicated that the screening tool results were consistent with his understanding of basin processes controlling erosion. A direct comparison is difficult because TMDL output is in-stream sediment loads at certain points, whereas RUSLE output specifically excludes stream areas. Thus, in this comparison, the RUSLE output may be used as a screening tool to identify potential source areas for the in-stream loads.

Next, NRCS HEL output (Figure 5) was visually (qualitatively) compared with the RKLS output. The HEL erodability determination was accomplished by dividing RKLS by T (the soil loss tolerance factor). In this case, the LS, K, and T values utilized are those available in NRCS soil surveys. The R-factor is from older available R maps. The methodology is not particularly sensitive to which LS value is selected from the published range (so long as a consistent choice is made) because the computation is

only used to put each soil map unit into one of three categories ranked 1 to 3 (where 1 is considered HEL). If a soil received a rank of 2, a more detailed analysis is accomplished by a qualified soil scientist to categorize the soil as a 1 or 3 (for a detailed description of this process, contact NRCS).

So, what you get is a map with only two values (HEL and NHEL). A visual comparison of the ODA RKLS layer to the HEL designated lands shows good consistency between the two methods. Areas of inconsistency (e.g., northern part of the basin in low topography) appear to be the result of division of RKLS by T. Areas of relatively thin or thick soil may have a strong influence on T. The Northern part of the Umatilla basin typically has only a thin veneer of soil overlying Columbia River Basalts indicating much less soil loss is tolerable for sustainable production of crops (i.e., lower values of T). Since the ODA RKLS layer is only designed to show areas where sediment may be vulnerable to movement into waterways, it is insensitive to soil thickness which may result in the apparent inconsistency.

Summary and Conclusions

Preliminary review of the newly generated RKLS layer indicates that the data is consistent with previous attempts to understand sediment delivery in Oregon watersheds. It is, however, the first time this type of modeling has been conducted over such a large area. Future work with GIS driven tools will allow analyses of basins for planning, monitoring, and allocation of resources.

However, the limitations of this approach must also be considered. First, erosion was not calculated – only erosion vulnerability based upon environmental variables. Second, as the RUSLE was designed primarily for agricultural regions, output in non-

agricultural regions may be inconsistent. Finally, the scale of the project (30m pixels and worse) must be considered. As erosional processes are often driven by relatively small features (<5m,.e.g. - consider the effect of a logging road on overland flow), output should be treated as qualitative, not quantitative. In other words, look at the pattern of erosion (vulnerability), not the values of individual cells.

The university partnerships with ODA generated a number of benefits. First, in cooperation with ODA, Oregon State University volunteered no-cost technical expertise and use of computational facilities for development of the screening tool. Second, the partnership with CWU and the use of CWU's GIS lab allowed a calculation which was not possible using the resources available at ODA. It was one of those fortunate occurrences where both parties felt they got the best of the deal – CWU was happy with its payment, ODA thought they got things done cheaply.

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Figure 4: RKLS factor output.

Figure 4: HEL output.

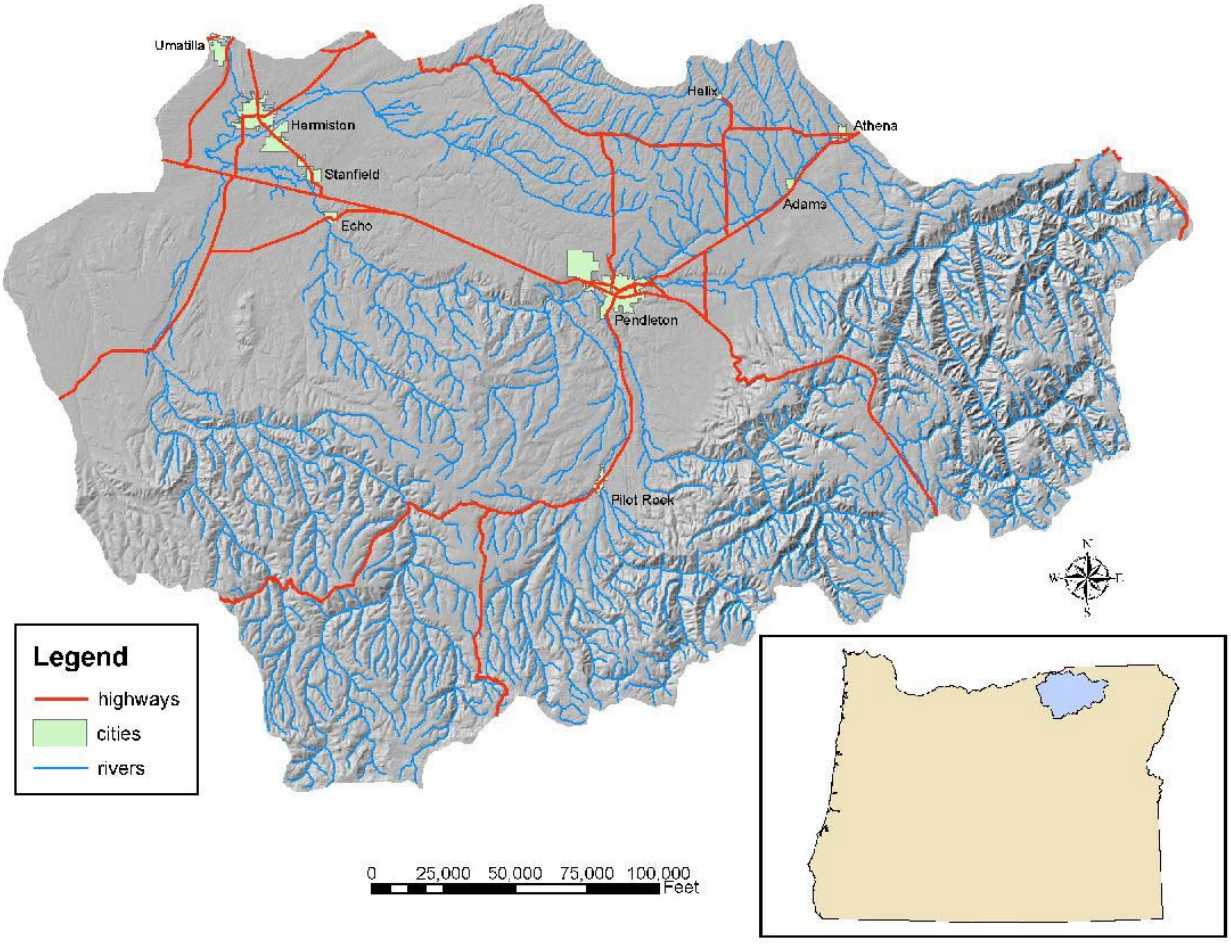

Figure 1 – Site location Map, Umatilla River watershed.

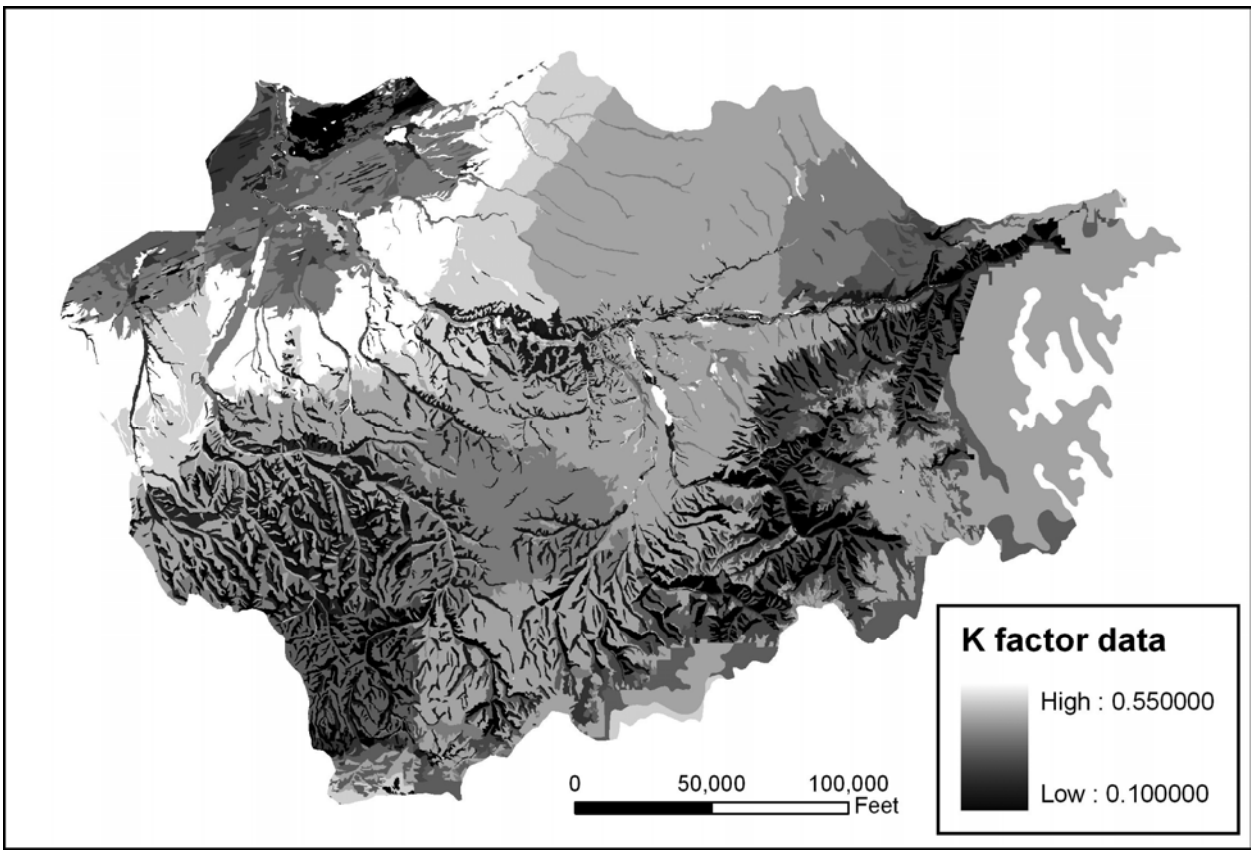

Figure 2: K-factor data for the Umatilla River watershed.

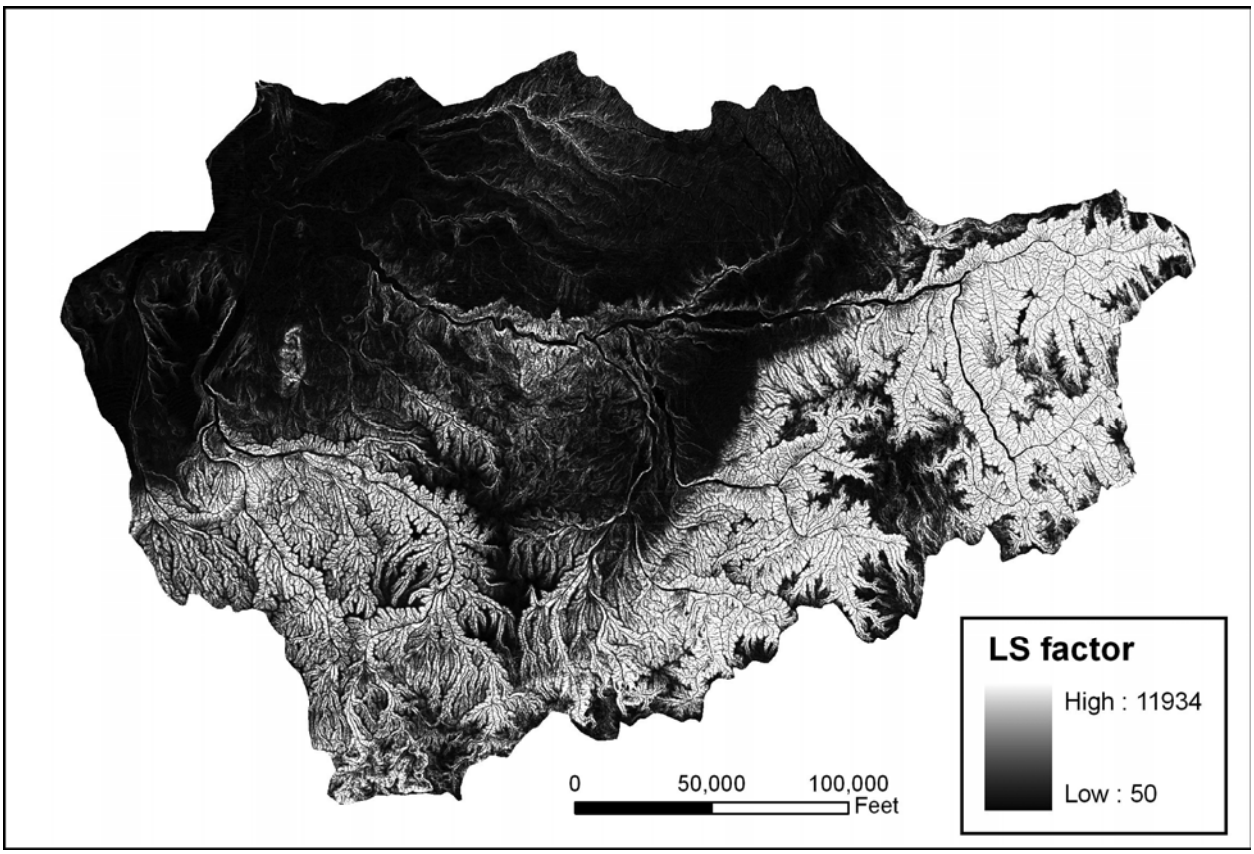

Figure 3: LS factor output for the Umatilla River watershed.

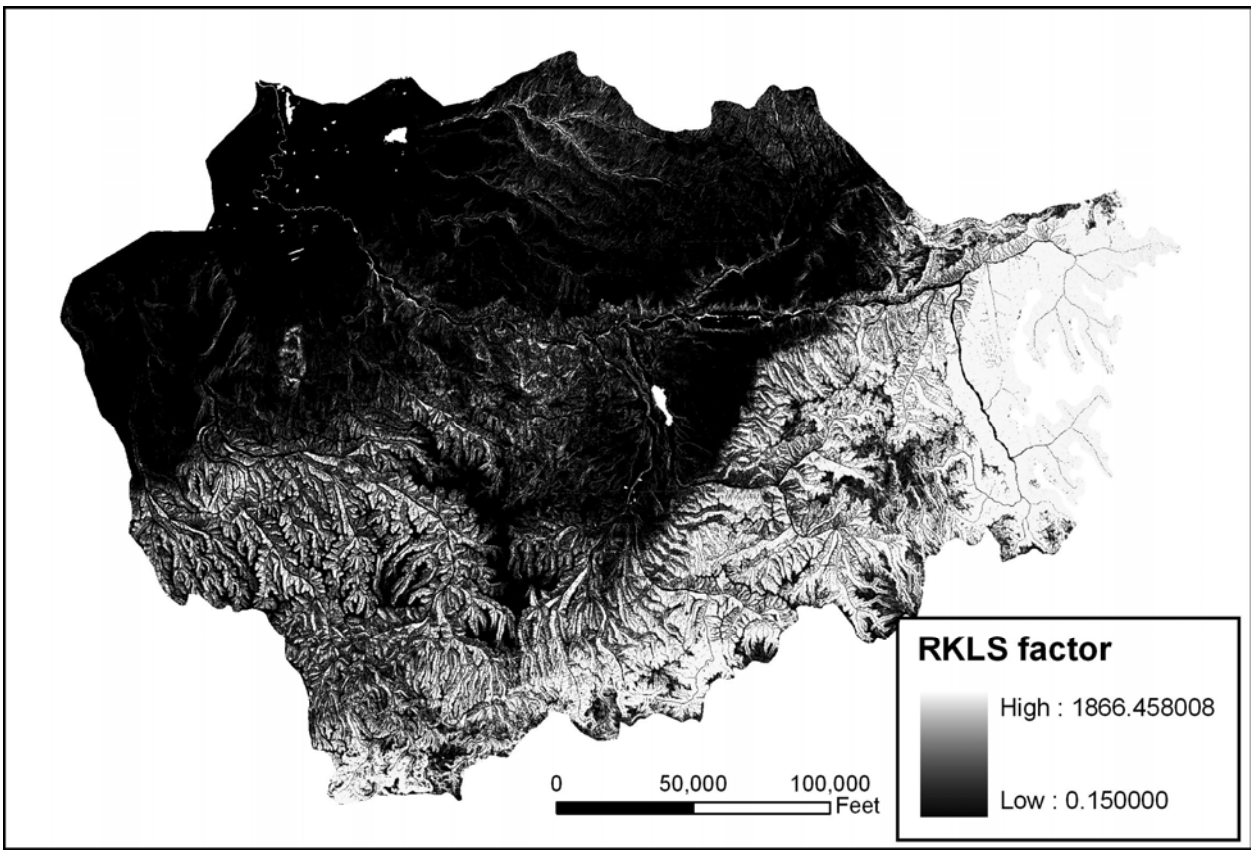

Figure 4: RKLS factor output.

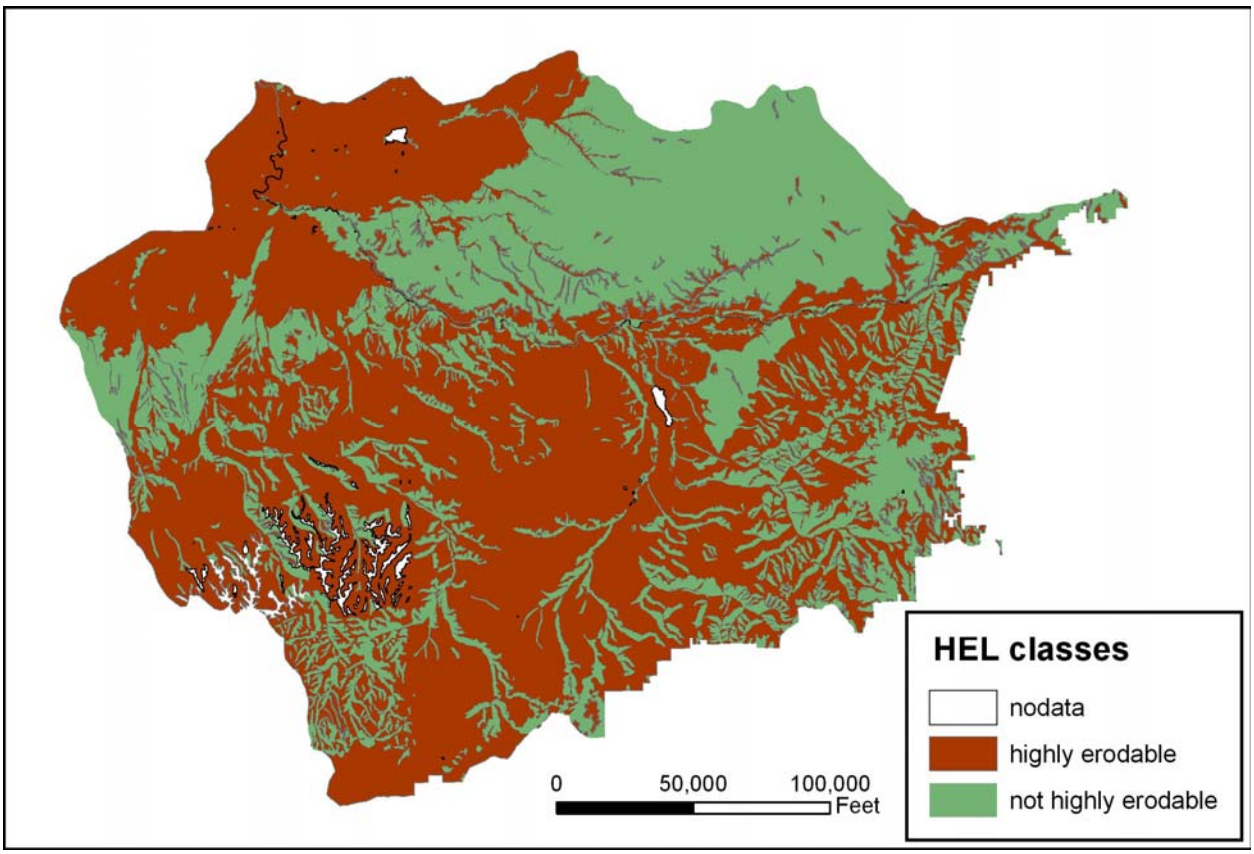

Figure 5: HEL map.