Development of Online Tools to Support GIS Watershed Analyses

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In 1996 there was a meeting in Tucson of hydrologists from every Forest Service region, as well as Forest Service research scientists engaged in watershed-related activities. This meeting was organized by the Stream Team (which has since been enveloped by the National Stream and Aquatic Ecology Center). The focus of the meeting was to identify tools that needed to be developed to support watershed management. One of the suggested tools was a GIS-based application that could run on the internet. At that time, federal websites were in their infancy, and the development of GIS tools for watershed analysis was only just beginning. Scientists at the Forest Service Rocky Mountain Research Station (RMRS) took this challenge to heart. In 1999, with support from the San Dimas Technology and Development Center, they introduced the first ever online interface to the Water Erosion Prediction Project (WEPP) model to predict soil erosion for forest road segments and forest hillslopes disturbed by wildfire (Figure 7), as well as for forest management (Elliot 2004). These interfaces were quickly adapted by the Forest Service and other land management agencies.

Figure 7: Wildfire-impacted hillslope, from the 2012 High Park Fire (photo credit: Steven Yochum).

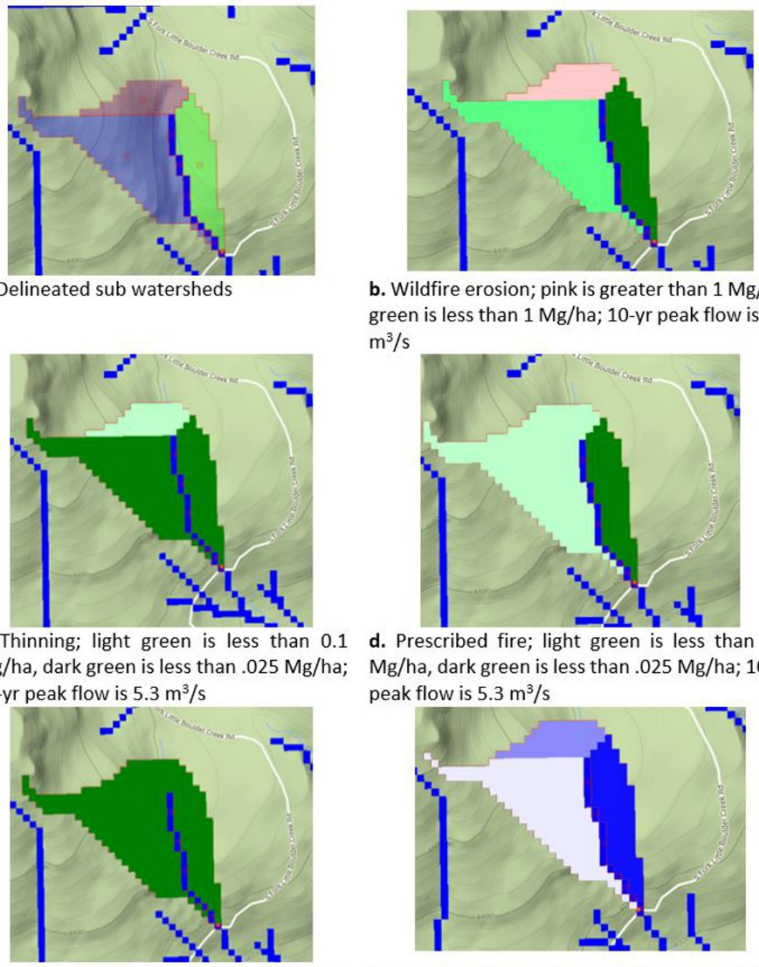
In the late 1990s, a GIS interface was developed by the USDA Agricultural Research Service (ARS) National Soil Erosion Research Laboratory for the WEPP Watershed Version (Cochrane and Flanagan 1999). The interface ran in ArcView, and shortly after introducing it a GIS wizard was developed to aid in applying GIS tools to predict erosion from hillslope polygons delineated by the wizard using the WEPP model (Renschler 2003). Two grants were received from the Joint Fire Science Program to further enhance this tool, known as GeoWEPP, for forest conditions. It was upgraded to run in ArcMap 8.x and continues to be upgraded for current versions of ArcMap by the State University of New York, Buffalo. When field personnel tried to apply this tool, however, many found that they did not have the time to develop the level of GIS skills required to use GeoWEPP. In the early 2000s, the ARS also developed a proof of concept online GIS watershed tool that was not intended for widespread application (Flanagan and others 2004).

In 2009, the Army Corps of Engineers, Chicago Office, approached RMRS to develop an online sediment delivery tool that could be applied to forested watersheds in the Great Lakes Basin. RMRS, in collaboration with the ARS and Washington State University, began the development of a user friendly online GIS tool to support forest watershed management. The team built on the Flanagan and others (2004) prototype, and upgraded it with a Google Map interface to zoom into sites. A comprehensive forest soil and management database similar to the FSWEPP database (Elliot, 2004) was added. The interface accessed digital elevation data from a USGS server and an 800-m climate database from the Natural Resource Conservation Service (NRCS; Frankenburger and others 2011). The interface also accesses the USGS land cover database and NRCS Soil Survey Geographic Database (SSURGO) Soils Database. For a single run, the watershed area is limited to about 400 ha (1,000 acres). On larger watersheds, spatial variability of weather becomes important, with higher elevations of the watershed receiving more precipitation, and much of that as snow. Work is ongoing to incorporate climate variability into the model and increase the area that can be modeled.

The skill level necessary to use the model is similar to that required to use other online mapping tools with advanced features, such as Google Earth. An online set of instructions can be downloaded to guide the use through the steps necessary to carry out a post-wildfire run, or a set of fuel management runs. Figure 8 summarizes the four recommended scenarios for a fuel management analysis (low-severity wildfire; thinning, prescribed fire, forested). This example is from the East Deer Creek watershed in the Colville National Forest, a watershed that provides municipal water to a nearby town. To use this tool, the user first zooms to a site of interest, builds a channel network, and selects an outlet point for the sub watershed of interest (Figure 8a). This sub watershed is then run for the four scenarios. The results of each run can be saved as maps and tables, and allow the user to compare the potential sediment delivery from forest management to that from an undisturbed forest and a wildfire. Figure 8 shows some of the results from the four runs.

Figure 8f shows the distribution of predicted surface runoff plus lateral flow following a prescribed burn. Note that not all hillslopes respond the same way to a prescribed burn. The maps shown in Figure 8b – e are useful in helping managers decide which hillslopes may be at risk to the greatest erosion, and prioritize those hillslopes for treatment. The example analysis shows that the hillslope at the top of the watershed has the greatest erosion risk, so managers may consider practices other than prescribed fire to treat this slope, like thinning followed by mastication, or doing a prescribed burn in early summer when conditions are damp, and the loss of duff will be minimal when burning slash or understory.

Users can export the results of each run for importing into ArcMap, where the results from several runs can be displayed in a single map. A recommended approach for summarizing the model outputs is outlined in Table 1 (Elliot 2013). With this approach, the sediment delivery associated with the disturbance is divided by the frequency of the disturbance to determine an average annual sediment delivery due to the disturbance. In the example in Table 1, the sediment deliveries averaged out over the time between every disturbance are less than the annual sediment delivery from an undisturbed forest, suggesting that in the long term, sediment delivery on this watershed is not impacted by these disturbances. Table 1 also shows the estimated sediment delivery the year of the disturbance, which may be of interest to downstream water users in that year. The interface can also predict return period values for daily sediment delivery, a number that can be considered a reasonable estimate for a Total Maximum Daily Load. Figure 8b – e also shows the predicted peak flow rates at the outlet of this watershed, which is at a road-stream crossing. Note that the estimated post wildfire peak flow is nearly 20 times greater than



a. Delineated sub watersheds

b. Wildfire erosion; pink is greater than 1 Mg/ha, green is less than 1 Mg/ha; 10-yr peak flow is 8.8 m^3/s

c. Thinning; light green is less than 0.1 Mg/ha, dark green is less than .025 Mg/ha; 10-yr peak flow is 5.3 m^3/s

d. Prescribed fire; light green is less than 0.1 Mg/ha, dark green is less than .025 Mg/ha; 10-yr peak flow is 5.3 m^3/s

e. Undisturbed forest; predicted hillslope erosion is 0; 10-yr peak flow is 0.47 m^3/s

f. Prescribed fire: surface runoff and lateral flow; dark polygon is 150 mm/yr, lighter polygon is 120 mm/yr, and lightest polygon is 105 mm/yr

Figure 8: Example of a set of runs on the online interface. The watershed area was limited to only 32 ha (80 a) for this example, located in the Colville National Forest. The interfaces determined that the watershed was 96 percent forest. The erosion rates shown are for estimated hillslope erosion.

Table 1: Summary of a fuel management analysis. Column 3 is the average predicted sediment delivery for the year following the disturbance; Column 4 is the average annual sediment delivery following the disturbance divided by the frequency of the disturbance. In this watershed, erosion rates from wildfire, prescribed fire, and thinning are all sufficiently low that when averaged over the frequency of the disturbance, they are unlikely to change the long term average sediment yield. This analysis assumes all hillslopes are treated the same, and that the fire return interval is increased from 40 to 60 years if fuel management practices are applied.

Unmanaged				**Managed**			
Land Use	Disturbance Frequency (yr)	Disturbed Erosion (Mg ha^{-1})	Avg Annual Erosion (Mg ha^{-1} yr^{-1})	Land Use	Disturbance Frequency (yr)	Disturbed Erosion (Mg ha^{-1})	Avg Annual Erosion (Mg ha^{-1} yr^{-1})
Forest	1	0.1	0.1	Forest	1	0.1	0.1
Wildfire	40	0.8	<0.1	Wildfire	60	0.8	<0.1
				Thinning	20	0.4	<0.1
				Rx Fire	20	0.5	<0.1
Weighted Average			0.1	Weighted Average			0.1

the peak flow for an undisturbed forest. The online documentation shows how to carry out an analysis where not all hillslopes are treated the same in a given year

An online interface to be used after wildfire is under development. It can currently predict the erosion following a wildfire, and work is ongoing to allow users to compare this to pre-fire conditions and to evaluate the benefits of mulching. Another interface is under development for the Lake Tahoe Basin that is incorporating enhanced output analyses to predict delivery of phosphorus and fine sediment (silt- and clay-size particles and aggregates). Once complete, it can be applied nationwide. A prototype interface is also under development for predicting sediment delivery from roads within a watershed. Because the national road database is so large, further resources will be needed to develop a consistent road database to support it. The road interface has been used once to support an analysis in a sensitive area within the Colville National Forest. A similar interface was also developed for post mining conditions where a user could upload a post mining digital elevation model, but the interface is not currently online. It includes advanced features to aid users in evaluating the effectiveness of sediment basins. If there is sufficient interest, the post mining interface can be reactivated.

Management Implications

With the use of online tools for GIS watershed analyses, key advantages are that:

- The time required to assemble the necessary database for a GIS watershed analysis is eliminated; specialists can focus on modeling and not GIS data acquisition and formatting.
- There is no need to rewrite watershed management software every time a new version of proprietary GIS software is released.
- Training time on how to apply GIS tools to watershed analyses is reduced.
- Online NRCS soil and climate databases can be readily accessed to support other planning activities.

References

Cochrane, T.C.; Flanagan, D.C. 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. Journal of Soil and Water Conservation. 54, 678-685.

Elliot, W.J. 2004. WEPP internet interfaces for forest erosion prediction, Jour. of the American Water Resources Assoc. 40(2): 299-309.

Elliot, W.J. 2013. Erosion processes and prediction with WEPP technology in forests in the Northwestern U.S. Trans ASABE. 56(2): 563-579.

Flanagan, D.C.; Frankenberger, J.R.; Engel, B.A. 2004. Web-based GIS application of the WEPP model. Paper No. 042024. Presented at the Annual International Meeting of the ASAE, 1-4 August, 2004, Ottawa, Canada. St. Joseph, MI: ASAE. 12 p.

Frankenberger, J.R.; Dun, S.; Flanagan, D.C.; Wu, J.Q.; Elliot, W.J. 2011. Development of a GIS interface for WEPP model application to Great Lakes forested watersheds, Paper No. 11139. Presented at the International Symposium on Erosion and Landscape Evolution, 18-21 September, 2011, Anchorage, AL. St. Joseph, MI: Am. Soc. Ag & Bio Engrs. 9 p

Renschler, C.S. 2003. Designing geo-spatial interfaces to scale process models: The GeoWEPP approach. Hydrological Processes 17: 1005-1017.