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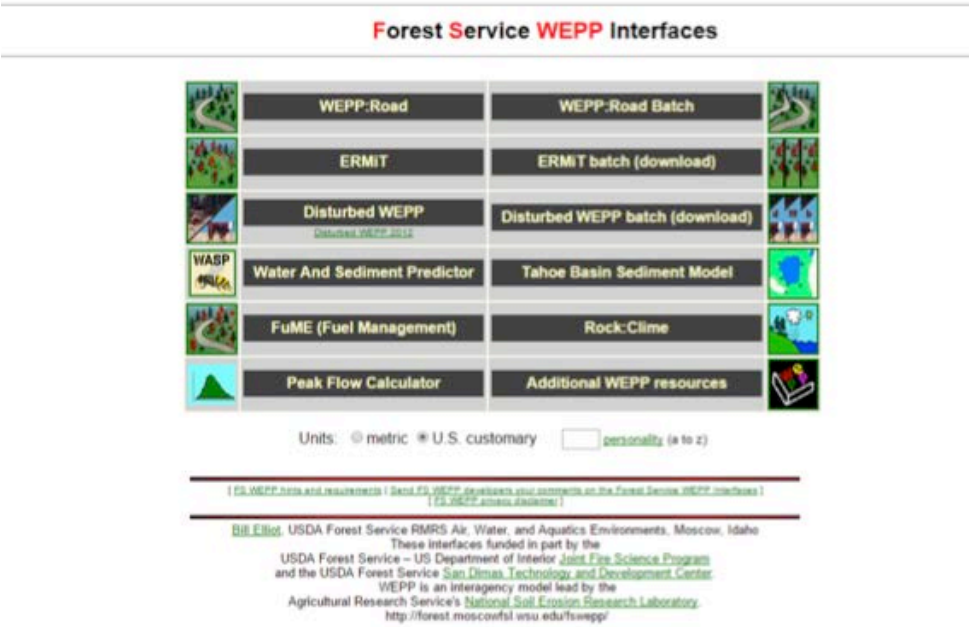
From Watersheds to the Web: Online Tools for Modeling Forest Soil Erosion

Forest soil erosion can lead to topsoil loss and harmful sedimentation. In this photo, Rocky Mountain Research Station (RMRS) scientist Pete Robichaud explains how to measure soil infiltration rates, while a Korean scientist has his smartphone ready to estimate erosion risk in this Korean forest using WEPP software he can access via RMRS. (Photo Courtesy of Pete Robichaud).

SUMMARY

Forest erosion can lead to topsoil loss, and also to damaging deposits of sediment in aquatic ecosystems. For this reason, forest managers must be able to estimate the erosion potential of both planned management activities and catastrophic events, in order to decide where to use limited funds to focus erosion control efforts. To meet this need, scientists from RMRS (and collaborators) have spent over a decade developing a suite of online tools that can be used to predict erosion potential of forest alterations such as road building, forest management, and wildfire, as part of the Forest Service–Water Erosion Prediction Project (FS-WEPP). WEPP: Road was designed for predicting erosion from roads—a chronic source of forest sediment—and provides an estimate of the average annual sediment delivery of a road or road network. The Erosion Risk Management Tool (ERMiT) can estimate of the amount of post-fire erosion, and it also allows the user to evaluate the effect of different erosion control treatments options. Disturbed WEPP allows managers to model erosion from many disturbed forest and rangeland erosion conditions (such as management activities), including low and high severity burns. Also in development is the WEPP Online GIS Watershed Interface, which allows watershed-level erosion predictions on any PC with access to Google Maps. FS-WEPP is being continually refined, improved, and expanded upon to increase its usefulness, and to enable managers to run predictive watershed models for better land management decision-making and more desirable outcomes.

It is easy to take the soil beneath our feet for granted, but the process of erosion can cause this life-sustaining resource to simply blow away or wash downhill in a relatively short amount of time. Soil erosion is a widespread problem in both agricultural and forested ecosystems, and is the number one cause of land degradation worldwide. The most famous example of wind erosion in the US is the Dust Bowl of the 1930s, when extended drought combined with poor farming practices on the high plains led to vegetation loss, and the loosened top soil dried up and was swept away in enormous dust storms. In the Rocky Mountains, most forest soil erosion starts with precipitation, which can either soak into the ground or run off across the land surface and into channels and waterways.



Screen shot of the main screen accessing the online FS WEPP suite of interfaces at http://forest.moscowfsl.wsu.edu/fswepp/ (accessed 31 Oct 2014). The main tools discussed in this article are WEPP:Road, ERMiT, and Disturbed WEPP. The other tools listed above are briefly described in the call out box, "Other FS-WEPP Erosion Prediction Tools."

"Natural resource managers are concerned about soil erosion because of its impacts on both soil productivity and offsite water quality," states RMRS research engineer Bill Elliot.

The soil tends to stay put when the water is able to infiltrate back into the forest floor. But when the ground is saturated and the water starts to move downhill, it often takes soil with it.

How much soil erodes, and where it ends up, is of utmost important to forest managers. The background rates of soil erosion in forests are extremely low—generally under 0.5 ton per acre annually—but both natural and human-caused disturbances can increase that rate more than 100 fold. Forest fire and road construction are the main agents of surface erosion in the Rockies, with activities such as forest thinning and other management activities making a minimum contribution. Erosion not only causes topsoil loss, but also deposits sediment in downstream waterways, creating problems for aquatic life and people using the water. According to Bill Elliot, Rocky Mountain Research Station (RMRS) Research Engineer, "Natural resource managers are concerned about soil erosion because of its impacts on both soil productivity and offsite water quality."

It is crucial that forest managers be able to predict the erosion potential of both planned activities (such as timber harvesting or road building) and catastrophic events such as wildfire so that they can put their limited funds towards the best course of erosion control. To meet this need, RMRS research engineers Bill Elliot, Pete Robichaud, and Randy Foltz, along with collaborators Dennis Flanagan (ARS National Soil Erosion Research Lab), Erin Brooks (University of Idaho), Joan Wu (Washington State University) and others, have developed a suite of simple-to-use and easily-accessible online erosion prediction tools for managers working in forested

Roads create low-infiltration strips in a high-infiltration environment (for example, the surrounding forest in this photo) and are a major cause of erosion in forests. Here, the road is showing erosion due to poor surface drainage (photos from http://www.fs.fed.us/GRAIP/gallery/).

"WEPP is different from other erosion prediction tools because it deals with delivery of sediment off site," explains Elliot. "Most agricultural models are more concerned with loss of soil productivity and are less concerned about where the soil eventually ends up."

conditions. These tools were designed as part of the Water Erosion Prediction Project (WEPP), which was launched two decades ago, and has been continually refined, improved, and expanded upon over the years. Funding to support the development of these tools over the past 20 years has come from RMRS, the San Dimas Technology and Development Center, the National Fire Plan, the Joint Fire Science Program, the Army Corps of Engineers, and the Southern Nevada Public Land Management Act.

THE WHERE AND WHY BEHIND WEPP

The original WEPP model was an outgrowth of the Universal Soil Loss Equation, which had been widely used by engineers to predict long-term soil losses. The basic WEPP model, or the "engine", is a Fortran computer program (which can be compiled on either Windows or Linux machines) housed at the USDA-Agricultural Research Service (ARS) National Soil Erosion Research Lab in Indiana, where Flanagan and his colleagues make improvements, corrections, and release updated versions of the model every 1-2 years. "WEPP is different from other erosion prediction tools because it deals with delivery of sediment off site," explains Elliot. "Most agricultural models are more concerned with loss of soil productivity and are less concerned about where the soil eventually ends up."

Seeing a clear need for the Forest Service to be able to predict the erosion consequences of management activity, Elliot and collaborators took the basic model and developed the FS (Forest Service)-WEPP online interface for forest road segments and hillslopes starting in 2000. The usefulness of the WEPP program lies in its simple user interfaces. Although the model requires hundreds of input variables to run, the online interfaces require only the minimum from the user, relying on large online databases to fill in the needed information. According to Elliot, "The FS-WEPP interfaces have been really popular, with more than 2 million runs since the 2000 release."

From the original hillslope model, WEPP has grown to encompass a wide variety of erosion prediction tools for specific applications (such as road building, fire, and forest management operations) at both the hillslope level and larger spatial scales. Both the basic WEPP model and FS-WEPP are based on decades of research and development by scientists doing everything from collecting mud samples in the rain to writing code for computer programs. Users visiting the FS-WEPP webpage today will find a variety of online erosion prediction tools, including WEPP: Road for predicting road erosion, Erosion Risk Management Tool (ERMiT) for the post-fire environment, and Disturbed WEPP for modeling erosion from forest management activities or fire. A further WEPP development is an online GIS interface which allows watershed-level erosion predictions from any PC with an internet connection—no GIS software required.

Severe wildfire can turn forests into a moonscape with the capacity to produce large volumes of sediment-laden runoff when it rains. This severe surface erosion occurred following the Klamath Complex wildfire near Happy Camp, California. Photo by N. Wagenbrenner.

Forestry operations, such as thinning, can be a source of erosion, but to a lesser extent than roads and fire. RMRS scientists measure cover on a skid trail that has been covered with slash to minimize erosion risks. Photo by W. Elliot.

USING WEPP TO PREDICT EROSION FOR COMMON FORESTRY SCENARIOS

Road Erosion

Roads are a chronic source of sediment from forests, producing some amount of erosion every year that they are in use. Randy Foltz explains, "Roads are erosion problems because they create low-infiltration strips (the road itself) in a high infiltration environment (the surrounding forest)." When a road is built, the soil is deliberately compacted for greater ease of vehicle travel; this compaction also reduces water infiltration and increases runoff. The amount of traffic is a factor in erosion. More traffic leads to greater compaction, and it also generates loose sediment on the surface that can be washed off with rainfall runoff. Also, without active management, most dirt roads develop wheel ruts over time. "This is a problem because you want to get the water off the road quickly, and wheel ruts don't allow you to do that," says Foltz. Ruts collect water, which then runs down the road in a concentrated flow path (think of running your garden hose on bare soil in your yard)—the longer the path, the more runoff is collected, and the more soil is dislodged. If the road gets too eroded, it becomes unusable and difficult to repair when budgets are tight.

Because of the ability of forest roads to generate sediment, it is important to know in general terms how much soil is coming from a road segment, which can be done with the online **WEPP:Road** tool. According to Foltz, "Our road model is focused on the road characteristics that have the greatest effect on sediment delivery, and can be easily determined by the user." To use this tool, managers usually start with a combination of field surveys, mapping, and GIS tools to estimate the road segment length and gradient, road width, surface conditions (e.g., rutted), road ditch condition (bare or vegetated) and traffic level. This information is then entered into the WEPP:Road interface, which can be run for a single road or in batch mode (up to hundreds of road segments). The output is an estimate of the average annual sediment delivery of a road or road network. "Most of the sediment will be coming from just a few places on the road network, and if you can identify those areas, you can concentrate your mitigation efforts there and reduce the erosion rate of the road network overall," notes Foltz. He adds, "These same principles are true for ATV trails – they tend to not be as compacted due to lighter vehicles, but otherwise they present the same types of erosion problems."

> ***"Most of the sediment will be coming from just a few places on the road network, and if you can identify those areas, you can concentrate your mitigation efforts there and reduce the erosion rate of the road network overall," explains research engineer Randy Foltz.***

Good road design can minimize erosion problems by shortening the flow path of runoff. Road designs that help to do this include cross sloping (so that water runs off diagonally) and creating grade reversals (dips) when going up a hill. "With dips, you are going up more than down, so you're still climbing, but by making the road more like a roller coaster, you break up the flow path into shorter pieces," notes Foltz.

Post-Wildfire Erosion

Wildfire changes the landscape dramatically. "A landscape that was full of vegetation can become a moonscape after a severe fire," notes Pete Robichaud. "Also, soils can become water-repellent when hydrocarbons from the smoke move down and condense onto the soil particles, and the water from rain cannot infiltrate normally." This altered landscape, with its patches of bare and water-repellent soil, has the capacity to produce large volumes of runoff, and the large amount of sediment it contains poses threats to fish, downstream water users, infrastructure, and private property.

The **Erosion Risk Management Tool (ERMiT)** is an online FS-WEPP model available to managers for the post-fire environment. "Wildfires are episodic and there is often a large erosion response when the precipitation follows," according to Robichaud. "ERMiT provides an estimate of the amount of erosion that you may get after a fire, but it is unique in that it also provides erosion probabilities based on factors like the type of storm that would likely hit area after the fire, variability in soil properties, and soil burn severity." ERMiT is now used by the majority of the Forest Service Burned Area Response (BAER) teams (with over 10,000 model runs in 2013) to provide guidance as to what to expect after a fire and the estimated increase in erosion.

Another unique feature of ERMiT is that it allows the user to select different erosion control treatments, so they can evaluate what will happen if they choose between various options. Robichaud explains, "Users can use ERMiT to quickly compare and contrast different types of treatments on the hillslopes to ask, where and how do we want to spend the money to reduce erosion risk?" From the 1970s to the 1990s, aerial seeding and contour-felled logs (placing logs perpendicular to slopes) were the main erosion control treatments used. "We've done a lot of research on treatment effectiveness over the years, and we've learned the benefits and limitations of a variety of treatments, including these two," says Robichaud. Research has shown that the most effective treatment for reducing post-fire erosion is straw mulching, with a reduction in sediment delivery ranging from 20 to 90%. He explains, "Mulching works well in a landscape affected by fire, where there is nothing else protecting that soil."

Research engineer Pete Robichaud explains, "Users can use ERMiT to quickly compare and contrast different types of treatments on the hillslopes to ask, where and how do we want to spend the money to reduce erosion risk?"

Erosion from Forest Management

In the past decade, management of western forests has focused on reduction of fuel loads to reduce wildfire severity, and in most cases this involves forest thinning. "When you are doing a thinning operation, you might want to think about how you'll manage the areas most likely to erode," suggests Elliot. Erosion from thinning is likely to come from disturbances to the forest floor, such as compaction (which increases runoff) and creation of roads and skid trails. Forest management is also likely to change the fire return interval and subsequently the erosion patterns. The **Disturbed WEPP** interface can be used by a manager who wants to evaluate the impacts of forest management on erosion and sediment delivery.

Disturbed WEPP allows users to describe numerous disturbed forest and rangeland erosion conditions, including low and

Other FS-WEPP Erosion Prediction Tools

There are several additional tools available on the FS-WEPP site. The **Tahoe Basin interface** is a customized version of Disturbed WEPP, but contains Tahoe-specific soils and predicts not only runoff and erosion, but also delivery of phosphorus. It also determines the fine sediment that is delivered, which is of particular concern in the Tahoe Basin. The **WASP** (Water and Sediment Prediction program) is under development and is intended to aid users in evaluating the impacts of forest management on water yield. FuME (Fuel Management) was developed to aid in synthesizing multiple WEPP runs associated with fuel management as described under the Disturbed WEPP applications. With a single entry, **FuME** carries out a dozen WEPP runs for thinning, prescribed fire, wildfire, and road erosion, and synthesizes the results on a single output page. The **Peak Flow Calculator** was developed originally in response to a request from post-fire rehabilitation teams in Australia. Output from an ERMiT run or from a runoff amount specified by the user is combined with small watershed characteristics to estimate the peak flow. This is useful following fire for managers to quickly evaluate the risk that a road culvert in the fire area fails to pass an expected flood flow. The **Rock:Clime** Interface was developed to build weather input files for WEPP Windows using a more detailed database of monthly rainfall distributions than is currently available for the WEPP Windows interface. The WEPP:Road, Disturbed WEPP, and ERMiT batch programs can also be downloaded from this site.

Management Applications of Selected Online WEPP Erosion Prediction Tools

Erosion Prediction Tool	Management Application	Scale	User inputs	Main output provided
WEPP:Road	Modeling erosion on current or proposed forest roads	Project or Subwatershed (Batch mode)	Climate station; soil texture; road design details; surface, and traffic level	Average annual sediment delivery
ERMiT	Modeling erosion after a wildfire	Project or Subwatershed (Batch mode)	Climate station; soil texture; veg type; hillslope gradient and length; burn severity class	Single-storm probability of exceeding a given sediment delivery
Disturbed WEPP	Evaluating impacts of forest management on erosion and sedimenatation	Project or Subwatershed (Batch mode)	Climate station; soil texture; treatment/veg type; hillslope gradient and length; % cover; % rock	Annual sediment delivery with several different return periods
Tahoe Basin Sediment Model	Same application as Disturbed WEPP, customized for Lake Tahoe Basin with phosphorus content of runoff	Project	Climate station; soil texture; treatment/veg type; hillslope gradient and length; % cover; % rock	Annual sediment delivery with several different return periods; phosphorus concentration and delivery
Online GIS Watershed Interface	Watershed-level erosion modeling	Watershed	Area of interest (delineated on Google Maps); watershed outlet point; land use; soil data	Spatial soil loss and runoff and sediment delivery for small watersheds

high severity burns. The general approach is to estimate the level of erosion from an undisturbed forest, and then the erosion from a wildfire using Disturbed WEPP. The post-wildlfire erosion rate is then divided by the frequency of wildfire to get an "average" erosion rate that is added to the undisturbed forest to estimate the background level. Erosion rates associated with thinning, harvesting, and prescribed fire are also estimated, averaged, and added in, with the wildfire erosion rate possibly being modified assuming it will be less frequent or severe after thinning. Output provides mean annual runoff depth, erosion rates, sediment yields, and the probability of a given amount of erosion occurring during the year following a disturbance. According to Elliot, "The ability to evaluate the minimal impacts of forest operations to offset the severe impact of a wildfire is one of the greatest applications of this tool."

ONLINE GIS INTERFACES FOR WATERSHED-SCALE EROSION MODELING

WEPP was originally designed to be used at the level of a hillslope. But, as Erin Brooks points out, "A lot of our forestry projects cover larger areas, even up to the watershed level." One example is a large-scale timber harvest, where the project may be a significant distance from a lake, but the Forest Service needs to be able to predict how it will affect lake sedimentation. In a watershed, you may have hundreds of hillslopes that are draining down to an outlet, which quickly becomes too cumbersome for the hillslope version to model. "For this, you need a Geographic Information System (GIS) with spatial layers that describe the soils, the management, and slope so that it can automatically build your watershed," says Dennis Flanagan.

GEOWEPP, a watershed-level WEPP tool, was created as an extension of a commercial GIS program to address this need. But, GIS software takes a fair amount of expertise to use, can be costly, and requires a high-powered computer, limiting the potential numbers of GEOWEPP users. "We asked," Flanagan explains, "how can we do this on the internet, where all of the calculations and heavy-duty work can be done on the server side?"

Enter the free, wildly popular and ubiquitous online software—Google Maps. "Everybody loves using this software to zoom in on a restaurant or street address," remarks Brooks. "We thought, if we can run our watershed model online using Google Maps, the user doesn't need a superfast computer, just a fast internet connection. It works for the entire country, and when combined with other freely available-government databases, does all the really challenging and sometimes tedious parts of setting up and running the model and getting output files."

According to Flanagan, using the **WEPP Online GIS Watershed Interface** is straightforward. The user zooms into the area of interest and delineates the channel network. When the user selects a watershed outlet in the channel network, the software delineates the watershed boundaries, and divides the watershed into hillslope elements of about 10 acres (4 ha) and channel segments 200 to 400 ft (60 to 120 m) long. He explains, "Once the model is set up in terms of climate, soils, land use, and slope, you can run the model. The calculations are all done on a server and the user will get estimates of the soil losses and runoff from each of the hillslope elements and channel segments." He notes, "At the watershed scale, using a GIS approach is the most practical way to model soil erosion."

The watershed tools are useful for identifying hillslopes that may be a high erosion risk should a wildfire or management activity occur. These high-risk hillslopes require special treatment to minimize erosion risk, such as removing flammable underbrush with hand crews, or with a mulching machine called a masticator. The watershed tools also allow the user to determine the combined or "cumulative effects" on runoff and sediment delivery of treating numerous hillslopes at the same time, or sequentially during a treatment period that could be as long as 20 years.

"When we created the FS-WEPP in 2000," said Elliot, "we kept the interface really simple so it could be used by someone using a telephone modem with a slow internet connection. One of the unanticipated benefits of this simplicity is that the models can now be used out in the field on a smartphone."

FURTHER ON DOWN THE ROAD WITH WEPP

The scientists behind the WEPP tools are always working to increase their usefulness and accessibility, but some of WEPP's user-friendly features were inherent in the original design. "When we created the FS-WEPP in 2000," said Elliot, "we kept the interface really simple so it could be used by someone using a telephone modem with a slow internet connection. One of the unanticipated benefits of this simplicity is that the models can now be used out in the field on a smartphone." Also, the models lend themselves to being used anywhere in the world, and according to Elliot, WEPP has been tailored for use in workshops as far away as Greece, Lebanon, and Australia. "What you find," he explains, "is that the condition of the site is far more important than anything else about the soil. Is it a road? A forest? Is it rangeland? Recently burned? Wherever you are in the world, the impact of disturbance far overshadows any other kind of soil property."

A current focus of the WEPP team is furthering the development of the online GIS interfaces for new applications. Currently, one interface has been tailored for the Great Lakes forested watersheds, and another—as described in the call-out box earlier in this article—is being adapted for the Lake Tahoe region that will look at impacts of wildfire and other disturbances on erosion and phosphorus inputs into the lake. Also in the works are GIS interfaces that on focus on wildfire (in which the user can incorporate the burn severity maps developed from satellite images and used by post fire managers) and also one for reclaiming surface mines. With the WEPP online GIS interfaces, Elliot stresses, "We are doing the best we can to make them as solid as possible, but new users have to understand that like with any new computer program, there will be some growing pains over the next few years." The ends will justify the means though, according to Brooks, because, "The development of these online GIS tools will give many more people access to doing watershed-level simulations for predicting erosion." Ultimately, it is the WEPP team's hope that tools like theirs enable watershed managers the world-over the ability to run predictive watershed models to optimize land management decision-making, resulting in more desirable outcomes for watershed and forest health.

KEY FINDINGS:

- Forest soil erosion is caused by disturbance, which can increase the erosion rates to more than 100-times that of the background level. Managers need to be able to predict the erosion potential of both natural and human-caused disturbances in the landscape to protect topsoil and water quality.
- The Forest Service–Water Erosion Prediction Project (FS-WEPP) was developed to provide managers with a suite of online erosion-prediction tools specifically for the forested environment.
- FS-WEPP hillslope models, including WEPP: Road, Erosion Risk Management Tool (ERMiT), and Disturbed WEPP can be run in for a single hillslope, or in batch mode for multiple hillslopes to predict erosion potential of roads, the post-fire environment, and forest management activities. The Tahoe Basin Sediment Model is a refinement of Disturbed WEPP, and includes phosphorus and fine sediment content of runoff.
- Development of online GIS interfaces that can run on any PC are a current focus of the FS-WEPP team. A WEPP Online GIS Watershed Interface is currently available and others are under development, including one for post-fire erosion modeling and one for surface mine reclamation.

FURTHER READING

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PETE ROBICHAUD is a Research Engineer with the USDA Forest Service's Rocky Mountain Research Station lab in Moscow, Idaho. He earned his M.S. and Ph.D. in Agricultural Engineering from the University of Idaho. He is responsible for modeling and mitigation techniques of erosion from timber-harvested and burned areas in a forest environment. Pete's current research includes spatial variability, hydrophobic soil conditions, effects of prescribed fire and wildfire on erosion, and monitoring methods and mitigation techniques.

RANDY FOLTZ is a Research Engineer (retired) with the USDA Forest Service's Rocky Mountain Research Station lab in Moscow, Idaho. He received an M.S. in Civil Engineering from New Mexico State University and a Ph.D. in Civil Engineering from University of Idaho. He was responsible for the development of the soil armoring algorithms and use of WEPP on forest roads. Other research topics have included erodibility of road aggregates and the benefits of reduced tire pressure on erosion from forest roads.

DENNIS FLANAGAN is an Agricultural Engineer and Lead Research Scientist at the USDA-ARS National Soil Erosion Research Laboratory, located on the campus of Purdue University in West Lafayette, Indiana. Dennis received his M.S. and Ph.D. degrees from Purdue University. His research work deals with soil erosion by water mechanics and prediction. In the erosion prediction area, Dr. Flanagan is continuing to work on the Water Erosion Prediction Project (WEPP), with major efforts in graphical interface development and linkage of WEPP with a geographic information system (GIS).

ERIN BROOKS is a research scientist in the Department of Biological and Agricultural Engineering at the University of Idaho in Moscow. He received his M.S. in Agricultural and Biological Engineering from the University of Minnesota and his Ph.D. in Biological and Agricultural Engineering at the University of Idaho. He has more than 15 years of experience developing hydrologic models to assess the effectiveness and impact of upland management practices on surface runoff, stream flow and the transport of sediment throughout a watershed.

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