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The Technical Newsletter of the National Stream and Aquatic Ecology Center

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A Rapid Response Database in Support of Post-Fire Hydrological Modeling

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Being prepared for an emergency is important. Every year wildfires threaten homes and lives, but danger persists even after the flames are extinguished. Post-fire flooding and erosion (Figure 1) can threaten lives, property, and natural resources. To respond to this threat, interdisciplinary Burned Area Emergency Response (BAER) teams assess potential erosion and flood risks, and if deemed necessary, develop remediation plans to protect lives and natural resources. BAER teams operate under tight deadlines – typically burn scars must be assessed and treatments recommended within two weeks of fire containment. Process-based and spatially explicit empirical models are currently under-utilized compared to simpler, lumped models because they are both difficult to set up and require properly formatted spatial inputs. Engineers at the Forest Service and Michigan Tech Research Institute

Figure 1: Wildfire-induced flood damage and sediment deposition from the 2012 High Park Fire, Colorado (Photo credit: Steven Yochum).

StreamNotes is an aquatic and riparian systems publication with the objective of facilitating knowledge transfer from research & development and field-based success stories to on-the-ground application, through technical articles, case studies, and news articles. Stream related topics include hydrology, fluvial geomorphology, aquatic biology, riparian plant ecology, and climate change.

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(MTRI) teamed up with NASA to improve access to predictive tools and datasets for modeling post-fire erosion and runoff. To facilitate operational use of models in conjunction with earth observations of burn severity, we have developed an online database (Figure 2) that rapidly serves out properly formatted spatial model inputs that have been modified with burn severity maps to support the GeoWEPP watershed erosion prediction software.

The overall objective of the online database is to provide BAER Team specialists, land managers, and researchers with the basic tools and spatial data needed to incorporate burn severity maps into process-based erosion models. End users may select a historical fire or upload a new soil burn severity map into the database. Once uploaded, the burn severity map is combined with vegetation and soils data and then delivered to the user pre-formatted for model input.

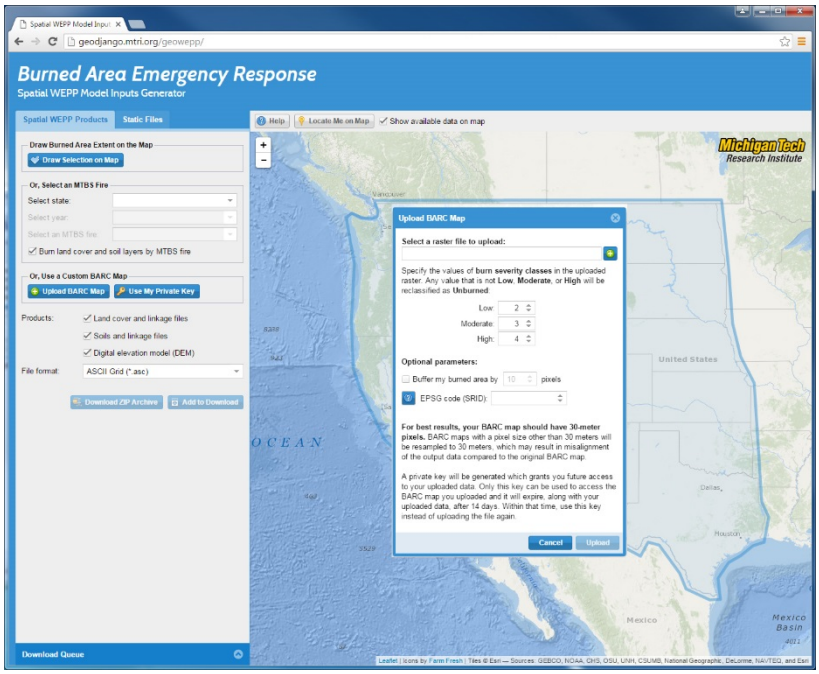

Figure 2: Online interface to the post-fire erosion modeling database.

Earth Observations of Burn Severity

One of the first and most important priorities of a BAER Team is the development of a burn severity map that reflects fire-induced changes in both vegetative cover and soil properties. Remote sensing is often used to quantify the sudden changes to a watershed brought about by a large wildfire. One helpful product is a Burned Area Reflectance Classification (BARC) map which is generated by the U.S. Department of Agriculture (USDA) Remote Sensing Application Center (Parsons et al. 2010; RSAC 2011) and the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center. A BARC map is a four-class, satellite derived map of post-fire vegetation condition. Many algorithms exist for mapping post-fire vegetation conditions, but the most widely accepted algorithm is the differenced Normalized Burn Ratio (Key and Benson 2006) which is well correlated with field measurements of burn severity (Robichaud et al. 2007b). Field measurements of soil conditions are collected in order to verify or adjust BARC maps, and the resultant product is known as a soil burn severity map (Figure 3). Parsons et al. (2010), *Field Guide for Mapping Post-Fire Soil Burn Severity*, is a valuable guide for such verification. Ideally, a soil burn severity map is used in the creation of spatial model inputs for hydrological modeling.

Post-Fire Erosion Processes

Forest soils are normally covered with a protective duff layer (fresh and decomposing leaf litter and organic debris; Elliot 2013) which protects soils by increasing infiltration and absorbing the erosive energy of falling raindrops and overland runoff. The amount of remaining ground cover after burning is a primary control on post-fire erosion rates (Benavides-Solorio and MacDonald 2005) and is an essential input to post-fire erosion models. Wildfire reduces or totally removes both the protective vegetation canopy and ground cover protecting forest soil. Hot gases generated by burning duff can coalesce around soil particles, making soils water repellent, further increasing the risk of high runoff and surface erosion (DeBano 2000). The heat of the fire can also destroy soil structure, making soil particles more easily detached or erodible. In the absence of surface cover, raindrop impact can reduce soil aggregation and detach sediment. When combined with shallow overland flow, this shallow runoff can transport fine soil particles and ash to macropores, decreasing infiltration rates, and increasing runoff and erosion, and the runoff can further transport that material to eroding rill channels.

Immediately after a fire, debris flow risk increases because of the increased potential for surface runoff. Several years after a fire, the risk of translational landslides on steep slopes increases as surface

woody material and below ground root networks are no longer stabilizing these slopes, and soil water contents may be higher due to reduced evapotranspiration from the regenerating forests (Reid 2010).

US Forest Service Water Erosion Prediction Project (WEPP) Tools

BAER teams employ a wide variety of models. For a summary of some of the available hydrologic modeling tools and methods, refer to *A Guide for Pre-and Post-Fire Modeling and Application in the Western United States* (Kinoshita *et al.* 2013). Our web database application is focused on providing support for Water Erosion Prediction Project (WEPP) based models.

WEPP is a physically-based soil erosion model developed by an interagency team of scientists (Laflen *et al.* 1997). The surface hydrology component of WEPP utilizes climate, topography, soil, and vegetation parameters to predict plant growth, residue decomposition and soil water balance on a daily time step, as well as infiltration, runoff, and erosion on a storm-by-storm basis. WEPP then can provide runoff, erosion and sediment delivery by event, month, year, or average annual values for time periods ranging from a single storm to 999 years for either an individual hillslope or a watershed made up of many hillslopes, channels and impoundments. The WEPP model has a built-in stochastic weather generator (Cligen) which generates WEPP climate inputs from an extensive database of more than 2,600 weather stations within the US (Flanagan and Nearing 1995). In the continental US, these statistics can be modified using Rock:Clime and PRISM's monthly precipitation database to account for spatial variation and elevation effects. PRISM (Parameter-elevation Regressions on Independent Slopes Model) uses a digital elevation model (DEM), climate station data, and other spatial data sets to generate grids of climate data at a resolution of 4 km^2 or finer (Daly *et al.* 1997). Rock:Clime is an online interface that accesses precipitation data from PRISM to interpolate between weather stations in order to improve the stochastic climate file used by WEPP (Elliot *et al.* 1999). The interface gives users the option to adjust temperature by elevation using adiabatic lapse rate and is especially useful in remote mountainous terrain (Elliot 2004).

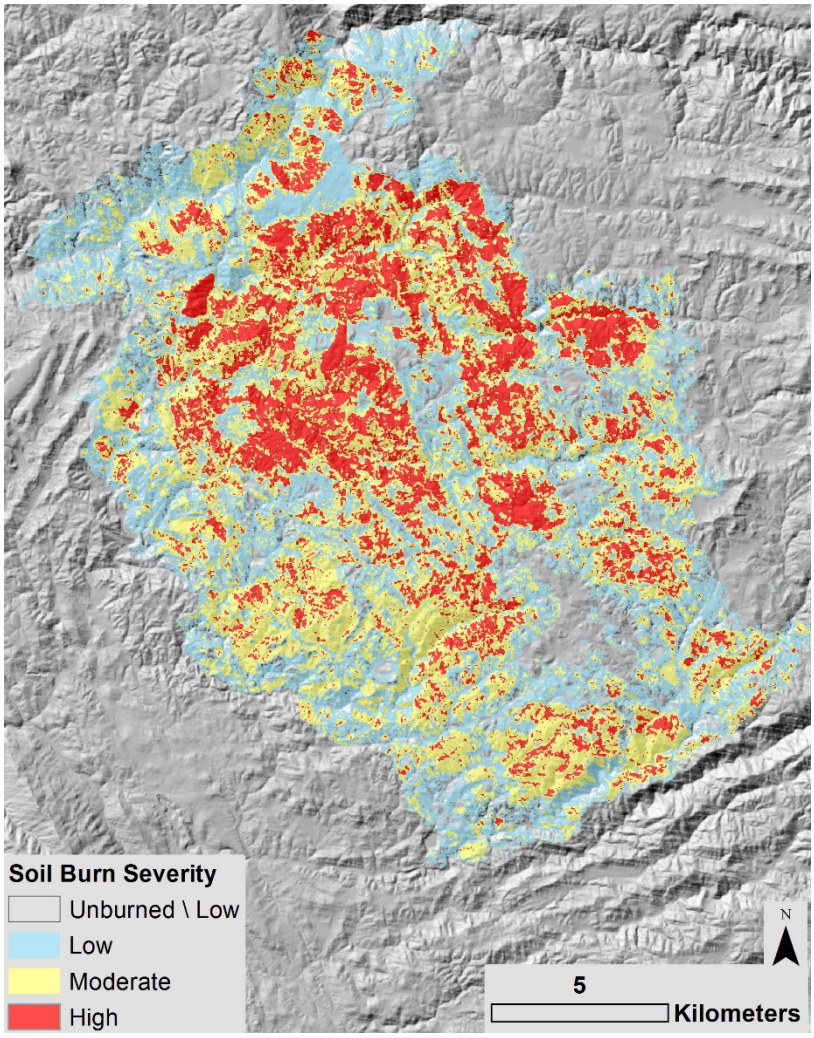

Figure 3: Soil Burn Severity (SBS) map from the 2015 Butte Fire, California.

WEPP technology includes two versions: a hillslope version to estimate the distribution of erosion on a hillslope and a watershed version that links hillslopes with channels and in-stream structures to estimate sediment delivery from small watersheds (< ~5 km^2). WEPP predictions of hillslope sediment delivery are ideal for prioritizing remediation on a hill slope scale regardless of fire size. For predicting peak flows from large burned watersheds BAER Teams typically utilize empirical model such as the USGS Linear Regression Model and Curve

Number methods (Elliot *et al.* 2010; Kinoshita *et al.* 2013; Yochum and Norman 2015).

Forest Service scientists have developed user-friendly online interfaces for the hillslope version to model forest hillslopes, road segments, and hillslopes following wildfire. The two main hillslope tools available for post-fire analysis are Disturbed WEPP, which predicts average annual surface runoff and erosion values, and the Erosion Risk Management Tool (ERMiT) that predicts the probability associated with the sediment delivery from a single runoff event (Elliot *et al.* 2006; Robichaud *et al.* 2007a). In order to support BAER teams, Excel batch spreadsheet tools for both ERMiT and Disturbed WEPP were created to allow users to run multiple hillslopes (Elliot 2013).

The watershed version of WEPP is best run using a geographic information system (GIS). The most commonly used of these tools, GeoWEPP, was developed by Renschler (2003) for ArcGIS (8.x, 9.x, and 10.x). The Geo-spatial interface for WEPP converts spatial soil, topography and land cover data into the input files needed for running WEPP watershed. Typically, the same soil and vegetation parameter files are used in the online Disturbed WEPP interface, the Windows interfaces, and the GIS tools. GeoWEPP uses the topographic analysis software, TOPAZ (Garbrecht and Martz 1999) to delineate watersheds and create required topographic files. After WEPP watershed has been run in the background, GeoWEPP uses the results to create maps of hillslope sediment delivery in the GIS. In addition, GeoWEPP can also predict return period analyses of peak runoff flow rates associated with the input scenario.

Post-Fire Erosion Database

One of the challenges of applying any GIS-based tool to post fire analysis is assembling the input data in a timely manner (Kinoshita *et al.* 2013, Miller *at al.* 2015). To facilitate operational use of spatially explicit process-based models we developed an online database that generates properly formatted model inputs for use in GeoWEPP. Future upgrades will include formatting inputs for the ERMiT and Disturbed WEPP Batch spreadsheets, and if there is demand, for other post fire models. Users may select a historical fire or upload a new soil burn severity map. Once uploaded, the soil burn severity map is combined with vegetation and soils datasets and then delivered to the user pre-formatted for modeling. Early application included creating input data for fuel planning projects using predictions of burn severity (Elliot *et al.* 2016). Modeling support for historical fires will enable researchers and land managers to more easily model cumulative watershed effects. Uploaded burn severity maps are uniquely identified by a key, which can either be shared or kept private by the uploading user to prevent unauthorized use of the map. Once the web database application is complete (early 2017), it will be transferred to one of the online servers provided by the Forest Service, Rocky Mountain Research Station.

Once a soil burn severity map is loaded to the application's database, it is combined with land cover and soil datasets in order to generate the spatial model inputs needed for hydrological modeling of burn scars. Model inputs are created to represent the fire area both in its burned and unburned state. Users download three types of spatial layers: soils, land cover, and a DEM that have been co-registered and projected specifically for hydrological modeling. The soil data are based on the SSURGO or STATSGO (STATe Soil GeOgraphic) Natural Resources Conservation Service soil databases (Soil Survey Staff 2014; USDA 1991). The DEM is provided by the USGS (Gesch 2007), and pre-fire land cover is derived from LANDFIRE Existing Vegetation Type (EVT) data (LANDFIRE 2011). The application delivers all the spatial inputs and parameter files needed for GeoWEPP in mere seconds. Previously, assembling and formatting this type of data would have taken at least several hours if not days (Miller *et al.* 2015). The GeoWEPP tool is limited in area to about 2 square miles because of computer memory, and the importance of ensuring the climate is correct as climates can be highly variable in mountainous landscapes. To address the needs of large fires, batching tools are under development to allow running dozens of 2-square mile watersheds automatically.

If a BAER team identifies an area with an exceptionally high erosion risk, or with critical values at risk downstream, one of the most successful methods for treatment is applying straw or hydro mulch (Robichaud et al. 2013). Treatment benefits can be evaluated over a landscape with GeoWEPP. Input files can be altered to describe the increased ground cover from mulching, and GIS tools used to show both the erosion risk on the landscape after mulching, and the polygons that have benefited most from the treatment. This provides BAER teams with justification for applying expensive mulch treatments, and allows them to spatially target hillslopes.

Operational Use of the Database

Having the datasets available rapidly means more time for BAER teams to model the effects of proposed remediation treatments, predict peak flows at vulnerable road culverts and other values at risk from flooding and excessive sediment, and consider different climate scenarios. Climate is a huge source of uncertainty in modeling potential post-fire erosion and runoff. To account for this variability GeoWEPP is often used to run WEPP watershed for multiple years of forecasted climate using first year post-fire conditions. The results are then averaged to estimate typical first year response. An advantage to modeling multiple years is it enables a return period analysis, which can be utilized to predict peak flows at watershed outlets for 2-, 5-, 10- or 25-year return interval events. A multi-year run with return period analysis can be used to predict peak flows at culverts when the modeler selects the road crossing as the watershed outlet. A disadvantage to multiple year runs are they require more processing time.

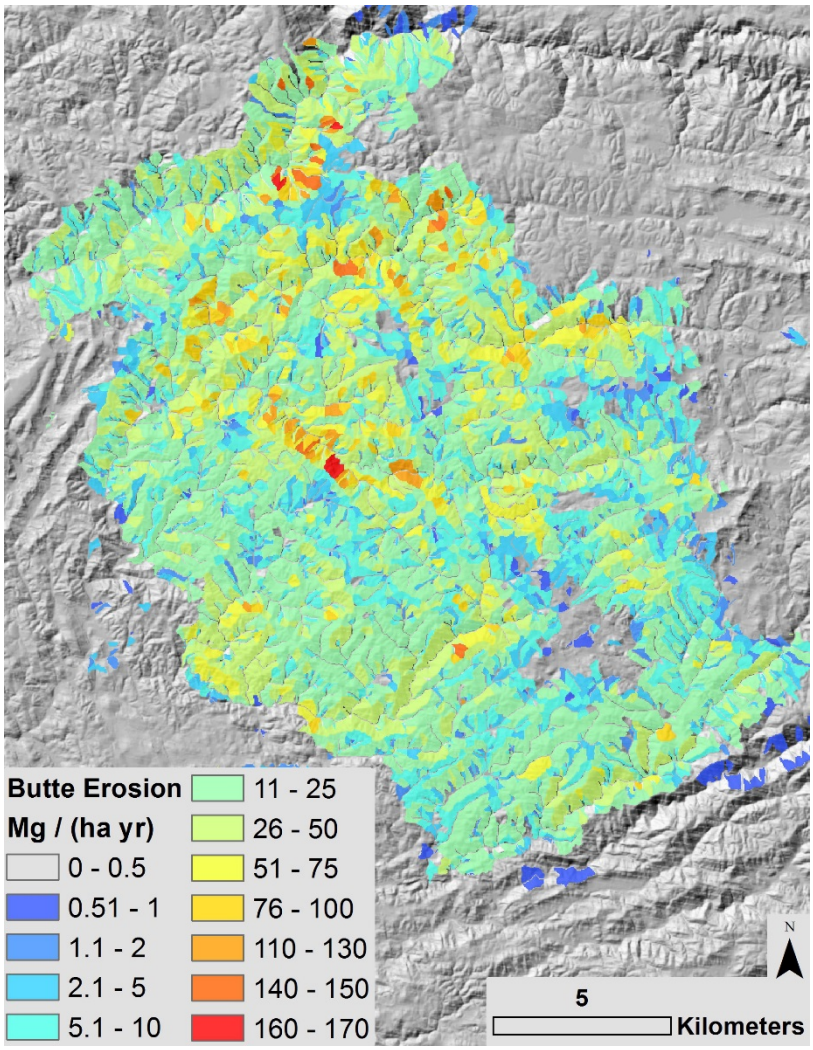

Figure 4: Post-fire predictions of annual hillslope sediment yield for the 2015 Butte fire. Erosion predictions are high as a "wet" climate containing a 10 year storm event was used in the modeling to simulate potential El Niño events.

The online database has been used to provide modeling support for eight fires that burned in 2014 and 2015, in Idaho, Oregon, and California. An example product is provided for the Butte Fire (Figure 4). The French (13,800 acres) and Silverado (968 acres) fires were small; predictions of post-fire erosion and runoff could be generated in GeoWEPP within just a few hours of receiving the soil burn severity maps. Modeling the Silverado fire was challenging as multiple scenarios were considered to assess the threat to values at risk (homes) at the base of the Silverado Trail watershed. The BAER Team made use of several model types because of the high potential risk to these homes. Modeling scenarios were carried out to estimate the hydrological impact the fire would have on peak flow rates for 2-, 5-, 10-, and 25-year return interval events. The effects of mulching treatable portions of the watershed were modeled at two different rates - 2.5 and 3.7 Mg ha-1 in order to estimate the effectiveness of the treatment in mitigating peak flows (Gallegos 2014). Larger fires like Happy Camp (134,000 acres) required one to two days to complete a modeling scenario. The BAER Team on the King fire (97,700 acres) wanted to consider several climate scenarios including predictions of average first year post-fire erosion, post-fire erosion from a single 5 year return period storm, and erosion after proposed mulching treatments. On the Valley (76,000 acres) and Butte fires (71,000 acres; Figure 4), a wet year containing a 10 year storm event was used to address BAER Team concerns of a wetter year due to El Niño (see last article, this issue).

Assembling the data needed to run spatially explicit erosion models can be a daunting task even without time constraints, therefore preparing the required input data ahead of time makes sense. Further preparation is needed to ensure BAER Teams have the expertise to use the selected model and that the

model is properly installed. Work will be ongoing in the next two years to expand the database to cover the remainder of the lower 48 states. Our vision is that advanced GIS surface erosion and mass failure prediction tools should be readily available for post-fire analysis using spatial information from a single online site.

Management Implications

- Spatial inputs for post-fire hydrological models can be generated as soon as the burn severity maps are created.
- Spatial predictions of erosion and runoff from process-based models can be used operationally for remediation planning of hillslopes and road culverts.
- End users must also be prepared to use available modeling tools before they are needed. A manual for using the database with GeoWEPP is available.

Training Opportunity

A workshop covering the use of WEPP and spatial WEPP tools for BAER teams will be offered in Davis, California on March 22 and 23, 2016. Basic GIS skills are required for the training. For additional details, contact Mary Ellen Miller. To reserve participation, email Harley Brown.

Acknowledgements

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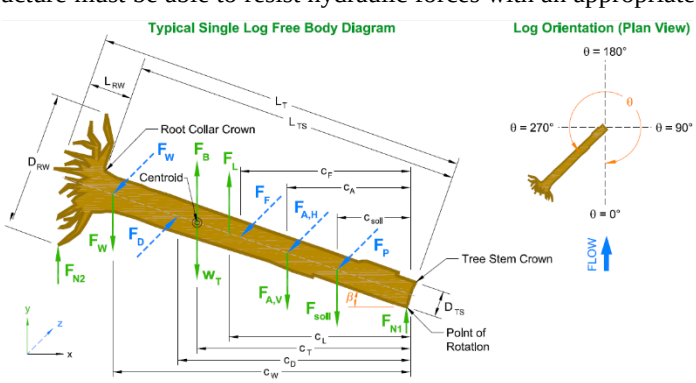
Notices and Technical Tips

- **Direct technical assistance** from applied scientists at the National Stream and Aquatic Ecology Center is available to help Forest Service field practitioners with managing and restoring streams and riparian corridors. The technical expertise of the Center includes hydrology, fluvial geomorphology, riparian plant ecology, aquatic ecology, climatology, and engineering. If you would like to discuss a specific stream-related resource problem and arrange a field visit, please contact a scientist at the Center or David Levinson, the NSAEC program manager.
- Are you interested in learning more about the huge **Ice Age Floods and Glacial Lake Missoula**? If so, you may be interested in this video on these massive floods. "Featured field evidence for the lake include strandlines above Missoula, Montana, giant current ripples at Camas Prairie, and striking rhythmites along Interstate 90 at Nine Mile Road near Missoula." This video was developed by Tom Foster and Nick Zentner.
- The National Stream and Aquatic Ecology Center has taken on the task for hosting a **large wood stability spreadsheet** developed by Michael Rafferty (this tool was previously available through Brian Bledsoe's webpage, at Colorado State University). Large logs are often placed in streams to benefit aquatic and riparian-dependent fish and wildlife as a part of stream restoration projects. When specifying the type of large wood structure to be used, restoration practitioners, planners, and local residents need to be assured that the constructed structures will likely remain in place under the expected conditions. To be considered stable, a structure must be able to resist hydraulic forces with an appropriate factor of safety. The design practitioner is typically forced to perform numerous complex and time-consuming calculations to achieve the desired level of safety, resulting in additional project time and expense. To assist these practitioners, an Excel spreadsheet tool was developed that applies computational equations and design guidelines to analyze virtually any proposed configuration of small-to-medium size structures. The tool and supporting references are available here.



- The Natural Resources Conservation Service has scheduled their **2016 Science and Technology Conservation Webinars**. The schedule is available here. The schedule includes *Grazing Strategies for Riparian and Wet Meadow Improvement in the Sagebrush Steppe*, *Getting to the Bottom of Resource Concerns: What concerns are really legit?*, *An Overview of NRCS's PLANTS Database and Web site*, and much more. All the webinars are recorded and available on demand.

Notices and Technical Tips

- On December 4, 2015, the President signed the Fixing America's Surface Transportation Act (FAST Act), which replaces the previous surface transportation bill (MAP-21). Although the FAST Act program structure is very similar to MAP-21, a significant difference is that the Forest Service will receive dedicated annual funding of $15 million rising gradually to $19 million in fiscal year 2020. Previously, the Forest Service had to annually compete for $30 million in funds with two other agencies, receiving about $11 million annually.

  Each region will be asked to submit a (Federal Lands Transportation Program) program of projects for fiscal years 2016 through 2020. The integrated program of projects – including road, trail and watershed projects – will be used to develop a multi-year investment strategy as requested by the Office of Federal Lands Highway. The Chief's guidance is to maximize an integrated blend of projects across the following Federal Highway Administration program emphasis areas: (1), supporting the transportation goals of maintaining transportation facilities in a state of good repair, reducing bridge deficiencies and improving safety (on both road and trail systems); (2), improving access to or utilization of high-use federal recreation facilities and high-use federal economic generators; and (3), supporting the resource and asset management goals of the USDA Secretary, including ensuring our national forests and private lands are conserved, restored, and made more resilient to climate change, while enhancing water resources.

  The Forest Service has noted that one of the three program emphasis areas for funding is supporting the resource and asset management goals of the USDA Secretary, including ensuring our national forests and private lands are conserved, restored, and made more resilient to climate change, while enhancing water resources. Program goals include **reducing erosion, improving aquatic organism passage, and increasing the percentage of watersheds that are fully functioning** according to the watershed condition framework.

  All forest-level hydrologists, fish biologists, and engineers interested in submitted proposals for aquatic organism passage and related road removal, relocation or maintenance projects for watershed benefit, and to implement essential projects for priority watersheds defined by the watershed condition framework over the next 5 years, should work with their regional engineers. All deliverables must be submitted to the Washington Office engineering staff by uploading all documentation to a Washington Office Federal Lands Transportation sharepoint site (currently being developed) by no later than March 4, 2016.

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Mid-Winter Drought Conditions: El Niño Storms Bring Much-Needed Relief

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There has been a great deal of interest in the ongoing El Niño conditions in the equatorial Pacific, and the potential impacts that this climate phenomenon will generate with respect to snowpack and drought-relief across California and the West this winter. Typically, El Niño winters bring above-normal precipitation to much of California, where the most extreme drought conditions have persisted over the past several years. Past El Niño winters, such as in 1982-83 and 1997-98, brought heavy rainfall that generated flooding and landslides in California, and there is much concern for similar impacts especially as a result of numerous large fires in the Sierra Nevada last summer. In this article, we will evaluate the current, mid-winter snowpack in critical watersheds in the West and examine the observed precipitation anomalies as of early February 2016.

The El Niño/Southern Oscillation (ENSO)

Technically, El Niño refers to the periodic warming of the upper-ocean in the eastern and equatorial Pacific, and is the "warm-episode" counterpart to La Niña, which refers to periodic cooling in the same region. The inter-annual cycle of warm and cold episodes is often referred to as the El Niño/Southern Oscillation (ENSO), with

atmospheric oscillations measured using the Southern Oscillation Index (SOI, the difference in atmospheric surface pressure between Papeete, Tahiti and Darwin, Australia). The atmospheric signal is more variable, so NOAA uses the Sea-Surface Temperature (SST) anomalies from the Nino 3.4 region in the central equatorial Pacific, averaged over 3-month timescales, as their official measure of the ENSO cycle. Five consecutive 3-month running means are used to define warm and cold episodes using NOAA's Oceanic Niño Index (ONI), and for El Niño the magnitude the warm episode is defined as a:

- **Weak El Niño:** Episode when the peak ONI is greater than or equal to 0.5°C and less than or equal to 0.9°C.
- **Moderate El Niño:** Episode when the peak ONI is greater than or equal to 1.0°C and less than or equal to 1.4°C.
- **Strong El Niño:** Episode when the peak ONI is greater than or equal to 1.5°C.

El Niño events occur every 2 to 7 years, and they drive numerous changes in precipitation and temperature patterns across the globe, including- North America (Ropelewski and Halpert 1987; Halpert and Ropelewski 1992). Figure 5 illustrates the "typical" pattern associated with El Niño winters across North America, and the observed teleconnections associated with this climate phenomenon. Over California and the Southwest, the relationship between El Niño and above-average precipitation is weaker than in the tropical and sub-tropical Pacific, and depends significantly on the strength of the El Niño. The stronger the episode (i.e., the larger the SST departures across the central equatorial Pacific are), the more reliable the signal in this region has been.

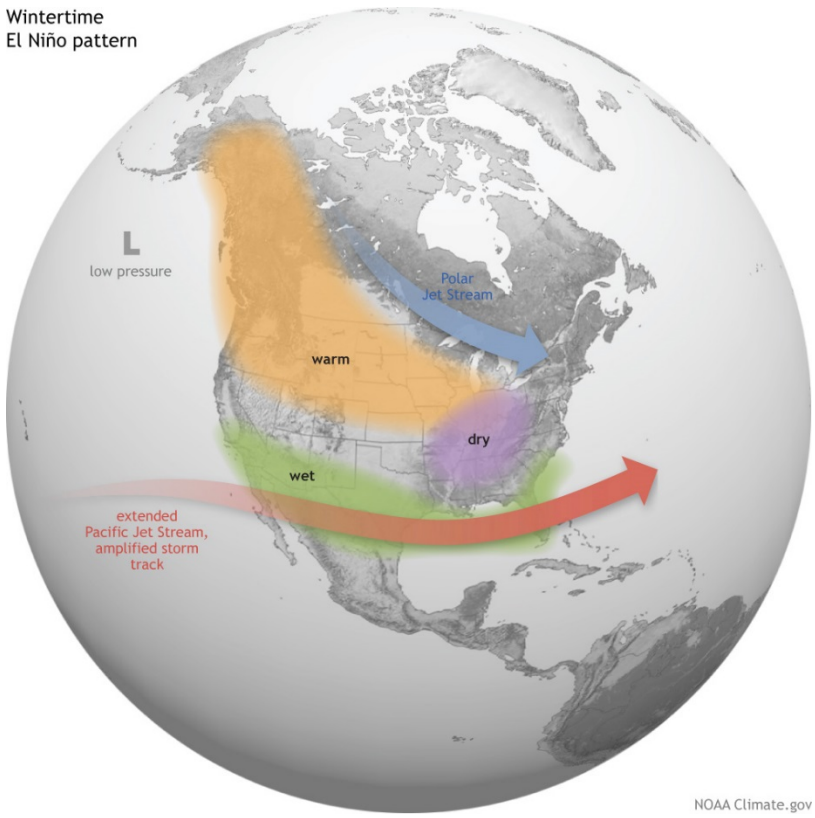

Figure 5: The typical El Niño winter pattern across North America (NOAA Climate.gov). Note the extended Pacific jet stream, and the amplified storm track that enhances precipitation across the Southwest and Southeast U.S.

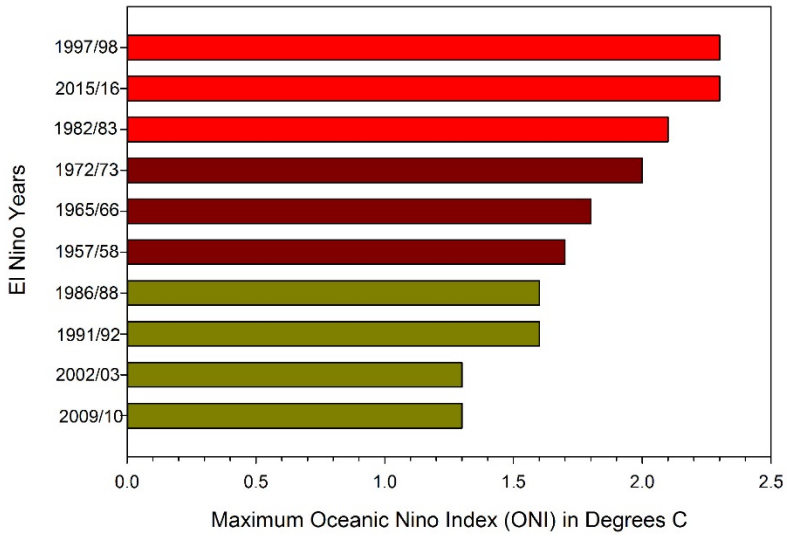

Figure 6: The top-10 strongest El Niño episodes since 1950, based on NOAA's Oceanic Niño Index (ONI).

Sea-surface temperature anomalies for the top-ten El Niño events since 1950 are provided (Figure 6), based on sea-surface temperature (SST) anomalies measured in the central equatorial Pacific (the Niño 3.4 region). The current El Niño is tied for the strongest in the historical record, with ocean surface temperature anomalies in the Niño

3.4 region warming to 2.3°C above the long-term mean; which equals those measured at the peak of the 1997-1998 El Niño. Therefore, there is a definite expectation for above-normal precipitation and drought-relief across California and the Southwest this winter. The question is whether it will materialize or not?

Mid-Winter Snowpack Conditions

It is relatively early in the snowpack-generating season in the western U.S., although the winter season to-date shows greater-than-normal snowpack accumulation from Colorado and Utah to the south and from Idaho (south of the panhandle) to the west (Table 1). Most of the states are currently experiencing greater-than-normal snowpack, with the exception of Wyoming and Montana which are at 87 and 92% of median, respectively. Excluding Wyoming and Montana, all of the western states have greater snowpack than last year, with such states such as California experiencing much greater snowpack for February 1st (127% of median in 2016, 19% in 2015).

The most substantial snowpack (compared to 30-year medians) is in Oregon, southern Idaho, Nevada, and California, with Oregon's South Umpqua basin having the greatest snowpack compared to its historical record (209% of median). Last year this lower-elevation basin had no snowpack on February 1st. The basin with least snowpack compared to its historical record is the Tongue River in Wyoming (Missouri Basin), at 53% of median.

Management Implications

Despite the beneficial moisture received across the West and Intermountain regions so far this year, it will take quite a lot more snow and rainfall to erase the long-term precipitation deficits. This is especially true in California which has had a record drought the past 4 years, and sequential wet winters with significant snowpack are needed to bring the surface and ground water resources back to their normal condition, and to recover surface reservoir storage. This bears out in the most recent US Drought Monitor, with more than 60% of California remaining in D3-D4 (Extreme-Exceptional) drought conditions.

References

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Table 1: February 1 snowpack update, with each State's minimum and maximum snowpack basins. ----: Data summary not available. (Data courtesy of the Natural Resources Conservation Service, Snow Survey and Water Supply Forecasting Programs).

State/Basin or Watershed	Percent of Median	
	2016	2015
New Mexico	120	75
Zuni-Bluewater	92	68
Mimbres	157	106
Arizona	116	----
San Fransisco-Upper Gila	95	67
Verde	140	28
Colorado	112	83
Yampa-White-North Platte	103	78
San Miguel-Dolores-Animas-San Juan	122	65
Utah	115	84
Bear River	101	89
Southeastern Utah	165	90
Nevada	133	45
Truckee	114	31
Northern Great Basin	158	44
California	127	19
Sage Hen Creek	106	27
Sprague River	141	22
Wyoming	87	----
Tongue River	53	97
Laramie River	107	87
Montana	92	100
Sun-Teton-Marias	62	91
Headwaters Mainstem Missouri	112	122
Idaho	----	----
Coeur d' Aleme River	74	52
Bruneau River	153	88
Oregon	----	----
Lower Columbia - Sandy	94	15
South Umpqua	209	0
Washington	109	----
Snoqualmie	85	15
Okanogan	146	90
Alaska	----	----
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