

Application of SAC88 to Estimating Hydrologic Effects of Fire on a Watersheds¹

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Abstract: SAC88 is a major revision of the Sacramento Model, which was developed in 1969 with minor revisions through 1973. Two of many 1988 changes make it possible to estimate hydrologic effects of a fire in a watershed where pre-fire parameters can be calibrated or estimated: (1) Evapotranspiration, treated as extracted from six root-zone layers under pre-fire conditions, may be limited to one to five layers in the burned area; (2) An infiltration-rate limiting value, large for an unburned area, may be substantially reduced for an area where high soil temperatures and ash are thought to have created hydrophobic soil surface conditions. The application of sample rainfall sequences under pre-fire and post-fire conditions may be used to evaluate hydrologic effects of fire or other drastic changes in watershed vegetation.

THE SACRAMENTO MODEL

The Sacramento Model was developed in 1969 by National Weather Service and California Department of Water Resources hydrologists as a tool to be used in their cooperative river forecast program (Burnash and others, 1973). It is a computerized conceptual, deterministic, lumped-parameter model of watershed processes from the application of liquid water through the generation of runoff. Snow accumulation and melt processes and channel routing may be handled separately by linked models. Several minor modifications were made to this model through 1973. Since that time, it has been applied extensively by National Weather Service hydrologists and others throughout the world (Bartfeld and Taylor 1980; Burnash and Bartfeld 1980; Leader and others 1983; Twedt and others 1978)

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The model includes both an impervious area that varies in size with wetness, and a permeable area. The permeable area includes five storages in two categories in the soil mantle - tension water that is filled preferentially and emptied only by evapotranspiration and free water that drains vertically and horizontally in response to gravity. The tension water storages are treated as one upper level and one lower level storage in the model, and the free water storages as one upper level and two lower level storages, with the upper level free water storage draining very rapidly both horizontally and vertically and the lower level free water storages draining at two different slower rates. Runoff is generated as direct runoff from water applied to impervious areas, subsurface drainage from each of the three free water storages, and surface runoff when the rainfall rate exceeds the rate at which water can enter the upper level storages.

SAC88 REVISIONS

SAC88, a major revision of the Sacramento Model, was begun in December 1987 (Ferral 1988). The changes made are summarized in the list that follows.

1. Thresholds that had caused abrupt transitions in the rainfall-runoff relationship have been smoothed by diverting increasing fractions of applied water into free water storages as tension water deficiencies diminish.

2. Upper-level outflow functions that drive both quick - response subsurface outflow to stream channels and percolation to deeper layers have been modified so that surface runoff is less likely to be dominant.

3. Partial area runoff caused by rainfall or snowmelt on seepage outflow areas has been modified to be controlled by outflow rates instead of by lowerzone tension water contents.

4. More layers are used in tension water accounting to allow for differing availability for evapotranspiration of near- surface and deeper soil moisture. This also allows drastic changes in effective root depth after wildfire or clear cutting to be modeled realistically. Two layers defined by the modeler are converted into six layers by the model.

5. A limiting surface infiltration rate now can be defined to account for effects of very intense rainfall or of hydrophobic soil conditions after a fire.

6. A uniformity parameter can vary the drying and wetting functions which affect runoff production.

APPLICATIONS OF THE REVISED MODEL

Changes 4 and 5 above are most relevant to the concerns of this Symposium. The Sacramento Model has been applied to dozens of small watersheds in California. It is part of the ALERT program (Automated Local Evaluation in Real Time), a cooperative National Weather Service program for local flood warnings and other purposes based mostly on radio raingages and streamgages reporting to a microcomputer that stores data as received and generates hydrologic forecasts automatically, at frequent intervals. The greatest concentration of these systems is in Southern California, where many flood-prone communities are below forested or brushcovered watersheds.

After SAC88 has been incorporated into the ALERT software and the watersheds have been recalibrated, it will be possible to make reasonable quantitative estimates of the hydrologic effects of wildfire and of subsequent revegetation. Early tests indicate that recalibration with SAC88 is easy to do. Common parameters change little from the old Sacramento Model to SAC88. A new calibration with SAC88 is no more difficult than a new calibration with the old Sacramento Model. Expert analysis will be required to estimate changes in effective rooting depth after a fire, but the model will have the capability to apply those changes to subsequent rainfall as it occurs.

Another possible use of SAC88 is to apply it to a watershed denuded by wildfire using the Extended Streamflow Prediction (ESP) mode of the National Weather Service River Forecast System

(NWSRFS). This would test the effects of applying historical rainfall sequences, starting with the present day of the year and present soil moisture and rooting depth conditions, to a calibrated watershed. Such a test could estimate both the probable increases in water yield and the probability of damaging flood flows in the post-fire rainy seasons.

Hydrologic effects of proposed vegetative management schemes, such as clear cutting or brush removal, could be analyzed similarly. A drastic vegetative change over only part of a watershed could be analyzed by treating it as two watersheds, one unchanged and one modified, and apportioning the resulting streamflows.

As an example of such an analysis, this model was applied to inflow to the San Antonio Reservoir in Monterey County, California. The calibration period was October 1967 through September 1979. The watershed as calibrated has an available root-zone soil moisture storage capacity of 11.4 inches. The calibrated model was applied to the watershed for the period October 1977 through September 1979 assuming two different conditions; an undisturbed watershed and a watershed burned or clear-cut in late September 1977. The burn or clear-cut was presumed to reduce the effective root-zone soil moisture capacity subject to evapotranspiration from 11.4 inches to 4.8 inches, with only the upper three of the model's six soil moisture levels permeated by roots.

The computed mean basin precipitation for the 1977-78 water year over the 330 square mile drainage was about 29.5 inches. For the 1978-79 water year, the precipitation was about 17.5 inches. Computed runoff for the undisturbed basin condition was about 12.6 inches in 1977-78 and 4.1 inches in 1978-79. Computed runoff for the burned or clear-cut basin condition was only about 12.7 inches in 1977-78, little changed from the undisturbed condition, but 8.5 inches in 1978-79, more than double the undisturbed condition runoff. This delay in runoff effects can be explained by the large soil moisture deficit in late September 1977, and a much smaller deficit, 4.8 inches, in late September 1978, for the modified watershed. Without vegetative modification, the soil moisture deficit in late September 1978 would have been more than eleven inches.

The calibrations and analyses were done with daily rainfall data, so there was no attempt to model the possible effects of a hydrophobic layer on infiltration and runoff. Such effects would be greatest immediately after a fire, so these would be most likely to be observed in the first post-fire rainy season.

CONCLUSION

SAC88, a major new revision of the Sacramento Model, is expected to be useful in estimating the hydrologic effects of fire or other drastic vegetative changes on a watershed.

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REFERENCES

- Bartfeld, Ira; Taylor, Dolores B. 1980. A case study of a real time flood warning system on Sespe Creek, Ventura County, California. In Proceedings, Symposium on storms, floods, and debris flows in Southern California and Arizona, 1978 and 1980, Committee on Natural Disasters, National Research Council, September 17-18, 1980, Pasadena, California.
- Burnash, Robert J. C.; Bartfeld, Ira. 1980. A systems approach to the automation of quantitative flash flood warnings, Proceedings, Second Conference on Flash Floods, American Meteorological Society, March 18-20, 1980, Atlanta, Georgia.
- Burnash, Robert J. C.; Ferral, R. Larry; McGuire, Richard A. March 1973. A generalized streamflow simulation system, conceptual modeling for digital computers, National Weather Service and California Department of Water Resources.
- Ferral, R. Larry. 1988. SAC88-A major revision of the Sacramento model. Unpublished draft, supplied by author.
- Leader, David C.; Burnash, Robert J. C.; Ferral, R. Larry. An incident of serious landslide occurrences related to upper zone soil wetness as computed with the Sacramento streamflow model, Proceedings, International Technical Conference on Mitigation of Natural Hazards through Real-Time Data Collection Systems And Hydrologic Forecasting, World Meteorological Organization and California Department of Water Resources, September 19 -23, 1983, Sacramento, California. Unpublished manuscript supplied by author.
- Twedt, Thomas M.; Burnash, Robert J. C.; Ferral, R. Larry. Extended streamflow prediction during the California drought. In: Proceedings, Western Snow Conference, April 18 - 20, 1978, Otter Rock, Oregon.