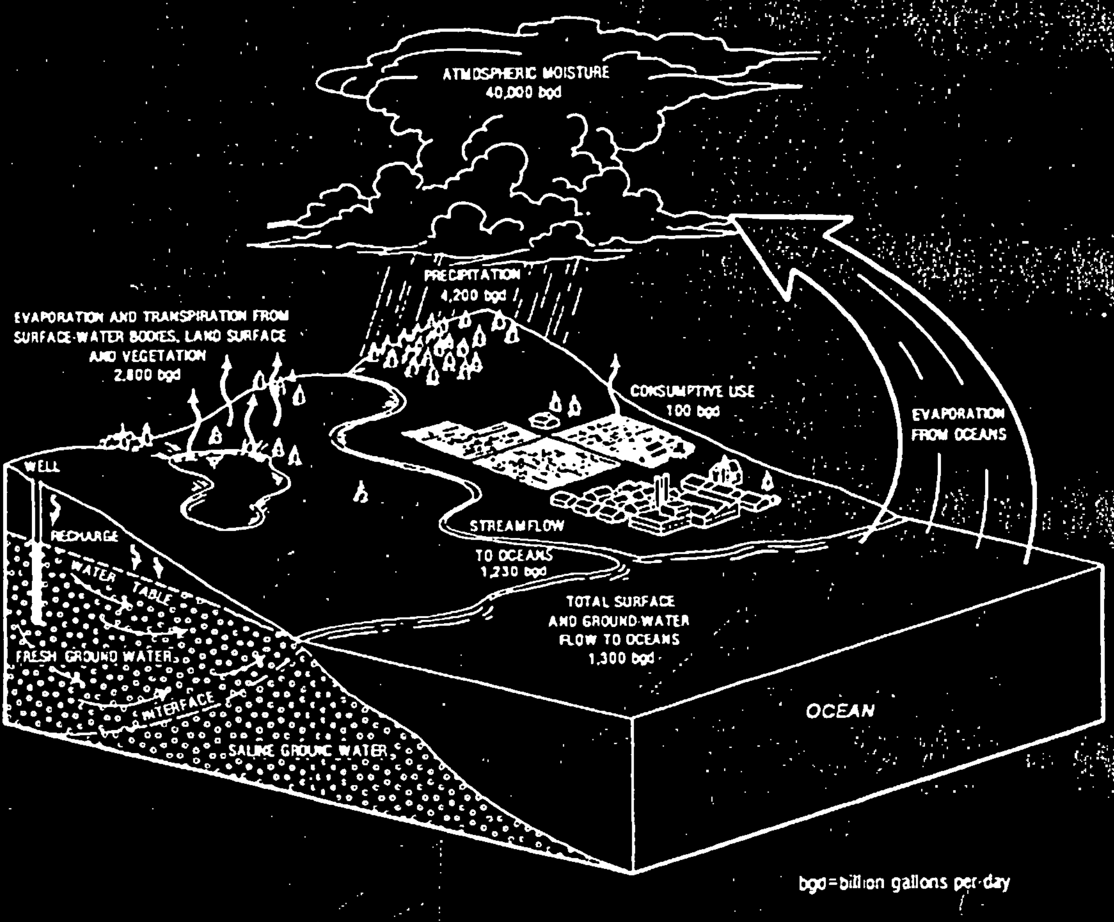
# PROCEEDINGS OF THE FEDERAL INTERAGENCY WORKSHOP ON HYDROLOGIC MODELING DEMANDS FOR THE 90'S

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U.S. Geological Survey Water-Resources Investigations Report 93-4018

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# VALIDATION STRATEGIES BASED ON MODEL APPLICATION OBJECTIVES

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## ABSTRACT

Validation methodologies which are based on specific modeling objectives are presented for an event based, unsteady state, research model, KINEROS, and a continuous, quasi-steady state, management model, Water Erosion Prediction Project Watershed Version (WEPPWV). The modeling objectives for KINEROS are to investigate the effect of geometric model simplification and spatial variability of input parameters on performance over a wide range of events. The methodology for KINEROS includes sensitivity analysis over a range of events to minimize the set of calibration parameters. The procedure, coupled with using distributed parameter multipliers alleviates the problems associated with parameter interaction and identifiability. The modeling objectives for WEPPWV are to investigate the effects of simplifications of the rainfall-infiltration-runoff process on model performance in terms of management applications. The methodology includes parameter calibration of a complex model to be used as a benchmark for comparison and using those parameter values in validation of increasingly simpler representations of the hydrologic process. Results of this study indicate that model validation should be performed in a multi-stage fashion when the model is complex in terms of geometric or hydrologic sub-process representation. Systematic and careful analysis of interim calibration and validation results must be carried out to avoid the modeling bane of hidden, but compensating errors. This is particularly true when models are being constructed from sub-components which may synergistically affect the final output.

## INTRODUCTION

The objectives of the development of hydrologic research and management models are complementary, but have different emphases. The researcher is interested in both understanding and explaining the hydrologic process while the manager is interested in using a model to arrive at a decision. In both cases, validation is an important part of model development. For the researcher, it is necessary as part of the scientific method; for the manager, it is necessary for confidence in any decision based on the model because these decisions have policy, economic, human and environmental ramifications.

This study examines two validation strategies using the research model KINEROS (Woolhiser et al., 1990) and the management model WEPPWV (Lane and Nearing, 1989). KINEROS is a distributed event rainfall-runoff model which uses a four point finite difference scheme to solve the kinematic wave equations for overland and channel flow. The overland flow supply rate is computed by solving the Smith-Parlange (1978) infiltration equation given one or more rainfall time-intensity distributions. The model is distributed in that a watershed can be represented by a number of overland and channel elements but also that within an overland flow element infiltration parameters can be represented by a probability distribution (Woolhiser and Goodrich, 1988).

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The WEPPWV model overland flow hydrologic components are composed of a climate generator, rainfall disaggregation scheme which represents the rainfall intensity distribution by a double exponential function, the Green-Ampt Mien-Larson infiltration equation, and peak flow regression equations based on the kinematic wave model for a single plane. The channel hydrology components consist of a transmission loss equation and a regression relationship for peak flow for the channel elements. In contrast to KINEROS, WEPPWV simplifies how the geometry of the watershed and the hydrologic sub-processes are represented. In addition, because the operational mode of the WEPPWV model is continuous simulation, parameters which control the hydrologic components are updated to account for the effects of temporal changes of plant growth, water balance, soil, and management practices.

The objectives of this paper are to illustrate the interpretation and expectations of model validation results by 1) validating the KINEROS model with emphasis on minimizing the set of calibration parameters, verifying the model response within sub-areas of the watershed, and assessing the impact of input rainfall representation of model validation; and 2) extending the KINEROS study using the WEPPWV model with emphasis on the relative sensitivity of model process simplification on model output.

## METHODOLOGY

Two important steps in the validation process are identification of sensitive parameters and verification to insure that the calibrated model can simulate the processes being modeled. Including only the most sensitive parameters in calibration is equivalent to increasing the number of observed data used in the calibration process (Beck, 1987). Studies specific to the models used in this analysis (Goodrich, 1991: Tiscareno et al., 1992) have shown that model output is most sensitive to the rainfall intensity distribution, effective saturated conductivity ($K_e$), and the hydraulic roughness coefficient. The latter two are used in this study as calibration parameters. In the case of distributed models or models which are made up of several components, validation of the internal model output and component model output are also necessary. Internal and component model validation are important in order to ensure that the final model output is not a result of compensating errors.

The subwatersheds of the USDA-ARS Walnut Gulch Experimental Watershed used for the KINEROS validation are the LH-6 (0.4 ha), LH-2 (1.4 ha), and LH-4 (4.4 ha) and for the WEPPWV validation LH-5 (0.2 ha), LH-1 (1.3 ha), and LH-3 (3.68 ha) (Renard, 1970 and Figure 1). Note that by using the nested watersheds LH-6 and LH-2 for watershed LH-4 and LH-1 for LH-3, internal model validation is possible and some degree of interior model confidence can be established. The watersheds are characterized by desert brush vegetation, sandy loam soils with significant rock content, high amounts of soil surface erosion pavement, and are subject to high intensity precipitation from air-mass thunderstorms of limited spatial extent. Model performance for both calibration and validation is evaluated by the coefficient of efficiency, E (Nash and Sutcliffe, 1970) and visual examination of scatter plots of measured versus simulated. If the model predicts observed runoff with perfection, $E = 1$. If $E < 0$, the model's predictive power is worse than simply using the average of observed values.

*KINEROS* - The input rainfall data are derived from two raingages about 300 m apart and are weighted using a space-time rainfall interpolation scheme described by Goodrich (1991). This study also investigated the level of geometric model complexity (basin discretization) required for distributed rainfall-runoff modeling using KINEROS and therefore employed large scale maps to derive a very detailed representation (large number of model elements) of the LH-6, 2, and 4 watersheds (Figure 1). Geometric model element parameters are derived from the large scale topographic maps and field measurements of channels. Infiltration parameters ($K_e$) were derived from soil texture from 17 soil samples distributed in LH-4. For KINEROS the validation process consists of a calibration phase in which observed data is used to alter field estimated parameters and verification in which an independent set of runoff events is used to assess 1) model performance by visual means and the efficiency statistic, and 2) assessment of model performance on subwatersheds internal to the primary watershed to insure internal model performance.

For calibration and verification it is unrealistic to consider adjustment of parameters on a large number of individual model elements. Beven (1989) concluded that, for modeling continuous flow, more than four or five parameters will result in identifiability problems. Therefore, a scalar multiplier approach is taken in which a multiplier for each major element parameter is employed. To visualize this concept, imagine a catchment made up of two overland flow elements, one with a field estimated Manning's roughness of 0.05 and the other with 0.08. With a roughness multiplier of 2 the respective roughness become 0.1 and 0.16 so the relative ratio between the two field estimated roughnesses is maintained. This concept becomes more advantageous when the catchment is represented by many elements when only a single multiplier is used for each main element parameter (such as hydraulic roughness) to reduce the overall adjustable parameter space a small dimension. Using the multiplier approach, univariate sensitivity analysis of model runoff, peak flow, and time to peak to multiplier changes is used to identify the most sensitive parameters. This knowledge, coupled with modeler knowledge of which parameters are most uncertain (subjectively derived) results in selection of a parsimonious calibration parameter space of three multipliers. They were uniform basin multipliers for $K_e$, the coefficient of variation of $K_e$ ($C_v$), and hydraulic roughness. The resulting small number of calibration parameters largely satisfies the concerns regarding overparameterization while minimizing parameter interaction and identifiability problems.

An acceptable multiplier for each watershed is found by using E as an objective function for a common set of ten calibration events on each of the three watersheds. When final multipliers are applied to initial field estimated parameters, the resulting values are checked to insure that they are physically realistic and are not acting as mere fitting parameters. These calibrated parameter multipliers are used to model runoff response for an independent verification event set. The validated model is also used to the assess effects of geometric model simplification on model performance as each watershed is also modeled as a single overland flow plane element using a simplification methodology described by Goodrich (1991).

*WEPPWV* - The watershed geometric representation used for WEPPWV is shown in Figure 1 and is similar to the simplified geometry used for KINEROS. The calibration and validation procedure begins with an evaluation of how well the calibrated Green-Ampt and kinematic wave equations can reproduce observed runoff characteristics using the observed rainfall intensity distribution from a single raingage. The next step is to sequentially simplify the rainfall input and peak flow calculation (Table 1) until the model structure is the WEPPWV model as will be applied by the end users. Step one is a test of the best possible model response; step two examines the effect of approximating the event rainfall by the disaggregation scheme; step three examines the effect of approximating the kinematic wave equation; and step four is a test of model parameter estimation and updating. For steps one, two, and three, the model is run in a single event mode; for step four the model is run in continuous daily simulation mode.

Table 1. Sequential validation steps for the WEPPWV.

| Step | Process | | |
|---|---|---|---|
| | Rainfall | Peak Discharge | Parameter Estimation |
| 1 | Observed event | Kinematic wave | Calibration |
| 2 | Disaggregated event | Kinematic wave | Calibration |
| 3 | Disaggregated event | Approximate method | Calibration |
| 4 | Disaggregated daily | Approximate method | Model computed |

## RESULTS AND DISCUSSION

*KINEROS* - For the optimum multipliers the KINEROS model performs very well as judged by the efficiency statistic (E) for both the calibration and validation event sets for the three watersheds used in the analysis (Table 2). Extrapolation capability is demonstrated as the model simulated runoff from events well outside the calibration range (observed runoff volume from 0.4 to 12.3 mm; validation range 0.08 to 47.8 mm). The large drop in E for Qp for the LH-6 validation event set was largely due to poor model performance on the largest event in the validation set. Typical scatter plots for the validation results of observed versus simulated runoff volume and peak runoff rate are shown in Figure 2 for LH-4.

Table 2. KINEROS calibration and validation coefficient of efficiency (E) for runoff volume and peak discharge using optimum multipliers.

| Basin | Calibration efficiency | | | | | | Validation efficiency | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Volume | | | Peak | | | Volume | | Peak | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 1 | 2 |
| LH-6 | .98 | .97 | .81 | .95 | .94 | .86 | .98 | .98 | .79 | .77 |
| LH-2 | .97 | .88 | .88 | .97 | .93 | .93 | .93 | .92 | .93 | .89 |
| LH-4 | .97 | .96 | .89 | .98 | .88 | .88 | .99 | .99 | .92 | .96 |

1 - two raingages, maximum number of overland and channel flow elements
2 - two raingages, one overland flow element, no channel elements
3 - one raingage, maximum number of overland and channel flow elements

An overall assessment of internal model accuracy using the nested LH-6 and LH-2 is obtained by using the parameter multipliers of LH-4 on the internal model representations of LH-2 and LH-6 for catchment runoff simulations. When this is done for LH-6, E equals 0.91 and 0.86 for runoff volume and peak rate, respectively and for LH-2 comparable E values are 0.96 and 0.97. The good efficiencies obtained by using LH-4 multipliers for the internal watersheds suggests a good deal of internal model accuracy.

To test the sensitivity of model response to the rainfall intensity distribution, one raingage is used as input with the calibrated parameter multipliers (see 1 RG rows in Table 2). For the calibration event set, the efficiency statistic E for runoff volume drops substantially. Simulation comparison also points out that runoff variations induced by rainfall variability far outweigh parameter perturbations used in the sensitivity analysis. The uncertainty in rainfall input due to small- and large-scale spatial variability suggests that the confidence in the calibration can only be equal to or less than the certainty of rainfall input data. This has been pointed out by numerous investigators (for example, see Troutman, 1983) but not at the scale of 300 m. As many models are tested on small research watersheds it is important to recognize the limitations imposed by the assumption of spatially uniform rainfall on parameter identification and model validation, particularly when runoff is a result of thunderstorm rainfall.

A parallel conclusion can be drawn by examining the model response when 1 overland flow plane model element (1 Elem rows in Table 2) and 2 raingages are used as input. Comparing these results to the one raingage results indicates that the error introduced by simplifying the geometry of these watersheds to a single element is less than or equal to the error from using one raingage for the calibration set. Therefore, unless there are major differences in land use, basin discretization should not exceed the ability to resolve input rainfall variability.

*WEPPWV* - The model efficiencies for calibrated runoff volume are similar in magnitude to those of KINEROS when a single raingage is used as input (Table 3). The lower efficiencies for calibrated peak discharge can be attributed to the fact that peak discharge is computed by a generalized regression relationship which obviously does not represent the hydrologic processes on these watersheds. The lower efficiencies for the validation of LH-3 are the combination of more small events in the validation set of LH-1 (calibration mean runoff volume=4.1 mm, validation runoff volume=2.8 mm) and problems in parameter identification due to physical changes in LH-1 (Van Der Zweep, 1991). The lower efficiencies for peak discharge for LH-5 are indicative that the roughness value was poorly identified in calibration.

Table 3. WEPPWV calibration and validation coefficient of efficiency (E) for runoff volume and peak discharge.

| Basin | Calibration efficiency | | Validation efficiency | |
|---|---|---|---|---|
| | Volume | Peak | Volume | Peak |
| LH-5 | .79 | .65 | .75 | .27 |
| LH-1 | .91 | .81 | .22 | -1.02 |
| LH-3 | .85 | .76 | .57 | .06 |

The sequential validation results are illustrated using LH-5 as an example. Referring to Figure 3, note that while the efficiency for runoff volume decreases as the model is simplified, the efficiency for peak discharge increases. The decrease in efficiency for runoff volume from step one to steps two and three is due the disaggregation model structure which always underestimates the observed peak rainfall intensity. The decrease in step four is due to the parameter estimation component which in this case estimated a value for $K_e$=2.03 mm/hr significantly lower that the calibrated value of 7.7 mm/hr. The increase in efficiency of peak discharge is a result of compensating errors within the model including the underestimation of peak rainfall, under estimation of $K_e$, and overestimation of the hydraulic roughness.

This study suggests that validation of a complex model, whether it is complex in the manner in which it represents a watershed (geometric complexity) or in the manner in which it represents the hydrologic sub-processes (process complexity), cannot be a one step analysis. The peak discharge efficiency in step 4 above would indicate that the model is doing a good job when in reality the output is a consequence of compensating errors in the peak discharge sub-processes.

The trend in recent years among Agricultural Research Service's and other agency's modeling efforts has been to incorporate modules from previously written models into the current model, particularly for management application models. For example, the WEPP model use the water balance routines from the SWRRB model (Williams et al., 1985) and the crop growth routines from the EPIC model (Williams et al., 1983). The Soil Conservation Service is amassing a suite of models under broad categories such as hydrology, plant growth, and earth science with the ultimate goal of linking these components together depending on a given management objective (SCS, 1992). Given the results of this study, model validation becomes a multi-stage process for geometrically and hydrologically (sub-process) complex models. Systematic and careful analysis of interim calibration and validation results must be carried out, particularly when models are being constructed from sub-components which may synergistically affect the final output.

## CONCLUSIONS

Analysis of the study watersheds with the research model KINEROS with a multiplier applied to a small set of the most sensitive parameters offers a method to achieve a parsimonious calibration-validation parameter set to avoid identification and interaction problems. Additionally, if one is to apply a distributed watershed model, model response in interior subwatershed must be verified before any conclusions can be drawn regarding interior watershed dynamics. The importance of identifying the dominant processes controlling catchment response was also demonstrated by illustrating that excessive catchment discretization is unwarranted if rainfall variability is not described on a comparable scale. The WEPPWV results demonstrate the importance of component model validation and the role of compensating errors in producing the model output. The comparison of the KINEROS and WEPPWV results demonstrates that the validation expectations of the researcher can be high, but those of the manager will be lower because of the approximations and simplifications necessary to implement a management model under the constraints of time and money. To understand and interpret validation results of a model's output necessitates a systematic analysis of the model components and their interactions.

## REFERENCES

Beck, M. B. 1987. Water quality modeling: a review of the analysis of uncertainty. *Water Resources Research*. 23(8):1393-1442.

Beven, K. J. 1989. Changing ideas in hydrology-the case of physically based models. *Journal of Hydrology*. 105:157-172.

Goodrich, D. C.. 1991. Basin scale and runoff model complexity. Univ. of Arizona, Dept. of Hydrology and Water Resources Tech. Rep. No. HWR 91-010, 361 p.

Lane, L. J. and M. A. Nearing. 1989. USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation. NSERL Report No. 2. USDA-ARS National Soil Erosion Research Laboratory. West Lafayette, In.

Nash, J. E. and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models, I. A discussion of principles. *Journal of Hydrology*. 10:282-290.

Renard, K. G., 1970. The hydrology of semiarid rangeland watersheds. USDA-ARS pub. 41-162.

SCS. 1992. TECHIS Summary. Draft document. Tech. Infor. Systems Div., Ft. Collins, CO.

Smith, R. E. and J.-Y. Parlange. 1978. A parameter-efficient hydrologic infiltration model. *Water Resources Research*, 14(33):533-538.

Tiscareno, M., V. L. Lopes, J. J. Stone, and L. J. Lane. 1992. Sensitivity of the WEPP Watershed model for rangelands conditions. ASAE Summer Meeting, N.C. Paper No. 922018.

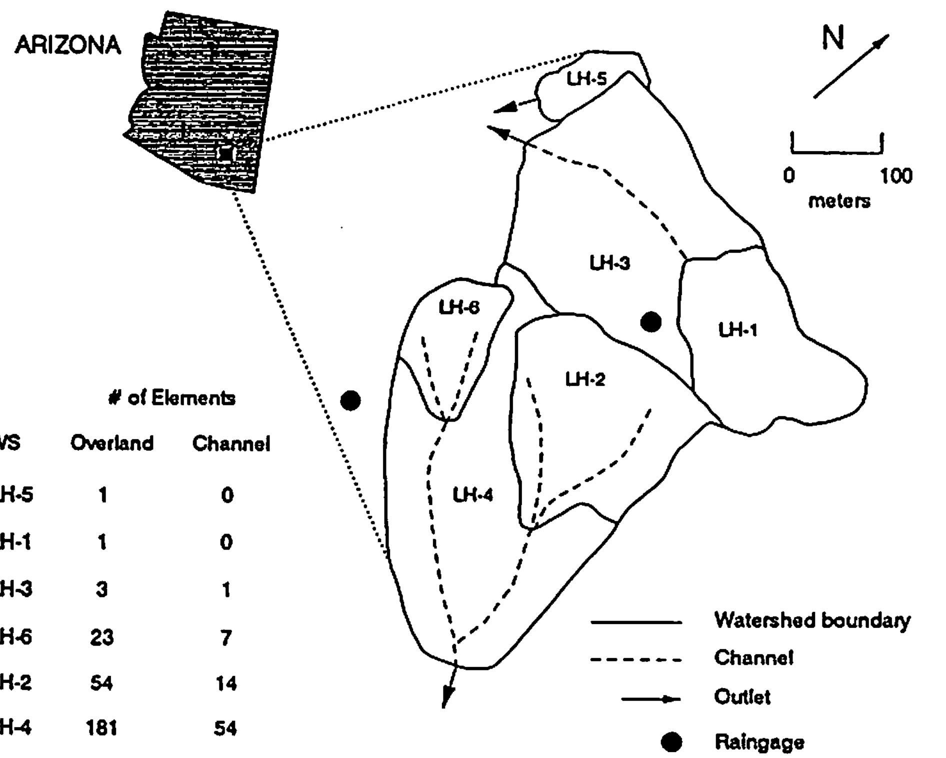
Troutman, B. M. 1983. Runoff prediction errors and bias in parameter estimation induced by spatial variability of precipitation. *Water Resources Research*. 19(3):791-810.

Williams, J. R., K. G. Renard, and P. T. Dyke. 1983. A new method for assessing the effect of erosion on productivity-The EPIC model. *J. Soil Water Conservation. 38:381-383.*

Williams, J. R., A. D. Nicks, and J. G. Arnold. 1985. Simulator for water resources in rural basins. *ASCE Journal of Hydraulic Engineering*. 111(6):970-986.

Woolhiser, D. A. and D. C. Goodrich. 1988. Effect of storm rainfall intensity patterns on surface runoff. *Journal of Hydrology*. (102):335-354.

Woolhiser, D. A., Smith, R. E., and D.C. Goodrich. 1990. KINEROS, A kinematic runoff and erosion model: documentation and user manual. USDA-ARS, ARS-77, 130 pp.




| | # of Elements | |
|---|---|---|
| WS | Overland | Channel |
| LH-5 | 1 | 0 |
| LH-1 | 1 | 0 |
| LH-3 | 3 | 1 |
| LH-6 | 23 | 7 |
| LH-2 | 54 | 14 |
| LH-4 | 181 | 54 |

Figure 1. Lucky Hills Watersheds location map and maximum number of overland and channel elements used by KINEROS and WEPPWV.

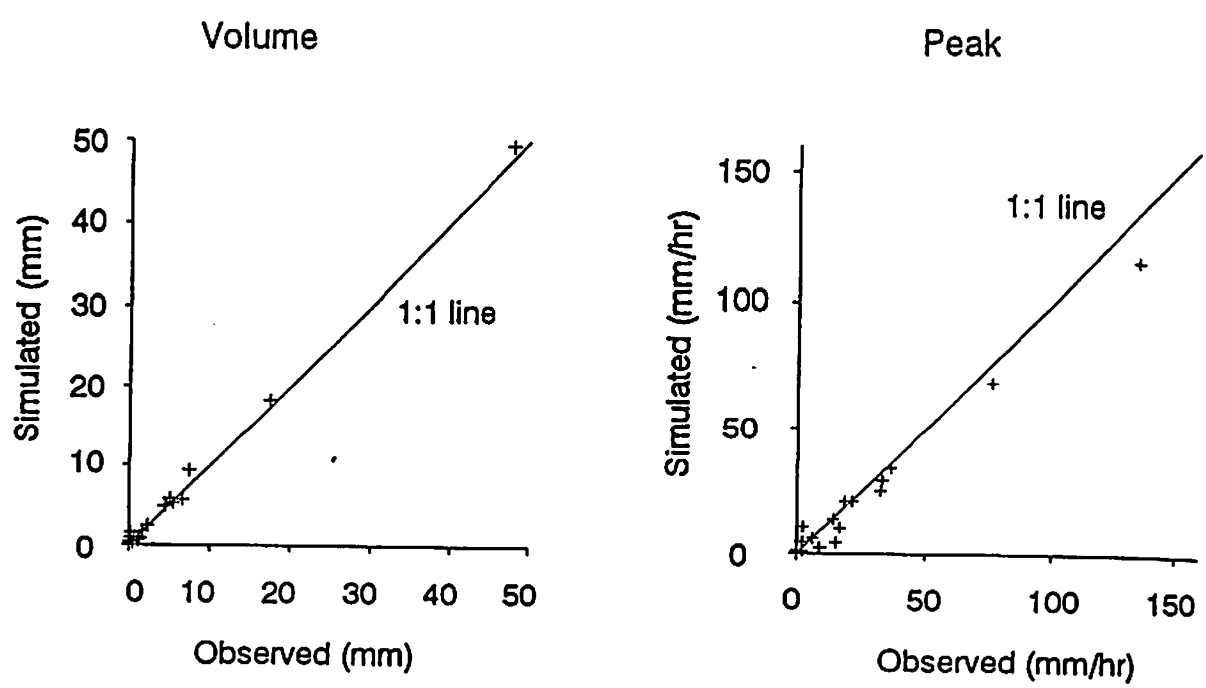



Figure 2. Scatter plots for KINEROS validation for runoff volume and peak discharge for LH-4.

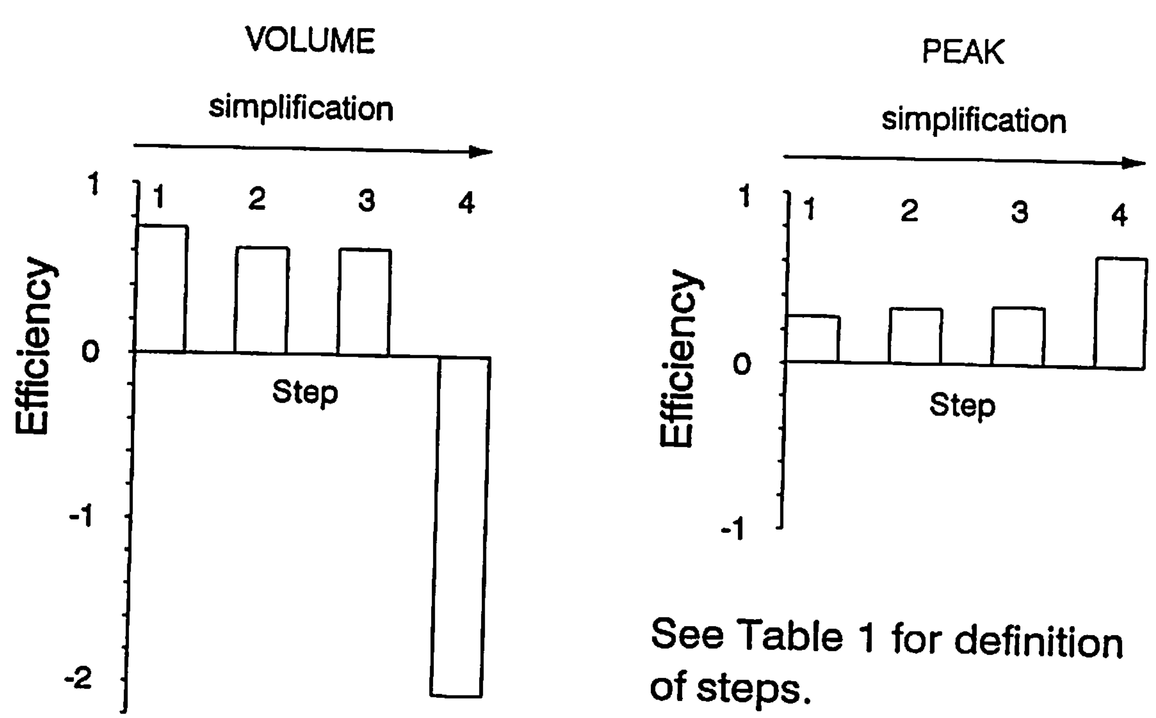



Figure 3. WEPPWV Validation efficiencies for runoff volume and peak discharge for LH-5.