Author 3	
Title	**Watershed Resources Management (WRM) Model 1. Model Description**
Keywords	
Description	**Watershed Resources Management (WRM) Model 1. Model Description**
Category	**Agricultural Engineering**
Publisher	**Computers and Electronics in Agriculture**
Publication Date	**1995**
Signature	

②

Reprinted from

Computers and electronics in agriculture

Computers and Electronics in Agriculture 13 (1995) 195–216

Watershed resources management (WRM) model
1. Model description

C.C. Mbajiorgu

Department of Agricultural Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

ELSEVIER

Computers and electronics in agriculture

GENERAL INFORMATION

Audience: All scientists, engineers, environmentalists and economists concerned with applications of computers and electronics to agriculture and related industries.

Aims and Scope: *Computers and Electronics in Agriculture* provides international coverage of advances in the application of computer hardware, software and electronic instrumentation and control systems to agriculture, forestry and related industries. The latter include horticulture (in both its food and amenity aspects), forest products, aquaculture, animal/livestock science, veterinary medicine and food processing.

The journal publishes original papers, reviews, applications notes and book reviews on topics including computerized decision-support aids (e.g., expert systems and simulation models) pertaining to any aspect of the aforementioned industries; electronic monitoring or control of any aspect of livestock/crop production (e.g. soil and water, environment, growth, health, waste products) and post-harvest operations (such as drying, storage, production assessment, trimming and dissection of plant and animal material). Relevant areas of technology include artificial intelligence, sensors, machine vision, robotics and simulation modelling.

Publication information: *Computers and Electronics in Agriculture* (ISSN 0168-1699). For 1995 volumes 12 and 13 are scheduled for publication. Subscription prices are available upon request from the Publisher. Subscriptions are accepted on a prepaid basis only and are entered on a calendar year basis. Issues are sent by surface mail except to the following countries where Air delivery via SAL mail is ensured: Argentina, Australia, Brazil, Canada, Hong Kong, India, Israel, Japan, Malaysia, Mexico, New Zealand, Pakistan, PR China, Singapore, South Africa, South Korea, Taiwan, Thailand, USA. For all other countries airmail rates are available upon request. Claims for missing issues should be made within six months of our publication (mailing) date. Please address all your requests regarding orders and subscription queries to: Elsevier Science B.V., Journal Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, tel. (+31-20)4853642, fax (+31-20)4853598.

In the USA and Canada: For further information on this and other Elsevier journals please contact: Elsevier Science Inc., Journal Information Center, 655 Avenue of the Americas, New York, NY 10010, USA. Tel. (212) 6333750; fax (212) 633 3764; telex 420-643 AEP UI.

US mailing notice: *Computers and Electronics in Agriculture* (ISSN 0168-1699) is published monthly except in February, May, July and October (total 8 issues) by Elsevier Science (Molenwerf 1, P.O. Box 211, 1000 AE Amsterdam). Annual subscription price in the USA is US$ 400.00 (valid in North, Central and South America), including air speed delivery. Second class postage paid at Jamaica NY 11431.

USA POSTMASTER: Send address changes to Computers and Electronics in Agriculture (ISSN 0168-1699), Publications Expediting Inc., 200 Meacham Avenue, Elmont, NY 11003.

AIRFREIGHT AND MAILING in the USA by Publications Expediting Inc, 200 Meacham Avenue, Elmont, NY 11003.

Back volumes: Please contact the Publisher.

ELSEVIER Computers and Electronics in Agriculture 13 (1995) 195–216

Computers
and electronics
in agriculture

Watershed resources management (WRM) model
1. Model description

C.C. Mbajiorgu

Department of Agricultural Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

Accepted 17 March 1995

Abstract

The Watershed Resources Management (WRM) model is a process-based, continuous, distributed-parameter watershed model incorporating conservation structures. Hydrologic processes on the watershed are modelled by finite differences of the mass, momentum and energy conservation equations. Physically-based empirical equations are also employed. Component program modules have been developed for Initialization, Timing, Rainfall-event, Ponded-infiltration, Runoff, Saturation-runoff, Kinematic-flow, Conservation-structures (terraces), Grass-waterways, Hydraulic-structures (reservoirs), Culvert, Evapotranspiration-event, Baseflow, Upland dry-period soil-moisture accounting, and Dual element dry-period (Subsurface-lateral) flow. Unrestricted spatial and temporal distribution are built-in. A Main sub-program maintains the sequence of system integration in consecutive operation of components.

WRM is applicable at the basin scale, in planning, forecasting and operational hydrology; in design flow estimation; to the study of environmental impacts of land-use changes, and to soil and water conservation planning. Its modular design makes it flexible and adaptable.

Keywords: Watershed; Water management; Water runoff control; Hydrologic modelling; Simulation model, calibration; Decision support system

1. Introduction

Betson and Ardis (1978) observe that one reason the science of hydrology is retarded is its traditional appendage to hydraulics. Hydrologic work, having been centred around hydraulics, has generally precluded the air-plant-soil complex. Hydrologic modelling requires the hydrologic cycle to be treated as a determinate system, or at least a definable system. In this regard, no model or modeling approach has been universally established.

According to Klemes (1982), the development of an adequate causal theory of hydrologic processes may be much more demanding than that of the theory of

SSDI 0168-1699(95)00011-9

relativity or the quantum theory. The problem of scale in modeling spatial and temporal variability is highlighted by Wagenet (1988), who suggests recognition of domains of macroscopic and microscopic behaviour. Ferreira and Smith (1988) highlight model balance as necessary for reasonable results and for meeting specific model application goals. They also considered the problem of the "measured data myth", whereby model results are questioned because of a lack of match with a particular set of measured data. There are uncertainties to be recognized in measured data due to scale, precision, lumping, recording and interpretation. DeCoursey (1988) notes that, in order to maintain computational integrity, there is a need to balance space and time scales in hydrologic modeling. Haan (1988) and Wagenet (1988) stress the need to specify confidence intervals on model output to inform on the risks involved in using them, and as a basis for model evaluation.

Much of recent research has been concerned with the provision of the large amounts of data required by physically-based, distributed parameter models (Abbott et al., 1986). The sophistication of field studies still lags behind that of modeling and the problem of scale remains, with most measurements being made at the point scale. On the other hand, model parameter values are required at the scale of watershed discretization. Potentially, remote sensing techniques can provide, on a cost-effective basis, large amounts of spatially and temporally distributed data which are integrated areally at a variety of scales. But this potential is yet to be realised, because, currently, models have structures which are incompatible with the characteristics of the data provided. Also, the understanding and usefulness of spectral data is yet to be achieved. However, some progress has been reported in the linking of models to Geographic Information Systems (Hodge et al., 1988; Wolfe and Neale, 1988).

Examples of current process-based, distributed parameter models include ANSWERS (Beasley et al., 1980), CREAMS (Knisel, 1980), SHE (Abbott et al., 1986) and AGNPS (Young et al., 1987). However, no model is known that represents *both* infiltration-excess and source-area runoff, as may occur at different locations on the watershed. Apart from SHE, the models are not capable of continuous simulation at the basin scale. But even SHE does not represent infiltration-excess runoff, soil erosion and related sediment transport, which may be important on agricultural watersheds. Also, hydraulic and conservation structures are not represented in most of the current models, and some of their component and process representations need to be updated as a result of fundamental research.

2. Model development

2.1. System conceptual framework and model structure

The infiltration-excess theory of runoff is based on a maximum intensity at which rainfall can enter the soil at a particular time, after Horton (1933). Rainfall in excess of this infiltration capacity results in overland flow. This concept is valid in areas of infrequent high-intensity rainfall, and where soils are poorly developed and/or vegetated.

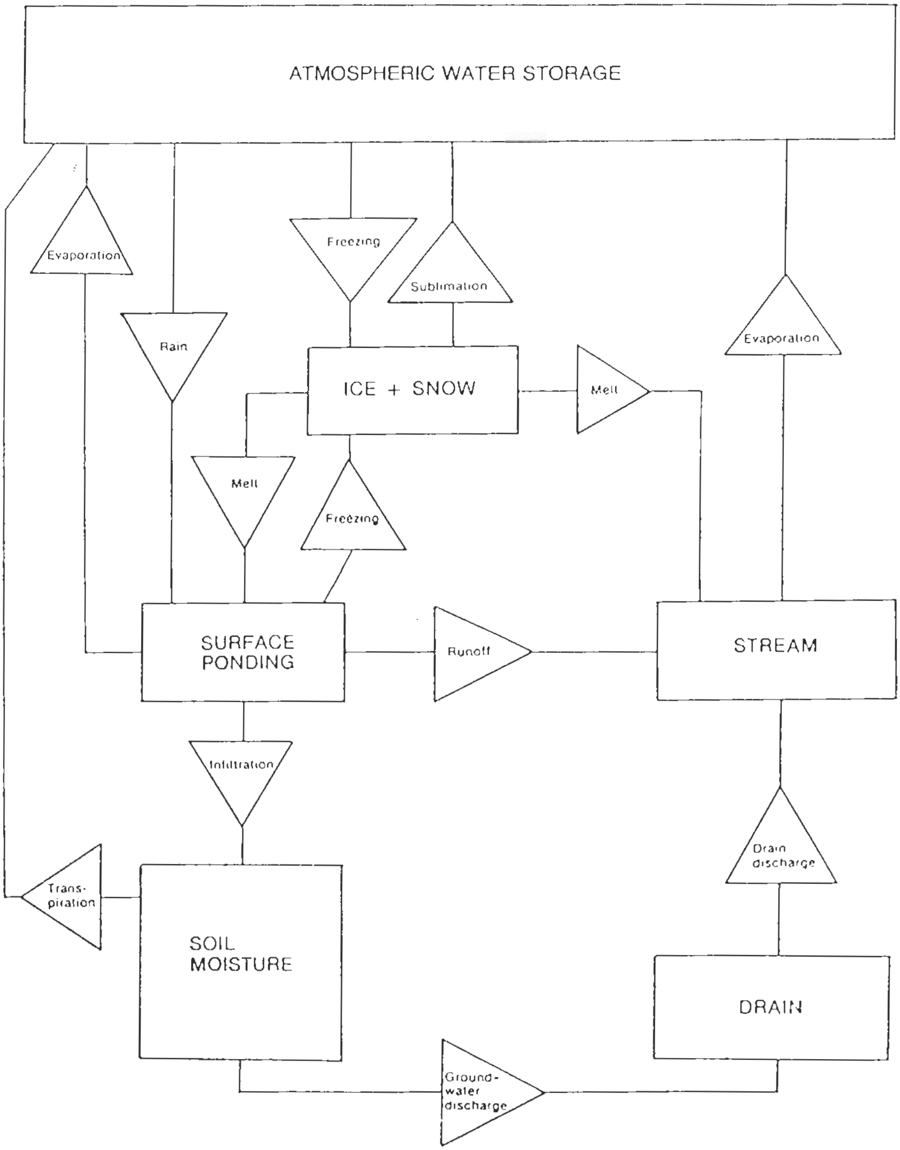

Fig. 1. Part of the hydrologic cycle affecting streamflow (after Vandenberg, 1985).

On the other hand, the saturation or source-area theory of runoff is based on the storage capacity of the soil. All rainfall is infiltrated until soil storage is filled, and subsequent rainfall causes overland flow. The concept is valid in areas of frequent low-intensity rainfall, and where soils are well developed and vegetated. Ishaq and Huff (1977a,b), and Chorley (1978), give details of the hydrologic properties of source areas.

The hydrologic cycle was considered as a set of storage reservoirs, between which water transfers take place at rates governed by physical laws. The physical laws relate the water transfer between adjacent reservoirs to their physical state. Thus, if transfer functions are known, the changing state of the system can be tracked through time; by a "system of double book-keeping, provided entries to the ledger are made at frequent enough intervals that the state just after the transfers have been entered provides the basis for calculating the transfer rates during the small time interval until the next entry is made" (Vandenberg, 1985). An illustration of this system is made in Fig. 1, where storage reservoirs are represented by rectangular boxes and transfer functions by triangles indicating direction of transfer.

Fig. 2 shows a schematic of the adopted spatial structure of the Watershed Resources Management (WRM) model, after Abbott et al. (1986). Spatial distribution of watershed parameters and hydrologic responses is according to watershed discretization, in the horizontal by an orthogonal grid network of elements and vertically by a column of layers at each element. Watershed drainage pattern is established from the possible flow directions leaving elements: directly out of the sides or out of the corners, as illustrated in Fig. 3. Grid spacing can be varied across the network and spacing in the vertical can be varied with soil type, vegetation type, and location on the watershed.

Mbajiorgu (1992) gives a comprehensive, rigorous and state-of-the-art theory of hydrologic process modeling, as employed in the WRM model. Also, both the infiltration-excess and source-area concepts are employed, but on different parts of the watershed. In discretising the watershed into elements or cells, the elements which contain the stream channel constitute the 'source area' and are referred to as dual elements, Fig. 4b. The remaining (upland) elements constitute the area of infiltration excess. During a prolonged rainfall event or a rainy season, the source area may enlarge to include elements adjoining the dual elements. Fig. 4a and b show the details of processes modelled in upland and dual elements, respectively.

2.2. *Mathematical representation of processes*

The WRM model is process-based, in that hydrologic processes of the water balance are modeled by finite difference formulations of the partial differential equations of mass, momentum and energy conservation. Physically-based empirical relations are also used. The process equations employed to represent the system are given independently by the following sources:

(1) Canopy interception storage, by Horton (1919)

(2) Evapotranspiration, by Holtan's model as presented by Saxton and McGuinness (1982) with related information from Doorenbos and Pruitt (1977)

(3) The infiltration model is the Green-Ampt equation, as solved by Chu (1978) for unsteady rainfall, with parameters estimated and management-practices effects incorporated according to Rawls and Brakensiek (1988), Brakensiek and Rawls (1988) respectively

(4) Saturated subsurface flow, as described by Kirkby (1975) — linear reservoir model — with time constant parameter estimated by Williams et al. (1984)

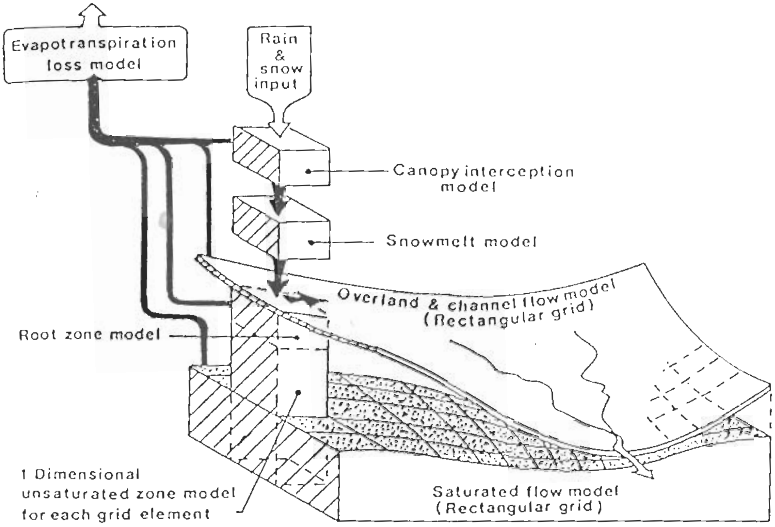

Fig. 2. Spatial structure of the European Hydrological System, SHE (after Abbott et al., 1986).

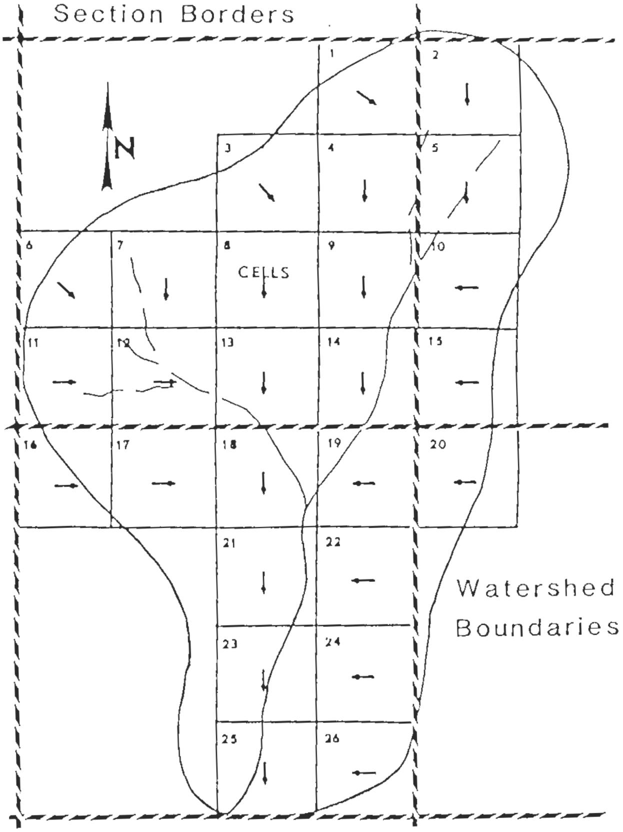

Fig. 3. Sample watershed discretization showing drainage pattern (after Young et al., 1987).

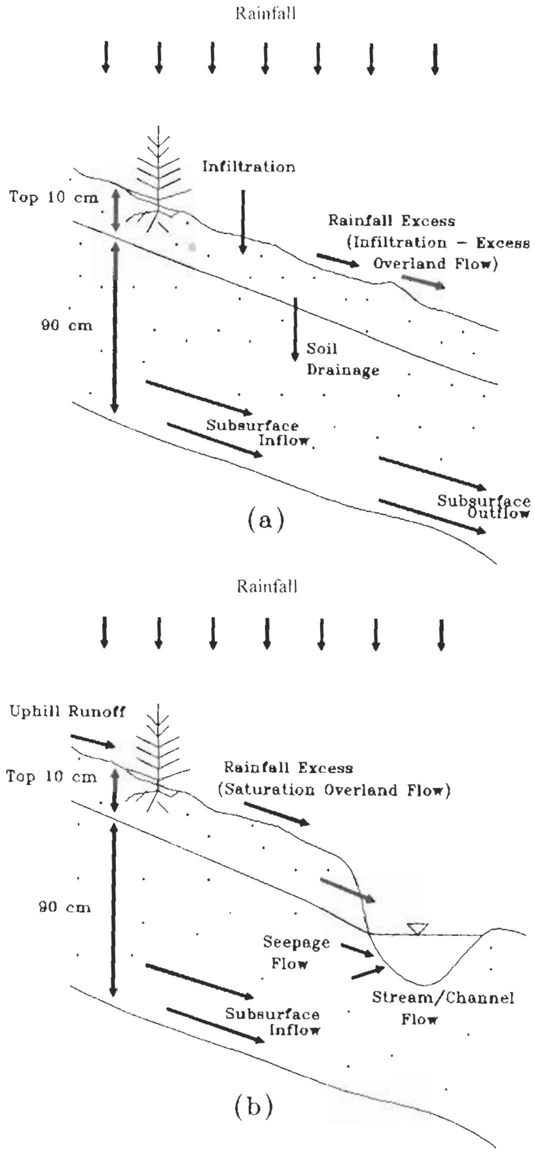

Fig. 4. Schematic representation of runoff processes in (a) an upland watershed elemental area, (b) a valley (dual) watershed elemental area.

(5) Overland and channel flow, by St. Venant equations with finite-difference formulation of kinematic approximation as presented in Chow et al. (1988)

(6) Reservoir routing model as described in Watt et al. (1989)

(7) Soil erosion and sediment routing models as presented by Foster et al. (1981), with overland-flow transport capacity estimation by Finkner et al. (1989); channel-

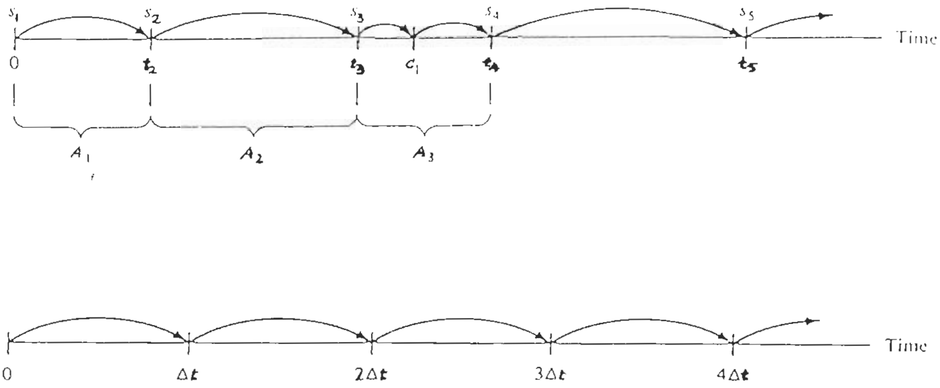

Fig. 5. Illustration of next-event and fixed-increment time advance mechanisms in simulation.

flow transport capacity estimation by Ackers (1988); and, soil erodibility parameters estimation by Liebenow et al. (1990)

(8) Terrace-channel flow and grass-waterway flow by kinematic model as presented in Chow et al. (1988), with related information from Schwab et al. (1981), and

(9) Culvert flow, as described in Schwab et al. (1981).

2.3. *Continuous simulation time advance*

Considering rainfall as one type of hydrologic event, and evapotranspiration as another, occurring between rainfall events, a dynamic mechanism was used to advance simulation time between events as well as during an event. In discrete-event simulation, the *next-event* time advance mechanism is used by which advance is from the time of one event to the time of the next event and periods of inactivity are skipped over. However, for continuous simulation the *fixed-increment* time advance mechanism is applied. This mechanism regularly updates system state variables at fixed time increments.

Fig. 5 illustrates the two time advance mechanisms, both of which are employed in the WRM model. In the figure, t is time, s represents the start of an event, and A is the duration of an event in which a condition may occur at c. The next-event time advance is used to determine *start-times* of events, while the fixed-increment time advance is used during each event (with increment size depending on event type). With rainfall and evapotranspiration, the two event types, consecutively interspaced, the duration of an event corresponds to the difference between its start-time and that of the next event.

3. Model components

The modular layout of the WRM computer program is shown in Figs. 6(a), (b) and (c), in which each title-subroutine calls all subroutines below it. The Main subprogram is for system specification and control. It calls the four subrou-

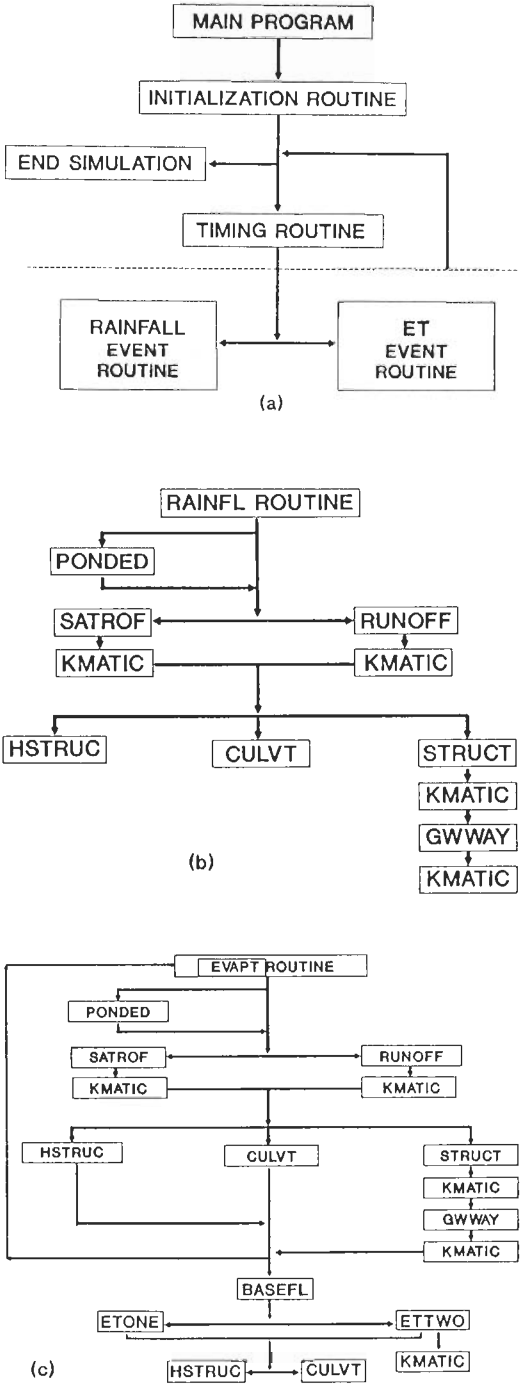

Fig. 6. WRM model layout (a) Main subprogram, (b) Rainfall-event routine, and (c) Evapotranspiration-event routine.

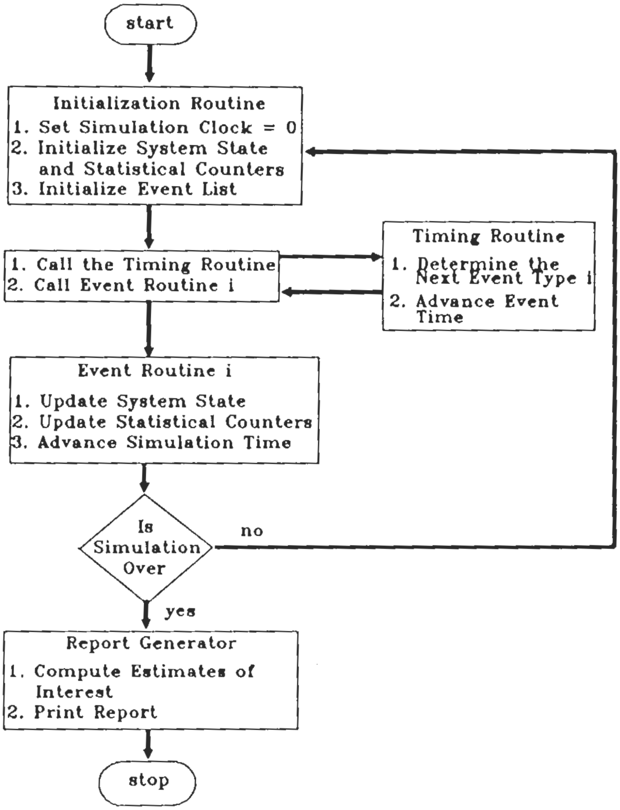

Fig. 7. Main subprogram.

tines, Initialization, Timing, Rainfall-Event and Evapotranspiration-Event, which are grouped as 1st Order Routines. Other subroutines are called from the event modules. Subroutine titles named in the model layout, Fig. 6, are cited in their respective logic flow charts shown below.

Fig. 7 shows the logic flow chart of the Main subprogram. Simulation starts with the Initialization subroutine, driven by a parameters/watershed input data file, which sets watershed/system specifications and the simulation clock; initializes system state variables and statistical counters; reads and/or computes parameters, and reads the events start-time list. Then the Timing subroutine determines event type, and simulation time-advance parameters and variables. In either of the event routines, two operations take place: (1) updating of system state, and (2) gathering information about system performance and updating of statistical counters. Essentially this is a repetitive calculation for a number of simulations that correspond to the number of time intervals in the duration of an event. Each event routine has two nested (FORTRAN statement) DO loops. The outer loop repeats calculations for the required number of simulations. The inner loop repeats calculations, during each simulation

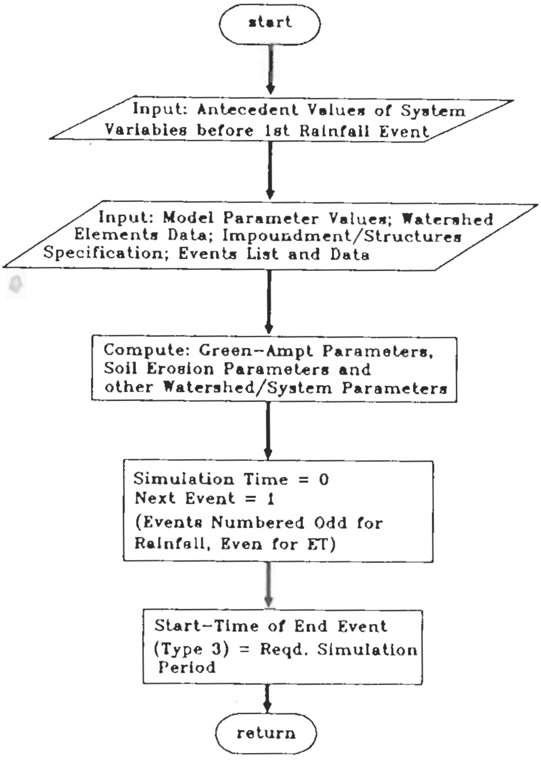

Fig. 8. Initialization subroutine.

interval, for the number of elements in watershed discretization. Calculations in the inner loop represent the heart of the model where the process equations are implemented. The Rainfall-event routine is driven by a breakpoint rainfall input data file, and the Evapotranspiration-event routine by a pan-evaporation input data file.

After completing operations in an event routine the Timing subroutine again determines whether to terminate simulation or to continue the cycle. The Report-Generator routine processes model output data, as could be done by an external program or package.

The logic flow charts of WRM model subroutines are shown in Figs. 8 to 22.

4. Model synthesis

Model components are operated consecutively as described in Model Development above, after Vandenberg (1985). This approach was used in the ANSWERS model (Beasley et al., 1980), and is justifiable on the basis of Nash's philosophy for hydrologic science (Nash, 1988). In a purely deterministic model, components are linked or coupled into a system. Such a system could hardly be integrated.

System integration in the WRM model is by solution of the mass balance equation

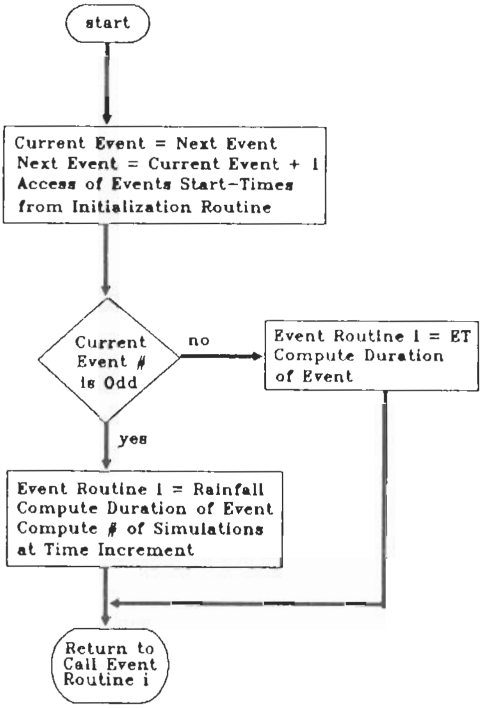

Fig. 9. Timing subroutine.

for the distribution of flow as a function of location (x) across the watershed, and time (t). For each watershed element during a time interval, the continuity equation is applied and state variables are computed from the related process equations. Chow et al. (1988) describe a nonlinear finite-difference formulation of the kinematic flow model, which is unconditionally stable in the explicit scheme, as employed in the WRM model. However, a smaller time step is used during and shortly after rainfall events, than in dry periods.

To represent interactions in the WRM model, watershed elements are numbered from the top left corner of the map, proceeding from left to right downward. The drainage pattern is established by designating flow receiving/outputting elements according to topography. In this regard, the following features were used:

(1) An element under execution in a current interval can receive inflow from an adjoining element or elements executed previously in the preceding interval, in addition to its basic inputs for the current interval;

(2) An element under execution in a current interval outputs to an adjoining element for further routing into the receiving element during the next interval.

For dual elements, the channel segment determines flow direction. By this provision the calculation sequence, which depends on elements' numbering, does not affect interactions as determined by the drainage pattern.

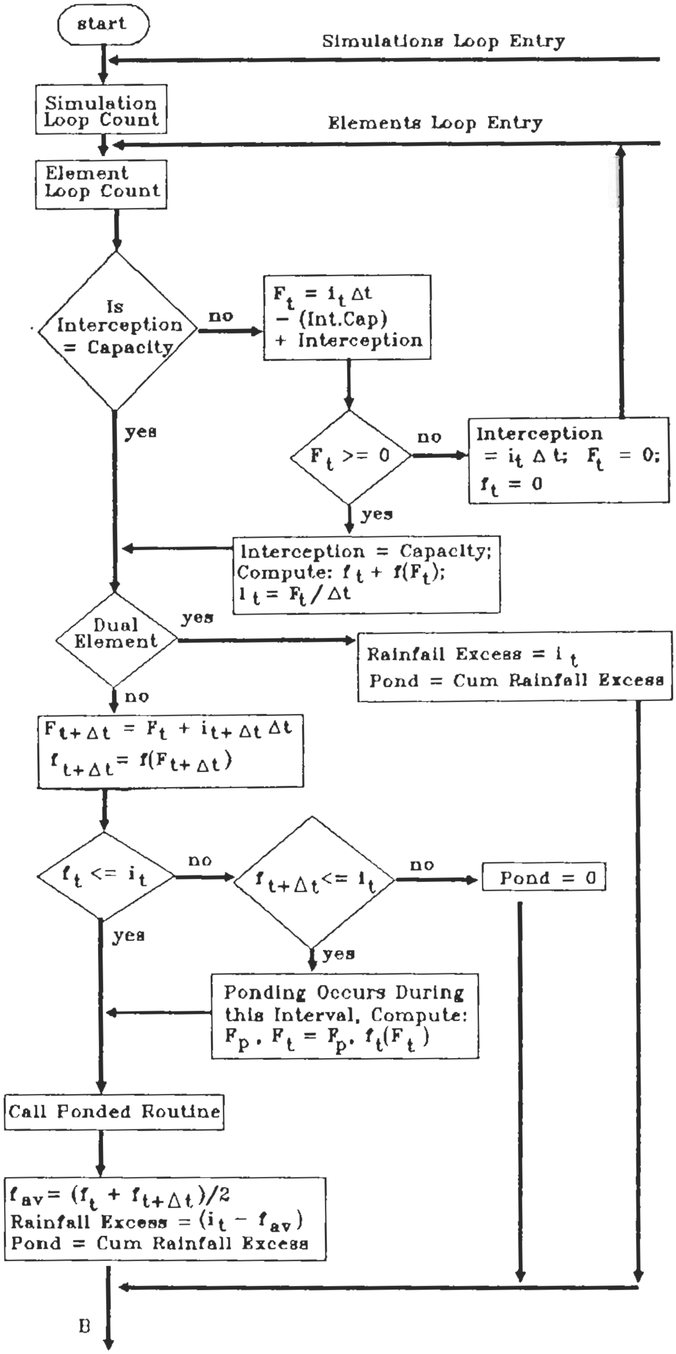

Fig. 10. Rainfall-event subroutine (RAINFL), continues on next page.

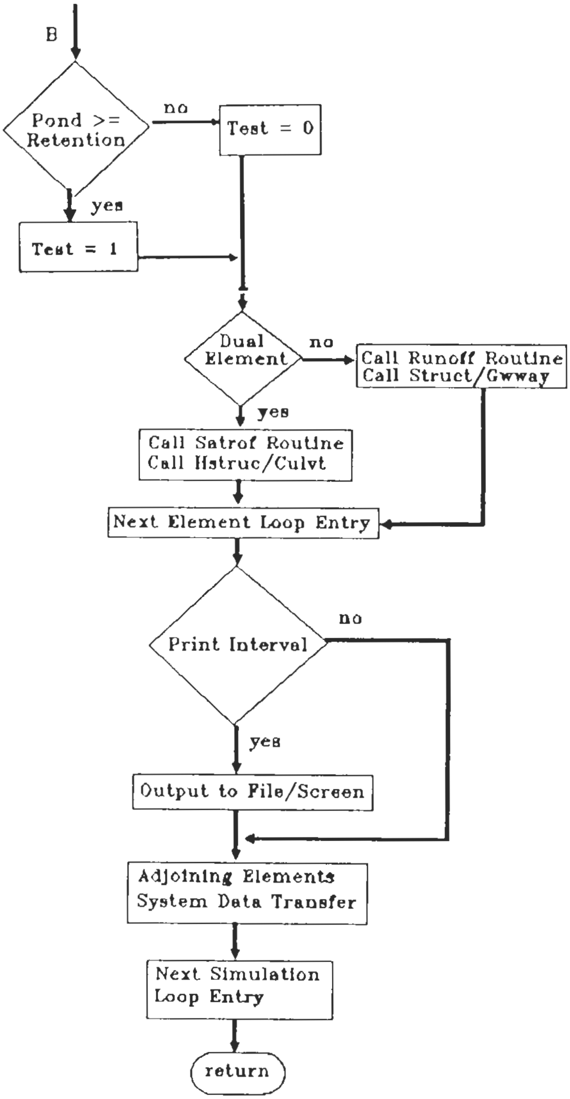

Fig. 10 (continued).

The WRM model outputs require a specified output interval, as different from simulation interval, and a specified monitoring location on the watershed.

5. Summary and conclusion

A continuous simulation model of watershed hydrology requires the repetition of system calculations over an extended period of time involving more than one event.

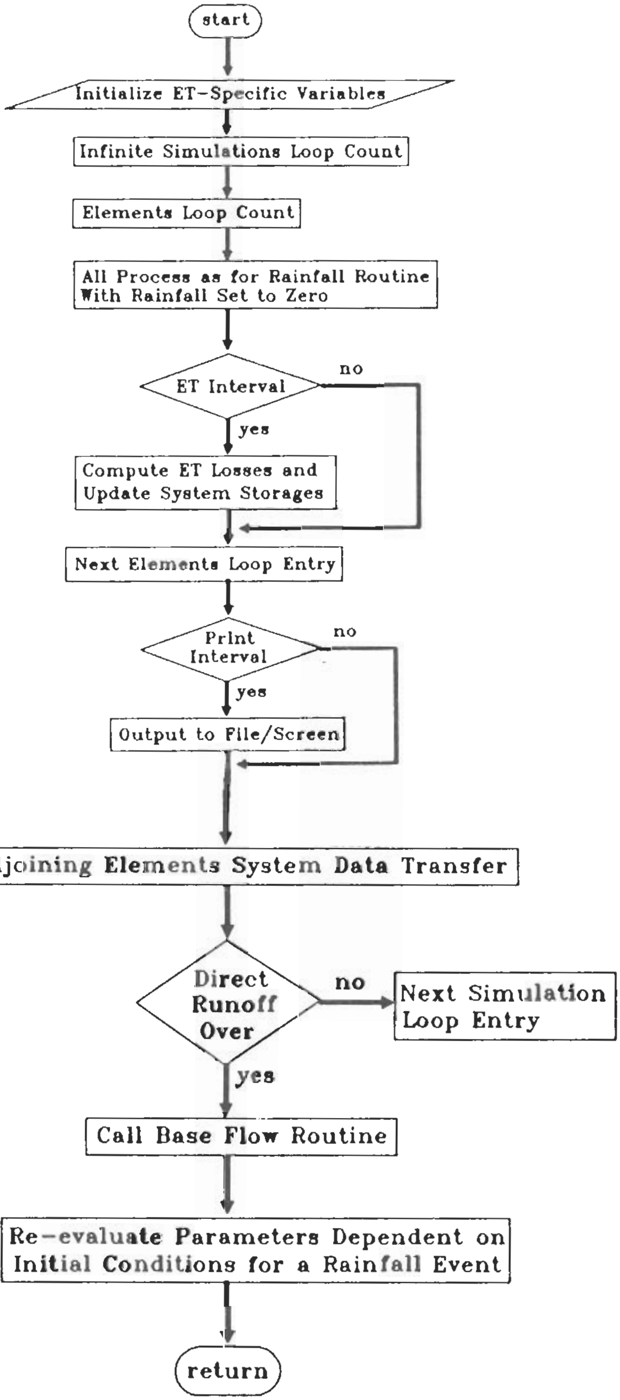

Fig. 11. Evapotranspiration-event subroutine (EVAPT).

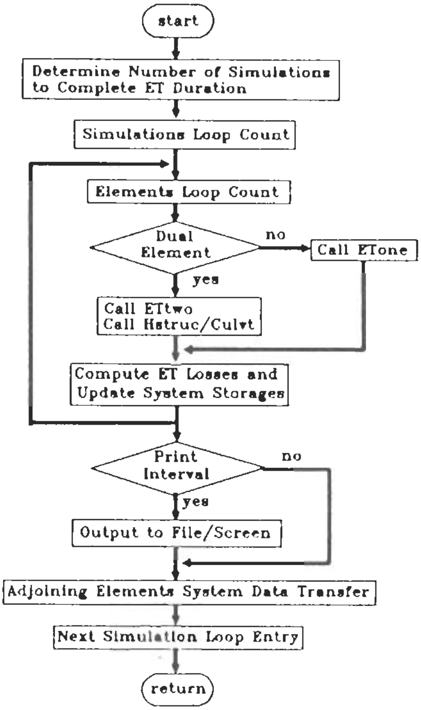

Fig. 12. Baseflow subroutine (BASEFL).

Both rainfall and between-rainfall processes need to be represented. Although simulation is not a real time exercise, it requires real-time data which may be measured, estimated or assumed. To reflect temporal variability in hydrologic activity, variable time scales need to be employed in continuous simulation. Also required are distributed parameter inputs, and representation of spatial variability in watershed characterization and system response. Additionally, to simulate management and conservation practices, representation of hydraulic and conservation structures, land surface treatments and vegetative cover are needed. The simulation of soil erosion and sediment transport on the land, through conservation structures and stream channels to deposition in impoundments, require special process-modelling considerations. The WRM model has been developed to meet the aforesaid requirements.

Model components may be updated or new components added, e.g., a snow-melt runoff module. Modular design ensures this flexibility.

Acknowledgements

This project was funded by the Canadian International Development Agency under an Agricultural Engineering linkage between Technical University of Nova Scotia (TUNS), Halifax, and University of Nigeria, Nsukka. The author acknowl-

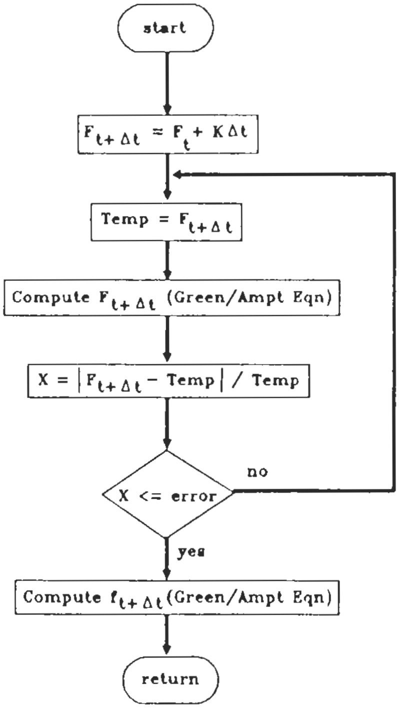

Fig. 13. Ponded-infiltration subroutine (PONDED).

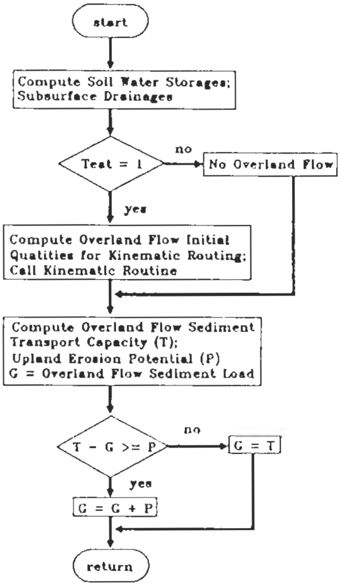

Fig. 14. Runoff subroutine (RUNOFF).

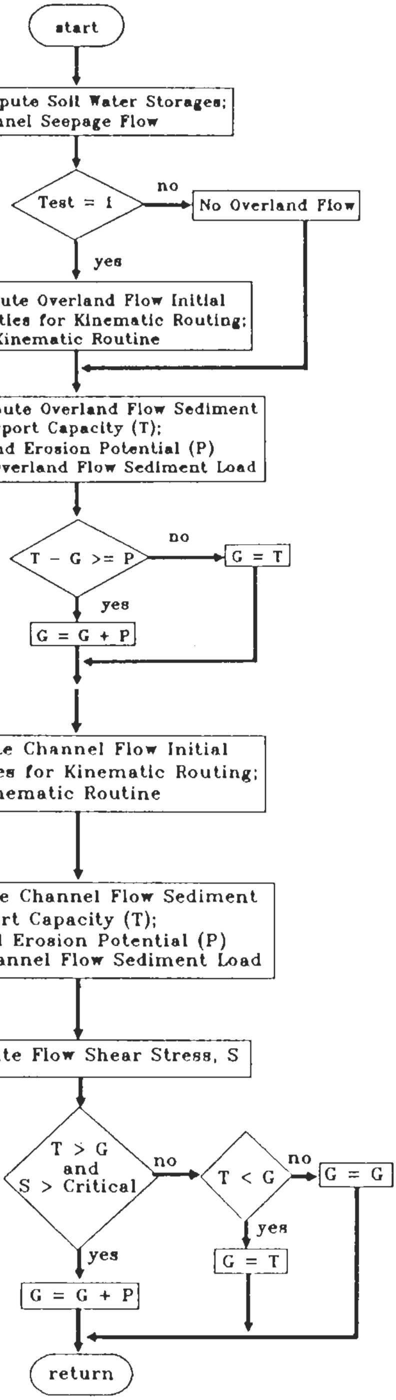

Fig. 15. Saturation Runoff subroutine (SATROF).

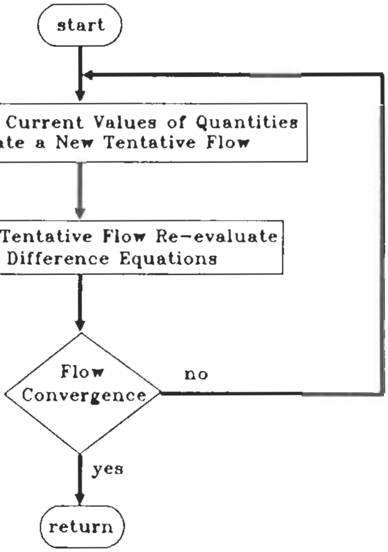

Fig. 16. Kinematic flow subroutine (KMATIC).

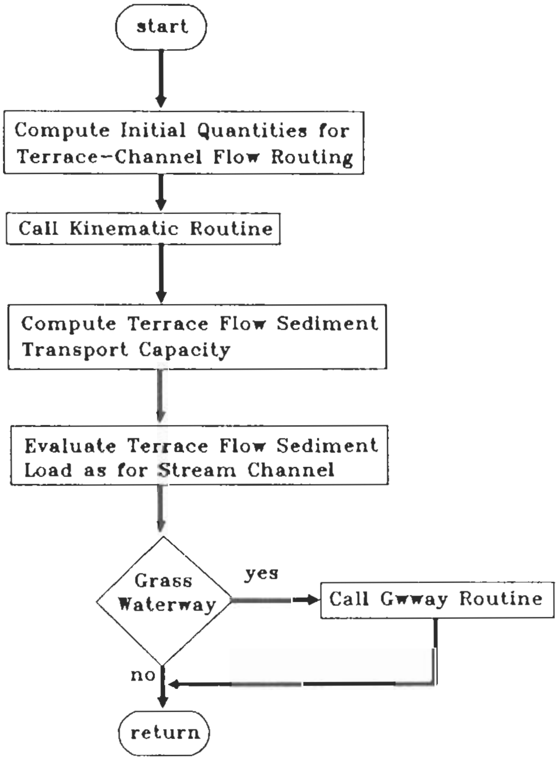

Fig. 17. Conservation Structures (terraces) subroutine (STRUCT).

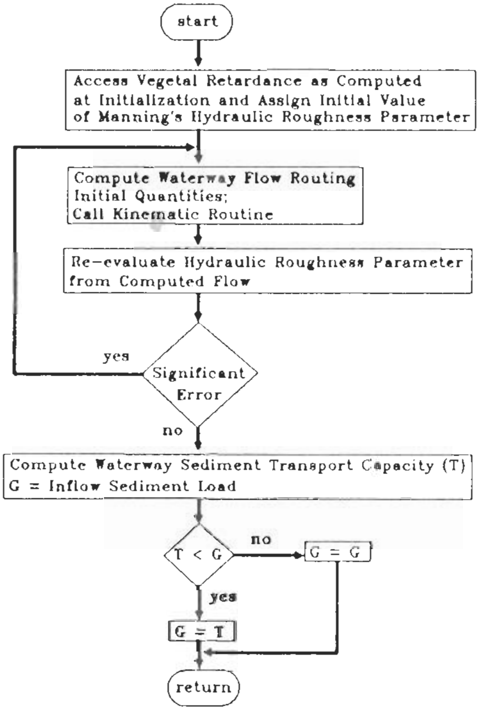

Fig. 18. Grass waterway subroutine (GWWAY).

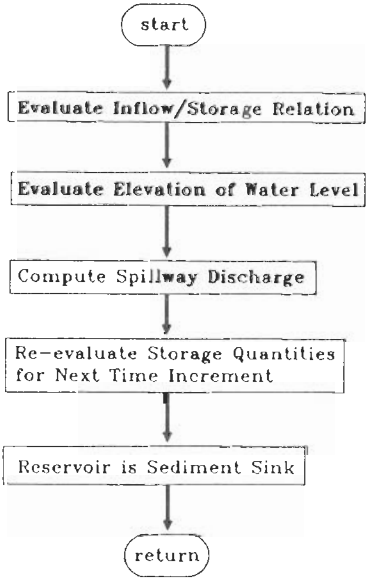

Fig. 19. Hydraulic Structures (reservoirs) subroutine (HSTRUC).

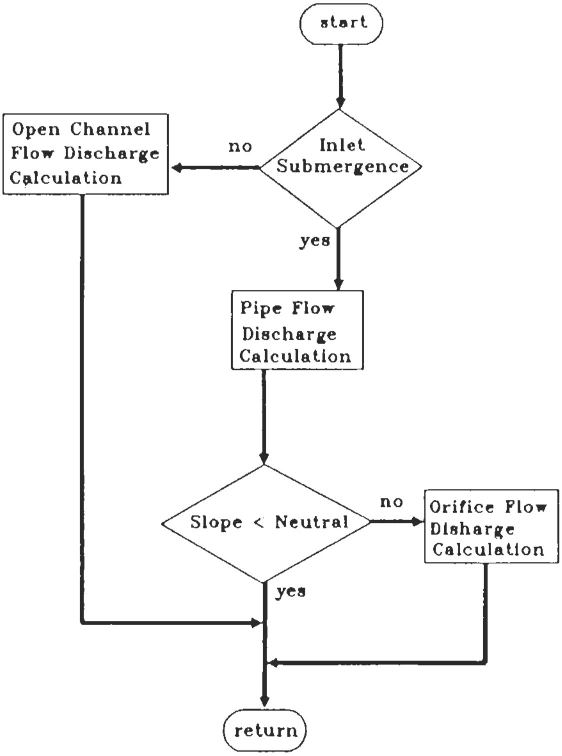

Fig. 20. Culvert structure subroutine (CULVT).

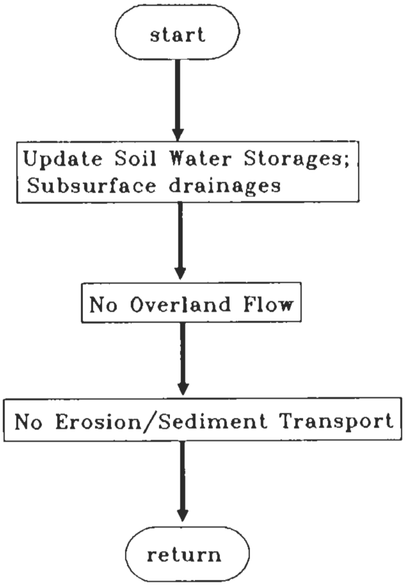

Fig. 21. Upland, dry period processes subroutine (ETONE).

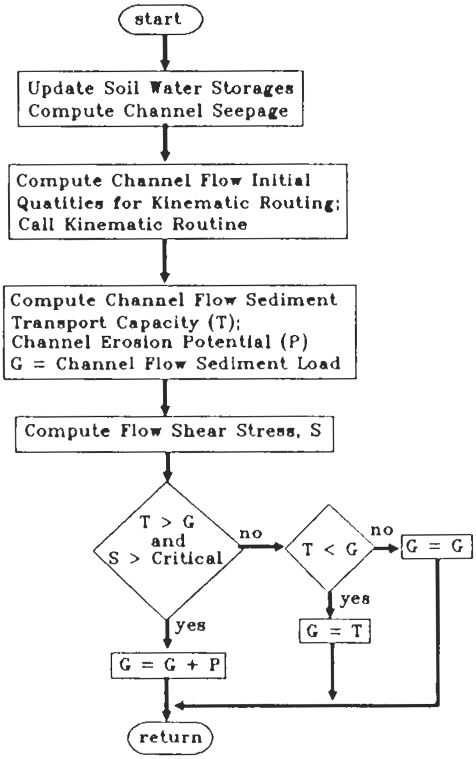

Fig. 22. Dual element, dry period processes subroutine (ETTWO).

edges the assistance of Dr. Jack R. Burney of TUNS, as well as that of Dr. Linnell M. Edwards of Agriculture Canada Research Station, Prince Edward Island, Canada.

References

Abbott, M.B., Bathurst, J.C., Cunge, J.A., O'Connell, P.E. and Rasmussen, J. (1986) An introduction to the European Hydrological System — Systeme Hydrologique Europeen, "SHE", 1: History and philosophy of a physically-based, distributed modelling system. J. Hydrol., 87: 45–59.

Ackers, P. (1988) Alluvial Channel Hydraulics. J. Hydrol., 100: 177–204

Beasley, D.B., Huggins, L.F. and Monke, E.J. (1980) ANSWERS: a model for watershed planning. Trans. ASAE, 23: 938–944

Betson, R.P. and Ardis, Jr., C.V. (1978) Implications for modeling surface-water hydrology, In: M.J. Kirkby (Editor), Hillslope Hydrology. John Wiley and Sons, Chichester, pp. 295–323.

Brakensick, D.L. and Rawls, W.J. (1988) Effects of agricultural and rangeland management systems on infiltration. ASAE Publ. 07/88, St. Joseph, MI, pp. 244–251.

Chow, V.T., Maidment, D.R. and Mays, L.W. (1988) Applied Hydrology. McGraw-Hill, New York, NY, 572 pp.

Chu, S.T. (1978) Infiltration during unsteady rain. Water Resour. Res., 14(3): 461–466.

DeCoursey, D.G. (1988) A critical assessment of hydrologic modeling. ASAE Publ. 07/88, St. Joseph, MI, pp. 478–493.

Doorenbos, J. and Pruitt, W.O. (1977) Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper 24, Rome, 193 pp.

Chorley, R.J. (1978) The hillslope hydrological cycle, In: M.J. Kirkby (Editor), Hillslope Hydrology. John Wiley and Sons, Chichester, pp. 1–42.

Ferreira, V.A. and Smith, R.E. (1988) The limited physical basis of physically based hydrologic models. ASAE Publ. 07/88, St. Joseph, MI, pp. 10–18.

Finkner, S.C., Nearing, M.A., Foster, G.R. and Gilley, J.E. (1989) A simplified equation for modeling sediment transport capacity. Trans. ASAE, 32(5): 1545–1550.

Foster, G.R., Lane, L.J., Nowlin, J.D., Laflen, J.M. and Young, R.A. (1981) Estimating erosion and sediment yield on field-sized areas. Trans. ASAE, 24: 1253–1262.

Haan. C.T. (1988) Parametric uncertainty in hydrologic modeling. ASAE Publ., 07/88, St. Joseph, MI, pp. 330–346.

Hodge, W., Larson, M. and Goran, W. (1988) Linking the ARMSED Watershed Process Model with the GRASS Geographic Information System. ASAE Publ., 07/88, St. Joseph, MI, pp. 501–510.

Horton, R.E. (1919) Rainfall interception. Mon. Weather Rev., 47: 603–623.

Horton, R.E. (1933) The role of infiltration in the hydrologic cycle. Trans. Am. Geophys. Union, 14: 446–460.

Ishaq, A.M. and Huff, D.D. (1977a) Hydrologic source areas, A: a technique for identifying. In: H.J. Morel-Seytoux et al. (Editors), Modeling Hydrologic Processes. Proc. Fort Collins 3rd Int. Hydrology Symp. Water Res. Publ., Fort Collins, CO, pp. 495–510.

Ishaq, A.M. and Huff, D.D. (1977b) Hydrologic source areas, B: runoff simulations. In: H.J. Morel-Seytoux et al. (Editors), Modeling Hydrologic Processes. Proc. Fort Collins 3rd Intern. Hydrology Symp. Water Res. Publ., Fort Collins, CO, pp. 511–523.

Kirkby, M. (1975) Hydrograph modeling strategies, In: Peel et al. (Editors), Processes In Physical and Human Geography (Bristol Essays). Heinemann Educational Books, pp. 69–90.

Klemes, V. (1982) Empirical and causal models in hydrology, In: V. Klemes (Editor), Scientific Basis of Water Resource Management. National Acadamic Press, Washington, DC, pp. 95–104.

Knisel, W.G. (Editor) (1980) CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. USDA Cons. Res. Rep., 26, 640 pp.

Liebenow, A.M., Elliot, W.J., Laflen, J.M. and Kohl, K.D. (1990) Interrill erodibility: collection and analysis of data from cropland soils. Trans. ASAE, 33(6): 1882–1888.

Mbajiorgu, C.C. (1992) Watershed Resources Management Model: A Process-based, Continuous, Distributed-Parameter Mathematical Watershed Model Incorporating Conservation Structures. Ph.D Thesis, Tech. University of Nova Scotia Library, Halifax, NS, 341 pp. (unpublished).

Nash, J.E. (1988) Foreword. J. Hydrol., 100: v–viii.

Rawls, W.J. and Brakensiek, D.L. (1988) An infiltration model for evaluation of agricultural range management systems. ASAE Publ., 07/88, St. Joseph, MI, pp. 166–175.

Saxton K.E. and McGuinness, J.L. (1982) Evapotranspiration. ASAE Monogr., 5: 229–266.

Schwab, G.O., Frevert, R.K., Edminster, T.W. and Barnes, K.K. (1981) Soil and Water Conservation Engineering. John Wiley and Sons, New York, NY, 3rd ed, 525 pp.

Vandenberg, A. (1985) A Physical Model of Vertical Infiltration, Drain Discharge and Surface Runoff. Environment Canada NHRI Paper No. 25, IWD Tech. Bull., 137, 57 pp.

Wagenet, R.J. (1988) Modeling soil hydrology: perspectives, perils and directions. ASAE Publ., 07/88, St. Joseph, MI, pp. 1–9.

Watt, W.E., Lathen, K.W., Neill, C.R., Richards, T.L. and Rousselle, J. (Editors) (1989) Hydrology of Floods in Canada — A Guide to Planning and Design. National Research Council of Canada, Ottawa, ON, 245 pp.

Williams, J.R., Jones, C.A. and Dyke, P.T. (1984) A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE, 27(1): 129–142.

Wolfe, M.L. and Neale, C.M.U. (1988) Input data development for a distributed parameter hydrologic model (FESHM). ASAE Publ., 07/88, St. Joseph, MI, pp. 462–469.

Young, R.A., Onstad, C.A., Bosch, D.D. and Anderson, W.P. (1987) Agricultural Non-Point-Source Pollution Model. A Watershed Analysis Tool. USDA Conserv. Res. Rep., 35, 77 pp.

Computers and electronics in agriculture

Submission of articles. Manuscripts should be submitted in triplicate to R.L. Olson (Americas) or to S.W.R. Cox (rest of the world). Review articles should be submitted in triplicate to M.A. Foster. Book reviews to C.J. Studman (addresses on inside front cover). Authors whose native language is not English are strongly advised to have their manuscripts checked by an English-speaking colleague prior to submission.
Authors in Japan please note: Upon request, Elsevier Science Japan will provide authors with a list of people who can check and improve the English of their paper (*before submission*). Please contact cur Tokyo office: Elsevier Science Japan, 20-12 Yushima 3-chome, Bunkyo-ku, Tokyo 113; tel. (03)-3833-3821; fax (03)-3836-3064.

All questions arising after acceptance of the manuscript, especially those relating to proofs, should be directed to: Computers and Electronics in Agriculture, Elsevier Science B.V., P.O. Box 1527, 1000 BM Amsterdam, The Netherlands, tel. (+31-20)4853276, fax (+31-20)4853258.

Electronic manuscripts. Electronic manuscripts have the advantage that there is no need for the rekeying of text, thereby avoiding the possibility of introducing errors and resulting in reliable and fast delivery of proofs.
For the initial submission of manuscripts for consideration, hardcopies are sufficient. For the processing of *accepted papers*, electronic versions are preferred. After *final acceptance*, your disk plus two, final and exactly matching printed versions should be submitted together. Double density (DD) or high density (HD) diskettes (3½ or 5¼ inch) are acceptable. It is important that the file saved is in the native format of the wordprocessor program used. Label the disk with the name of the computer and wordprocessing package used, your name, and the name of the file on the disk. Further information may be obtained from the Publisher.

Proofs. One set of proofs will be sent to the author to be checked for printer's errors. In case of two or more authors please indicate to whom the proofs should be sent.

Reprints and page charges. There is no page charge. Fifty reprints of each paper and 100 reprints of each review article published will be supplied free of charge. Additional reprints can be ordered on a reprint order form which is included with the proofs.

COMPUTERS AND ELECTRONICS IN AGRICULTURE HAS NO PAGE CHARGES

All contributions will be carefully refereed for international relevance and quality. Submission of an article is understood to imply that the article is original and unpublished and is not being considered for publication elsewhere.

For a full and complete Guide for Authors, please refer to
Computers and Electronics in Agriculture, Vol. 12, No. 2, pp. 175–181

0168-1699/95/$09.50

PRINTED IN THE NETHERLANDS