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Watershed resources management (WRM) model
2. An application to the Upper Wilmot watershed

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Watershed resources management (WRM) model
2. An application to the Upper Wilmot watershed

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Abstract

A sensitivity study of the Watershed Resources Management (WRM) model was carried out and the model parameters requiring adjustment for calibration determined. The model was applied to two sub-watersheds (Curley's and Mayne's) of the Upper Wilmot Watershed, Prince Edward Island, Canada, over a duration of 5 months (May–September, 1990). Calibration was performed by adjusting parameters for agreement in the first event of the simulation. Simulated and recorded hydrographs for the remaining events were compared for validation. Independent validation of the model for the two sub-watersheds is demonstrated. Based on output for the Curley's sub-watershed the model was evaluated by demonstrating structural effects as simulated for different conservation planning scenarios.

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

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1. Introduction

A sensitivity study of the Watershed Resources Management (WRM) Model was used to determine which parameters require a more precise evaluation for model operation. Matching and comparison of continuous recorded and simulated streamflow hydrographs were performed for two sub-watersheds (Curley's and Mayne's) of the Upper Wilmot Watershed, Prince Edward Island, Canada. Curley's sub-watershed has an area of 140 ha, and Mayne's an area of 412 ha. A duration of 5 months, May 5 to September 30, 1990, was covered by all simulations with each parameter varied systematically over a range of reasonable values. Directly-measurable parameters, to which simulations were sensitive, were evaluated at representative field sites. Parameters of low sensitivity were assigned values from published data, and other sensitive parameters were evaluated indirectly from related measure-

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ments and used for model calibration. Termed "calibration parameters", these refer to the small subset of model parameters whose values may be varied in model calibration. The model was calibrated by adjusting calibration parameters for an order of magnitude agreement between simulated and recorded flows in the first rainfall event. The model was validated by comparison of simulated and recorded hydrographs for subsequent events in the series.

As a technique, sensitivity analysis is used to assess the relative change in a model response or output due to a change in inputs or model parameters. The aim is to determine which of the inputs or parameters are more important than others and, therefore, require a more accurate estimation. For a simple model, such as an explicit function, the derivatives of the function with respect to inputs and parameters give the sensitivity in explicit closed-form solutions. However, for complex simulation models, sensitivity is commonly expressed as relative changes by graphs or tables.

2. Model parameters

The sensitivities of the many parameters in the WRM Model were investigated by intensive experimentation on the model, by which experience was gained in typical model responses to changes in parameter values within a reasonable range. Hydrograph plots were used to assess sensitivities. The sensitivity study led to a classification of the model parameters as follows: (1) Sensitive, Directly-Measurable Parameters; (2) Low-Sensitivity Parameters, and; (3) Sensitive, Indirectly-Evaluated or Non-Measurable Parameters.

The sensitivity of model parameters in mutual interaction was not investigated, due to the complexity of the model. The parameters were investigated one at a time, with other parameter values fixed. Only the indirectly-evaluated parameters were adjusted in the model's calibration. Sensitive measurable parameters were evaluated as accurately as point-scale measurements allowed, and low-sensitivity parameters were evaluated from published data in the literature.

The sensitive, measurable parameters are mainly all the soil parameters, and watershed specification data relating to conservation practices and structures. Others are watershed parameters such as antecedent soil-water content and soil depths in the top and sub-soil zones. Since watershed definition and specification parameters should be as exact as possible, they are grouped with this class.

The low-sensitivity parameters are mainly vegetation parameters; parameters relating to pan-evaporation, such as pan coefficient and bare-surface evaporation coefficient; and watershed parameters relating to vegetation cover and growth. Also of low sensitivity are parameters used to determine overland-flow sediment transport capacity (sediment transport coefficient and Darcy-Weisbach hydraulic roughness parameters), as well as the surface-residue parameter. However, these erosion and sediment transport parameters are highly interactive with the hydrologic system variables and inputs.

Sensitive, indirectly-evaluated or "calibration" parameters comprise the Manning's (1891) hydraulic roughness for overland flow, channel flow and terrace-channel

Table 1
Sensitivity of Calibration Parameters (WRM Model)

Name of parameter	Rating (1–5) [a]	Effect on hydrograph
MANN1	3	Overland flow timing
MANN2	5	Drainage network flow timing
MANN3	3	Terrace flow timing
BFLOW	2	Minimum drainage network outflow; runoff volume
KRET	4	Initial abstraction; runoff volume/peak
KSTORE	4	Long-term runoff timing/volume
Measurable parameters	3–5	Varied/interactive
Vegetative parameters	1	Not significant to flow hydrograph

[a] 3–5 = very sensitive; 2 = sensitive; 1 = low sensitivity.

flow (MANN1, MANN2 and MANN3, respectively); baseflow constant-discharge (BFLOW); surface retention (KRET); and, subsurface drainage (KSTORE). Apart from the baseflow parameter, which sets the watershed outlet minimum discharge due to aquifer interaction, these parameters are process-based. KSTORE adjusts an empirically estimated subsurface drainage coefficient to a specific watershed, while KRET relates vegetation height and density, retardance index, and land slope to surface retention. Mannings roughness parameters control surface drainage rate, thus affecting runoff timing and hydrograph shape. But KRET also affects volume of runoff and peak flow, by increasing or decreasing the hydrograph as a whole. It can also be used to delay initiation of runoff, as for the case of rainfall following a dry period. The parameter KSTORE is sensitive to long-term runoff timing and is particularly useful for controlling subsurface flow discharge. A summary of the sensitivity ratings of these parameters is shown in Table 1, as a guide to model application. The ratings show how the parameters may be treated in their estimation.

3. Description of the Upper Wilmot watershed

The upper reaches of the Wilmot River straddle the boundary between Queens and Prince Counties in the central region of the province of Prince Edward Island (P.E.I.), Canada, approximately 7 km south-east of Kensington and 35 km north-west of Charlottetown. The area of the Wilmot River watershed is 81 km^2. However, the study area designated as the Upper Wilmot Watershed (UWW) comprises the upper 35 km^2. Land slopes in the UWW are between 2 and 5%. Due to the undulating nature of the topography, individual farmlands and fields are not regular in slope degree or orientation, even over small areas. The climate of the area is cool and humid, with average annual precipitation of 1040 mm. Average potential evapotranspiration during the growing season, May to September, is 450 mm.

Soils in the UWW are predominantly the Charlottetown series (75.9%), classified as a well-drained Orthic Humo-Ferric Podzol derived from fine sandy loam glacial till or residual material. Parent material clay, and silt plus clay, contents vary from 8

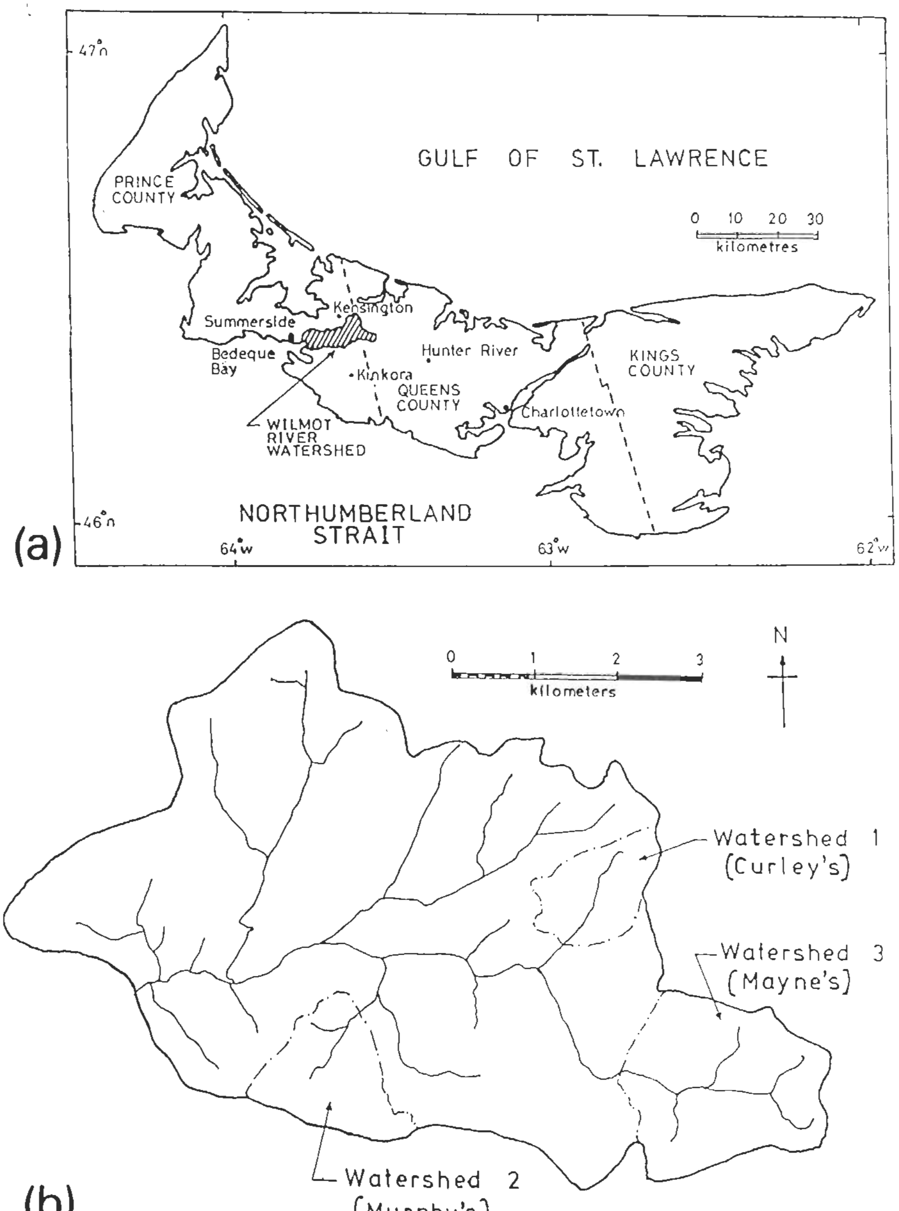


Fig. 1. (a) Location of Wilmot River Watershed in Prince Edward Island. (b) Location of study waterheads in the Upper Wilmot Watershed.

to 18%, and 35 to 50%, respectively. This soil association represents areas with good water transmissibility in the upper solum, but with moderate to very slow movement in the compact subsoil. All soils found in the UWW are characterised by low natural fertility levels, low organic matter content (<4%), and light to medium textures throughout the solum. Surface textures throughout the area are quite similar, being fine sandy loam. Eighty-seven percent of the soils are classified as well-drained, mostly of the Charlottetown series.

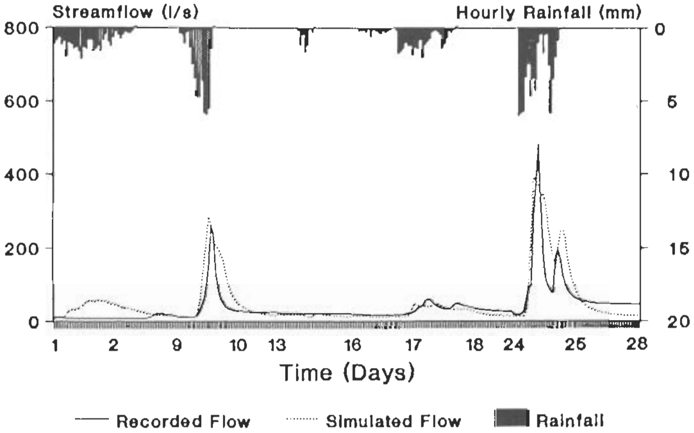
The natural vegetation of the area falls within the Acadian forest region and, original stands dominantly deciduous. However, current forested areas have been adversely affected by logging, fires and general mismanagement (Burney, 1989).

The location in the UWW of the sub-watersheds, *Curley's* and *Mayne's*, studied in this work is shown in Fig. 1. A more detailed description of the sub-watersheds including topographic maps, soil maps, property and field boundaries, is presented by Burney (1989).

4. Results of model application

The WRM model was calibrated for this application by adjusting parameters for reasonable agreement between simulated and recorded flow in the first rainfall event. By reasonable agreement is meant an order of magnitude correspondence between the simulated and recorded series, which is consistent within the duration of an event. Model validation was performed by comparison of simulated and recorded hydrographs in the subsequent events of the series, by superposition of hydrograph plots.

The model was calibrated and validated after Watt et al. (1989). Fig. 2 shows the comparison of validation hydrograph plots for the Curley's sub-watershed. Similarly, Fig. 3 is for the Mayne's sub-watershed. The plots are sampled from a single continuous simulation over the period from May 5 to September 30, 1990. Although breakpoint rainfall data was recorded for the period, the corresponding streamflow



Time From May 6, 1990 (Julian Day 126); 18:02 hours in the day.

Fig. 2. Simulated and Recorded Hydrographs for Model Validation, Curley's sub-watershed.

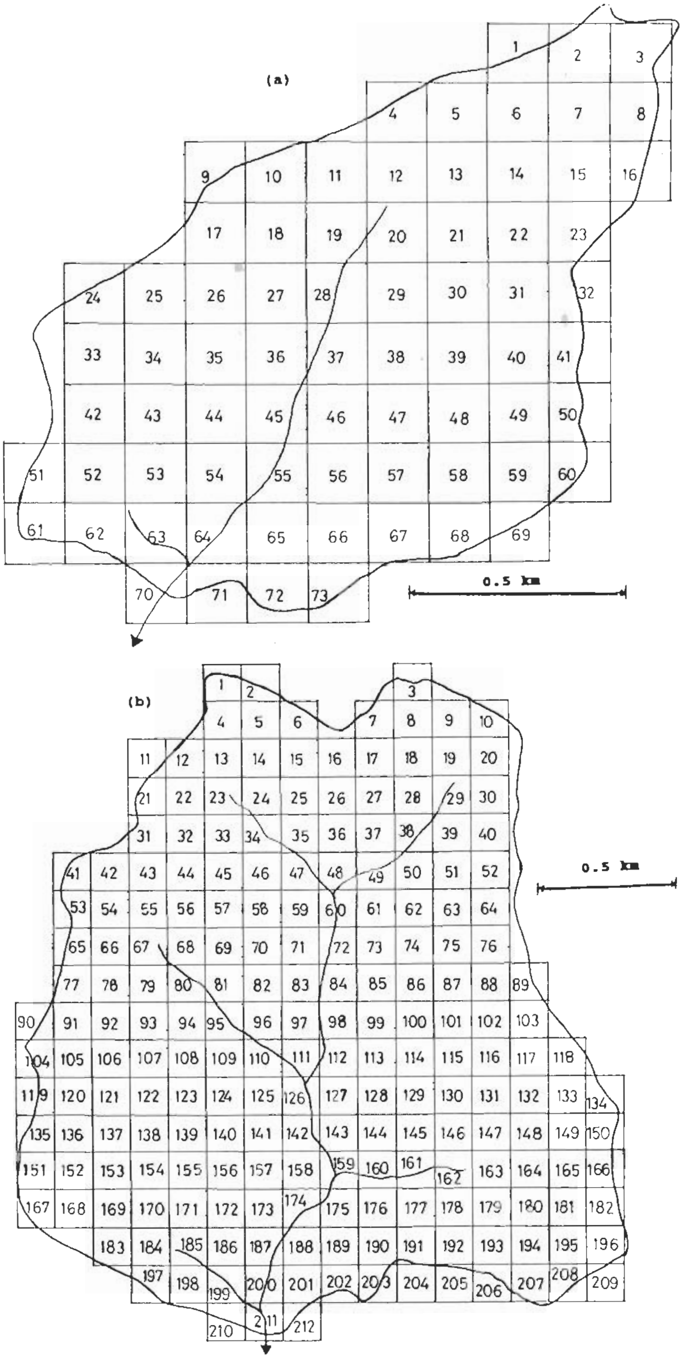


Fig. 4. Watershed discretization into square elements (a) Curley's sub-watershed, scale 1 : 8,700; (b) Mayne's sub-watershed, scale 1 : 14000.

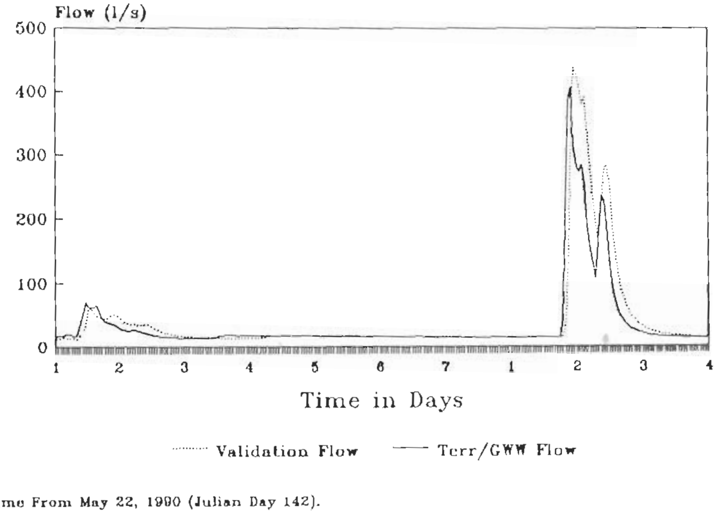


Fig. 5. Effect of Terraces/Grass-waterway System on Stream Discharge, Curley's sub-watershed.

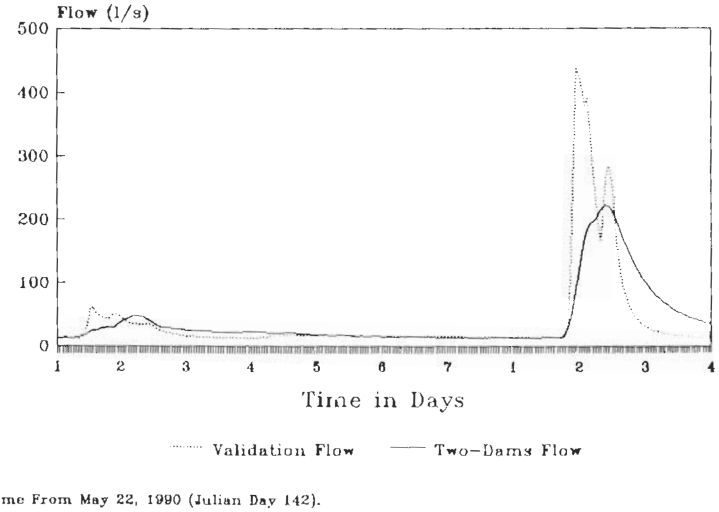
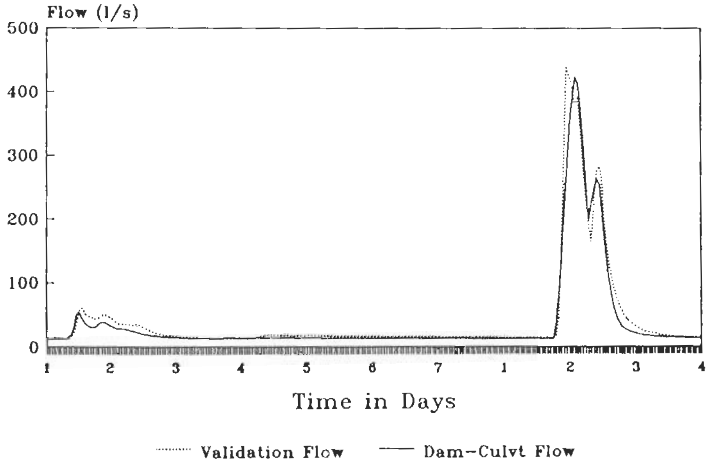


Fig. 6. Effect of Two Dams on Stream Discharge, Curley's sub-watershed.

effects, of these hypothetical or "what-if" conservation-structures scenarios (Mbajiorgu, 1992). Typical results are shown for the effect on streamflow of the terraces/grass-waterways system in Fig. 5, the 2-dams alternative in Fig. 6, and the dam-culvert alternative in Fig. 7. These results were used in model evaluation, with due consideration for the modeling assumptions, limitations in physical and operational



Time From May 22, 1990 (Julian Day 142).

Fig. 7. Effect of a Dam and Culvert on Stream Discharge, Curley's sub-watershed.

representation, theoretical approximations, and limitations of availability/accuracy of model testing data.

Fig. 5 shows a slight attenuation of hydrograph peaks, with the main features of the hydrographs reproduced as for model validation hydrographs, by the terraces/grass-waterways structural effect. On the other hand, Fig. 6 shows both attenuation of peaks and modification of hydrograph features by storage, as the effect of two reservoirs created by a dam at a remote upstream location and another dam at the watershed outlet. Likewise, Fig. 7 shows both attenuation and modification of hydrographs, though much smaller than that of Fig. 6, as the effect of a remotely located dam with a culvert at the watershed outlet.

A somewhat more complex comparison between the structural effects can be made across Figs. 5, 6 and 7. The figures agree with the reasonable assessment of dams as more effective in conserving water. Figs. 5 and 7 indicate that the terraces/grass-waterway effect did conserve more water (by lowering peak flows), in addition to conserving soil, than the effect of the remotely located dam with a culvert downstream. However, these interpretations depend on an assumption of uniform specification of each type of structure in multiple location.

6. Conclusion

Subject to the above discussion, the results of model evaluation indicate performance and an adequate system representation. A continuous simulation model of watershed hydrology requires the repetition of system calculations over an extended period of time involving more than one event. 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 input, 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 was developed with all of the aforesaid in mind. In this study, the model validation process has been initiated with good results independently obtained for two sub-watersheds.

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