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Assessment of cumulative watershed effects using WASTED model

B. K. PURANDARA
Hard Rock Regional Centre, National Institute of Hydrology, Belgaum - 590 001, Karnataka (India)
G. H. BELT
Emiritus Professor, University of Idaho, Moscow, ID, USA

Abstract

In the present study an attempt has been made to understand the applicability of WATSED model, a computer based model to estimate the Cumulative Watershed Effects. The study has been carried out in two parts, (i) sensitivity analysis and, (ii) model application to Malaprabha representative basin, Belgaum district, Karnataka, India. . The sensitivity analysis of the model indicated that, though the parameters such as rainfall, monthly runoff and peakflow, mass erosion coefficients etc are taken into consideration, these factors do not show any direct impact on model output. However, it is observed that the model is very sensitive to alternative forest cutting and soil disturbing activities including silvicultural practices, alternative road construction practices and wild fire. In the second part, runoff and soil loss were estimated. The runoff coefficient obtained through WATSED model is 0.5 and the soil loss predicted by the model is 189 tonnes/sq km/year which is almost double the observed soil loss for the year 1987-88. The projected soil loss for the year 1996, without any management activities (after 8 years of recovery period) is 83 tonnes/sq km/year which is reduced by more than 50%. Based on the study, it is understood that the model can be used for the estimation of cumulative watershed effects due to various management activities. However, for broader application, it is suggested that the model must be oriented to take cognizance of climatic, soil and hydrological data availability and data constraints in order to make it a generally applicable user tool for realistic water resources decision making, rather than merely a multi-parameter site specific user tool.

INTRODUCTION

The cumulative effects of land management activities on water quality, stream channels, and water dependent resources from the introduction of sediment and changes in quantity and timing of water flow are ever increasing concerns to land managers. However, the introduction of Cumulative Watershed Effects (CWE) analysis has been slow, even agonizing at times. Among forest hydrologists, the effects of forest practices on elements of the hydrologic cycle are well known. Undoubtedly, this knowledge was a precursor to early efforts by soil and water resource specialists to protect soil and water resources not only at the project level but also at the basin level. For if a forest practice is known to affect some stream flow characteristic, it should follow that a variety of forest practices spread over the landscape over time would have some cumulative effect on stream flow. Changes in the environment that results from forest practices occur either as individual effects or as cumulative effects. Individual effects result from single management activity such as road building or clear-cut logging. Increased size of peak stream flows in a small watershed following extensive disturbance of soil during tractor yarding in a single clear-cut area is an example of an individual effect. For cumulative effects to be of any consequence, individual effects must be of sufficient magnitude to be detected at some point offsite, i.e. downstream from the location of the forest practice responsible for the individual effect. Cumulative effects, however, can occur either onsite or offsite. Onsite effects are caused by several practices combining over time or by a single practice being repeated over time. Offsite effects usually result from several practices combining in both time and space.

Past research has focused largely on individual effects either at the plot level or at the level of small watersheds. Although there are many examples of how a particular stream flow characteristic was altered by certain forest practices, how to use such information in the context of forest land management planning over a landscape has been a major problem. In fact, an important part of the cumulative effects issue is the so-called `scaling up' of research results, i.e. extrapolating results from plots to the scale of small watersheds and results from small watersheds to the scale of large watersheds.

The scientific literature is replete with results of studies to determine effects of forest practices on hydrologic processes and stream flow. Reduced interception and transpiration following logging results in higher annual water yield following logging (Rothacher, 1970; Harr et al; 1983; Harr, 1986; King, 1989). In general, the greater the proportion of a watershed that is logged, the greater the increase in annual water yield (Bosch and Hewlett, 1982). Minimum flows in summer are also increased markedly following clear-cut logging except in watersheds where fog drip is a substantial source of water.

Forest roads and skid roads also can influence stream flow, but the increase in storm runoff attributable to such soil disturbance are unlikely to be of any consequence except where roads, skid trails, and other forms of compacted soil occupy substantial proportion of small watersheds. In areas of steep slopes and shallow soils, road-cuts can intercept subsurface flow, and convert it to surface flow (Megahan, 1972; Burroughs et al., 1972) and thus have the potential to augment storm runoff in small watersheds.

From the above discussion, it is imperative that the cumulative watershed effects are significant and it needs timely assessment for proper forest land management. Therefore, in the present study, an attempt is made to apply the WATSED model developed by US Forest Service to estimate water yields in response to cumulative watershed effects on the third and fourth order watershed. Here, the model is applied to a large basin (Malaprabha representative basin) by dividing it into number of 3rd and fourth order watersheds.

STUDY AREA

The Malaprabha representative basin lies in the extreme western part of the Krishna basin. It extend in between 74^{o}20' and 74^{o}30' E longitudes and 15^{o}20' and 15^o 40' N latitudes and encompasses an area of 540 sq km of the Belgaum district in the Karnataka state (Fig.1). Two major roads run through the Malaprabha representative basin are Belgaum - Goa (NH - 4A) and Belgaum - Mapusa state highway. This representative basin is the major source of water yield for the Naviluteerth dam constructed at 40 - 45 km downstream of its mouth. This dam impounds 1377 MCM water and provides water for irrigation approximately for 2.17 lakh hectare land.

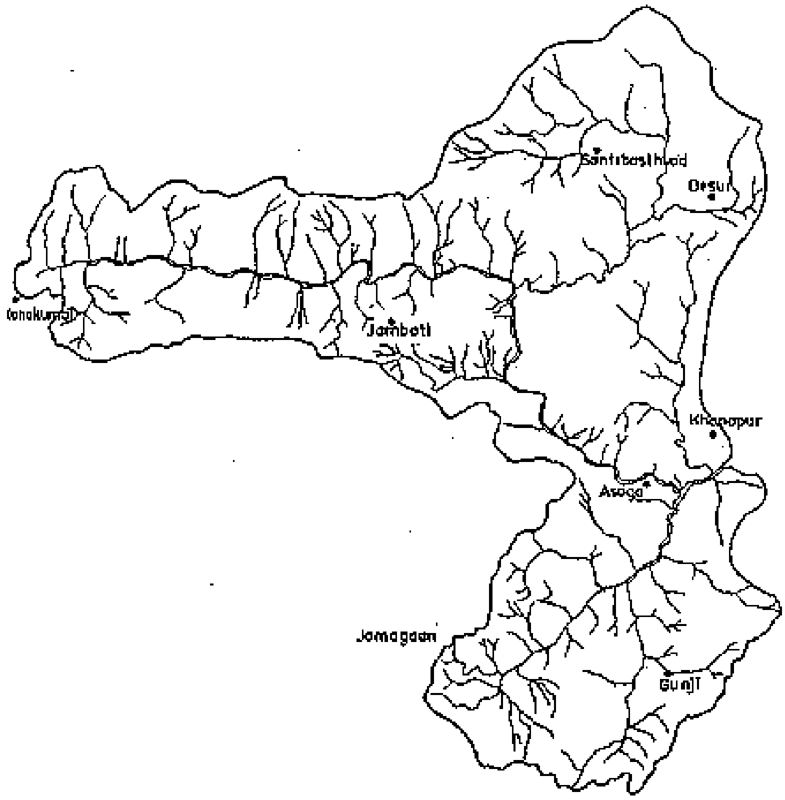


Figure 1. Malprabha representative basin.

Geologically, the Malaprabha representative basin comprises of two main geological formations (i) tertiary basalts, (ii) sedimentary formations of Pre-Cambrian age. Pedologically speaking, the basin rocks are covered by thin (0.5 m) to thick (10m) layer of soils which are divisible into two major groups. These are red loamy soils and medium black soils. Land use pattern of the Malaprabha representative basin is very complex comprising of forest, agriculture, shrubs and barren land (table 1).

Table 1. Land use pattern of Malaprabha sub-basin (After Rawat et al, 1992).

Category	Area in sq km	Percenatge of area
Forest	338.58	62.65
Shrubs	104.22	19.35
Agriculture	90.99	16.85
Barren	6.21	1.15

WATSED MODEL

The Region 1 Water Yield and Sediment Model (R1-WATSED) is a modified version of the Watershed Response Model for Forest Management (WATBAL) developed on the

Clearwater National Forest. The original model began as a computerized version of the Northern Region's `Water Yield Guidelines' to estimate water yields in response to cumulative effects on third and fourth order watersheds. Systematic procedures were added to estimate mass and surface erosion.

In a redesign of the original model, area specific coefficients are structured as input parameters to the modules in R1 - WATSED. Erosion curves have been developed for the primary management activities (roads, logging, site preparation and fire). These curves distribute surface and mass erosion over time. Delivery ratios are included by land type. Additional curves for grazing, mining and other activities may be developed as well.

Model Design

Eleven external data files need to be maintained as part of the R1-WATSED model, (fig. 2). These files are structured as independent data bases that once established can be modified when new information becomes available without affecting the model.

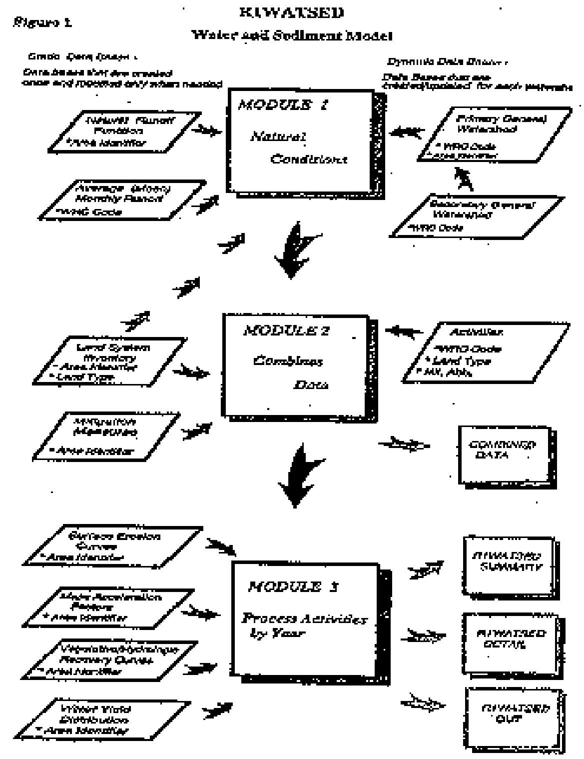
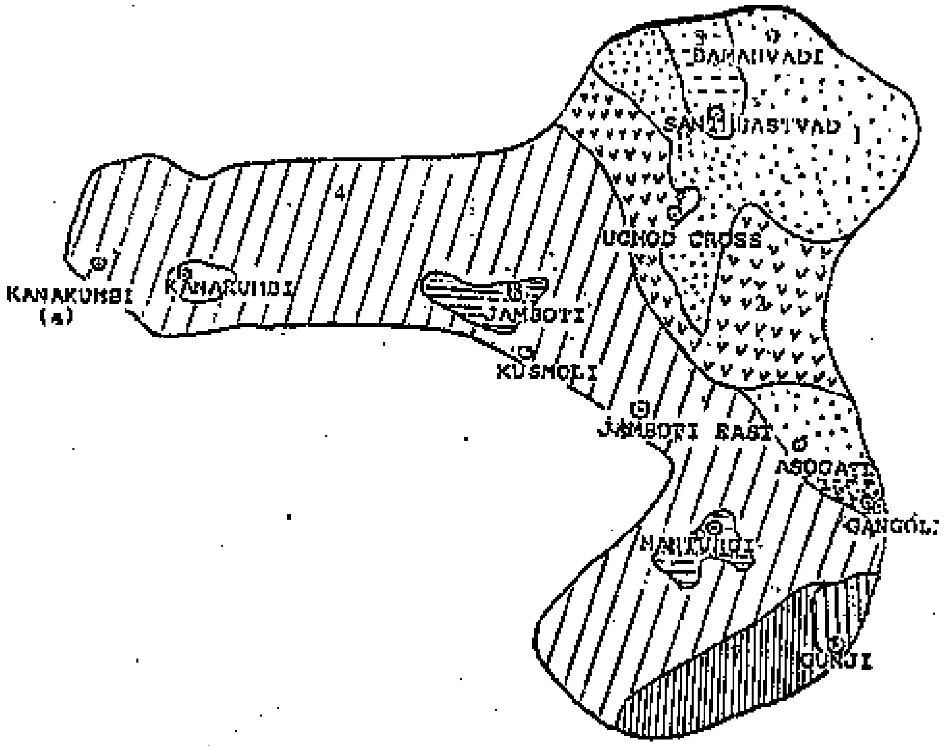


Figure 2. Diagrammatic representation of WATSED model.

Input Data

The input data required by WATSED model for execution include a Land System Inventory(LSI), Precipitation-Runoff-relationship, Surface erosion, Mass acceleration factors, Vegetative/hydrologic recovery curves, average (mean)monthly distribution of water yield, distribution of increased water yield by aspect and mitigation measures. An initial set of values is supplied for each data base if calibrated data is not available. Area specific data should be used.



1. Agriculture Land having medium black soil underlain by tertiary Basalt
2. Shrub having medium black soil underlain by tertiary Basalt
3. Barren land having medium black soil underlain by tertiary Basalt
4. Forest region having red loamy soil underlain by tertiary Basalt
5. Agriculture land having red loamy soil underlain by tertiary Basalt
6. Forest land having medium black soil underlain by tertiary Basalt
7. Forest land having Red loamy soil underlain by Pre-cambrian Sedimentary rocks
8. Agriculture land having Red loamy soil underlain by Pre-cambrian Sedimentary rocks
9. Barren land having Red loamy soil underlain by Basalt

Figure 3. Land system inventory units of Malprabha representative basin.

In the present study, the whole Representative basin is divided into smaller watersheds varying in size and shape. Rainfall data has been collected from three raingauge stations located at Kankumbi, Jamboti and Khanapur. Average annual Rainfall varies between 1730 mm at Khanapur and 5900mm at Kankumbi. The relief of the Malaprabha representative basin varies between 668 and 1038 m from the mean sea level. The average slope of the basin is 1.9 m/km. The drainage density based on flat low lying depositional areas and more than 2.5 km/sq km on convex hill crests in southern part of the basin. The runoff data (1980-1990) and sediment yield data (1987-88) has been collected from Karnataka Irrrigation Department.

Primary File-LSI : The Land System Inventory (LSI) file is a primary data source for the model. This inventory contains basic land type data for a designated area. Each forest has delineated land types on the basis of morphology, parent material, soils, and vegetative types(fig 3). To incorporate local calibration in WATSED the original LSI file was revamped to include correlation factors for surface erosion curves, delivery ratios, and mass acceleration.

Three User Supplied Files : The remaining three files of the ten used by WATSED ae user supplied data for the analyses of water shed.

General Watershed data base: Two of these external files contain data specific to the given watershed. The primary general watershed data base contains identifiers and summary values (i.e. total acres, total natural sediment, precipitation and runoff by acre feet). The water yield increase factors (F-value)by elevation are also included.

Total area of the representative basin	= 540 sq km (divided into 13 sub-units)
Precipitation - AF	= 2668 mm
Natural Sediment	= 92 tonnes/sq km/year
Runoff	= 793 mm
Peakflow	= 960.51 cumecs

(All units were converted to FPS system and given as an input data)

Secondary Watershed Data Base : This file stratifies the watershed by land type, precipitation zones and acres. Multiple precipitation zones for a given landtype can be entered. This secondary Data Base is accessed only when summary values in the Primary General Watershed Data Base are empty (Zero filled).

Activity Data Base : This file contains activities by watershed both past and proposed. Currently, the activities include roads, logging, site preparation, grazing, mining and fire. These activities must be stratified by land type. Each activity's land type must be identified in the designated LSI or the activity record will not be processed. This activity file is kept in order by watershed, year, activity, type and stand or project id. This facilitates the aging and processing of projects through WATSED model.

The data on management activities were not available. Therefore, based on field information provided by the local people are considered for the study. Major activities considered for the analysis were, Fire, Logging, Roads and Site preparation. In the case of road construction, only major roads are taken into account. Land use and cropping pattern data were also collected from Command Area Development Area offcice, Belgaum.

RESULTS AND DISCUSSION

Sensitivity Analysis

Sensitivity analysis has been carried out to assess the significance of individual data sets required by the model. This was done by using available data for a Charlie Creek watershed near Moscow, Idaho, USA. The models sensitivity is checked for various parameters which are essential for the model application. Analysis of the results indicated that parameters such as rainfall, runoff, peakflow and surface erosion information does not show any significant influence on the model. However, it is observed that, the model is quite sensitive to management activities such construction of roads, logging operation, site preparation, grazing, mining and fire. Therefore, it is necessary to collect most reliable information on such activities.

Application of WATSED Model to Malaprabha Representative basin

WATSED automates the procedures developed in the R1/R4 Guide for predicting Sediment Yields from Forested Watershed. Its Primary Objective is prediction of in-stream sediment resulting from land management activities. This approach separates the erosion and delivery processes and consider them individually for each land type. The natural sediment yield is firs estimated for the undisturbed watershed by land type. The on-site erosion from each management activity is calculated by analyzing mass and surface erosion separately. Therefore, this is the major constraint in the present analysis, i.e., the non-availability of proper management data.

The model was run by assuming that during the year 1986- 1987 there were lot of management activities in the watershed. Based on the above assumption, the runoff value was predicted by the model for a period of 10 years which varied between 33 % and 64 %. The model predicted the water yield as 50% and sediment yield as 189 tonnes/sq km/year for the year 1987-88. However, the observed runoff for the year was 37% (Shetty, 1994) and the sediment yield was 92 tonnes/sq km/year (Rawat et al., 1992) in the Malaprabha representative basin. The model has predicted an increase in yield by 13 % (13 % higher than the observed) which could be due to the forest conversion and other management processes. This shows that the water yield predicted by the model is in reasonable agreement with the observed data. It is also evident that the water yield is minimum in the year prior to forest conversion (before clear-cut) and other management processes. Maximum yield was observed in the year immediately followed by forest conversion. According to the model prediction there is an increase in water yield by 17 %(compared to the previous year) due to the above processes in the year following year and showed a declining trend with time. Since there were no observed data available with the authors for the rest of the years, validity cannot be checked properly. However, in the case of sediment yield, the variation in the predicted and observed value are quite large which can be explained as follows. In the case of WATSED model, the increase in sediment yield could be due to the immediate effect of various management activities which was considered for the study (fire, logging, roads and site preparation). However, in the following years, the impact of forest conversion declines and there will be considerable reduction in the sediment yield. For this purpose, the sediment yield was projected for the year 1996 without considering any management activities after the year 1987-88. The predicted value showed a reduction in sediment load by 56 % (compared to 1987-88) in the year 1996. i.e., the sediment yield obtained by using the model is 83 tonnes/sq km/year. To arrive at any final conclusion, a large set of observed data are required. Authors are in the process of refining the predicted values by collecting more and more information.

CONCLUSIONS

Any physical model, to be effective, the model must simulate the impacts of forest activities on water production by considering cause and effects on a more physical, conceptual and process basis. Further, the model should be dynamic in structure, i.e., it must be able to incorporate temporal changes in model variables which reflect the changes in water utilisation by trees with growth and age, management treatments, and deforestation. Therefore, it is necessary that the model must be oriented to take cognizance of climatic, soil and hydrological data availability and data constraints in order to render it a generally applicable user tool for realistic water resources decision making, rather than merely a multi-parameter, site-specific research tool.

RECOMMENDATIONS

Based on the study, some of the suggestions are listed below for further improvement of the model.

Instead of Primary and Secondary watershed data files it can be taken as a single unit and a general climate data file can be generated.

As the sediment yield is the major output, a theoretical base should be generated to estimate various erosion processes based on intensive field investigations. Presently the model is based on locally derived empirical stream flow and sediment yield data.

Model sensitivity analysis shows that important parameters such as rainfall, runoff, peakflow and erosion processes does not show a marked influence on the model. Therefore, it is necessary to incorporate the above parameters in a more sensible way.

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