Catchment Development Impacts on River and Estuarine Systems

B D Gardner
C G M Archibald

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Foreword

As an integral part of coastal zone management strategy, the Natal Town and Regional Planning Commission (NTRPC) is deeply concerned about the intense pressures placed by both the formal and informal sectors upon the natural resources of the area.

After careful consideration of a variety of options, catchment units have been selected as the ideal for evaluating aquatic resources. Through their adoption, a useful tool is available to planners wishing to apply a more pro-active stance when implementing environmental protection. In pursuit of this ideal, the NTRPC has commissioned the CSIR to develop a comprehensive water quality plan, one to reduce the risk of environmental degradation of any river basin earmarked for formal and informal settlement.

In 1990, the CSIR began this task and commenced evaluating state-of-the-art hydrological water quality models. As a result of this process, the Hydrological Simulation Programme - FORTRAN (HSPF) was selected. It was chosen for its capacity to most accurately simulate the water, sediment and constituents associated with diverse land-uses. By modelling different scenarios, it has been possible to provide a valuable tool for planners wishing to predict the sensitivity levels of specific environments. This report represents an initial programme and, compares two completely opposed scenarios. In each case tests were conducted to evaluate runoff and sediment yields, firstly for the conversion of all forest land to informal settlement and secondly, for the conversion of open land to informal settlement.

The Natal Town and Regional Planning Commission believes that the results presented in this report, although only the first stage in the development of such modelling, indicate the exciting potential of such an approach. This document should provide ideas and encouragement to planners and planning institutions wishing to incorporate the new technologies currently becoming available to decision makers. In particular, the predictive capability of such systems becomes especially attractive where costs inhibit the funding of full scale evaluations.

D.V. HARRIS
Chairman, Natal Town and Regional Planning Commission

Executive Summary

1. The Hydrological Simulation Program - FORTRAN (HSPF) catchment model has been used to assess the impact of catchment development scenarios in the Lower Mdloti - a typical coastal catchment.

   Two extreme scenarios were evaluated for runoff and sediment yield:

   * Conversion of all forest land to informal settlements
   * Conversion of all open land to informal settlements

2. The conversion of natural forest and open land to informal settlements is unlikely to increase catchment runoff significantly but, the increase in sediment yield could have significant impact on estuarine "*health* ".

3. The technologies being used by the CSIR on behalf of the TRP Commission are well developed and are designed to provide a basis for developing a comprehensive water quality plan to reduce the risk of environmental degradation of river basins earmarked for formal or informal urbanisation.

4. For under-developed river basins threatened with rapid urbanisation, a proactive environmental protection programme can be implemented before further catchment development occurs.

5. Planning strategies developed by the TRP can now proceed with quality information for evaluating the threat of siltation and excessive runoff on estuarine systems.

6. The modelling approach adopted for the Lower Mdloti catchment can be transferred readily to other catchments which are earmarked for urbanisation.

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- The CSIR for the funding of the visits to WATERTEK, Durban of Dr Rob Johanson during 1988 and 1991 to train the staff in the use of the Hydrological Simulation Program - FORTRAN model.

1. *Introduction*

The coastal zone of Natal is being subjected to intense pressures of urbanisation, both formal and informal, and therefore a clear understanding of the potential impacts of catchment development on coastal aquatic systems should receive appropriate attention. A primary goal is to utilise state of the art tools to respond optimally to competitive interests of downstream water users. A major conflict is often perceived to exist between plans for sustained development of catchments and public demands to conserve the quality of the water in particular and the environment in general.

Several practical issues require the attention of planners which relate to the threat of environmental degradation of coastal aquatic systems:

- How are decisions made about where urbanisation and other land-use changes should be made in terms of water resource management?
- How much of a particular catchment can we develop without impairment of the aquatic resources?
- How are decisions made about the type of land-use that can be sustained within a particular catchment without compromising the quality of river water in terms of beneficial uses?
- Where should a specific land-use be located to minimise the pollution impact on the vital water resources of the region?
- How is the choice made between FORMAL versus INFORMAL urbanisation within a catchment?
- What SITE SPECIFIC evidence is available to ensure protection of the water resources within a catchment earmarked for rapid urbanisation (formal or informal)?

The CSIR approach has focused on providing the planners with much needed information to assist in addressing all these questions. In so doing, management and planning of these systems will go a long way to converting high risk systems to low risk environments in terms of current threats posed by land-use changes. A plan of action would be the instrument through which the collaboration of all user groups can be solicited.

2. *Study Area*

The Greater Durban Functional Region was considered a high priority area requiring planning to accommodate the population overflow from the existing overcrowded urban (formal and informal) sectors of Durban.

The Mdloti River catchment, downstream of Hazelmere Dam (**Figure 1**), was selected because of potential urban expansion. It was an example of the type of coastal catchment likely to be impacted by urban development in the future. This provided the opportunity to investigate various development (changing land-use) scenarios.

It has become evident recently that the pressure zones for development are the Waterloo sub-catchment of the Umhlanga River and the Illovo catchment. There should be little difficulty in transferring most of the basic strategy and structure of the modelling approach to these and other catchments of concern.

3. *Purpose and Scope*

Cullen (1990) has stated that we are moving from a period of resource utilisation and exploitation to one of resource management. Concerns for traditional uses of water (potable, industrial, agricultural) are now joined by the higher values placed on recreation and conservation uses. Water resource management is now recognised universally to have critically important social, political and environmental benefits. Sustainable development (informal or formal) should therefore include the concept of conservation of environmentally sensitive ecosystems.

In South Africa, the Department of Water Affairs now has a major goal to ensure on-going equitable provision of adequate quantity and quality of water to all competing users at acceptable degrees of risk and cost under changing conditions (Department of Water Affairs, 1986). It is also now established Departmental policy that adequate water should be made available for environmental management of lakes, estuaries, wetlands and river systems. This is considered a legitimate major requirement in competition with other user needs.

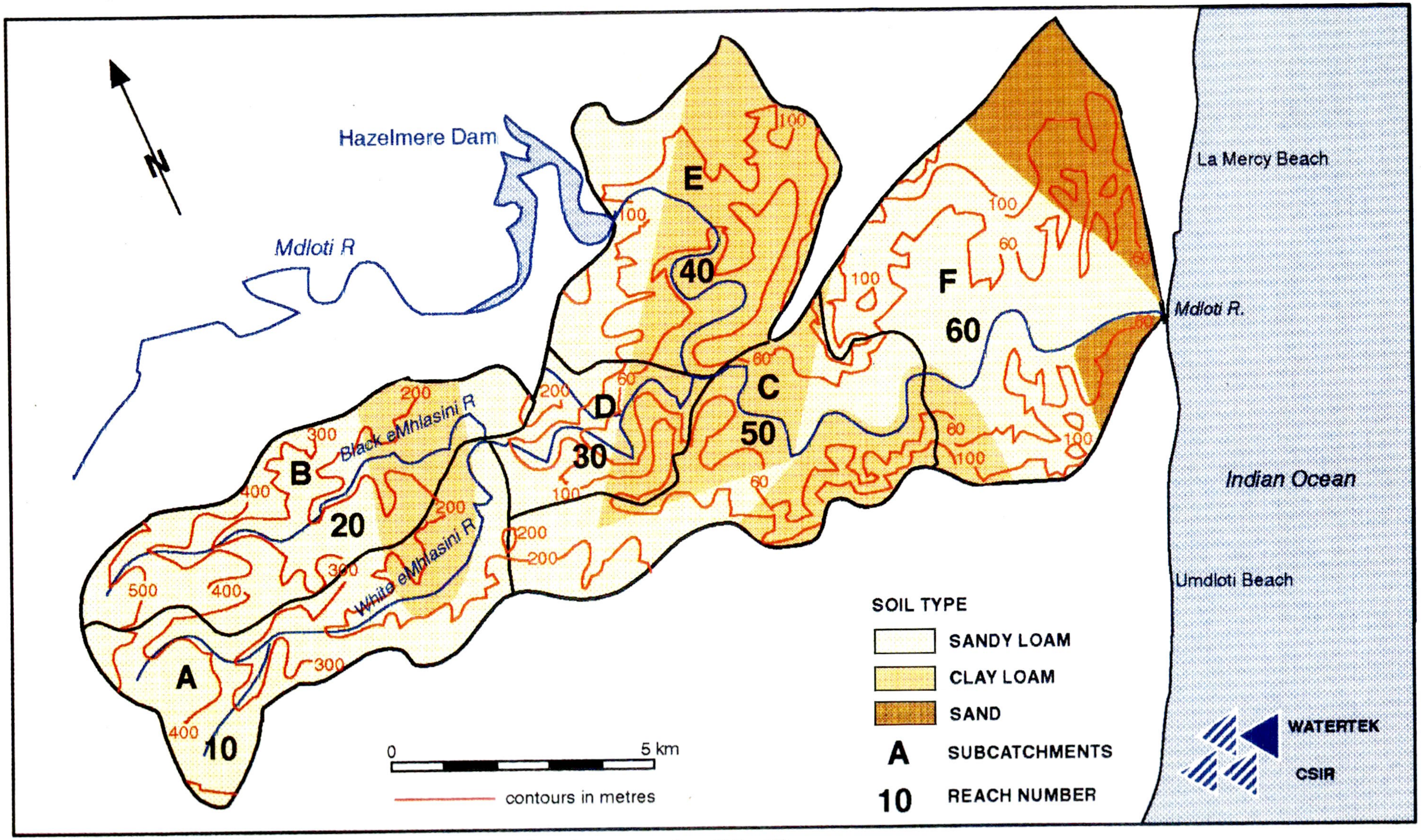

Figure 1: Mdloti catchment sub-divisions (A - F) and river reaches (10 - 60).

The reality of the situation, however, is that funds to achieve a balance between the demands of rapid urbanisation and protection of our water resources are not unlimited. Several issues of concern have therefore been identified and need to be addressed in the process of developing a water resource management protocol. The main issues of concern are summarised as follows:

Rate of urbanisation

Coastal aquatic systems are threatened by catchment development programmes which lack a water resource protocol to manage the risk of unacceptable water pollution problems in South Africa. This occurs because there is little information on the detrimental effect of rapid population development (e.g. low-cost, high-density, uncontrolled and unplanned informal settlements) on the quality of runoff water reaching the streams and estuaries (Field and Pitt, 1990).

The establishment of formal townships in South Africa allowed for forward planning and sufficient lead in time for the completion of essential services. However, the pace with which new formal urban complexes need to be proclaimed, planned and serviced has increased dramatically in these informal high-density areas (300 people per ha - McCarthy, 1989) in South Africa. The unplanned urban population growth rate is frighteningly high and the necessary services and infrastructure remain inadequate. A survey by medical staff (Department of Community Health, University of Natal, 1989) has revealed that 75 percent of residents of the rural districts used untreated water, and at least 50 percent of residents resorted to faecal disposal on open ground.

Population development patterns

Industrialisation in the metropolitan regions of South Africa has brought with it a wave of accelerated urbanisation in river basins. There has been a steady increase in the ratio of the urbanised population to the total population and Rivett-Carnac (1984) indicated that the ratio would change from 28,5 in 1978 to 54,6 in 1990. It was predicted that it would not be possible to accommodate the surplus population in the formal urban developments and that the carrying capacity of the natural resources would be exceeded! It was inevitable then that the rapid development would result in severe pollution threats to the river and estuarine systems.

Human safety and damage to infrastructure

There are real concerns for the physical safety of people located in housing projects in the lower reaches of a coastal catchment. The changing response of a catchment in terms of water quantity (reduced time lag of flood peak and increased volume of water) is largely a function of the ratio of impervious to pervious surfaces. Damage to infrastructure (coastal bridges) caused by excessive runoff has already been reported in 1976, 1984 and 1987, and loss of life was suffered on each occasion.

Human health risks

Bacteriological and chemical contamination of river water may result from the "*first flush*" from urban runoff, especially if river flow is not sufficiently sustained to carry the pollution out to sea. Many of the effects of runoff are associated with organic and toxic pollutant accumulations in the sediments and biota over a long period of time (Field and Pitt, 1990).

The major health hazard in a natural coastal aquatic system is expected to occur at low flows (April - September) when there is a minimal flushing of an estuary with fresh water. This is, however, also a period when the "*self purification* " processes in a river are likely to be effective. However chemicals from point source discharges, e.g. sewage effluents, are also likely to have maximum impact during low river flows since the volumes of return flows remain relatively constant throughout the year.

Physical degradation of aquatic systems

Siltation of an estuary is not a simple process but it is likely to occur during high river flows when turbulent conditions produce sufficient energy to carry the loose sediment from the sub-catchments and to scour the coarse main channel deposits. Silt loads in river systems therefore mainly reflect the runoff from catchment erosion through poor agricultural practices, natural erodibility of the soils and the destruction of existing vegetation during uncontrolled urbanisation.

Physical and sedimentological characteristics of estuaries situated along the eastern seaboard will be changed inevitably by the process of urbanisation. Paradoxically, the attractive physical features of estuarine systems (clean, relatively deep, open water) will be the first components to be degraded through the impacts from poor catchment planning and management (Cooper, 1989). The biological components of estuaries are also equally sensitive to destruction of vital habitats through sedimentation processes.

Excessive loads of chemical pollutants

Point sources have always been held to be the main source of nutrient enrichment and chemical pollution of estuaries. The main cause for concern in these cases is the occurrence and over-abundant growth of floating aquatics (e.g. hyacinth) and/or rooted marginal vegetation. Excessive organic enrichment will also contribute to oxygen depletion and release of H_2S concentrations sufficiently toxic to cause fish kills under certain hydrological conditions. Urban storm water runoff effects on sediment oxygen demand may also persist for a long time after the event (Field and Pitt, 1990).

River regulation

River basins have frequently been subjected to urbanisation and the concomitant need to supply water for potable, industrial and recreational purposes. Impoundment of the main channel leads to restricted and/or minimal flow regimes and the environmental consequences of these impacts have been well documented. Minimal flow regimes impact directly on sedimentological processes, mouth dynamics, tidal exchange and biota.

A summary of the water quality issues of concern (in terms of estuarine "*health* ") which need to be addressed in a holistic plan of action is provided in **Table 1**.

Table 1: Summary of catchment processes and water quality issues of concern.

Catchment Processes	Effects of Process	Issues of Concern (Outputs)	Measures of Estuarine "*Health*"
Urbanisation	Permeable:Non-permeable surface ratio change	Adverse change in runoff peaks and response times	Flash flooding damage to infrastructure Habitat wipe-out
Erosion	Soil export	Siltation patterns Pollution transport	Siltation "*Habitat suffocation effect*"
Population Growth	High-density informal/low-cost structures	Bacterial contamination	Water borne contact disease
Solid Waste Disposal	Toxic metal contamination	Degradation of aquatic communities	Boitic "*health*" indices
Effluent Disposal	Organic contamination	Oxygen depletion and release of Hydrogen Sulphide	Fish kills
Effluent Disposal	Eutrophication	Growth of undesirable aquatic macrophytes	Loss of recreation area Mechanical blockage

4. *Methodology*

Modelling approach

It is essential for planners, controlling authorities, developers and conservationists to assess different water quality management strategies. The development of a predictive capability is therefore necessary by utilising a suite of appropriate dynamic mathematical models.

While management can exercise some immediate control of the water release strategies, good management of the catchment and control of point sources are likely to have the most beneficial long-term effects. However, these remedial actions can be extremely expensive and should not be readily undertaken without some idea whether the cost will be worthwhile or if the consequences of NO ACTION will be more costly in the long-term.

The CSIR is utilising 1990s state of the art hydrological and water quality models, e.g. Hydrological Simulation Program - FORTRAN (HSPF) to simulate water, sediment and quality constituents washed off from various types of land-use. By modelling the various land-use areas and rivers in a catchment, the response to different development plans and ameliorative (conservation) management strategies can be predicted at sensitivity levels acceptable to planners.

Modelling of the Mdloti catchment below the Hazelmere Dam

A 1:10 000 relief map and the same size map showing the various land-uses of the catchment were supplied by S. Day of the TRP. The study area was divided into 6 sub-catchments according to the drainage patterns (**Figure 1**). The only recording rain gauge in the area was at the Experimental Station at Mt Edgecombe. This station was considered sufficiently close to the study area for representative rain gauge and evaporation data. The soils information was obtained from the SA Sugar Association (1984). No flow data of runoff into the estuary was available.

Hydrological Simulation Program - FORTRAN (HSPF)

The model used was the HSPF (Johanson, 1984), but recent modifications have been included (HSPF 9, 1989). This model has the capability of simulating both quality and quantity of runoff as well as in-stream processes in the receiving waters.

Modelling strategy

The lower Mdloti catchment was sub-divided according to land-uses and soil type (**Figure 2**). The hydrological and quality characteristics of surface runoff is determined mainly by land-use and soil type. There is also the advantage of being able to easily accommodate changes in land-use when testing "*what if*" scenarios.

Hydrological calibration

Most dynamic hydrological and water quality models require comprehensive data sets for calibration (e.g. measured stream flow, pollutant concentrations, etc.). Very little of such data were available for the Mdloti. It was necessary therefore to adopt the following approach.

For hydrological simulation of land segments, the Agricultural Catchment Research Unit (ACRU) Model (Schulze *et al*, 1989) was first set up for each land segment. The HSPF model was then set up for the same area, and its output adjusted to agree closely with that given by ACRU. The reason for doing this was that many of the parameters in the ACRU model are based on measurable field information, such as the soil texture and the depths of the A and B horizons (**Figure 3**). While these properties could not be measured directly

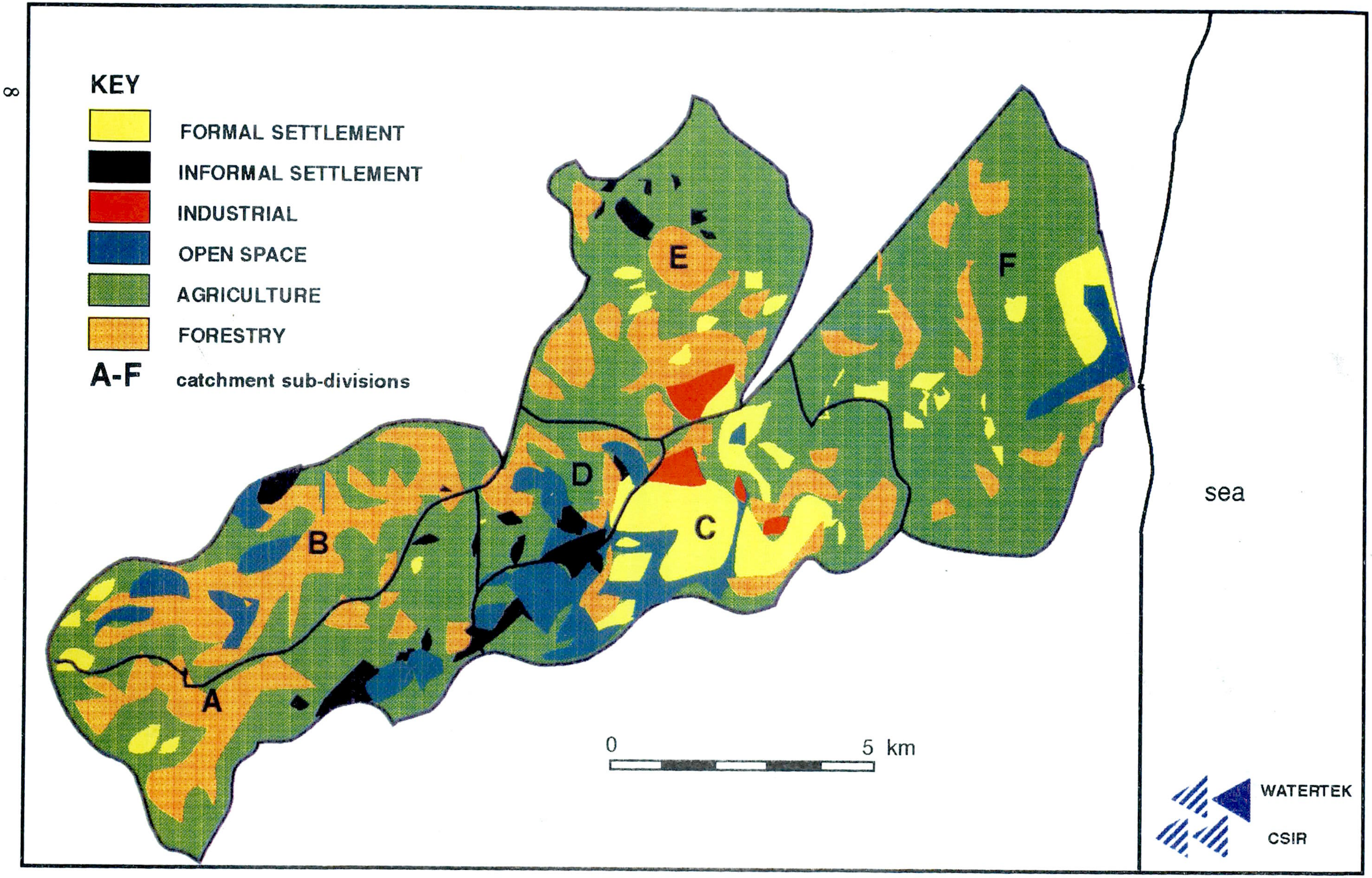

Figure 2: Mdloti catchment land-uses.

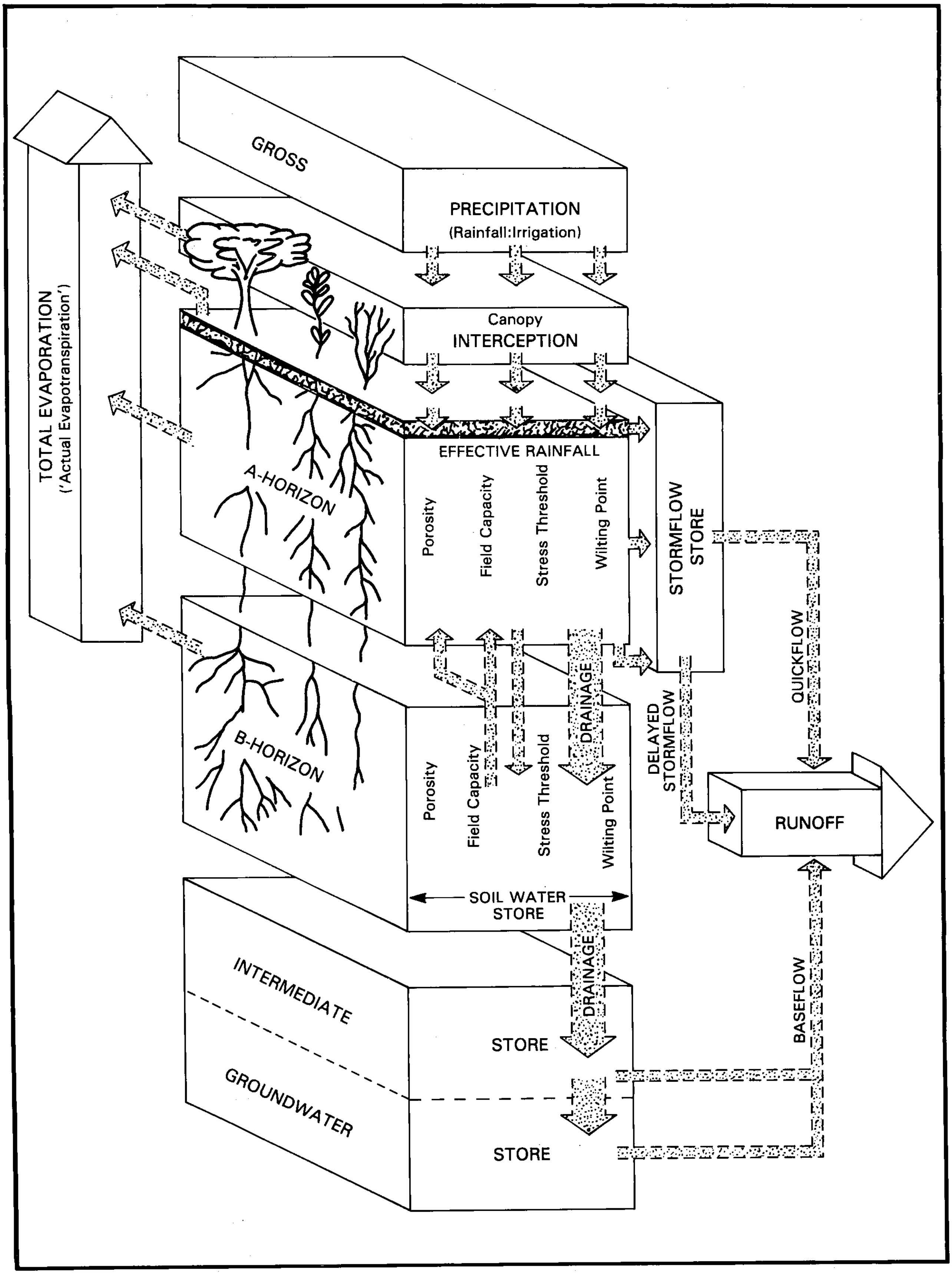

Figure 3: The ACRU agrohydrological modelling system: general structure. *(after Schulze et al., 1989)*

for HSPF, parameter values could be found that were typical of the type of soil being modelled. Unfortunately there is some uncertainty in the ACRU output because some parameters, which can have a significant effect on the outcome, are not easy to estimate reliably.

The output of the ACRU model was used to calibrate the HSPF model. In this process, it was found that some HSPF parameters could be derived directly from corresponding parameters in the ACRU model. For example: ACRU estimates the available soil moisture storage (mm) from the depths of the A and B soil horizons, their field capacities and their wilting points and porosities. The corresponding HSPF parameters are upper zone storage nominal (UZSN) and lower zone storage nominal (LZSN); their total was set equal to the ACRU number, with about 90 percent being allocated to LZSN. ACRU has parameters that govern the rate of outflow of "*quickflow*" (QFRESP) and "*baseflow*" (BFRESP). There is also correspondence between these and two HSPF, interflow recession constant (IRC) and active groundwater recession rate (AGWRC), parameters.

The ACRU model has a parameter, average monthly crop co-efficient (CAY), that indicates the effectiveness of a crop in extracting soil moisture through transpiration. HSPF has a similar parameter, lower zone evapo-transpiration (LZETP), which, although not exactly the same, behaves in much the same way. To make the division between "*stormflow*" and "*baseflow*" in HSPF correspond with that given by ACRU, the infiltration parameter (INFILT) was adjusted.

Using the above techniques, good correspondence between annual totals of "*stormflow*" and "*baseflow*" for the two models was obtained.

HSPF also has an interflow-inflow parameter (INTFW) that governs the division of "*stormflow*" between "*surface runoff*" and "*interflow*". Reasonable values were assigned. It was not possible to check them against ACRU, because ACRU operates on a daily time step which is too coarse to differentiate between these types of flow.

5. Application and Outputs of the Mathematical Modelling

The most updated revisions of HSPF (version 9, 1989) and ACRU (Schulze *et al.*, 1990) were used in the simulations. At the commencement of this demonstration modelling project, comprehensive data were available only up to 1985. There will be little difficulty, however, in upgrading this exercise by loading more recent data as these become available.

Summary of the hydrological results for calendar year 1985

Precipitation	1 164 mm
A-Pan evaporation	1 294 mm

In the absence of records of observed flow data, the output does appear to be reasonable. Clay loam has a low infiltration capacity, so baseflow is low and stormflow (surface plus interflow) is high. The opposite is true for sand (**Table 2**). Sandy loam behaves in between these extremes.

Table 2: Runoff predictions.

Land Segment	Soil Type	Runoff Components (mm)		
		Baseflow	Surface Flow	Total
Sugar cane	Sandy loam	150	340	490
Sugar cane	Clay loam	48	485	533
Forest	Sandy Loam	119	356	475
Forest	Clay loam	22	476	498
Open land	Sandy loam	179	381	560
Open land	Clay loam	48	494	542
Formal housing	Sand	340	235	575
Informal housing	Sandy loam	136	480	616
Informal housing	Clay loam	33	545	578

Sediment calibration of land-segments

Sediment simulation is complex, especially on areas where man's activities have had a significant impact on the vegetative cover. For example, there is apparently little sediment loss from well managed sugar cane fields, except when ploughing for re-planting (about once every 5 - 10 years). However, there is significant soil loss from the numerous access roads. In practice, the quality of "*conservation management* " varies considerably from farm to farm. It is not practical to account for all this variation, so these effects must be "*weighed*" when estimating parameters for a given land-segment.

Sediment washoff and scour are very sensitive to the intensity of rainfall and the resulting surface runoff. For example, rainfall (100 mm event) falling steadily over the whole day, would give a very different sediment yield compared with a 100 mm downpour in one hour. HSPF can operate at time steps down to one minute and therefore, provided adequate rainfall data are available, it can handle the rainfall "*intensity* " problem. For this project, one-hour rainfall data were available. To check the effect of varying the time step, selected land-segments were run at both 1 hour and 2 hour time steps. It was found that the larger time step resulted in a much reduced estimate of sediment yield, because of the "*smoothing* " effect on rain and runoff **intensity** with the larger time step (the effect on the total amount of surface and sub-surface **runoff** was minimal). Consequently, it was decided to use a time step of one hour even at the cost of the increased time required for the computer simulation runs.

There are limitations in the sediment algorithms in HSPF. The detachment of soil by rain parameter (KRER), and the removal by overland flow parameter (KRER) are empirical factors. These can only be accurately evaluated if there are observed data on the catchment under study, or from one close by with very similar hydrological properties. On the other hand, the ACRU model simulates sediment using daily total rainfall and the Modified Universal Soil Loss Equation (MUSLE). This equation uses parameters which have been estimated for the various conditions and crops in South Africa. Thus, in theory, it should give acceptable sediment yield results without calibration.

The above considerations led to the adoption of the following strategy for sediment washoff simulation.

Sediment washoff was simulated using ACRU for a few "*key* " land-segments, e.g. sugar cane on sandy loam. Simulation of sediment runoff with HSPF was done by using only the "*scour* " mechanism. The scour parameter (KGER) was adjusted to give the same results as ACRU (on an annual total basis). Values of KGER were estimated subsequently for the other land-segments considering their erodibility and land-use.

The results from these simulations are based on many estimates and can only be considered a rough approximation. Data for calibration were available from four small experimental catchments inside the study area and at La Mercy (Platford and Thomas, 1985; Haywood and Schulze, 1990; Maher, 1990). However, it was difficult to judge just how applicable the data were, because the experimental catchments were being used to test alternative management practices. These had been planted only three months before the start of the study period in January 1985. The degree of land cover in the early months of 1985, when a considerable quantity of the runoff occurred, was not as representative as that on a typical cane field. The soil losses from the experimental fields in those months were probably much higher than would be observed from a field with a mature cane crop.

The initial results for 1985, based on "*best estimates* " for the ACRU model, gave sediment yields from cane fields of about 15 tons/ha. Rooseboom (Grobbler, 1987) has estimated the annual average yield for the Mdloti catchment as about 4 tons/ha, which suggests that the ACRU-derived values are high. This is consistent with information obtained from Platford (pers. comm.) of the SA Sugar Association. He estimates that the "*erodibility factor*" (K) for sandy loam soils in cane growing areas to be 0,15, whereas the ACRU model User's Guide indicated a value of 0,4. Bearing in mind that the total precipitation for 1985 was 1 164 mm, which is about average (although the majority of that rain occurred in two very

Table 3: Sediment loss per land-use segment.

Land Sement	Sediment Loss (tons/ha)
Sugar cane on sandy loam	5.76
Forest on clay loam	0,0 *
Formal housing on sand	2,94
Informal housing on clay loam	24,40

*Note: * This was assumed to be natural forest and not being subjected to man's activities.*

intense episodes in February and October), it seemed that the initial results were, indeed, much too high. Based on the above factors, the erosion-controlling factors were adjusted.

Erosion is extremely sensitive to land cover and the amount of surface runoff. This is illustrated by the results in **Table 3**.

Simulation of channel hydraulics

The HSPF model can route runoff through a series of river "*reaches*" to the catchment outlet. For this study, six reaches were used, each corresponding to the six sub-catchments shown in **Figure 1**.

To accomplish this "*storage routing*", the hydraulic properties of the reaches needed to be estimated. It was assumed that the cross section of each reach had a symmetrical shape (**Figure 4**). The length and longitudinal slope of each reach and "*Manning's n*" (a measure of hydraulic roughness) for the incised channel and floodplain were also estimated. Most

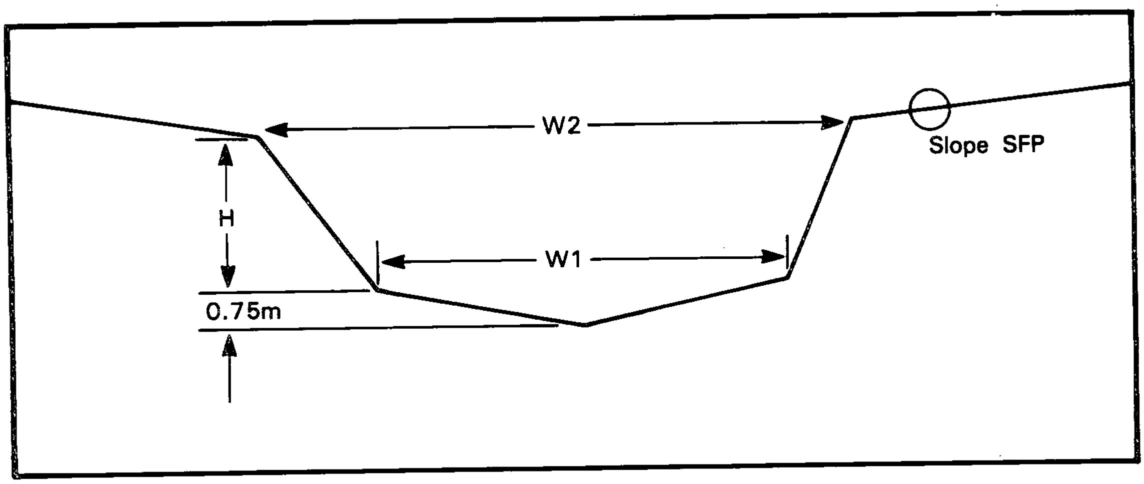

Figure 4: Standard reach cross section used for the Mdloti.

of the dimensions were estimated from 1:10 000 orthophotos and personal observation in the field. Once a "*typical*" cross section had been estimated, its properties were fed through a small computer program (USGS) to generate the type of information used by HSPF. These data are contained in "*Function Tables*" (FTABLES) which are part of the user supplied input menu for the HSPF model.

Simulation of channel sediment transport

HSPF provides several choices for routing sediment along channels.

a. The simplest is to treat the sediment as "*conservative*"; that is, it is swept along with the current just like a dissolved substance.

b. The more realistic but costly approach involves estimating the relative quantity of sand, silt and clay in the sediment, and treating each according to its properties.

c. A compromise approach involves treating the silt and clay as conservatives, while allowing the sand to be deposited and scoured as the hydraulic situation dictates.

The third alternative (c) was followed. This is not unrealistic as over a period very little of the silt or clay will remain in the reach. An estimate of the composition (sand, silt and clay) for each soil type was made. The sediment washed off from each land-segment was then sub-divided on this basis. The sediment is treated as three constituents that have to be routed separately through the channel system. The HSPF software is extremely flexible in the way it handles connections between computational elements. The user simply specifics all the connections in the "*NETWORK*" block in the model input menu.

Since Reaches 10 through 40 (**Figure 1**) are relatively steep and have mainly rocky channels, the initial bed-sediment storage for those reaches was set to zero. While this permits deposition, scour is limited to material previously deposited during the period of simulation. However, the lowest two reaches have floodplains and their channels run in sandy alluvium. For these, allowance for the possibility of scour of sand was made by having a non-zero initial bed sand content.

Silt and clay washed rapidly through the system but sand was scoured from Reach 50 and deposited in Reach 60. In 1985, about 8 100 tons of sand was scoured from the bed of Reach 50, representing about 30 percent of the sand load that was passed on to Reach 60. In Reach 60, about 18 500 tons were deposited, leaving only 17 500 tons to be washed out of the system. The simulation indicated scour in Reach 50 because, even during the dry season, about 100 000 cubic meters of sand-free water was released from Hazelmere Dam each day. This "*hungry*" water picked up sand in Reach 50, and re-deposited it in the relatively flatter Reach 60. These occurrences may be real and peculiar to 1985 or may be due to incorrect estimates of the shape and size of reaches. This can only be determined by a more comprehensive investigation of the catchment.

Planning scenarios

One of the greatest concerns in the urban and peri-urban areas of Natal is the choice between extensive "*informal*" settlements or planned formal sites in undeveloped sub-catchments. Informal development is characterised by crowded conditions, stripping of much of the natural vegetation and poor sanitation. Typically, runoff increases because less vegetation is present to remove water out of the soil by evapo-transpiration. The ground is probably more "*trampled*", reducing infiltration capacity. Sediment loss increases because of the higher surface runoff and the loss of vegetative cover.

To estimate the possible effects of future informal development on the hydrological and sediment regime of the river, two extreme scenarios were evaluated:

1. **Conversion of all forest land to "*informal*" settlement.**

   The rationale for considering this possibility is based on the premise that forest land is probably more readily "*available*" to the informal settler than most other current land-use zones, and the effects will have a drastic impact on the aquatic resources.

2. **Conversion of all "*open*" land to "*informal*" settlement.**

   It may be less likely that open land will be converted in this way on such a large-scale. Most open land is being reserved for some specific purpose, such as formal housing development. Nevertheless, this scenario has been included.

It is most unlikely that all forest or open land will be converted to informal housing. These exercises, however, will prove useful for planners to estimate the maximum consequence of certain development. The consequences of intermediate development scenarios can then be simulated. An example of outputs has been provided in **Table 4** and demonstrated in **Figures 5 - 9.**

Table 4: HSPF simulation outputs for informal development.

	Existing Situation	Conversion to Informal Settlements	
		Forest	Open Land
Hydrology (mm) Average runoff from catchment	520	542	524
Sediment (tons) *Silt and Clay:* Total scoured from the land (and washed to the estuary)	19 000	44 000	26 000
Sediment (tons) *Sand:* Total scoured from the land Deposition in channel system Outflow (to estuary)	28 000 10 000 18 000	69 000 51 000 18 000	44 000 26 000 18 000
Sediment (tons) *All Sediment:* Total scoured from the land Outflow (to estuary)	47 000 37 000	113 000 62 000	70 000 44 000

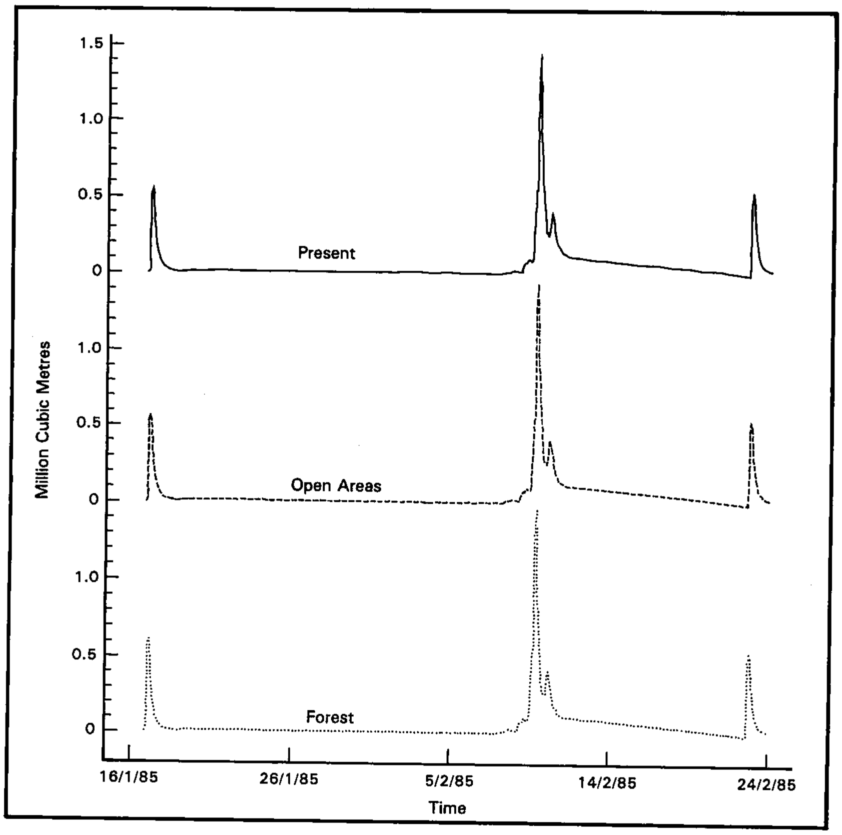

Figure 5: Mdloti sub-catchment simulation scenarios: Effect on hourly runoff of converting open areas or forest to informal settlements.

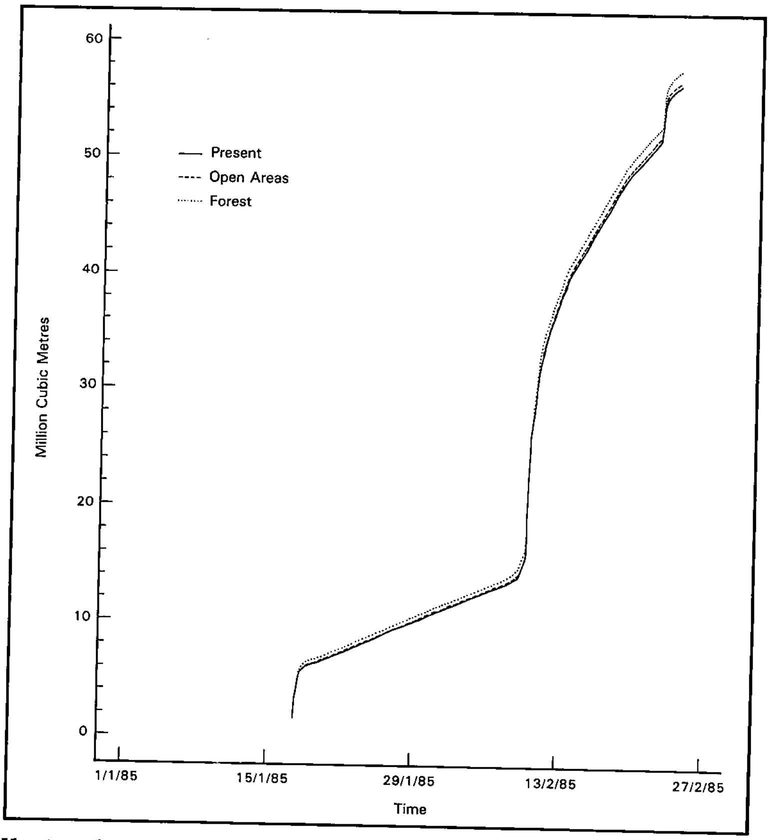

Figure 6: Mdloti sub-catchment simulation scenarios: Effect on accumulated hourly runoff of converting open areas or forest to informal settlements.

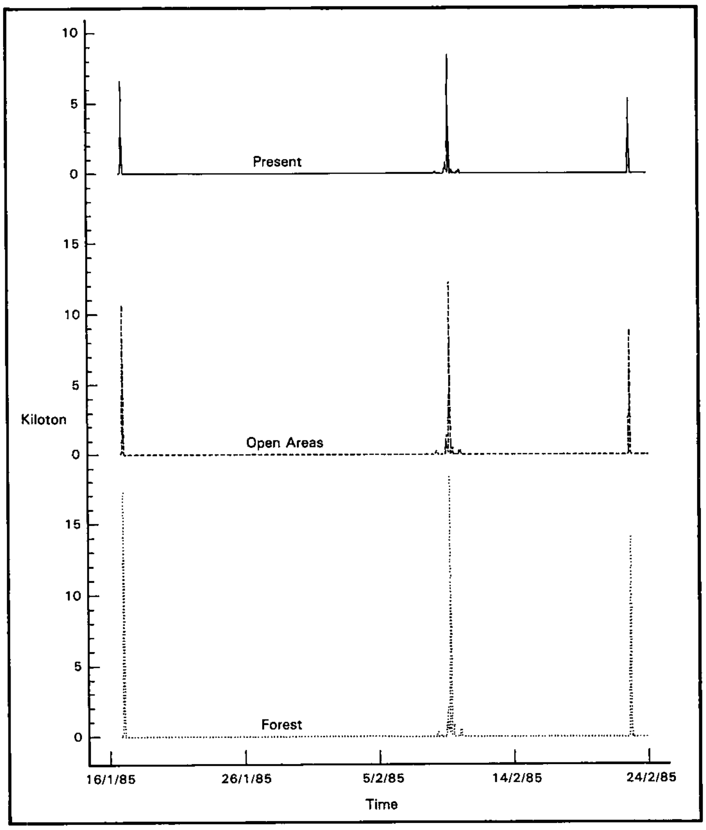

Figure 7: Mdloti sub-catchment simulation scenarios: Effect of converting open areas or forest to informal settlements on the quantity of sand washed off hourly.

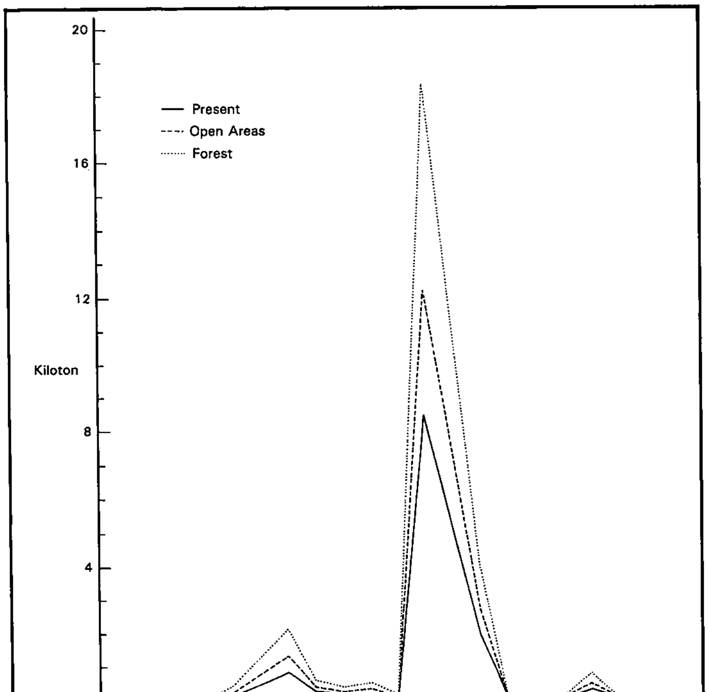

Figure 8: Mdloti sub-catchment simulation scenarios: Effect of converting open areas or forest to informal settlements on the quantity of sand washed off hourly during February 9.

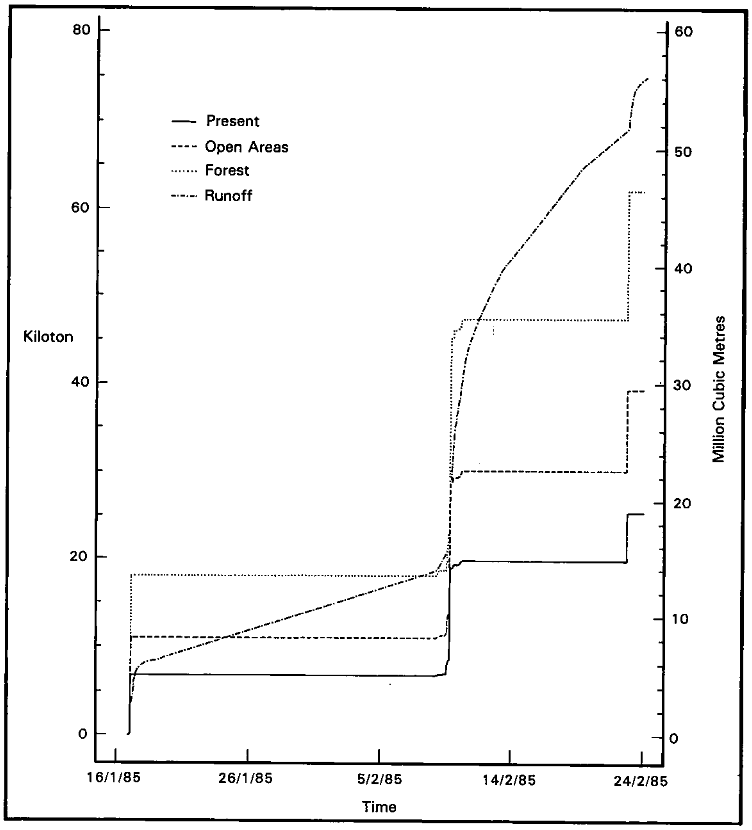

Figure 9: Mdloti sub-catchment simulation scenarios: Effect of converting open areas or forest to informal settlements on the total accumulated quantity of sand washed off hourly.

6. *Conclusions*

Conversion of natural forest or open land to informal use is likely to increase the total annual runoff significantly, but the increase in sediment yield could be quite dramatic.

The conversion of natural forest which constitutes 17 percent of the present Lower Mdloti catchment area will only cause about 4 percent increase in the total runoff from this catchment. However, the projected total increase in silt and clay washed into the rivers will be over 120 percent and sand nearly 150 percent. Conversion of the open areas (7 percent of catchment area) would boost the total runoff by less than 1 percent but, increase the total silt and clay load by about 25 percent and the sand load by more than 50 percent.

All the silt and clay scoured from the catchment is assumed to wash out to the estuary. This is consistent with the concept of treating these fractions as "*conservatives*" with properties similar to dissolved substances. In the estuary, there is the possibility that in the presence of seawater, the silt and clay will coagulate and settle out thus rapidly reducing the size of the estuary. The "*health* " of the estuary will be severely impaired.

Even with conversion of land-use, the outflow of sand to the estuary will not change significantly, because the transport capacity is governed by the hydraulics of the river. The excess sand is deposited in the lower parts of the channel system (Reaches 50 and 60). This modelling demonstration indicates that, even with the mild scouring action provided by the sand-free water released from Hazelmere Dam, sand is being transported downstream. Thus over a period, all sand washed off the catchment into the river bed will be transported to the estuary. The prognosis for the Mdloti lagoon (and other similar water bodies) is not good. The estuary will shrink to a size that can be maintained by tidal action alone.

7. *Possible Extension for Modelling*

1. The modelling simulation of the Lower Mdloti sub-catchment is transferable and could be applied to catchments earmarked for formal development, e.g. Waterloo site in the Umhlanga catchment and the Illovo catchment.

2. The modelling simulations could also be extended to include other water quality parameters. This exercise would best be linked with water quality planning and implementation procedures.

3. For under-developed river basins threatened with rapid urbanisation, it would be advisable to use mathematical modelling to develop a best management plan for minimising adverse water quality impacts.

4. Heavily impacted areas could also be modelled, as a cost-effective procedure to evaluate the benefits of best management options to reduce pollution.

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