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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

An integrated, basin-wide planning approach for the River Malaba catchment

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This paper describes a study carried out to investigate one possible approach to the development of catchment management plans for Uganda, using the River Malaba catchment as a case study. The approach involved considering the entire river basin as an integral planning unit, as opposed to planning for individual projects separately. A simulation model of the catchment was established using MIKE BASIN, a modelling tool for integrated river basin planning. The model was then used to investigate planning scenarios involving existing, proposed and hypothetical water uses in the area. Through this process, the planning approach was evaluated with respect to the validity and significance of modelling results, data requirements and steps involved. The approach was considered valuable in contributing to the sustainable development of water resources for the area, as it facilitated the integrated consideration of the impacts of individual projects on the performance of the system as a whole.

Introduction

In 1995, the Government of Uganda, through the assistance of the Danish International Development Agency (DANIDA), completed the formulation of a national Water Action Plan (WAP). The overall stated objective of the WAP was "to manage and develop the water resources of Uganda in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs" (WAP, 1995).

In accordance with this objective, the Water Resources Management Department (WRMD) of the Directorate of Water Development (DWD) set out to develop Water Resources Management Plans (WRMPs) for all catchments in the country. These WRMPs were aimed at:

- Promoting sustainable and environmentally sound utilization of water resources in the various catchments;
- Providing reliable Water Resources information to guide potential water-related developments in the catchments;
- Establishing the existing major water users and polluters in the catchments;
- Establishing reliable baseline data concerning the status of water quantity and quality, for use in managing the Water Abstraction and Waste Discharge permit system.

The River Malaba catchment was selected as a starting point for the development of these catchment WRMPs. It was planned that, using this as a pilot catchment, suitable procedures and methodologies for catchment management planning would be identified, developed and tested. These procedures, if found satisfactory, would then be available for application to other catchments in the country. At the Earth Summit in Rio de Janeiro in 1992, it was recognized that sustainable development should become a priority item on the agenda of the international community. Prior to that, the Mar del Plata Action Plan (UN, 1989) recommended the formulation of Master Plans for countries and river basins to provide a long-term perspective for planning of resource conservation and use. It also recommended the use of such techniques as systems analysis and mathematical modelling as planning tools wherever appropriate.

This paper describes a study that was undertaken in order to investigate one possible approach to the catchment management planning process, and to evaluate the procedures involved. A river basin Water Resources system typically consists of several component sub-projects. The approach investigated in this study involved considering the entire river basin as one integral planning unit, rather than planning for the individual component sub-projects separately. By establishing a simulation model of the entire river system, the performance of the system as a whole in response to changes in the individual components could then be evaluated.

One important characteristic of water is mobility. This implies that the several water uses taking place at different locations in the same river basin cannot be considered as being independent. Secondly, few river systems are completely undeveloped; none is fully developed. The typical planning problem is to fit additional elements optimally into a partly developed system. Thirdly, plans are based on assumptions regarding the future. Subsequent changes in technology, economic development, and public attitudes may differ from those anticipated or predicted. Plans must therefore be amenable to revisions and modifications over time.

The above factors all pointed to the relevance of the

planning approach investigated in this study. With this approach, the impact of individual system components on the use of resources in the entire basin would be evaluated through water balance studies. Planned or proposed new developments would be tested for compatibility with existing projects, and their parameter limits set in conformity with requirements of the system as a whole. By establishing a computer simulation model of the system, ease of revisions and modifications in response to changing planning scenarios would be ensured.

Materials and methods The study area

The River Malaba catchment is part of a broader division referred to as the Lake Kyoga basin, which is one of the eight major surface water basin delineations for Uganda. The Lake Kyoga basin covers an area of 26,796 sq km; the area considered in the study as the River Malaba catchment covers about 6,455 sq km (see Fig. 1).

The main river reach modelled in the study has its origins on the slopes of Mount Elgon, from where it forms the border between Uganda and Kenya for several kilometers before turning into Uganda. There it flows through the districts of Mbale, Tororo and Pallisa, before finally discharging into Lake Kyoga. Along its journey through the three districts it is referred to as R. Lwakhakha, R. Malaba and R. Mpologoma in succession.

Catchment delineation

Basic to the planning approach under study was the consideration of the entire catchment area as a planning unit (Petersen, 1984; Gustaffson, 1989; DHI, 1999). The first step therefore was to obtain topographical data to use in delineating the overall catchment boundary. For this, topographical maps consisting of sixteen sheets from the series Y732, Editions 1 to 3, of the Department of Surveys and Mapping were used. From these maps, three-dimensional coordinates of the area were extracted, at a regular grid spacing of 1 km, and were used to generate a combined contour plot using Surfer.

The next step was to select river branches and tributaries to include in the supply configuration, and incorporate the resultant network in the topographical map. For this, Arcview GIS coverages for the districts of Mbale, Tororo, Pallisa, Bugiri, Iganga and Busia were used. These coverages had been created under the National Biomass Study (NBS) conducted by the Forestry Department. Through an appraisal of these maps, the prominent, mainly perennial river branches were identified and selected for inclusion in the schematic river representation.

The resultant network consisted of one main river composed of the Lwakhakha-Malaba-Mpologoma reaches, together with nine tributaries. The contour map was then superimposed on this network, and by carefully following the topography as indicated by the contours, a watershed was traced out for the schematized river network, marking the overall physical system boundary.



Subsequent stages of the river basin modelling would require a division of the basin into subcatchments corresponding to the various branches of the river network. For this reason, after delineating the boundary of the entire catchment as described above, subcatchments were demarcated in a similar manner. These subcatchments were even further subdivided at a later stage, after the river branches were also subdivided and nodes introduced. This resulted in a total of seventeen sub-catchments.

Identification of development measures

The next goal was to identify the points or locations, present or potential, drawing upon the water resources of the system. The targeted water-related activities were urban areas drawing domestic, commercial and industrial supplies, areas of potential irrigation development, and river reaches with hydropower potential. Sources used to obtain this information included:

- Field trips, which involved visits to the relevant environmental, water supply and agricultural offices in Mbale and Tororo, as well as a general reconnaissance of the study area;
- Records in the WRMD Water Permits office in Entebbe, pertaining to Water Abstraction and Waste Discharge permit applications for the study area;
- Discussions with personnel involved with the Eastern Centres Water and Sanitation Project (ECWSP);
- A review of literature that included reports relating to

Water Resources studies conducted under the Small Towns Water and Sanitation Project (STWSP), district state-of-environment reports obtained from the Ministry of Planning, and district development master plans obtained at the district planning offices.

As an outcome of this exercise, twelve water use points were identified for inclusion in the study. These included four existing surface water supply schemes, three proposed surface water supply schemes, two proposed groundwater supply schemes, and three existing irrigation schemes.

Other system information

In addition to identifying the supply and demand configurations, it was also considered necessary to locate the points within the system where measured hydrological and meteorological data existed. Nine streamflow-gauging stations were identified within the study area. For six of these, historical records consisting of daily discharges in cumecs were obtained from the Hydrologic Database (HYDATA) at the WRMD. Rainfall records for ten stations located within the study area, consisting of daily rainfall in mm and covering a period of twelve years, were obtained from the Uganda Meteorological Department (UMD) in Kampala. However, evaporation records consisting of monthly evaporation in mm/day were available for only two stations located at Busia and Tororo respectively.

Preparation of simulation input data

For purposes of the study, the primary criterion for evaluation of system performance through simulation modelling was water availability or deficiency at points of interest within the system. The process to be simulated involved water entering and being routed through the system, with abstractions and return flows due to the various water use points taken into account, all represented both spatially and temporally over the selected planning horizon.

The required simulation input data thus consisted of two categories, namely:

- Time series of catchment runoff (generated through rainfall-runoff modelling), as the basic inflow to the system;
- Time series of water demands at the various water use points, representing abstraction of water from the system.

This data was derived as described below.

Rainfall-runoff modelling

In order to obtain an idea of the spatial distribution of rainfall in the study area, isohyetal maps were plotted, based on monthly rainfall totals for selected months. The months chosen were those corresponding to the highest monthly rainfall recorded at each station. From studying these maps, it was decided that it would be appropriate to use a process of Mean-Area-Weighting to derive the rainfall applying to each sub-catchment in the model. To derive the ratios to use in the weighting, Thiessen polygons were constructed, demarcating the zones of influence of the measurements at each gauging station. These polygons were superimposed on the diagram showing sub-catchment boundaries. Then, for each sub-catchment, weighting ratios were computed by measuring the area of overlap with each Thiessen polygon crossing the sub-catchment, and calculating this as a ratio of the total sub-catchment area.

To generate time series of runoff to use in the simulation modelling, a rainfall-runoff model called NAM, developed by the Danish Hydraulic Institute (DHI), was used. NAM is a generalized lumped, conceptual rainfall-runoff model that simulates the overland flow, interflow and baseflow components of the water cycle as a function of the moisture content in four storages. Because of the need to calibrate the rainfall-runoff model using a comparison between simulated and observed discharge, and given the absence of measured data in many of the sub-catchments, it was found necessary to model four lumped sub-catchments upstream of existing gauging stations, rather than model all seventeen sub-catchments separately. In addition, a specification was made of evaporation data to use in the rainfall-runoff model. The time series file used for this was prepared by averaging the monthly records obtained for Busia and Tororo. Based on the fact that these two data sets did not vary widely from each other, it was assumed that the derived data would be sufficiently representative of conditions in the entire study area

In addition to specifying parameter values and meteorological time series, discharge extracts from gauging station records covering the simulation period were prepared. For each sub-catchment, a time series file of measured discharge was specified, for use in calibrating the model. The model calibration process involved assigning suitable values to nine parameters relating to the four storages modelled by NAM, and adjusting the values of these parameters in an iterative, trial and error procedure until a close fit was obtained between simulated and observed discharge hydrographs.

Output from the rainfall-runoff modelling consisted of simulated time series of daily discharges for each sub-catchment, covering the simulation period. The discharge values were subsequently converted to specific runoff by dividing them through by the corresponding sub-catchment areas. The resulting files were later used as input to the river basin simulation model.

Water demand time series

It was planned to set up a river model simulating the prevailing system status, and subsequently use this model to predict system performance over a future ten-year planning horizon. This meant that for each water use activity, data in the form of time series of monthly demands, relating to present abstractions as well as projected demands, had to be obtained. The data used for the various schemes is outlined below.

Existing schemes

For the NWSC Mbale and NWSC Tororo water supply schemes, records obtained showed that these schemes were operating below plant capacity (with averages of 37% for Tororo, 20% for Mbale at Manafwa, and 78% for Mbale at Bunkoko). Recorded historical abstractions and return flows were used in setting up the model. For subsequent simulation scenarios, rather than using demand projections, demands corresponding to operation at plant capacity were investigated. These demand values were then iteratively reduced to establish the threshold demands that could be integrally satisfied using the existing plants.

The Tororo pipeline scheme consists of a 100 mm diameter transmission main running from Lwakhakha to Tororo. It was constructed to supply water to the railway station, to operate the steam engines of the past, but at the time of study it was being used to provide water to the railway staff quarters as well as several consumers living along the transmission line. However, there was no flow-measurement structure at the intake, nor along the pipeline; actual flow values were therefore unknown. The demand time series values used were estimates based on a supplied population of approximately 420, with a per-capita consumption of 100 l/d.

When Kibimba Rice Scheme was purchased from the Government of Uganda by Tilda (U) Ltd in 1997, the new owners established a first crop covering 178 hectares. Being the first crop, Tilda adopted an irrigation-scheduling procedure based on experiences in India. A subsequent appraisal of the performance of the irrigation and drainage system led to proposals for extensive rehabilitation works. These proposals included the use of an irrigation pattern to cater for two crops per year, planted on an area of 1,150 hectares, at 65% overall efficiency. For this study, therefore, two demand time series files were prepared for Kibimba. The first one represented irrigation demands as used for the first crop, while the second contained the proposed irrigation demand pattern subsequent to rehabilitation and expansion of the scheme. However, for purposes of the four scenarios investigated through sub-modelling as later described, only the former was used.

Proposed schemes

Lwakhakha, Budaka and Busolwe water supply schemes were planned projects under the Eastern Centres Water and Sanitation Project (ECWSP), designed to provide water to the respective towns. Water demand projections for these schemes were obtained from the design reports for the respective schemes. For Lwakhakha, it was planned that water would be abstracted from the river. The latter two schemes, however, were planned as groundwater schemes, with water abstracted by means of boreholes. To cater for this, the fraction of the demand attributed to groundwater sources was set at 100% in the respective time series files.

The Malaba pipeline, designed under the Small Towns Water and Sanitation Project (STWSP), consisted of a 150 mm diameter pipeline to transmit water from Tororo to Malaba. It was not planned to have a separate river intake, but would instead be connected from the NWSC reservoir supplying Tororo town. However, for purposes of this study, the demand attributed to this pipeline was considered as a separate abstraction occurring at the same river point as that for NWSC Tororo.

A hypothetical scheme, the Tororo phosphates factory, was derived from an idea conceived and expressed to the DWD by a politician in the area. The idea was to pump a considerable amount of water from R. Malaba up one of the rocky hills surrounding Tororo town, and use it in an industrial process to extract phosphates out of the hill. There was no existing design for this project, but it was included in the study as an example of how the model could be used to provide design guidelines for future projects. Demand time series used for this scheme contained hypothetical values that were varied in order to establish the maximum abstraction rate yielding satisfactory flows at points further downstream.

Simulation runs

For the river basin simulation modelling, MIKE BASIN was used. Also developed by DHI, MIKE BASIN is a modelling tool for integrated river basin planning and management. It accommodates a basin-wide representation of water availability, sector water demands, multipurpose reservoir operation, transfer/diversion schemes, and possible environmental constraints. MIKE BASIN provides a mathematical representation of the river basin, encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, existing as well as potential major schemes, and their various demands of water.

The first step in developing the model was to schematize the natural river system by representing it with a node-branch structure. This was done by importing as a background image within MIKE BASIN the schematized network drawing described earlier, as shown in Figure 2. Using the appropriate MIKE BASIN tools, branches of the schematized network were digitized following the background river network as a guide. The various water activities were inserted at appropriate locations on the network (Figure 3). Also, nodes were inserted at the ends of branches, at confluence and diversion points, and at locations of water abstraction and return flow, as shown in Figure 4.

Model schematization was completed by defining subcatchment areas contributing runoff to each branch, and specifying attributes for each water use activity. The attributes consisted of inflow node, return flow node, water demand time series filename and water allocation priority information.

For purposes of the study, it was decided to limit simulation runs to a portion of the entire model, by selecting a sub-model out of the larger model of the system. It was considered that sub-modelling would provide a better opportunity to investigate in detail a variety of planning scenarios, while achieving the overall goal of evaluating the planning approach under study.

Using the selected sub-model, four planning scenarios were simulated. The four scenarios were selected as a means of investigating the following model functions:

- evaluating the present system configuration;
- investigating the effect on the present system of changes in abstraction rates at individual components of it, thereby determining the values that would ensure adequate system performance;
- predicting system performance upon implementation of designed new projects;



Figure 2. River network imported into MIKE BASIN



Figure 3. Location of Water Demands



node numbers

setting capacity limits for probable future system additions

It should be noted that the selected scenarios, applying to only a portion of the entire model, served to demonstrate some possible situations the model could be used to investigate. They were in no way exhaustive, having been selected simply to help in assessing the planning method under study.

Results

For each of the four planning scenarios investigated, model results consisted of:

- a table showing the percentage to which water demands were satisfied for each month over the planning horizon.
- a table of relative water deficits for each month;
- a table of actual values of water extraction, water demand, deficits, groundwater abstractions, and return flows for each month;
- a graphical plot of time series of water extraction and water demand, plotted on the same axes to highlight the occurrences of water deficits;
- a graphical plot of the river network, with bar charts illustrating the variation of flows at different points within the system over the planning period.

A summary of results for the four planning scenarios that were investigated in the study is presented in Table 1. Noteworthy, for instance, is the fact that Kibimba Rice Scheme results showed substantial water deficits occurring during the rice-growing months, particularly in the months of land preparation, planting and initial crop development. This would imply that it would not be possible to maintain the irrigation schedule adopted for use with the first crop, much less the more ambitious one planned after expansion, by relying solely on water derived from sub-catchment runoff. If the schedules were to be sustained, it would be necessary to consider alternative sources to augment supplies during the critical months, such as the exploitation of groundwater resources.

However, as already mentioned, the primary purpose of the study was not to explicitly and comprehensively model and analyse the river basin system, but rather to assess the planning approach used. The discussion that follows is therefore in this light.

Discussion Significance of model results

It was seen that model results enabled the prediction of the occurrence of water deficits at points in the system, given particular combinations of development measures, present or potential. This would enable the planner to establish capacity guidelines for future developments in order to prevent or minimize such occurrences. Model results were thus able to provide information to guide potential developments, thereby promoting the sustainable utilization of the catchment's water resources.

However, water resources development decisions are usu-

ally based on more than physical considerations. Economic, sociological and political factors all play a role in the decision to implement a given project. This multi-factorial situation calls for an analysis that goes beyond the simple application of mathematical modelling of physical system elements. Even the application of "rules-of-thumb", or decisions based on an experienced planner's intuitive choices or value judgements, cannot be entirely disregarded, but should form an integral part of the entire planning process. As such, the results of a physically based mathematical model such as employed in this study can only guide or complement the decision-making process; they are not conclusive in themselves.

Overall assessment of planning approach

Any piece of applied research must be tested against two questions: "Does it work?" and "Does it help?" This study set out to assess, through application, a planning methodology involving the use of an integrated basin-wide approach and employing the establishment of a simulation model representing the river basin Water Resources system. Below is an assessment of the approach.

"Does it work?"

Validity of results

Computer modelling is completely quantitative; everything - parameters, variables, relationships, and even external influences - must be described by numbers. The validity and usefulness of modelling results is dependent on the extent to which the model adequately represents the actual system. The maxim "garbage in, garbage out" holds particularly true in this case.

A simuland is adequately modelled when those factors which significantly influence the results are described with an accuracy commensurate with the accuracy required of the results. At the river basin scale, the study is of reconnaissance level, aimed at establishing and evaluating broad parameter limits. The approach that was used in the study would therefore be adequate so long as the specification of such parameter values closely represents the system.

In identifying existing, proposed and potential development measures, the planning level was taken into consideration. This meant that "small" users such as the numerous individual subsistence rice farmers or domestic water abstractors were considered insignificant, or were lumped together with the major users where appropriate, which was sufficient at the scale of the study.

However, groundwater use was not explicitly modelled. As a result, the model was inexhaustive; it did not provide a direct means of investigating conjunctive use scenarios, for example. For a truly integrated approach it would be necessary to incorporate such considerations within the modelling process.

During the study, the need to obtain accurate data of adequate quantity, spatial distribution and time span was

not fully met. Available stream flow gauging stations were few, and meteorological data obtained was limited by the fact that it had to be purchased. The problem of insufficient monitoring networks and limited access to data is one that is likely to play a major role in impeding the usefulness of planning approaches such as described above.

"Soft" variables

In developing countries, engineering projects are viewed as engines of development. Often, projects are conceived and implemented out of socio-political rather than engineering considerations. The approach used in this study evaluated projects on the basis of water balance requirements, and did not account for such "soft" variables as political preferences; still, it did serve as a means of evaluating the engineering viability of implementing such projects within the context of an integrated river-basin system. However, it would be preferable for these "soft" considerations to be explicitly incorporated as part of the modeling process.

"Does it help?"

A catchment model for planning and monitoring

Winston Churchill once said, "It is always wise to look ahead, but foolish to look further than you can see". There is no way the planner can be absolutely certain that projections of future conditions are absolutely correct. The need to establish a plan that is amenable to modifications with changing objectives over time was pointed out earlier. With the establishment of a computer model representing a particular catchment, ease of implementation of such modifications to the catchment WRMP can be ensured. In addition, the model could then be used in association with systematic monitoring of projects following completion of construction, in order to verify the planning evaluations.

Anticipate-and-prevent strategies

Planning on an individual project basis poses the risk of implementing Water Resources developments that cause adverse effects on, and affect the sustainability of, other existing or future projects. Rather than settle for a react-andcure approach in dealing with such impacts, the approach studied would permit a foresight into the occurrence of such conflicts. Plans would then be formulated in such a way as to prevent the occurrence of such undesirable effects.

Impacts and trade-offs

The approach, and in particular the modelling software selected, did succeed in presenting model results in such a way that impacts and physical trade-offs between system elements were clearly discernible. Decision-makers could then use the results as a basis for choices to implement or not implement a plan component, or vary project parameters until acceptable trade-offs were achieved. However, trade-offs are usually particularly important in economic terms, an angle that the approach used in the study did not include.

Scenario	Location	Performance	Overall Sub-System Performance
Scenario 1: Present Situation	NWSC Tororo	Demand is fully satisfied for most of the planning horizon; Exceptions occur in the early months of 2005 and 2006, with almost 100% deficits. Overall demand satisfaction is 97.8% over the entire planning horizon.	As mentioned in the study description above, the simulation results reported were for a sub-model selected out of the entire model of the basin. The furthest node downstream for the selected sub-model was node 5 (see Fig. 4). For Scenario 1, flows at node 5 ranged from a minimum of 0 (signifying a complete drying of flow) to a maximum of 119 m ³ /s, with the mean flow for the entire simulation being 18 m ³ /s.
	Tororo Pipeline	Performance similar to NWSC Tororo above. Overall demand satisfaction over the planning horizon is 98%.	
	Kibimba Rice Scheme	Substantial deficits occur throughout the rice-growing season, implying the inability of the system to cope with the irrigation schedule modelled. Deficits over the entire planning horizon average 16.7%	
	River Nodes 2, 3 and 5	Very low stream flows are predicted during the critical months of January and February 2005 and 2006.	
Scenario 2: NWSC Tororo at plant capacity	NWSC Tororo	With NWSC Tororo at plant capacity, the predicted performance trend is as for Scenario 1 above, but with the overall demand satisfaction dropping to 96.9%.	Flows at Node 3 ranged from 0 to 80 m³/s, with a mean value of 12 m³/s.
Scenario 3a: Lwakhakha project introduced; NWSC Tororo at present demands	Lwakhakha Project	Demands for this scheme are fully satisfied throughout the planning horizon.	Node 2 ranged from 0 to 62 m^3/s , with a mean of 9 m^3/s ; Node 3 ranged from 0 to 80 m^3/s , with a mean of 12 m^3/s .
	NWSC Tororo	Similar trend as in Scenario 1, with overall demand satisfaction at 98.9%.	
Scenario 3b: Lwakhakha project introduced; NWSC Tororo at plant capacity	NWSC Tororo	With NWSC Tororo at plant capacity, overall demand satisfaction levels would drop to 97.8%. Streamflows at River Node 3 would be quite low during the critical early months of 2005 and 2006.	Overall performance at Nodes 2 and 3 were the same as for Scenario 3a.
Scenario 3c: Lwakhakha demands increased until water deficit occurrence at the scheme	Lwakhakha Project	The threshold value for abstractions at Lwakhakha was identified at 0.005m3/s, corresponding to an overall water deficit of 1.9%.	Overall performance at Nodes 2 and 3 were the same as for Scenario 3a.
Scenario 4: Tororo Phosphates factory introduced	Tororo Phosphates Factory	The threshold value for the rate of water abstraction at this hypothetical scheme was established as 0.001 m3/s. However, it would be preferable to design for a lower value than this, because of the undesirably low stream flows that are seen to occur further downstream in two months of the planning horizon.	Node 3 ranged from 0 to 80 m ³ /s, with a mean of 12 m ³ /s.

Table 1: Summary of Simulation Results

Note: Scenarios 2, 3 and 4 do not affect Kibimba, given its location (see Fig. 4).

Conclusions

From the discussion above, it may be concluded that the planning approach investigated in the study, namely the use of an integrated basin-wide approach in catchment management planning, is valuable as a means of ensuring sustainable water resources development, since it succeeds in facilitating the following:

- Evaluation of the impact of changes in individual system components on the availability and use of water resources in the entire basin;
- Investigation of the effect of new additions on the performance of the system as a whole;
- The establishment of threshold capacity values, or parameter limits, to ensure compatibility of development measures;
- The generation of reliable hydrological and stream flow data to guide Water Resources developments in the basin;
- The performance of trade-off analyses between alternative development measures;

• The establishment of a flexible, dynamic computer model of the system to facilitate future resource planning and management.

In light of identified shortfalls during the study, it is recommended that further research be carried out aimed at the development of a catchment model not only limited to a representation of the physical system parameters, but also extending to the performance of economic analyses of system behavior, and providing for both quantitative and non-quantitative decision variables and constraints.

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