

THE POTENTIAL ROLE OF GEOGRAPHIC INFORMATION SYSTEMS AND SIMULATION MODELLING IN THE ENVIRONMENTAL MANAGEMENT OF THE COOUM RIVER. CHENNAI *

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The problems involved in the environmental management of Cooum River in Chennai, India, relate not merely to pollution and environmental degradation but to a complex situation involving link-ages between social, economic and physical systems. For managing this complex problem, an Adaptive Environmental Assessment and Management (AEAM) approach is considered. The use of a series of workshops of the key actors, the development of a dynamic system model and the potential role of geographic information systems are discussed. Details of the procedure for operationalizing the AEAM process for the Chennai project are presented.

1 INTRODUCTION

1.1 The Cooum River

The Cooum** river and its surrounding area are a highly stressed environment in the Chennai (formerly "Madras") region of southern India. This urban stream, which is similar in environmental condition and quality of water to an open sewer, is a threat to public health, aesthetically repugnant and a handicap to the development of industries such as tourism.

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** Also spelt Coovum. Coovam, and Kuvam.

1.2 Adaptive Environmental Management and GIS

This paper presents a framework for the development of a rehabilitation and management strategy for the Cooum river. The strategy involves working through an application of the Adaptive Environmental Assessment and Management (AEAM) process. Adaptive Management is a systems-based approach designed to deal with uncertainties inherent in environmental change [15, 18, 24, 36]. It makes use of existing data and brings together scientific experts, representatives of the public, planners and policy makers in a series of workshops to make use of best-available knowledge and to design interventions in the system in such a strategy involves working through an application of the Adaptive way as to generate knowledge and facilitate learning [14, 18 p. 8]. The research proposed here adopts the basic philosophy, as well as the workshop and dynamic system modelling techniques of the standard AEAM process. This research program involves two workshops (August 1997 and April 1998) in which various experts in Chennai are brought together to scope and define a problem situation centred on the Cooum river, to design a system model of the Cooum river and its sub-basin (which will be developed by the researcher), and to use this dynamic system model to explore management alternatives for the Cooum system. The research is intended to be completed by the end of 1998.

Emphasis is placed, in the system modelling component of this process, on the use of a geographic information system (GIS). A GIS is "a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes" [7]. Since environmental problems have intrinsic spatial characteristics, GIS is particularly useful in addressing such problem situations. This largely accounts for the current "boom" in GIS technology in India, and its rapid adoption in Indian academic institutions and planning agencies.

The work presented in this proposal will couple the GIS "IDRISI" and the water quality simulator "DESERT" within a system designed to construct and evaluate management scenarios for the Cooum river and its environs. Although the coupling of GIS with dynamic system models is not yet common, Steyaert and Goodchild [34] indicate that GIS has

the potential to make important contributions to the modelling process as a preprocessor of data, in the storage and management of large spatial databases, for analysis of data and model results, and in the visualization and presentation of simulations. For example, consider that water quality model parameters are derived from land-uses, human activity and topography in the area surrounding the Cooum river. A GIS is ideally suited to model this type of information, process it so that parameters for the water quality model are derived, and display it for visual interpretation of polluting factors.

2 RESEARCH QUESTIONS: GOALS

There are three general questions this research will address. The first question focuses on the application of the Adaptive Environmental Assessment and Management process, which has been found useful for environmental management in developed countries since the early 1970s. Is the adaptive management approach and program transferable to a developing country situation, specifically to India where funds are relatively scarce, implementing agencies are fragmented, data is sparse or unreliable and bureaucracy, institutional inertia, and programmatic management approaches are entrenched?

Second, can the integration of a GIS within a modelling system enhance the adaptive management process? That is, can the integration of this technology and its associated means of handling environmental information allow planners, managers and other workshop participants to hypothesize and experiment more easily with changes in land-uses, zoning or regulation, or engineering interventions which will affect the environmental condition of the Cooum river?

Finally, how can we expect the environmental condition of the Cooum river and its surrounding area to respond to various management alternatives over different periods of time? For example, are there particular sequences of interventions which, when modelled, stand out as particularly effective over different time scales?

The general research questions, above, can also be operationalized with the following goals:

1. To evaluate the usefulness of GIS in support of environmental modelling within the process of adaptive environmental assessment and management.
2. To evaluate techniques and procedures associated with Adaptive Environmental Management and Assessment in the Chennai context.
3. To contribute to the general discussion and planning process for environmental management of the Cooum river in Chennai by modelling the Cooum system and by facilitating a process in which various management scenarios for rehabilitation and maintenance of the Cooum system are developed, compared and evaluated.
4. To provide a useful tool in the form of a GIS database and a working system model to planners, researchers and other interested parties in Chennai. In this sense the research is intended to be applied and will result in a product to be deposited at the Chennai Metropolitan Development Authority (CMDA) and the University of Madras.

3 STUDY AREA

The Cooum river, one of several rivers in the Chennai Basin in Southern India, runs into the Bay of Bengal through the Chennai Metropolitan Area, a city of 5.4 million people (in 1991). The head of the Cooum is 48 km west of Chennai where surplus from the Cooum tank joins the Kesavaram Anicut. This river has been described as a languid stream which is almost stagnant and does not carry enough water except during the monsoon. It has also been noted that the Cooum "receives a sizeable quantity of sewage from its neighbourhood for disposal" [35]. Waste from industry, households, slum settlements, agriculture and urban animal husbandry all contribute to the pollution of the Cooum river.

The Chennai Metropolitan Development Authority (CMDA) has expressed concern over this highly stressed environment and has indicated the need for action to stabilize, rehabilitate and sustain the river and surrounding areas. Specifically, item no. 25 in the *Development Strategy for Madras 2011: An Agenda for Action* [10] illustrates this concern;

“No. 25: Expedite and Complete Cleaning of Water Ways: The water ways in the City are presently public health hazards. To improve the quality of living as also to improve the City’s potential for tourism it is necessary that the action plan framed for cleaning and maintaining the water ways is implemented within next two years.”

While a fair amount of recent information exists concerning the physical condition of the Cooum River and associated issues [1, 9, 22, 26, 28-30, 32, 37], no comprehensive or holistic study exists which considers ecological parameters in conjunction with patterns of human settlement and activity. This is unfortunate as the origin of the problem is human-induced, through activities which are reflections of processes of rapid population growth, poorly controlled development and poverty. One is presented with not merely a problem of pollution and environmental degradation but a complex problem situation involving linkages between social, economic, and physical systems.

Natural complications of the problem situation arise from the dry, hot climate of the Chennai region. The summer (south-west) monsoon regularly fails and exposed water experiences high rates of evaporation. In addition, the coastal area of Chennai is extremely flat [35] so the Cooum river has a low stream flow. Its non-turbulent nature reduces the river’s capacity to absorb organic wastes. The spatial character of the environmental problem is local, the environs of the Chennai Metropolitan Area, and regional, both because the river extends back to its head-water 48 km west of Chennai and because the environmental degradation of the river is associated with the overall process of development in the Chennai-centred region and the Chennai basin. Temporally, the situation is long term. Rapid development and

population growth, (and the pollution of the Cooum river) began decades ago, stimulated by policies of industrial development in the central government's five year plans [20].

The nature of the environmental management decisions to be made regarding the Cooum river are broad in scope with a long time horizon. Normally this leads to high cost solutions and to greater likelihood of disagreement among vested interests, concerned parties, politicians and bureaucrats [4]. Also, public policy and decision making in Tamil Nadu and Chennai is decentralized, with the result that environmental problems are likely to be addressed in a piecemeal, distributive or regulatory way. (See Khato and Ross [23] for an earlier analysis of water pollution policy in India).

4 METHODOLOGY

4.1 Adaptive Approach to Environmental Management

Adaptive Environmental Assessment and Management (AEAM) is rooted in the understanding that we have incomplete knowledge of the complex and evolving systems in which we intervene, and that management of these systems is an ongoing learning process in which we will probably never achieve full knowledge and complete understanding [17 p. 13, 36 p. 8]. However, this should not stop resource managers from intervening in a system where lack of intervention is clearly costly or damaging. Instead, intervention should be designed as experiments so that knowledge about systems is maximized and learning occurs from unexpected events. Thus, the adaptive approach actively operates the learning cycle for the purpose of generating reliable knowledge, which is necessary for sustainable development to occur [24 p. 54].

Specific analytic techniques employed in adaptive environmental assessment and management depend on the nature of the problem being addressed. However, two general procedures are always available. These are the use of a series of workshops to bring together key actors, and the development of a dynamic system model. These techniques are

described below, and their application in the Chennai context is discussed in a later section.

4.2 Workshops

Holling [17] describes adaptive management as a process involving two groups of people: 1) a small core group of analysts and support staff (in this case, the researcher with two research assistants), and 2) key cooperators in the management project. It is the role of the core group to integrate information through the application of systems techniques such as computer modelling, mathematical analysis, etc. This group also coordinates the project, bringing together the second group in a series of workshops which are central to the approach.

The first workshop initiates the problem analysis and usually brings together about 25 key actors; scientists, managers and policy people, to scope, define and focus the problem [13]. This fundamental workshop considers all elements of the project, including the determination of goals and objectives, the allocation of tasks for subgroups, discussion of key variables, indicators and information needs, possible management actions, the spatial extent and time horizon, and the development of a framework for (and perhaps a crude working version of) a system model [17]. Less tangible, but very important, products of this first workshop include facilitation of communication between actors and the creation of an atmosphere conducive to the generation of creative management alternatives [13].

Further workshops will address more specific tasks. Participants involved in these workshops, such as, decision-makers, and scientists, depend upon the particular stage of the process and the task to be performed. Tasks of secondary workshops may include further definition of management goals, construction and refinement of the dynamic system model, exploration of uncertainties and scenario analysis for the development of alternative management actions.

4.3 Models

Also associated with AEAM is the development of computer simulation models as decision support tools to help to develop and

explore management options [17 p.14]. This process requires the construction of symbolic models which employ mathematical or logical symbols to represent the relationships between components of the system. Simulation comes from subjecting inputs to mathematical and logical operations to achieve a prediction of outputs. The term “dynamic” indicates that the simulation is iterative, with each iteration representing a step forward in time and the model state values changing with each iteration [16].

A major advantage of system modelling is that it creates a simplified laboratory world in which management actions can be tested [13]. This helps to alleviate the problem of reproducibility in complex real-world problem situations. That is, simulation testing and experimentation can be performed with no irreversible adverse effects to the ecosystem. A full range of management actions and creative alternatives can be explored. In addition, the use of simulation models brings together integrated and multi-disciplinary teams, forces assumptions to be explicitly stated, and highlights further data and analysis needs [13, 15].

The involvement of workshop participants in the development of a dynamic system model also ensures that all participants understand the model’s capabilities and limitations [14, p.245], increasing the usefulness of the computer model to non-technical users. In addition, the visible results of a running model generates a sense of ownership and acceptance, and links the system’s dynamics with the users’ perception. Graphical presentation of results, user friendly software and ‘hands-on’ gaming increase the utility of the model and the impact of modelling on decision making [13].

5 POTENTIAL ROLE OF GIS WITHIN AEAM

5.1 GIS Applications

GIS has the ability to manipulate and display spatially referenced data, and therefore its potential to support the modelling component of the AEAM procedure. Steyaert and Goodchild [34] list four areas where

GIS may contribute to simulation in environmental management: as a preprocessor of data, storage and management of large spatial databases, analysis of data and model results, and in the visualization and presentation of simulations.

5.2 Preprocessing, Data Storage and Management

Environmental modelling may require large and diverse spatial datasets. For example, land use and land cover data, digital elevation models and remote sensing imagery provide useful information for modelling environmental and ecological processes. GIS provides a convenient means of storing and managing such data. Steyaert and Goodchild [34] note that GIS has automatic 'housekeeping' functions, such as documentation of data layers, and provides uniform access to diverse data integrated into the system.

Basic functions of GIS also lend themselves to the preparation of data for modelling the environment, whether the modelling system is a GIS or an external programme. Map digitizing, import and editing (data collection), generalization and re-sampling, projection changes and data extraction (through windowing and other means) are some ways in which GIS can preprocess data [34]. Also significant is the ability to reformat and export data in formats useable to other packages, (especially, in this context, to simulation modelling packages).

5.3 Spatial Analysis

Spatial analysis is perhaps the most important contribution that GIS can make to the modelling component of AEAM. One such opportunity for GIS is to add a 'spatial specificity' component to modelling. For example, traditional watershed modelling employs a "lumped-model" or "lumped-systems" approach which averages variables with spatial attributes, such as land use and elevation, within watersheds without consideration of their spatial characteristics [27]. In contrast, distributed parameter modelling expressly considers spatially controlling parameters, such as soils and land use [12]. This provides for more accurate system simulations, simultaneous simulation of conditions at

all points throughout the watershed (allowing the simulation of processes with both temporal and spatial characteristics), and allows the extrapolation of plot-sized studies to the entire watershed. With distributed parameter modelling, for example, a watershed may be divided into a grid of cells each with topographical and other attributes. Variables such as runoff, erosion and chemical transport can be modelled and, spatial relationships, such as upland areas contributing to potential problems, and areas in need of remedial action may be identified [12].

This cell-based distributed parameter modelling procedure is similar in concept to analysis performed in raster-based GIS. In addition to the performance of such analyses through multiple iterations, GIS can make two other potential contributions to distributed parameter modelling. First, analysis in a GIS can parameterize the model. For example, Blaszczyński, as reported in Steyaert and Goodchild [34] derived the parameters required to apply the revised universal soil loss equation (e.g., terrain slope length, steepness, land cover and management, runoff and rainfall) in a dynamic model of surface water quality through spatial analysis of terrain, soil survey and land use data in a GIS. At the other end of the process, GIS can be used to analyse the results of the model. For example, the use of boolean logical operators and reclassification functions would facilitate the identification (and mapping) of the upland problem areas referred to in the above example from Engel et al. Such functions are generic to GIS.

5.4 Visualization and Presentation

Another category of the potential contributions of GIS to the AEAM process is the visualization and presentation of simulation results. In addition to standard tabular and graphical reporting functions, cartographic mapping capabilities are an important component of any GIS. Thus, a GIS brings increased capability to present and display results. The importance of this capability is indicated by the persistent reference in the adaptive management literature to the significant communicative role of clear visual presentation of results [13, 17, 36].

6 GIS AND SIMULATION MODELLING FOR ENVIRONMENTAL MANAGEMENT

6.1 A Coupled System for Modelling the Cooum River and its Environs

A coupled GIS and water quality simulator is currently being developed by the researcher which will be used (i) in an attempt to generate creative management alternatives for the rehabilitation of the Cooum river, (ii) to test the workshop and modelling components of AEAM in the Chennai context, and (iii) to evaluate the usefulness of GIS within the adaptive management process. In support of environmental management of the Cooum river, GIS is envisioned as working in conjunction with other software for dynamic simulation of water quality. The coupled system modeller is intended to be similar in concept to the model for integrating GIS with ecological simulation models presented by Coleman *et al.* [8] (see Fig. 1). This framework

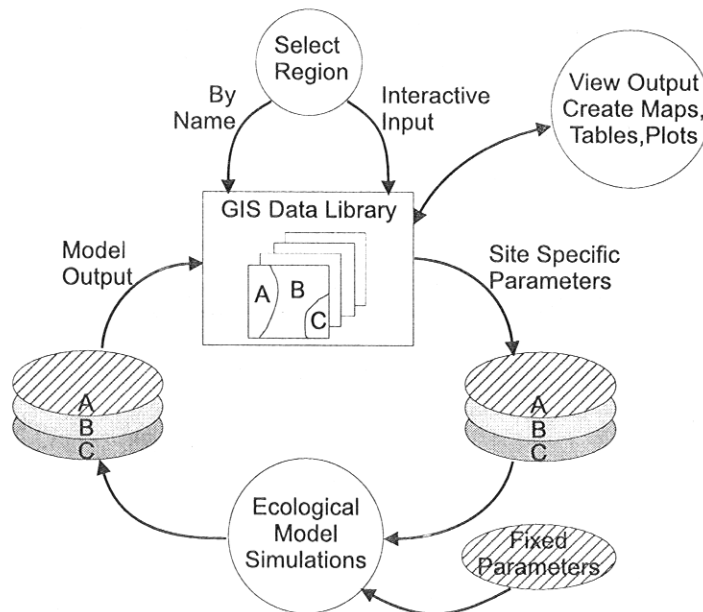


Figure 1: Conceptual design of the flow of data in an integrated GIS/ecological simulation model. (Source: Coleman *et al.*, 1994, Figure 24.4, p. 406).

places GIS in the role of preprocessing information, data storage and management, parameterization of variables for simulation model input, and output and display of the simulation results. Dynamic simulation is performed by a simulation module separate from the GIS. Dynamic simulation modules and the GIS module are integrated (more or less transparently to the user) through a menu-driven interface which provides users with a suite of data management, areal selection, modelling, output and display functions, and variable and parameter options.

Thus, the Cooum River system modeller is modular in design. This will facilitate maintenance and revision of the various components. The core of the system modeller is a GIS module incorporating the GIS IDRISI which will be coupled with a simulation module consisting of the water quality simulation system DESERT. These two “stand-alone” software packages will be linked together by an underlying platform developed in Visual Basic that will handle tasks such as data conversion and transport and also provide the user with a graphical user interface (GUI) and scenario management module. The basic architecture of the environmental management decision support system is presented in Fig. 2. Fig. 3 summarizes the flow of data.

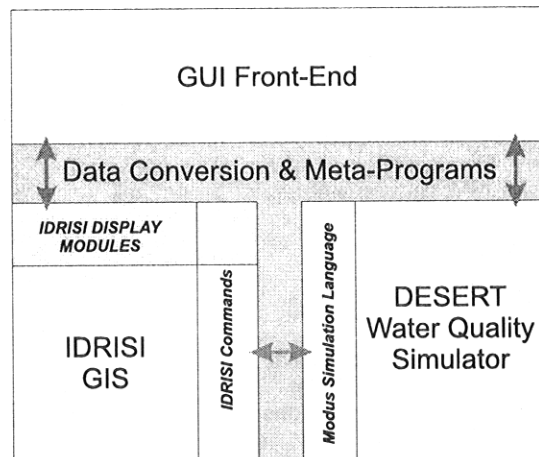


Figure 2: Coupled and modular architecture of the Cooum River system modeller.

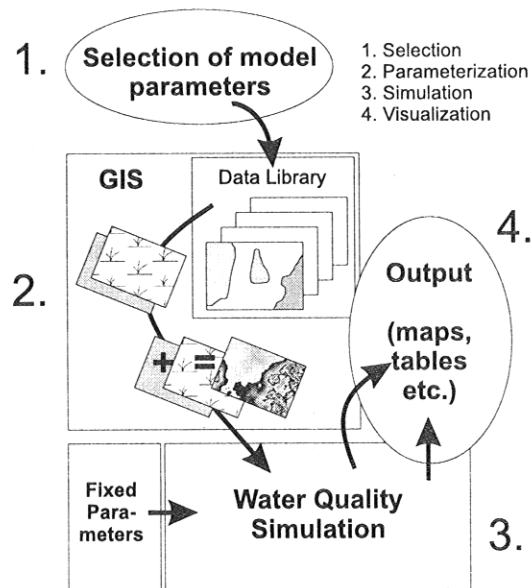


Figure 3: Conceptual design of the flow of data in the prototype Cooum River GIS/water quality simulation model.

The GIS module for this system will consist of IDRISI, a raster-based geographical analysis package developed through the IDRISI Project at the Graduate School of Geography at Clark University. The GIS module provides a platform for spatial data storage and management, and will include a hydrological module, which in combination with land-use data layers will help to parameterize reaches of the Cooum river (as point source or lateral inflows) for simulation in DESERT (Decision Support System for Evaluating River Basin Strategies). Model specifications, and parameters to be produced by IDRISI, will be passed from the scenario management module to the GIS as batch files.

DESERT is a package designed for water quality assessment and decision making in emission control which was developed by the International Institute for Applied Systems Analysis in Laxenburg, Austria and the Institute for Water and Environmental Problems in Barnaul, Russia [21]. Simulations in DESERT will be parameterized through the construction of InfoTable files which contain information

(generated in IDRISI) on quantity and quality of inflows into reaches of the river system. Simulation runs may be set up and controlled using DESERT's C-like MODUS Simulation Language.

The user performing scenario analysis or gaming with this system will be presented with a scenario manager which will present a series of choices through check boxes, pull-down menus, buttons and imagemaps, allowing the user to set up scenarios for various management options. The scenario manager will be implemented in Visual Basic.

The simulation framework makes it possible to explore a range of scenarios and management options, such as determining the effects of increased levels of income in a particular section of the city, or upgrading sewage treatment at various locations, or enforcing pollution controls on industries within a certain distance of the river. The scenario options that the scenario manager module will present to the user, the corresponding GIS data layers to be employed, and the selection of simulation model parameters which may be set by the user will be determined through a series of workshops in the adaptive management process.

7 OPERATIONALIZING THE AEAM PROCESS IN CHENNAI

7.1 Logistics

The Cooum project will involve two substantive three-day workshops, each involving 25-30 participants. The first workshop will involve determination of the scope of the problem and goal setting, the identification of system components, relationships, indicator variables and sources of data, the development of a framework for scenario analysis with a system model and discussion of possible management alternatives. In the second workshop, the same participants will undertake gaming in pursuit of creative management scenarios. They will also evaluate the usefulness of management alternatives generated through this process, the coupled system modeller and the workshop and modelling process overall. Smaller working groups may meet for short

sessions between workshops in order to help build and test the system model.

The project venue will be the Department of Geography at the University of Madras where facilities (such as a GIS computer lab) are available through the Madras-Waterloo Linkage Program.

7.2 Participants

Participants in the workshops will include scientists, policy people, managers and representatives of concerned groups. For managers and policy makers, participation in the workshops has already been confirmed from agencies such as the Chennai Metropolitan Development Authority, the Tamil Nadu Pollution Control Board, the Corporation of Chennai, and the Chennai Metropolitan Water Supply and Sewerage Board. Scientific input will be gained by participation of people from Chennai's two postgraduate universities and several undergraduate level colleges. Academics from a variety of disciplines and institutions have expressed interest in participating in the workshops. Public participation will come from the many non-governmental organizations in Chennai. For example, representatives from the M.A. Chidambaram Institute of Community Health, Exnora International, the Citizens' Waterways Monitoring Program and the UNHCS Chennai Sustainable Development Support Project will participate.

7.3 Key Research Needs and Data Requirements

Workshop exercises to identify important variables and indicators of system processes are intended to lead to an understanding of key research needs and data requirements. However, some of these may also be anticipated. First, basic topographical information will be required. Topographical maps of the Chennai area are available at the University of Madras at 1:50 000 and 1:25 000 scales. However, these are old (last updated in 1970-71), some are in poor condition and there are also gaps in the collection. For these reasons they may be insufficient for the construction of a digital topographic template for the area. The

acquisition of remote sensed data, however, can supplement and update this information. Such data can be acquired from the Indian National Remote Sensing Agency in Hyderabad.

Other information to be incorporated into the GIS and system model, (that is, indicator variables of system processes), will likely be broken down into categories such as Hydrology, Water Quality, Ecology and Human Activity. Hydrological data includes streamflow (discharge, velocity at selected sites), stream cross-section information and surface runoff. Water quality information will include such indicators as phosphorus and nitrogen, total suspended solids, dissolved solids, biological oxygen demand and pH. Ecological information such as the presence of algae and fish and the condition of potential fish habitat may also be seen as important by workshop participants. Information regarding human activities will be particularly important. Agricultural activities such as levels and types of fertilizer used for particular crops in the area will help to determine non-point-source contaminants of the river. The composition and amount of industrial effluents from particular types of industry, and enumeration of industry along the waterways in Chennai will provide information regarding point-source contamination within the city. Census information (based on corporation district maps) will contribute to an understanding of domestic waste and sewerage in the vicinity of the Cooum. Such information will be incorporated into the GIS as attributes of land cover data layers.

Much of this information has already been generated and only needs to be collected from various sources and converted to digital format. For example, the ODA report [30] on the Sludging of Madras Waterways contains information on stream bed sediments and water quality. Point locations of stormwater outlets are mapped in the *Stormwater Drainage Master Plan for Madras City and Pre-Feasibility Study for Madras Metropolitan Area, Interim Report* [25], and sewerage maps are available from the Chennai Metropolitan Water Supply and Sewerage Board. Sewerage information has also been published in the Madras 2011 plan [33]. The official land use plan for the Chennai Urban Agglomeration (CUA) also exists in digital form at the CMDA. Access to

key information from agencies such as the CMDA and the Tamil Nadu Pollution Control Board is already confirmed for this project.

Collection and assessment of water pollution data will be facilitated by the use of the Rapid Assessment Approach (RAA), a method of pollution assessment designed for use in developing countries by the World Health Organization [38], or a modified application of RAA for water pollution, such as that employed by Bangsrove [2]. This method provides an indication of total amounts and combinations of industrial and domestic wastes (per area, per unit time) where the researcher provides information such as population, level of income, industrial production, number of cars, etc.

On the other hand, some of the required data likely to be scattered in obscure and forgotten reports and will have to be pulled together by the core research group or by workshop participants. Although preliminary field work indicates a promising situation for data availability, it is almost certain that some needed data will not exist at the present time. In this case, it may be possible to use surrogate variables, or to extrapolate information from studies of other areas to apply to the Chennai situation. Aside from access to adequate and appropriate data, an understanding of the relationships among the components of the system is required. This highlights the importance of the participation of scientists in the workshops with expertise in diverse areas such as hydrology, economics, and human and physical ecology.

8 EXPECTED RESULTS

Several products, both academic and applied are expected to result from this research. First, in a practical sense, several scenarios representing different management options will be evaluated in terms of their effects on hydrology and water quality of the Cooum river system. A product from the generation and evaluation of these scenarios by workshop participants will be the development of a report for submission to the "High Power Committee" of the Government of Tamil Nadu which is looking at surface waters in the Chennai Metropolitan Area, and also to the Chennai Metropolitan Development Authority. It is expected that

the scenario analysis performed by workshop participants will feed directly into current discussions on management of urban surface waters in Chennai, and that the report coming from the workshops will be relevant to planners and policy makers dealing with the situation.

A further result will be the development of an ongoing dialogue about management of the Cooum River. There is currently much interest in, and concern about the urban environment, especially the waterways, in Chennai from various agencies and interest groups. Indeed, there have been previous discussions on the waterways, and the Cooum river itself. However, these seem to have been once-only affairs and tended to result in non-specific recommendations to clean the waterways after reviewing their condition. By bringing together the same group of people for more than a single workshop, and by maintaining communication by post-workshop key informant interviews and post-workshop reports, it is hoped that a more lasting dialogue will develop. In fact, it is the hope of the researcher that a standing working group on the Cooum and other waterways in Chennai will coalesce out of the workshop series.

A tangible result of this research programme will be the development of a database and the construction of a system to model the Cooum river and surrounding area, both of which will be given to appropriate agencies and interested parties. The Chennai Metropolitan Development Authority, for instance, has expressed interest in acquiring the system and the associated database after it has been constructed, as has Mr. Dattatri, of the UNHCS "Sustainable Chennai Support Project" who is developing a GIS-based Community Information Service for dissemination of information to voluntary and community-based organizations in Chennai.

9 CONCLUSIONS

The successful generation of creative management alternatives for the rehabilitation and maintenance of the Cooum river largely relies on the participation of those with local expertise and knowledge in various professional and academic fields in the process of problem definition and scoping, goal setting, data collection, model evaluation and scenario

analysis. Adaptive management provides a potentially useful framework for such a participatory management exercise as well as a theoretically sound approach for dealing with environmental problems. Adaptive management has been successfully employed in developed countries since the early 1970s and has the potential to contribute to environmental management in developing countries as well.

The integration of GIS with the simulation modelling component of the adaptive management process has the potential to enhance modelling and scenario analysis within AEAM by allowing planners and managers to hypothesize and experiment more easily with the land-uses which lead to water quality problems in the Cooum river. The coupling of GIS, simulation and scenario management modules together as a system modeller will facilitate this process while allowing the flexibility to maintain modules individually, or even to replace modules altogether with more up-to-date revisions of the software.

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