An Adaptive Ecosystem Approach to Rehabilitation and Management of the Cooum River Environmental System in Chennai, India

by

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AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

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ABSTRACT

BUNCH, MARTIN J. AN ADAPTIVE ECOSYSTEM APPROACH TO REHABILITATION AND MANAGEMENT OF THE COOUM RIVER ENVIRONMENTAL SYSTEM IN CHENNAI, INDIA

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This research investigates the application of an adaptive ecosystem approach to the problem of the Cooum River and environs in Chennai (formerly Madras), India. The Cooum River is an extremely polluted urban stream that flows into the Bay of Bengal through the heart of Chennai, India's fourth largest metropolis. During the dry (non-monsoon) season, the upper reaches of the river are dry and flow in the river may be attributed primarily to the production of sewage by the city's population. The river is essentially a foul-smelling open sewer.

Complexity of the problem is due as much to human factors (population growth, poverty, uncontrolled urban development, jurisdictional conflicts, modes of behaviour of the citizenry, and institutional culture) as to physical characteristics of the system (flat topography, tidal action, blockage of the river mouth by sand bar formation, and monsoon flooding). Uncertainty in the situation is both structural (regarding main processes and activities in the system and the nature of relationships among the various actors and elements), and parametric (having to do with scarcity, poor quality and restricted access to data).

This work has drawn upon methods and techniques of Adaptive Environmental Management and Soft Systems Methodology to operate the ecosystem approach and address the problem. Specifically, this has involved a series of workshops which have brought together planners, researchers, NGOs, and other stakeholders in a participatory process oriented toward problem definition, system identification and conceptualization, determination of objectives for management, and the generation and exploration of management interventions. In addition, a central component of the program has been the development of a loosely-coupled GIS, environmental simulation model, and a decision support module. This is based upon a framework provided by participants in the first workshop in the series, and operationalizes a common understanding of the system.

In addition to generating new insight into the nature of the problem situation, the research has provided a potentially useful tool to planners, managers and researchers in Chennai in the form of a GIS database and decision support system (DSS). Aside from the tool itself , it was found that the *process* of developing a conceptual model, and attempting to represent this in the DSS has made a significant contribution to understanding of the Cooum system. In particular, this process forced assumptions to be stated explicitly and publically, highlighted areas of uncertainty and led to new understanding in participants' conception of the problem situation. The program of research also provided a much needed forum for open debate and exchange of information which was removed from the restrictive institutional culture of government departments.

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Acronyms Used in this Work

ADB	Asian Development Bank
AEAM	Adaptive Environmental Assessment and Management
BOD_5	5-day biochemical oxygen demand
CATWOE	A 'Root Definition' mnemonic used in SSM (Customer, Actor, Transformation, Weltanschauung, Owner, Environment)
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
CMWSSB	Chennai Metropolitan Water Supply and Sewerage Board ('Metrowater')
DO	Dissolved oxygen
DESERT	*DE*cision *S*upport system for *E*valuating *R*iver basin s*T*rategies
DSS	Decision Support System
EWS	Economically Weaker Section
FSV	Future Search Visioning
GIS	Geographic Information System
GOI	Government of India
GOTN	Government of Tamil Nadu
GUI	Graphical User Interface
GRASS	Geographic Resources Analysis Support System
HAS	Human Activity System
HIG	Higher Income Group
HUDCO	Housing and Urban Development Corporation of India, Ltd.
INTACH	Indian National Trust and Cultural Heritage
LIG	Lower Income Group
IAS	Indian Administrative Service
ISI	Indian Standards Institute
MIG	Middle Income Group
MMDA	Madras Metropolitan Development Authority (now the CMDA)
MMWSSB	Madras Metropolitan Water Supply and Sewerage Board (now the CMWSSB)
NGO	Non-governmental Organization
ODBC	Object Database Connectivity
OGDI	Open Geospatial Datastore Interface
OLE	Object Linking and Embedding
OOP	Object Oriented Programming
PCB	Pollution Control Board (same as TNPCB)
PNS	Post Normal Science
PWD	Public Works Department (same as TNPWD)
RD	Root Definition
SSM	Soft Systems Methodology
STP	Sewage Treatment Plant
SWD	Storm Water Drainage
Tcl/Tk	Tool Command Language/Tool Kit
TNPCB	Tamil Nadu Pollution Control Board
TNPWD	Tamil Nadu Public Works Department
TNSCB	Tamil Nadu Slum Clearance Board
TNWSDB	Tamil Nadu Water Supply and Drainage Board (same as TWAD)
TWAD	Tamil Nadu Water Supply and Drainage Board (same as TNWSDB)
UNCHS	United Nations Centre for Human Settlements
WAMP	Citizens' Waterways Monitoring Programme
WRO	Water Resources Organization (of the TNPWD)

1

The Cooum River Environmental Management Research Program

Introduction

Leslie Currie (1991:3) has commented that "people who write on the aims of geography but do not combine its analytic and integrative roles simultaneously are surely missing the boat." Currie was referring to the need for cumulative synthetic theory in geography, and lamenting the tendency of some geographers to identify too strongly with neighbouring systematic fields. In opposition to the divisive influence of traditional disciplinary science on geography, and to emphasise the importance of synthesis, he stated (1991:2) that;

> I really have no time at all for those great minds who emphasise a unity of science corresponding to a unity of reality and the divisiveness of petty disciplines. There are only 'problems' to be tackled, applied or academic, and we must all contribute what we can. Essentially, this leaves the mature disciplines not only defining the problems but also judging the solutions in terms of their ground rules. One has to staunchly reject the numerous clarion calls to pursue knowledge where'er it may lead, since this means following physicists into their kind of climatology or economists into their sort of spatial economy, wherever their particular train tracks take them. We have to be willing to be naïve where specialist sciences are strong, knowing that we are sophisticated where they are weak.

Several aspects of Currie's statement set the context for the research presented in this thesis. First, Currie indicates that, in practice, research is directed toward the understanding and/or solution of problems rather than the illumination of a particular aspect of reality that has been deliberately extracted with a disciplinary scalpel. This research is problem centred.

Specifically, this work is intended to support programs for rehabilitation and management of the Cooum River in Chennai (formerly Madras), India. The Cooum is a highly polluted urban stream, which has long been recognized as a critical environmental problem within the city. The problem has many dimensions which might interest researchers in disciplines such as hydrology, anthropology, planning, engineering, geology, sociology, demography, geography and others. In fact, various aspects of the problem situation have been addressed, and interventions designed and implemented, from such disciplinary perspectives. Yet the problem remains.

Second, this research is both analytic and integrative, combining the known analytic strengths of several of the disciplinary sciences and their corresponding geographic sub-disciplines, and the holistic, integrative power of systems thinking, together in an ecosystem approach.[1] If traditional disciplinary science can be usually characterised as *systematic* and *analytic* in its approach, then this research has a distinctly *systemic* and *synthetic* flavour. In the investigation of the Cooum River problem, this research adopts an ecosystem approach, and as such it borrows from systems-based methodologies, heuristics, and tools to develop a systemic understanding of the problem situation. This understanding is interdisciplinary, holistic, integrative, and largely qualitative. It is used to selectively guide exploration of the problem situation using the tools, heuristics and methods characteristic of traditional (*i.e.*, positivist, reductionist) disciplinary sciences. This exploration then reinforms the qualitative understanding of the system of interest in the problem situation, in an iteration of a learning cycle.

This research may also be seen as 'pragmatic' or 'eclectic' science. That is, within a general framework provided by the ecosystem approach, this research employs those methods and tools which seem most useful and appropriate in the context of the problem setting. Patton (1990:39) termed this "situational responsiveness." Elliot (1999:240), has noted that, within her field of the geography of health and in human geography generally, the integration

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[1] A systems-based approach intended to promote an understanding of key inter-relationships among physical, biological and human elements of a situation, and the properties and behaviours of sets of these elements acting together as a whole.

of qualitative methods with quantitative analyses has been both complementary and productive. Such an integration of methodological paradigms is characteristic of the ecosystem approach employed in this research. Elliot noted that the guiding principle in undertaking integrated qualitative and quantitative approaches is *appropriateness of methods* chosen within the context of the problem addressed. This is certainly a guiding principle for this work, and I join Elliot in highlighting Patton's (1990:39) statement;

> Rather than believing that one must choose to align with one paradigm or another, I advocate a paradigm of choices. A paradigm of choices rejects methodological orthodoxy in favour of methodological appropriateness as the primary criterion for judging methodological quality. The issue then becomes whether one has made sensible decisions given the purpose of the inquiry and the questions being investigated.

Thus, this research is characterised by (1) an explicit orientation towards alleviation of a problem situation, (2) a synthetic, holistic, interdisciplinary approach, and (3) situational responsiveness in the choice of methods, tools and techniques. Specifically, this research, labelled the *Cooum River Environmental Management Research Program,* employs a framework for investigation of the Cooum River problem situation provided by the ecosystem approach. It draws upon heuristics, tools, methods and techniques, where appropriate, primarily from systems-based methodologies such as Adaptive Environmental Management (which is oriented toward dealing with uncertainty inherent in environmental change), and Soft Systems Methodology (which provides a means to address "messy" situations involving human activity).

This research was undertaken in the hope that it would make a contribution toward the rehabilitation and management of the Cooum River and environs. It was also intended evaluate and further develop the ecosystem approach in the context of the Cooum problem situation, and to expand the set of tools available to researchers and practitioners of the ecosystem approach.

The purpose of this work is to present the problem situation, approach, methods and results of the *Cooum River Environmental Management Research Program*. This chapter provides a basic introduction for the program of research through (1) a discussion of the study area and problem situation associated with the pollution of the Cooum River, (2) a basic overview of the research framework and methods, (3) a presentation of the objectives of this research and (4) a description of the organization of the thesis. The majority of attention in this chapter is given to a presentation of the study area and the problem situation.

Study Area and Problem Situation

The Cooum River is one of several rivers in the Madras Basin in Southern India (Figure 1.2). It flows to the Coromandel Coast and into the Bay of Bengal from west to east through the centre of the Chennai Metropolitan Area (CMA). Chennai, with a population of 3.9 million within the city limits and a metropolitan area population of 5.4 million persons in 1991, is the fourth largest city and third largest port in India. It is the dominant urban centre in the south of the country. The city is the capital of the southern Indian state of Tamil Nadu, and is situated at approximately 13º North latitude and 80º East longitude. Chennai city currently encompasses an area of 172 km^2, and the metropolitan area adds almost 400 km^2 of urban agglomeration to this figure (Nagaraj and Ramani, 1991:I.38). Figure 1.1 presents the geographical location of Chennai within India, and Figure 1.2 shows the city in its regional context.

The topography of the Chennai area is flat, with the terrain rising slightly inland from the coast. Mean elevation above sea level for the city is 22' or 6.7 metres, but most of the city is at or only slightly above sea level, making drainage a problem. The predominant soil in the district is alluvial, with

Figure 1.1: The regional setting of Chennai, in the southern Indian state of Tamil Nadu.

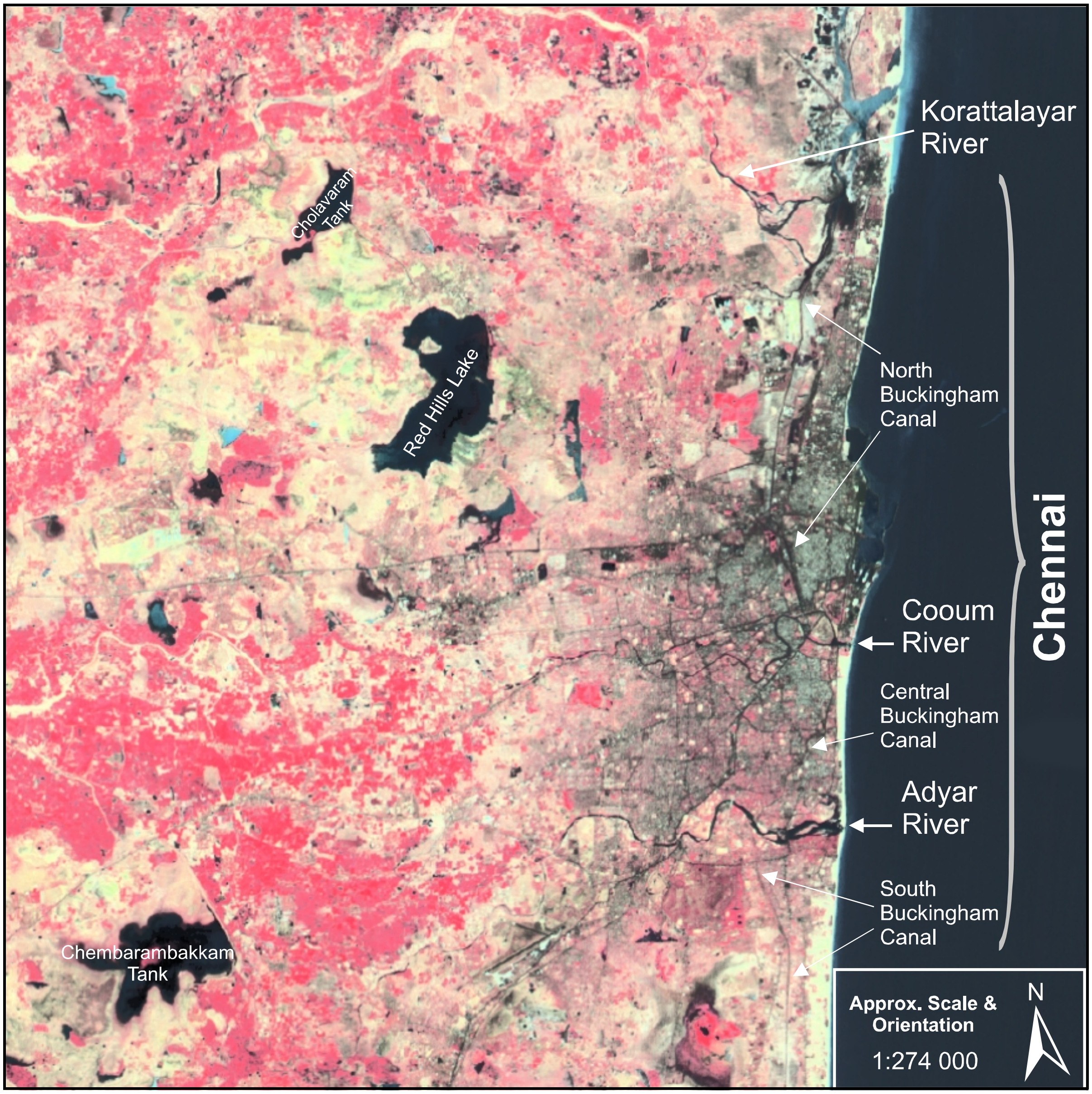

Figure 1.2: IRS satellite image of Chennai and surrounding region, with important surface water features indicated. Grey areas in this satellite image are the built-up areas of Chennai and the Chennai urban agglomeration. Reddish colours indicate vegetation, and bright whitish colours are typical of highly reflective sandy areas. Notice the absence of water in the Cooum outside (west) of Chennai. This image was acquired in August of 1988, a dry season for Chennai. (Technical note: this image is a false colour composite from bands 4, 3, and 2 of an IRS LISS-2 scene. The spatial resolution is 36.25 metres. The image is uncorrected geometrically and has been enhanced for visual interpretation using a histogram equalization stretch of the digital numbers).

Table 1.1: Climatic parameters of Chennai

Month	Mean Rainfall[1] (mm)	Mean Temp[2] (C)	Humidity[2] (%)	Sunshine[2] (hrs)	Wind Speed[2] (km/day)	Open Water Evaporation (mm)	Potential Evapotranspiration (mm)
Jan	36.6	24.6	73.5	8.2	122.4	124	114
Feb	11.5	26.4	73.1	9.4	182.5	146	132
Mar	8.6	28.7	70.5	9.5	196.8	192	170
Apr	13.4	30.9	70.2	9.7	235.2	213	153
May	40.2	32.9	64.8	9.8	266.4	238	171
Jun	53.4	32.4	59.2	7.1	266.4	198	200
Jul	99.1	30.7	65.0	5.8	220.8	170	170
Aug	130.8	30.8	67.1	6.0	213.6	167	165
Sep	125.2	29.8	73.4	6.4	168.3	153	129
Oct	290.6	28.4	77.1	6.3	134.4	136	127
Nov	352.3	26.1	78.0	6.0	129.6	111	103
Dec	146.2	25.2	76.7	6.8	134.5	112	105

[1] Rainfall data from 1901-1992, Meenambakkam Rainfall Station
[2] Other Climatic Data from 1983-1992
Source: Government of Tamil Nadu, 1997, Table 6: "Climatic Parameters of Madras":TOR-18, derived from data supplied by Meteorology Office.

scattered pockets of gravelly soil. Coastal areas and tanks (reservoirs) have predominantly saline, sandy soil (Government of Tamil Nadu, 1981:10-12). The subsoil is black clay with varying stiffness at different depths. Chennai receives an average of approximately 1300 mm of rainfall per year – most of this (~800 mm) falls during the North-East monsoon in the months of October through December.

Two main waterways flow through the city from west to east: the Adyar River in the south and the Cooum River through the geographical centre of Chennai. Also, the Buckingham Canal runs north to south along the coast through the city, and intersects both the Adyar and Cooum Rivers on their north and south banks. All the waterways in Chennai are considered to be polluted, but the Cooum River and Buckingham Canal are widely recognized to be the worst.

The Cooum has a length of approximately 70 kilometres and originates where surplus from the Cooum tank joins the Kesavaram Anicut[2] built across the Kortaliyar River in Kesavaram village. For approximately 18 kilometres in its lowest reaches, the Cooum winds

[2] An anicut is a dam in a stream, typically constructed to regulate flow for an irrigation system. (The word derives from the Tamil *anai kattu* meaning 'dam' or 'building') (Webster-Merriam, 1997).

through the built up area between the city limits and the Coromandel coast. The river drains a catchment of about 290 km^2, including about 140 tanks or reservoirs (Gowri, 1997:43). Within the city, the river's channel ranges from about 170-180 metres wide near the mouth with the river itself accounting for 140-150 metres of this, to a channel width ranging between about 45 and 100 metres and the river itself varying between 25 and 60 metres (Mott MacDonald, 1994, Table 3.12:49).

This river has been described as a "languid stream" which is almost stagnant and which carries little water except during the monsoon. It has also been noted that the Cooum "receives a sizeable quantity of sewage from its neighbourhood for disposal" (Government of Tamil Nadu, 1981:10). All along the river's course industries dispose of their waste and households toss their garbage (Table 1.2). Although parts of the city are serviced by primary and secondary sewerage treatment, in the most densely populated area surrounding the lower reaches and mouth of the Cooum River, raw sewage is diverted into the waterways and ocean (Srinivasan, 1991:III.17). Table 1.2 demonstrates this situation, indicating a total of 407 wastewater outfalls into waterways in Chennai (116 into the Cooum) that were identified by a consultancy firm in 1994 (Government of Tamil Nadu, 1997: TOR-3). Even this large number of wastewater outfalls is probably an underestimate. A more recent survey of pollution outfalls by an environmental NGO in Chennai identified 720 outfalls to waterways in Chennai (WAMP, 1999a).

For decades, the condition of the Cooum has been of concern. Srinivasa Chari wrote of the blockage of the mouth of the river, its low flow and "evil odour" as far back as 1939

Table 1.2: Wastewater outfall details for inner Chennai waterways

Waterway	Sewage	Storm Water	Industrial	Others	Total
Cooum River	*109*	*6*	*1*	-	*116*
Adyar River	58	23	-	-	81
Otteri Nullah	42	4	1	-	47
South Buckingham Canal	26	1	-	-	27
Central Buckingham Canal	30	-	-	1	31
North Buckingham Canal	58	5	3	1	67
Mambalam Drain	14	8	-	1	23
Captain Cotton Canal	13	-	-	-	13
Kodungaiyur New Drain	2	-	-	-	2
Total	352	47	5	3	407

Source: Wardrop Engineering (1995) as reported in Government of Tamil Nadu, 1997, Table 1:TOR-3.

(Appasamy, 1989:13). On the other hand, there are earlier records of the river being sufficiently clean to provide the water for daily ablutions, and of being navigable (Muthiah, 1999). As Chennai grew, however, the wastes that its citizens and industries emptied into the Cooum became more than the natural environment could assimilate. The river was transformed from an asset to citizens of Chennai, into a blemish on the city.

Many factors complicate the situation of the Cooum. One such complication arises from slums (Figure 1.3). These hutment areas have common open toilets and waste disposal areas along the river. In 1986 there were 37 slums, totally un-serviced by public amenities, situated directly on the banks of the Cooum River itself, and many more in its near vicinity (MMDA, 1986). Furthermore, excrement and other waste associated with animal husbandry in the city (which is often associated with slum dwellers), also contribute to pollution of the

Figure 1.3: A residential area (including a small hutment or slum area) backing onto the Cooum River. Notice the sludge on the banks of the river, the organic solid waste floating in the foreground, the open drain letting domestic wastewater into the river, the rubbish littering the banks and the open area reserved for defecation. (Photo by Martin J. Bunch, 1999).

Cooum. A survey in 1977 found a livestock population of 20 776 cattle, 18 639 water buffalo, 1 084 sheep, 5 949 goats, 331 horses and ponies, 878 pigs and 86 243 poultry and other birds *within* the built up area of the city proper (Government of Tamil Nadu, 1981:13). Although as of February 26, 1999 the Corporation of Chennai had begun to enforce regulations regarding livestock within the city limits, the number of cattle and water buffalo in the city in late 1999 was probably more than double the 1977 figure. The result of these and other activities is that along much of its course through the city of Chennai the Cooum River is a black, foul smelling, open sewer.

There are a wide variety of reported water quality indicators for this river. All indicate that the river is severely polluted, (although the indicators vary widely and are often based on undisclosed methods). The quality of water in the Cooum River is best demonstrated by values of the 5-day biochemical oxygen demand (BOD_5) which indicates the amount of organic content in the water by the amount of oxygen consumed by aerobic bacteria in decomposing it. These values have been reported as high as 315 mg/l in the Cooum River (Gunaselvan, 1999). Compare this to the expected BOD_5 value of raw sewage in the sewerage system in Chennai of 250 mg/l (Ananthapadmanabhan, 1998).[3] (Appendix III presents data for 44 water quality indicators of the Cooum River, which further demonstrates the severity of the problem).

Even more complexity is demonstrated when physical and hydraulic characteristics of the river are considered. The construction of the harbour has resulted in local modification of the strong litoral drift along the Coromandel coast. This has caused increased erosion of the coast north of the harbour, and deposition of sand in the south. One effect of the modified coastal currents is accentuation of the formation of sand bars which block the mouth of the Cooum (Mott MacDonald, 1994:22). This blockage, and insufficient flow during the dry season (which fails to keep the sand bar clear of the mouth), result in the trapping and stagnation of water in the lower reaches of the river. The sand bar also inhibits tidal waters which would otherwise enter the mouth of the Cooum and help to flush out some of the

[3]Also for comparison, the Indian Standards Institute (ISI) maximum BOD_5 loading for Industrial Effluents let into inland surface waters is 30 mg/l (Heggade, 1998:215).

polluted water.

Table 1.3: Typical dry season and flood velocities in the Cooum River

General Location	Dry Season (m^3/s)	Flood (m^3/s)
Upper Reach	0.24	2.50
Middle Reach	0.00	1.50
Lower Reach	0.10	1.80

Source: Mott MacDonald, 1994, Table 3.1:22.

Blockage of the mouth by the sand bar, and low flow of the river (Table 1.3), result in the accumulation of silt and organic sludge on the bed and banks. The sludge consists of a mixture of alluvium from the underlying alluvial basin, sediment transported from upstream, sediment transported into/across the river mouth by littoral drift, runnoff from the city streets, suspended solids from direct discharge of wastewater, and direct disposal of solid waste (Mott MacDonald, 1994:28). It is a combination of silt, sand and organic matter. Mott MacDonald (1994:48) indicate that the depth of soft sludge on the bottom of the Cooum River varies from about 0.3 to 0.7 metres (thicker in the lower reaches), with a probable average depth of about 0.5 metres. Organic dry sludge is found on the banks of the Cooum, with an average depth of 0.4 metres. The total volume of sludge in the Cooum that is of hydraulic and environmental concern is about 1 210 000 m^3. Sludge samples taken from the Cooum as part of a consultancy study in the early 1990s, were found to contain low concentrations of pathogenic parasites, (*e.g*., worms such as *Ascaris lumbricoides* and *Trichuris trichuria*). It is assumed that the sludge also contains *Crypsosporidium*, (a major cause of diarrhoeal disease) and enteric pathogens including *Vibrio Cholerae* (Mott MacDonald, 1994:42).

Other issues are also linked with the Cooum pollution problem. For example, some households and enterprises have illegal connections to the storm water drainage system rather than to the sewerage system, resulting in the improper disposal of waste waters. This is in turn associated with problems of enforcement of by-laws and regulations which are intended to ensure proper behaviour with respect to disposal of sewerage, solid waste, debris from construction, *etc*., and the corruption of officials. Many regulations exist which are oriented toward controlling polluting activity, but these are not often enforced. One study of water quality in the Cooum undertaken by researchers at the Institute for Water Studies of the Tamil Nadu Public Works Department (PWD) highlights the importance of this point by recommending that existing laws should be "strictly enforced" against the polluters of rivers in Chennai (Chengelvarayan *et al*., 1999:76).

In addition, health issues arise from the condition of the Cooum. In many places the river provides habitat for mosquitos which spread diseases such as malaria and filariasis. Although in many places the river is too polluted to allow the breeding of the *Anopheles stephensii* mosquito which carries malaria, the *Culex* mosquito, a vector for filariasis, does breed there (Mott MacDonald, 1994:42; Appasamy, 1989:36). Diseases such as cholera, typhoid, hepatitis and others, and pathogenic parasites, are associated with pollution of the water and the accumulation of organic (faecal) sludge. City dwellers living in the vicinity of the waterways are at higher risk with regard to health. This is especially true of those who have physical contact with the water, such as children playing in the river and fishers in stretches of the river near the city limits.

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. Item no. 25 in the *Development Strategy for Madras 2011: An Agenda for Action* (Dattatri and Anand, 1991:6) 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. [sic]

No action has occurred. Still, the development and implementation of a management plan for the Cooum River is a priority for agencies dealing with urban development and management of the urban environment in Chennai (Ranganathan, 1995). However, planners are presented with a situation of rapid development and industrialization, the poverty of a large portion of the population, the persistence of slums, political corruption, a drought-prone climate and limited resources. The problem is highly complex and extends beyond physical and ecological considerations.

Management of such an overwhelming, complex, and persistent problem is a nightmare. The problem is exacerbated because public policy and decision making in Tamil Nadu and Chennai are decentralized and sectoral. Jurisdiction to address environmental problems is distributed among a large set of inadequately funded, poorly coordinated or non-cooperating agencies, with the result that environmental problems are likely to be addressed in a piecemeal way (see Khator and Ross, 1991 for an analysis of water pollution policy in India). Recognizing such institutional aspects of environmental problems, the Government of India (1999:Ch11, Part 4) has stated that;

> The weakness of the existing system lies in the enforcement capabilities of environmental institutions, both at the centre and the state. There is no effective coordination amongst various Ministries/Institutions regarding integration of environmental concerns at the inception/planning stage of [projects]. Current policies are also fragmented across several Government agencies with differing policy mandates. Lack of trained personnel and comprehensive database delay many projects. Most of the State Government institutions are relatively small suffering from inadequacy of technical staff and resources.

Each of the many agencies involved in the situation, has jurisdiction over only part of the problem situation (Table 1.4). These agencies often do well within their own dominion, but budgets, time-lines and priorities to address various aspects of the problem situation differ among agencies. As a result, efforts of one agency may not be well coordinated with, nor supported by, complementary efforts of other agencies. In some cases, it may be that agencies find themselves in opposition to each other over projects that each considers to be within its own domain, and outside the purview of competing agencies.

In addition, the nature of the decisions needed regarding the Cooum River are broad in scope with a long time horizon. Normally this leads to high-cost solutions and to a greater likelihood of disagreement among vested interests, concerned parties, politicians and bureaucrats (Briassoulis, 1989:382). Also, the planning horizons of politicians and government agencies typically operate on a shorter cycle than appropriate to address environmental problem situations.

Furthermore, the dominant approaches to problem solving in the Indian context are based on traditional sectoral, technical scientific and engineering paradigms. Problem solving for environmental problems requires approaches that are interdisciplinary, holistic, participatory, and adaptive. One manifestation of the traditional orientation, and the dominance of engineers in Indian institutions, can be seen in the ‘Terms of Reference’ and call for bids to develop a master plan for Chennai waterways. Aside from the orientation itself towards a master planning process, the bid outlines team qualifications required to work on the project. The team is to consist of a project and team leader, eight (8) other engineers of various sorts, a hydrogeologist, an architect, a financial analyst, a data processing manager, and a (seemingly token) sociologist (Government of Tamil Nadu, 1997:LOI - 6).

Table 1.4: Administration of water supply and sanitation in the CMA.

Administrating Body	***Role***
Chennai Metropolitan Water Supply and Sewerage Board	Planning, construction, operation and maintenance of all water supply and sewerage systems in the CMA (so far restricted to the city and certain industries outside the city but in the CMA)
Tamil Nadu Water Supply and Drainage Board	Planning and construction only of all water supply and sewerage (urban and rural) in Tamil Nadu (excluding Chennai City but within the CMA)
Municipal Councils, Townships, Village & Town Panchayats in CMA	Operate and maintain systems in their area
Department of Municipal Administration and Water Supply, Government of Tamil Nadu	Administrative control of government bodies dealing with Water Supply (*e.g.,* CMWSSB, Municipal governments, TNWSDB or TWAD).
Tamil Nadu Housing Board, Tamil Nadu Slum Clearance Board	Design and construct independent water supply (and sanitation) systems in their projects
Irrigation Branch, Public Works Department, Government of Tamil Nadu	Operates and maintains surface sources of the city water supply and is in charge of the river courses in the CMA and city (to transfer to the Corporation of Chennai in the future)
Local bodies (Corporation of Chennai)	Collection and disposal of solid waste and storm water runoff
Chennai Metropolitan Development Authority	Planning and coordination, development control, special projects and new towns
Department of Social Welfare	Programs for disadvantaged sections of the population
Tamil Nadu Pollution Control Board	Pollution control, industry licensing from the pollution aspect
District Collector	Co-ordinating land acquisition processes

Source: Srinivansan, S., 1991:III.3; MMDA, 1991:163-164.

Also, while many studies and consultancy reports have been commissioned to investigate aspects of the problem (*e.g*., MMWSSB, 1991; ADB, 1994; ODA, 1995), no comprehensive study has considered ecological parameters in conjunction with patterns of human land uses, 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 urban development, and poverty. One is presented with not merely a problem of pollution and environmental degradation of a 'natural' system but, as outlined in the next chapter, with a problem situation of organized complexity involving linkages among cultural, social, economic, institutional, political and biophysical systems.

Nevertheless, many government agencies have made valiant attempts to improve the situation. The list includes agencies such as the Tamil Nadu Public Works Department, the Chennai Metropolitan Development Authority, the Corporation of Chennai, the Chennai Metropolitan Water Supply and Sewerage Board, the Tamil Nadu Slum Clearance Board and others. One of the largest projects undertaken was a Rs. 2.29 crores[4] (2.1 million USD in 1969) major improvement scheme undertaken from 1967 to 1972[5] (Appasamy, 1989:12-14). This involved channelization, excavation and lining of various stretches of the Cooum. A regulator and sand pump were installed. Boat jetties and a boat club were built. In 1999, the regulator was rusted and non-functional. The sand pump, which did not prevent the reformation of the sand bar, is defunct. The boat jetties have been turned into cattle sheds, or filled in by the corporation to deny breeding habitat to mosquitoes. A study conducted only 6 years after the completion of the project found levels of the 5-day Biochemical oxygen demand at 2 to 3 times higher than the limit acceptable for treated sewage effluent, and measures of faecal coliform bacteria at more than 1000 times the standard (Appasamy, 1989:27). The Cooum, at the time of this research, is more filthy than ever.

Although studies and proposals for maintenance of the waterway continued, no works were initiated for about a decade after the major improvements scheme in the early 1970s. After that period there have been some projects of a smaller scale, such as various desilting and dredging projects, and a current HUDCO financed, (Rs. 99 crore, or USD ~23 million), project aimed at de-silting and cleaning portions of the Cooum River, the Otteri Nullah, the Virugambakkam-Arumbakkam Drain and the Buckingham canal, the construction of flood banks, and slum clearance and relocation of slum dwellers (New Indian Express, 5.3.1999:5).

Lately the condition of waterways in Chennai has become an issue at the higher levels

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[4]In the Indian system, 1 crore is equal to 10 000 000 and 1 lakh is 100 000.

[5]This work was undertaken primarily by the Tamil Nadu Public Works Department.

of the State and Central governments. In early 1999 the Government of Tamil Nadu announced 3 "Millennium Projects" aimed at restoration and improvement of the waterways in Chennai, and financed by Rs. 300 crore (approximately USD 71 million) in loans from HUDCO. These will involve (1) the development of a Master Plan and the preparation of bid documents for the development of Chennai waterways for navigation, recreation and exploitation of real estate potential; (2) the removal of sand bars blocking the outlets of the Cooum and Adyar rivers; and (3) silt and sludge removal and the resettlement of slum dwellers. By February 1999, 37 companies had responded to bid on the first of these projects, and 7 companies had responded to the second, while the third had not yet opened for bidding (Hindu, 1.2.1999:3). Additionally, the Ministry of Environment and Forests, Government of India, is undertaking an evaluation of "scientific and engineering" aspects of projects associated with a proposal, announced in January of 2000, of an 800 crore (USD ~184 million) effort to clean Chennai waterways (Hindu, 1.10.2000).

Thus, not only is the situation of the Cooum River and environs a critical environmental problem, but it is also a timely one for this program of research. There exists an opportunity to contribute to efforts to address the problems of the Cooum and other waterways in the city. It is with this in mind that the following sections of this chapter introduce the approach undertaken in this research and the goals of the Cooum River Environmental Management Research Program.

The Program of Research

The *Cooum River Environmental Management Research Program* has been designed to explore the "problematic situation" associated with environmental degradation of the Cooum River and surrounding area, and to support efforts directed at rehabilitation of the river and management of the situation. The program of research employs an ecosystem approach that falls within the realm of post-normal science. This is science for the resolution of policy issues dealing with the environment, where the controlled laboratory environments and simple goals associated with traditional or "normal" science in the logical-positivist paradigm are absent. These are situations of complexity in which there may be uncertainty about basic facts, multiple and conflicting interests and values, high stakes and urgently required decisions (Funtowitz, 1999).

The ecosystem approach provides a general guide in terms of the identification and description of a socio-ecological system, the development of scenarios for management of the system, the selection of a management scenario to achieve a desirable and feasible vision of the future state of the system, its implementation, and ongoing management of the system. The framework also provides an indication of how to go about doing this. For example, understanding of biophysical systems is informed by traditional science and knowledge and complex systems theories, the human context may be understood by way of exploration of culture and preferences, and operation of the framework is informed by systems methodologies and collaborative processes (Kay *et al.*, 1999:739-40). As noted above, this is 'pragmatic' or 'eclectic' science – there must be consideration of the appropriateness of methods and tools employed within this framework.

The primary methodology for this research is derived from Adaptive Environmental Assessment and Management (AEAM). This methodology is rooted in systems thinking and is oriented toward managing environmental change in uncertain and complex situations. AEAM (also referred to as adaptive management or adaptive environmental management) emphasizes communication and participation, experimentation, learning from the experience of managing ecosystems, and flexibility in management programs in the face of new knowledge and changing goals. The approach intentionally operates a learning cycle.

Main operational components of adaptive management are (1) a series of workshops that bring together scientific experts, planners, policy makers and representatives of the public to make use of best-available knowledge and to design interventions in the system to generate knowledge and facilitate learning, and (2) the development and use of a simulation model as an aid in system understanding and the exploration of possible management scenarios. This particular research makes use of Geographic Information System technology in support of the system modelling component of adaptive management.

This research is also heavily influenced by Soft Systems Methodology (SSM). SSM is a methodology intended to deal with "messy" or complex, unstructured "problematic situations" centred about human activity. SSM involves the perception and interpretation of a real world problem situation and provides tools for expressing it. This expression of the problem situation leads to the identification of key themes which may be modelled as relevant systems of purposeful human activity. These conceptualizations are compared to the (perceived) problem situation, and used to stimulate thinking about organizational change. That is, expression, conceptualization and comparison lead to debate about action to improve the situation. Action in the real world changes the situation, which then requires new expression, conceptualization, debate, *etc.*. Thus, as with Adaptive Management, Soft Systems Methodology formally operates the learning cycle, employing learning from the experience of applying the methodology to further inform purposeful action in real world situations (Checkland and Scholes, 1990a:4).

Research Objectives

The severity and complexity of the Cooum situation have been demonstrated by the repeated failure of sectoral approaches to "solve" the problem. This work explores the notion that, where past efforts have failed, the ecosystem approach may succeed. That is, the application of an ecosystem approach can make a meaningful contribution to rehabilitation and management of the Cooum system.

The ecosystem approach applied in this work is heavily influenced by Adaptive Environmental Management and Soft Systems Methodology. It also makes extensive use of geographical information systems in support of environmental simulation modelling for exploration and learning about the Cooum system. Thus, the primary objectives of this research are:

❶ To apply the ecosystem approach to the problem of rehabilitation and management of the Cooum River in Chennai.

❷ To evaluate the usefulness of geographic information systems (GIS) in support of environmental modelling.

❸ To provide a useful tool in the form of a GIS database and system model to planners, researchers and interested parties in Chennai.

The first of these objectives has several aspects. Most notably, it was important to focus on a problem which is meaningful to those living and working in Chennai. I felt it is important that this research make a real contribution toward addressing a problem situation. Toward this end, a variety of individuals in Chennai were consulted before defining and undertaking a program of research. This particular problem (rehabilitation and environmental management of the Cooum River) was suggested by Mr. A.R. Ranganathan, a Chief Planner at the Chennai Metropolitan Development Authority. It was the first item on his list (literally) of problems needing attention. The problem also happens to be very timely because the Government of Tamil Nadu has called for tenders for projects addressing various engineering improvements and beautification programs for waterways in Chennai, with particular emphasis on the Cooum.

Second, this program of research is an experiment in the transfer of a set concepts and methods associated with holistic, adaptive and systems-based approaches which have been mostly developed and applied in a Western context. An attempt has been made to operationalize these in the Chennai situation – a situation in which agencies acting with regard to the problem are fragmented and compartmentalized, and the mode of management is characterized by hierarchical rather than collegial authority, command rather than participatory leadership styles, vertical and formal communications and low tolerance for ambiguity and uncertainty. This is a mechanistic bureaucratic environment with an orientation toward programmed planning approaches. It is not an environment in which experimentation, innovation and adaptation are rewarded.

The second stated objective is much less radical than the first. Adaptive management typically has a modelling component, (for example; dynamic simulation modelling of hydrology and water quality). GIS could make a contribution to this component of the adaptive management methodology by facilitating the construction and maintenance of a database, providing for spatial specificity in environmental model inputs, and visualizing data and model results.

The final objective is a practical one. If all else fails, and nothing but a PhD dissertation comes out of this work, then at least a practical and tangible contribution will have been made by generating a dataset that can be made available to anyone interested in using it. This is more important than one might think. Even simple topographic maps of the Chennai area are restricted material, and information such as consultancy reports and government documents and plans are typically difficult to acquire.

Organization of this Work

This work is organized into seven chapters. The first presented an introduction to the Cooum River Environmental Management Research Program. It discussed the study area and presented the basic problem situation. Primary objectives for this work and a brief discussion of the approach and methods employed have been included. The second chapter discusses the approach in more detail. Chapter 2 briefly addresses topics such as the nature of environmental problems and approaches to planning before proceeding to a presentation of the ecosystem approach, adaptive management and Soft Systems Methodology.

The following four chapters (3 through 6) present methods employed, and report on the results of various phases of the research. The third chapter discusses methods and results of the first workshop which was entitled "A System Study for Environmental Management of the Cooum River and Environs." The fourth chapter addresses the design and development of a simulation model of the Cooum system (a framework for which was developed during the first workshop). The fifth chapter discusses the methods and results of the second workshop entitled "Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs." The sixth chapter presents results of exploratory scenario analysis using the Cooum River Environmental Management Decision Support System.

Finally, the last chapter summarizes the findings presented in the previous chapters, and draws conclusions related to the program of research in general, its contribution to understanding of the problem situation, its effectiveness in achieving the objectives stated in the first chapter, and its future potential for guiding action in the problem situation.

Conclusions

There are several novel aspects of the Cooum River Environmental Management Research Program. The first is the application of an ecosystem approach, and in particular the application of adaptive management, to a problem situation in the Chennai area. Although an adaptive management approach has been tried in several developing areas in the past, such as the Nam Pong (ESSA, 1982) and Rio Caroni (Holling, 1978) basins, such a setting for adaptive management is still rare. More uncommon still is the significance of urban activities in the project. Although many adaptive management programs deal with urban areas within the ecosystem which is being managed, the author is unaware of any adaptive management program in which the rehabilitation and maintenance of an *urban* waterway is the explicit main objective. The application of AEAM to the Cooum River situation should help to identify the strengths and weaknesses of the approach both to urban areas and to developing country situations.

The application of GIS in the modelling process has also been relatively unusual in adaptive management projects in the past, although there are indications that this has changed. Also, GIS in support of environmental simulation modelling in general is becoming common. The potential for the useful application of GIS to AEAM is clear, and main actors in the development of adaptive management itself have noted the potential role of GIS within the process (Holling, 1995:18; Holling 1990:77). Thus, a main objective of the project is to evaluate the utility of GIS within the context of AEAM.

Finally, the application of concepts and techniques of Soft Systems Methodology in a developing country context and to a system primarily (at least initially) identified in biophysical terms, is rare. SSM is usually applied to human institutional and organizational problem situations, and to the design and implementation of information systems within these environments. This research will provide an opportunity to explore aspects of the methodology in a new context and should lead to findings about its robustness, or lack thereof.

2

An Adaptive Ecosystem Management Approach to the Problem Situation

Introduction

As outlined in the introductory chapter, this research is oriented toward support for rehabilitation and management efforts for the Cooum River in Chennai, India. It employs an ecosystem approach which draws primarily upon theory and methods provided by Adaptive Environmental Assessment and Management (AEAM) (Holling 1978; Walters, 1986; Lee, 1993; Gunderson *et al.*, 1995a). Operational aspects of this approach from adaptive management include (1) participatory workshops oriented toward problem definition, system identification, determination of goals and objectives, and the generation of management alternatives, and (2) the development of a system model of the Cooum River and its environs to be used for scenario analysis and system exploration. A geographic information system (GIS) was integrated into the system modelling component of this process.

Also, this particular application of the ecosystem approach is heavily influenced by Soft Systems Methodology (SSM) (Checkland, 1981; Checkland and Scholes, 1990a) which provides cognitive and methodological tools to deal with human activity systems. The overall approach and its context fall within the domain of ‘Post-Normal Science’ (Funtowicz and Ravetz, 1994), or science for the investigation and solution of policy issues having to do with the environment.

Before discussing the application of these methods in the Chennai context, and presenting of the results of this research, it is appropriate to provide some context and background for the approach itself. Thus, it is the purpose in this chapter to provide a brief overview of alternative approaches to environmental planning, the nature of environmental problems, and the ecosystem approach. Adaptive management (including the integration of Geographic Information Systems into the system modelling component), and Soft Systems Methodology also are described in detail.

The Nature of Environmental Problems

Environmental planners and managers deal with problems which are complex, ill-structured, plagued with uncertainty, and extremely political (Bardwell, 1991:603). Environmental problems have physical, social, economic and political implications, and may be seen as problem situations occurring due to a "mismatch" between socio-economic systems and physico-ecological systems (Bowonder, 1987:81-82)[1]. The nature and extent of problems are typically contested by various parties and the basic facts, data and forecasts associated with a problem may be in doubt. Environmental quality itself is a highly subjective and multi-dimensional concept. It may be perceived differently by various cultures, sub-cultures, institutions, socio-economic groups and individuals (Hackett, 1993:118-119; Feijoó and Momo, 1991:163; Bowonder, 1984:216).

Environmental problems are also characterized by the order and association of elements of the situation within an interconnected system. There is an underlying, albeit illusive, structure to the problem situation which gives pattern and organization to the whole. *Simply organized* problems, characterized by separability, reducibility and one-dimensional goal structures, are easily bounded and managed systematically. *Unorganized complexity* may be addressed with statistical techniques. However, there are relatively few cognitive or practical tools for coping with

[1]Bowonder describes this "mismatch" as occurring because the evolution of human systems occurs much more quickly than that of natural systems. Physico-ecological systems cannot adapt to the considerable changes socio-economic systems have undergone over the past several hundred years. The responses of natural systems to large-scale changes (the introduction of chemical wastes, for example) are not at the same speed as those of the input changes. This situation, and the lack of strong feedbacks between natural and human systems, result in rapid non-sustainable development (1987:81-82).

Table 2.1: Distinguishing properties of problems of organized complexity.

Category	***Property***
Ability to formulate the problem	Such problems have no definitive solution.
Relationship between problem and solution	Every formulation of the problem corresponds to a statement of solution and *vice versa*. Understanding the problem is synonymous with solving it.
Testability	There is no single criteria system or rule that determines whether the solution to this type of problem is correct or false. Solutions can only be good or bad relative to one another.
Finality	There is no stopping rule for such problems. There is always room for improvement. Political consequences are played out indefinitely.
Tractability	There is no exhaustive, enumerable list of permissible operations to be used in the solution of problems of organized complexity.
Explanatory characteristics	These problems have many possible explanations for the same discrepancy. Depending on the explanation one chooses, solutions take on different forms.
Level of analysis	Each of these sort of problems can be considered as a symptom of another problem. It has no identifiable root cause; since curing symptoms does not cure problems, one is never sure the problem is attacked at the proper level.
Reproducibility	Each problem is a one-shot operation. Once a solution is attempted, you can never undo what you have already done. There is no trial and error.
Replicability	Every problem is essentially unique.
Responsibility	The problem solver has "no right to be wrong." He or she is morally responsible for what is being done and must share the blame when things go wrong. However, since there is no way of knowing when a wicked problem is solved, very few people are praised for grappling with them.

Source: Mason and Mitroff (1981:10-12), after Rittle (1972).

organized complexity[2] (Mason and Mitroff, 1981:5-9). Properties characterizing problems of organized complexity are presented in Table 2.1.

Funtowicz and Ravetz (1994) provide further insight into situations of organized complexity. Referring to ordinary *versus* emergent complexity (both of which fall with the category of organized complexity, above), they note that *ordinary complexity* "involves structure and self-organization" and has a simple teleology (such as growth or survival) (Funtowicz and Ravetz, 1994:569-570). While it is possible, through the application of systems concepts and methods, to explain situations

[2]Environmental problem situations, those of organized complexity, are also known variously as *wicked, turbulent, ill-structured, fuzzy, soft, messy* or *real-world* problems (for examples see Rittle, 1972; Checkland, 1976; Trist, 1980; Mason and Mitroff, 1981; Morley, 1986; Bardwell, 1991).

involving organized complexity in a functional and mechanistic manner, *emergent complexity*[3] cannot be fully explained in this way. In situations involving emergent complexity, "some at least of the elements of the system possess individuality, along with some degree of intentionality, consciousness, foresight, purpose, symbolic representations and morality." This is the complication added by the activity of human beings.

Such characteristics of real world problem situations – situations of organized (and emergent) complexity – imply that broad participation of directly or indirectly affected parties is required in the problem-solving process, and that decisions must be based on information collected on a wide spectrum and from a large number of diverse sources (Mason and Mitroff, 1981:13). In addition to being participatory, interdisciplinary and comprehensive, environmental management should be flexible enough to allow for the individual nature of each problem (Bardwell, 1991:610).

Mitchell (1991:268-272), referring to problems of resource management and development, summarizes these characteristics in four categories. Thus, (1) such a situation will be multi-dimensional (having environmental, social/cultural and economic dimensions), (2) the components of the system will be interrelated and complex, (3) there will be uncertainty due to lack of information and understanding of the system, and (4) the problem situation will involve multiple (often conflicting) interests and participants. Any successful approach to environmental management will have to address all four of these fundamental issues.[4]

In response to these issues, Mitchell stated that a balanced perspective emphasising

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[3] In the systems literature, *emergence* usually refers to a property of a whole entity or system which is not evident in any of its component parts individually. Funtowicz and Ravetz (1994) are here using the term in a somewhat different manner.

[4]The description of the Cooum River problem situation presented in Chapter 1 demonstrates these four characteristics. For example, climatic characteristics, topography, tidal processes and coastal currents all play a role in the situation, as does poverty and slum formation, commercial and industrial activity, income distribution and water supply. These and many other components are interrelated, but the nature of the relationships are often not well understood or identified. Relationships that are known are described with sparse data of poor quality. Stakeholders include government agencies (*e.g.*, the TNSCB, CMDA, Chennai Corporation, PWD, CMWSSB), private interests (consultants, polluting and other affected business), NGOs (such as Exnora, WAMP and INTACH) and various individuals and groups of citizens.

sustainability and compromise is required and that a systems approach (particularly an "ecosystem approach") should be employed in managing the natural environment. Also, the process must handle uncertainty through flexibility and adaptiveness (*i.e*., responsiveness to new information and changing goals) and should be participatory, such that parties with a legitimate interest in the problem situation are involved in the determination of both the ends and means for environmental management (Mitchell, 1991:272). As will be discussed below, these are all characteristics of adaptive management. Mitchell's prescription for '*BEAT*ing' conflict and uncertainty (*B*alanced perspective, an *E*cosystem approach, *A*daptiveness, and participatory, cooperative *T*eamwork) provides a useful framework to present the characteristics of adaptive management. This will be undertaken below, following a brief introduction to Environmental Management and the Ecosystem Approach.

Environmental Planning

Environmental planning may be defined as, "an activity undertaken by individuals and organizations dealing with problems arising at the society-environment interface and devising courses of action to solve these problems" (Briassoulis, 1989:381). A variety of approaches have been taken to planning and management of the environment. This research makes use of an ecosystem approach and, in particular, adaptive environmental management to support environmental management of the Cooum River in Chennai, India. The question arises, however, 'Is application of this approach appropriate in the Chennai situation?'

Various other approaches to dealing with environmental problems have been pursued and should be considered. Some of the most prominent of these are briefly reviewed below. These may be considered 'ideal types' and it will be seen that the approach employed in this work displays characteristics of several of them.

A common approach to environmental planning and a logical extension of the traditional comprehensive planning model is *Comprehensive/Rational Planning* or *Synoptic Planning.* In its application to environmental problems, this approach has the basic premise that all things in nature are spatially and temporally interconnected (Briassoulis, 1989:384). It is also rooted in economic rationality which assumes that, given sufficient information, individuals are able to identify and systematically evaluate goals, values and objectives, and will make economically optimal decisions in choosing among them (Mitchell, 1997: 85). This approach tends to be quantitative but permits multiple iterations, feedback and elaboration of subprocesses (Hudson, 1979:388-389).

The comprehensive rational approach is characterized by (Briassoulis, 1989:384):

1. "Objective and exhaustive analysis of the environmental and socioeconomic conditions of an area along the lines of a systems analytic framework borrowing basic concepts from ecology."

2. Identification and generation of alternative solutions to the problem.

3. Selection of the best solution based on objective scientific criteria.

In this process a core group of experts is placed in the primary planning role (with the assumption that they are working in the public interest).

The comprehensive rational approach is the dominant approach in environmental planning (Briassoulis, 1989:384; Mitchell, 1997:84). It tends to have a bias, however, toward (often absent) centralization of control and power for its implementation, and assumes public, not pluralist interests (Hudson, 1979:389; Briassoulis, 1989:385). This approach does not include mechanisms for inter-jurisdictional cooperation, or to deal with pressure politics of interest groups. Also, science is not always as objective as commonly believed. Scientists may be sponsored by one or more interests in the situation, biases are built into scientific approaches themselves (Hudson, 1979: 394), and individuals may make decisions on the basis of incomplete information and non-economic criteria.

Another holistic model is the *Integrated Approach* which improves on the comprehensive approach primarily by narrowing the perspective to characteristics and interactions of a selected number of critical components of an environmental system. This more focussed approach makes planning and management more feasible in terms of the skills and capabilities of resource managers (Mitchell, 1989:305). Projects which employ an integrated approach that seeks only to identify and understand those components of a system that are most important in the problem situation are also likely to be completed within a more reasonable time frame than would be the case if a comprehensive approach were applied (Mitchell, 1997:57). The integrated approach also emphasises context. Considerations such as the state of the natural environment, prevailing ideologies, economic conditions, administrative and financial arrangements (Mitchell, 1990:8) are, for example, important in judging the feasibility of potential interventions in a system.

In practice, environmental planning often uses an *Incremental Planning* approach. In some instances, this is a crisis management approach. An "inevitable consequence of the world of politics," incremental planning is often employed when a problem has reached crisis proportions before it is addressed in "a disjointed, uncoordinated, piecemeal fashion“ (Briassoulis, 1989:385). However, the incremental approach is also seen by some as a practical and consistent approach in environmental planning. Charles Lindblom (1959), a prominent advocate of the incremental approach, indicated that for complex problems, the exhaustive consideration of all alternatives, values and goals required by the comprehensive/rational approach is impossible. In practice, decision-makers simplify complex situations by restricting themselves to successive limited comparison of relatively few values and options (Lindblom, 1959:84-85). Options are chosen which do not stray too far from the experience of the past and important possible consequences of policy options are often ignored. This reduces uncertainty and complexity for the decision-maker. The approach is politically pragmatic, dealing well with problems of ideological consensus and with fragmentation and imbalances of power and authority among jurisdictions and interest groups. However, this incremental, distributive planning mode works against holistic, environmentally sound solutions (Hudson, 1979:389; Briassoulis, 1989:386).

In contrast to incremental planning, *Transactive Planning* is process-oriented, where the focus is on the effect of planning on people, and not only on achieving specific planned targets (Hudson, 1979:389; Mitchell, 1997:89). This type of approach is characterized by participation, flexible and evolving plans, decentralized planning institutions and the transfer of control over social processes to the public. This approach is strong in the human dimension (psychological, social and institutional processes which facilitate growth and learning between planners and constituencies) but is not very feasible in centralized and bureaucratic environments (Hudson, 1979:392-393).

Transactive planning is a participatory planning model which attempts to find "win-win" solutions in common with interested parties and affected groups. Participation lends legitimacy to solutions. This is expected to increase the ease of implementation and enforcement of solutions (Briassoulis, 1989:388). Unfortunately, while consensus might be reached in relation to small-scale, local problems having limited scope and modest costs, the participatory approach is much less suited to large-scale problems where more ideological disagreement is evident.

On the other hand, when environmental problems are hotly contested, broad in scope, or solutions imply long-term commitment of resources, an advocacy approach to the situation (based in the adversarial tradition of the legal profession) may develop (Hudson, 1979:389-390). This reflects the philosophy that one cannot plan for multiple interests and that solutions to environmental problems reflect the perspective and interests of those served (Briassoulis, 1989:387). Aside from the danger of these solutions being environmentally unsound, this approach risks impasse.

The environmental planning approaches reviewed above are taken mainly from the experience of planning for environmental problems in the developed countries. The main form of environmental planning that has occurred in developing countries is the rational/comprehensive form. However, as in the more developed countries, this often evolves into adversarial or incremental forms of planning. For example, Khator and Ross (1991), in a study of water pollution policy in India, found that Indians typically take the incremental approach to environmental problems.

It should also be noted that these planning approaches are extremes and are often combined with other approaches. The *Mixed Scanning Approach* developed by Etzione (1967), for example, combines aspects of incremental and rational comprehensive approaches, attempting to build on their strengths while minimizing their weaknesses. It does this by combining "higher order, fundamental decision-making with lower order, incremental decisions that work out and/or prepare for the higher order ones" (Entzioni, 1986:8).

Many planning activities in developing countries, which attempt to employ the above planning approaches in various combinations have been increasingly viewed as unsuccessful. Rondinelli (1993b:3-4) provides some explanation of their failure. Referring to development assistance activities, he notes that high levels of uncertainty, complexity and risk make development planning and management in the third world more difficult in several ways. It is;

> a) More difficult and complex to state goals and objectives precisely, because development problems were not well defined or understood, "solutions" were not always clear or easily transferable; impacts of interventions could not always be predicted; and the objectives of multiple participants and stakeholders in the projects were not always consistent.
>
> b) More difficult to assess the feasibility of potential interventions through projects and programs because of the lack of complete knowledge of the dimensions of the problem or the most appropriate and effective interventions.
>
> c) More difficult and less effective to pre-design projects or programs in too much detail. Simply designing projects by the donor's standards and criteria was insufficient for ensuring effectiveness or sustainability. Participation by host country governments and beneficiaries became more critical.
>
> d) More difficult to keep the design and implementation phases of the project strictly separated under conditions of complexity and uncertainty because activities would have to be adjusted as they were carried out as more was learned about the local conditions in developing countries.
>
> e) More difficult to apply standard appraisal criteria such as financial rates-of-return or social cost-benefit analysis or predetermined technical standards because of the donors' inability to predict human reactions to interventions with any degree of certainty, and because the implementation of projects was not always completely under the donor's or even the host government's' control.

Rondinelli (1993b:4) concludes that,

> "...development projects that are really experiments in problem-solving and or in pursuing opportunities for economic and social change must be supported by management systems that encourage and reward experimentation, innovation, and adaptation."

An *Adaptive Approach* to planning and management is one such system. This is a major theme in environmental management and is a characteristic of many ecosystem approaches. Such an approach provides a general framework for the work undertaken in this program of research. Also, as already noted, this work draws heavily upon *Adaptive Environmental Assessment and Management (AEAM)*. These are detailed later in this chapter.

An Ecosystem Approach Framework

Environmental problem situations are characterised by high levels of uncertainty, disputed values, conflicting interests, and the inability to replicate interventions in evolving systems. It seems that any attempt to support decision making in this context, employing exclusively the approaches, methods and techniques of science from the logical-positivist tradition, are likely to be frustrated. Funtowitz (1999) notes that;

> In addition to its traditional achievements of discovery and application, science now has a new challenge. This is to contribute to the proper management of the natural environment, on which we all depend. Science for the environment is used for the resolution of policy issues. In this context, research lacks the supports of the controlled environment of the traditional laboratory and the simple goals of R&D. Scientific problem-solving becomes "post-normal".

Kay *et al.* (1999:16-17) noted that in this post-normal mode, decision making becomes a matter of "finding our way through a partially undiscovered country rather than charting a scientifically determined course to a known point." Furthermore, within this context, science must inform decisions that are "...in the end, an expression of human ethics and preferences, and of the socio-political context in which they are made." This requires an approach to environmental concerns that is able to deal with uncertainty, operate in situations in which decision stakes are high, accommodate new information and changing goals, and guide courses of action which take into account the conflicting interests and values of multiple stakeholders. While some of these requirements are met by one or another of the approaches to planning described above, none of these fit this role better than an ecosystem approach to scientific inquiry.

The ecosystem approach, as employed here, does not reject traditional science. Rather, it integrates it into a more holistic means of inquiry. Ecosystem approaches recognise that problem situations can be usefully conceptualized as systems of inter-related elements and actors. The identification of system characteristics such as structure and processes, various levels of hierarchy (subsystems, wider systems), emergent properties, communication and control mechanisms and feedback loops, can be a powerful aid in the understanding of environmental problem situations. The ecosystem approach draws upon systems-based approaches and collaborative processes to develop a qualitative understanding of the problem situation, including its cultural and political context. This understanding, or conceptual model of the 'system', is used to selectively direct further (likely traditional scientific) inquiry in the situation to develop knowledge about key actors, components and interrelationships. In this sense, the approach is similar to integrated models of planning described above.

Further discussion of the ecosystem approach is presented below in the context of adaptive management, so additional description of such an approach at this point is not required, except to present an overall ecosystem approach schematic or framework. Such a heuristic framework for an ecosystem approach has been developed by Kay and Boyle, (1999) and published in Kay, *et al*. (1999). A version of this provides a guide for the research undertaken here (Figure 2.1).

The main components of this framework are the generation of an understanding or 'system description' of the socio-ecological system(s) pertinent to the problem situation, the generation of alternative scenarios representing desirable and feasible possible future states of the system, the choice of a 'vision' of the future organization of the system (from possibilities generated in describing the system) to be encouraged in the real world, the design of an adaptive program to achieve that vision, and ongoing adaptive management of the situation. Operation of the framework is unlikely to be a linear process. For example, development of a system description includes the simultaneous development of an understanding of desirable and feasible alternative states (visions) of that system. Alternative scenarios for desirable and feasible configurations of the system may be a product of the development of such a system description, and not a distinct 'stage' in the sequence. Also, the whole of the framework is intended to be iterative, being subsumed in a process of ongoing adaptive management (illustrated by the 3 circles of governance, management and monitoring at the base of Figure 2.1). The schematic indicates that the primary influences to operationalize the framework come from systems approaches and collaborative processes. Specific methods and techniques are not prescribed. The choice of these should be sensitive to the context in which they are applied.

This research operates those parts of the framework having to do with the development of a system description and generation of management scenarios. (Other parts Figure 2.1, therefore, deserves some attention. Kay *et al*. (1999:17) noted that the framework "presumes that decisions about environmental issues involve mapping out a vision of how the landscape of human and natural ecosystems should co-evolve as a self-organizing entity to meet human preferences." The upper

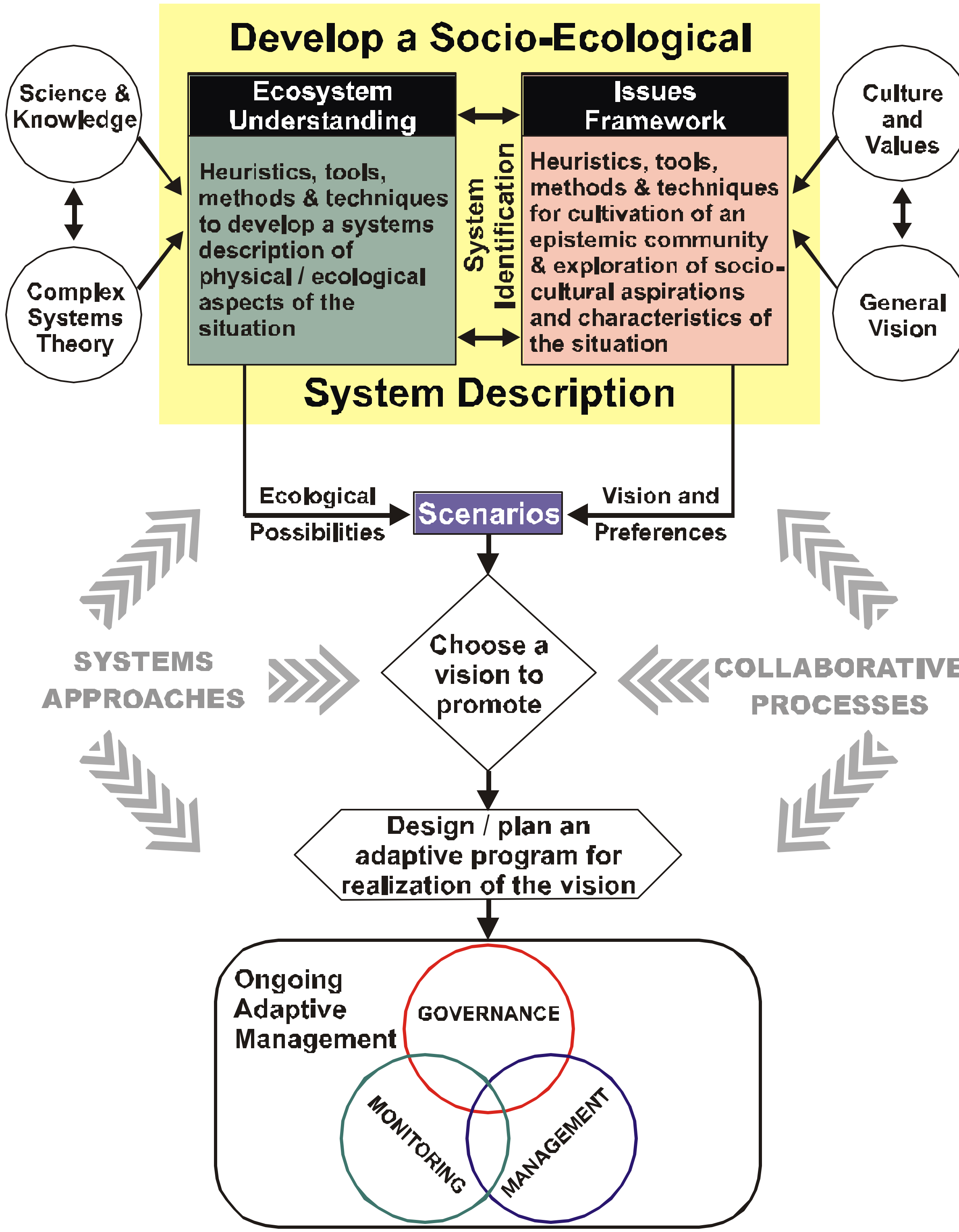

Figure 2.1: An ecosystem approach framework. (Adapted from Kay and Boyle, 1999 and Kay *et al*, 1999:739, in consultation with James Kay).

portion of the of the approach are beyond the scope of this work). The upper part of the schematic presented in schematic is about developing an understanding of those systems: how they are structured and how they function, what future states of the system are possible, which of these are desirable to encourage, and which of these are feasible to promote. The box in the upper left of the diagram represents the development of an understanding of the situation in systems terms and is informed by systems theories and scientific knowledge in general. The box in the upper right represents activities directed toward generating an understanding of the social, cultural, political and institutional context of the problem situation, the incorporation of perspectives and values of pertinent stakeholders, the influence of societal goals, the development of a 'vision' of how the system should evolve, and the promotion of collaboration, communication and cooperation among actors in the situation.

Together, these activities generate a description of a socio-ecological system within which management activities will occur. The development of this description informs the generation of scenarios that represent future states of the system. These scenarios are a selected set of those that are ecologically possible, and are both desirable and feasible to implement within the cultural, economic and political context of the problem situation.

Note that within this process there is flexibility as to how to go about activities such as defining the problem situation, identifying pertinent systems and generating scenarios. Tools are chosen according to the context for the particular situation to which the ecosystem approach is applied. This is a characteristic of pragmatic or eclectic science discussed in the introductory chapter. For this research, heuristics, methods and techniques associated with Adaptive Management and Soft Systems Methodology were employed. These were applied within a participatory process to generate a common understanding of the socio-ecological system(s) associated with the Cooum River problem situation. The main vehicle for this was two workshops, as described in the Adaptive Management literature, and which drew on tools and theory provided by the SSM community. In this application, alternative desirable and feasible future states for the socio-ecological system were explored with the aid of computer based, (GIS supported), scenario analysis.

Adaptive Environmental Management

Overview

In planning and managing for environmental problems, a framework suitable for dealing with complexity and uncertainty is crucial. One such approach is *Adaptive Environmental Assessment and Management (AEAM)*.[5] This is a systems-based (ecosystem) approach designed to deal with uncertainties inherent in environmental change. It makes use of existing data and brings together scientific experts, planners and policy makers in workshops to make use of best-available knowledge and to design interventions in the system in such a way as to generate knowledge and facilitate learning (Grayson, *et al*., 1994:246; Holling, 1978:8). This approach is anticipatory, developing solutions based on predictable future events, and flexible, allowing for changes in goals, revised predictions and new evidence. It is a continuous process of learning. There is also a strong emphasis on communication and participation in AEAM and the approach, as theorized and described in the core literature, can be seen as a marriage of soft and hard approaches to science in pursuit of social learning for sustainable ecosystem management.

Adaptive management first appeared in the Gulf Island Recreation Land Simulation study in 1968 as an attempt to "bridge gaps among scientific disciplines, technical experts, and policy designers" (Gunderson, *et al.*, 1995b:490). Following this, in the mid-1970s, the basic concepts of adaptive environmental assessment and management were developed by an interdisciplinary team of biologists and systems analysis, led by Canadian ecologist C.S. Holling, working at the International Institute of Applied Systems Analysts (IIASA) in Laxenburg, Austria (Lee, 1993:54). These ideas and their application have been published in scientific journals, reports and books. The heart of this effort is a series of four main books entitled *Adaptive Environmental Assessment and Management*, edited by C.S. Holling (1978), *Adaptive Management of Renewable Resources* by Walters (1986), *Compass and Gyroscope: Integrating Science and Politics for*

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[5]Adaptive Environmental Assessment and Management is also often referred to as Adaptive Environmental Management, Adaptive Resource Management, Adaptive Environmental Assessment, and Adaptive Management. These terms are used interchangeably here.

the Environment by Lee (1993), and *Barriers and Bridges to the Renewal of Ecosystems and Institutions*, edited by Gunderson, Holling and Light (1995a).

Although some of the concepts associated with adaptive environmental assessment and management have evolved as practitioners learned from applying the approach to various situations, the underlying premise has endured. 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 (Holling, 1995:13; Walters, 1986:8). However, this should not stop resource managers from intervening in a situation in which 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 (Lee, 1993:54). This is what makes the approach adaptive. New information from the experience of intervening in (and monitoring) the system informs continued management of the system, the experience of which generates new knowledge – and so on.

Adaptive environmental assessment and management has been applied to a wide range of situations. Some of these applications are presented in Table 2.2 and Table 2.3. These tables serve to demonstrate the range of problems which adaptive management has been used to address. The Environmental and Social Systems Analysts (ESSA, 1982:24) categorized these applications into *environmental impact assessment, research planning,resource management and policy,* and *project integration and synthesis*.[6]

As the focus of this work is on applications of AEAM to environmental management, the interest here is in ESSA's third category. Within this category, adaptive management programs fall

[6]ESSA's final category, *project integration and synthesis*, in some ways applies to all AEAM projects (1982:29). That is, it refers not just to integration of information through modelling, systems analyses, *etc.*, but also to integration between institutions, people and disciplines that is necessary for an interdisciplinary, participatory and cooperative approach .

Table 2.2: Some major AEAM applications. (Year is initial year of project).

User	***Project***	***Year***	***Location***
Environment Canada	Eastern Spruce Budworm Research and Management policy planning	1972	Fredricton, NB
Austrian Man and Biosphere program and IIASA	Environmental and Social Consequences of Development in the Alpine Village of Obergurgl	1974	Obergurgl, Austria
Arctic Project Office NOAA	Ecological Processes Study – Barrier Island Lagoon	1976	Barrier Islands, AK
Cdn. Dept. of Fisheries & Oceans	Management of West Coast Salmon	1976	Vancouver, BC
U.S. Fish and Wildlife Service	Charles M. Russell Refuge	1978	C.M. Russell Refuge, MT
Environment Canada	Porcupine Caribou Herd	1978	N. Slope AK, Yukon
U.S. Geological Survey	Truckee-Carson River Quality Assessment	1978	Reno, NV
B.C. Council of Forest Industries	The Assimilative Capacity of Aquatic Environments for Pulp Mill Effluent	1979	Vancouver, BC
Alberta Oil Sands Environmental Research Program	An Adaptive Environmental Assessment Approach to the Effect of Development of Alberta Oil Sands	1979	Ft. McMurray, AB
California Water Policy Center (USFWS)	Sacramento-San Joaquin Water Management System – Integrated Management	1979	Sacramento, CA
U.S. Forest Service	Western Spruce Budworm Research Planning	1980	Portland, OR
Mekong Secretariat, U.N. Bangkok, Ford Foundation	Application of AEAM to the Nam Pong Environment Management Research Project	1980	Bangkok, Thailand
B.C. Hydro and Power Authority	Mackenzie Delta Modeling for Environmental Studies of Liard River Hydro-electric Development	1980	Mackenzie Delta, NWT
NOAA/OCSEAP/BLM	Research Planning– effects of Bering Sea Petroleum Development on King and Tanner Crab populations	1980	Bering Sea
Ontario Ministry of Municipal Affairs and Housing	Integration of the Lakeshore Capacity Study	1980	Toronto, ON
Nat'l Power Plant Team (USFWS)	Acid Precipitation -- Research Needs	1980	Ann Arbor, MI
Cooperative Agreement between Assistant Secretary for Fish, Wildlife and Parks & Governor's Office, ND	Wetland Preservation and Protection in North Dakota	1980	Bismark, DA
Wyoming Game and Fish Dept.	Resource Development & Management, Jackson Hole	1981	Jackson Hole, WY
Petro Canada	Development and Application of a Site Selection Methodology for an LNG Facility on the BC coast	1981	Calgary, AB
Environment Canada	Beaufort Sea Hydrocarbon Development	1981	Beaufort Sea
Great Lakes Fisheries Commission	Training in Adaptive Environmental Assessment	1981	Sault Ste. Marie, MI
Biological Services Program, U.S. Fish and Wildlife Service	Development of the Beluga Coal Resource in Alaska	1981	Cook Inlet, AK
Environmental Protection Agency	Potential Impacts of Drilling Muds and Cuttings on the Gulf of Mexico Marine Environment	1981	Pensacola, FL
U.S. Bureau of Land Management	Saval Ranch Project – Research Planning and Management of Alternate Cattle Grazing Schemes	1981	Elko, NV
Environmental Protection Agency	Environmental effects of Developments in Mobile Bay	1981	Mobile Bay, AL
B.C. Ministries of Forests and Environment	Research Planning for the Integrated Wildlife Intensive Forestry Research Program	1981	Victoria, BC
Ontario Ministry of Natural Resources	Application of AEAM to Fisheries Management and Acid Rain Research: Algonquin Assessment Unit	1981	Toronto, ON
Canadian Department of Fisheries and Oceans	Research Needs and Data Base Management for Acid Rain Studies in Eastern Canada	1982	Toronto, ON
U.S. Forest Service	Development of Integrated Management Model of Forest, Fisheries, Wildlife Resources in SE Alaska	1982	Juneau, AK

Source: After ESSA, 1982: 12-13.

Table 2.3: Further examples of adaptive management programs.

Project	*Year*	*Reference*
Wildlife management and monitoring on the Galápagos Islands	1998	Gibbs *et al*., 1998
Sustainable Land Management for the Murray Darling Basin, Australia	1998	CSIRO, 2000
Endangered species management: adaptive disease management of White Sturgeon in Kootenai River, B.C.	1995/ 1991	LaPatra, *et al*., 1999
Adaptive management for water quality in the Latrobe River Catchment, Victoria, Australia	1994	Grayson *et al*., 1994
Restoration of upland habitat for nesting ducks and other birds in the Canadian Prairies	1993	Clark and Diamond, 1993
Wood duck nest box programs in Montezuma National Wildlife Refuge	1993	Semel and Sherman, 1993
Adaptive management and regulation of waterfowl harvests in the US	1993	Williams and Johnson, 1995; Johnson *et al*., 1993
Adaptive experimentation for the effects of forest fragmentation on boreal birds in northern Alberta	1993	Schmiegelow and Hannon, 1993
Goshawk Management on Arizona's Kaibab Plateau	1992	Dewhurst *et al*., 1995
Management of antlerless elk harvests in Idaho	1992	Gratson *et al*., 1992
Adaptive forest management for plants and animals of the Ozark forest	1990	Kurzejeski *et al*., 1993
Management of rabies disease and urban skunk populations	1987	Schubert *et al*., 1998
Adaptive management in the US National Estuary Program	1987	Imperial *et al*., 1993
Adaptive management of salmon and power generation in the Columbia River Basin	1984/ 1980	Lee, 1989; Lee and Lawrence, 1986; Volkman and McConnaha, 1993
Adaptive management of water quality and living resources habitat in the Chesapeake Bay and its catchment basin	1983/ 1977	Hennessey, 1994
Adaptive management of sockeye salmon in Rivers Inlet, B.C.	1979	Walters *et al*., 1993
Great Lakes Program	1972	Francis and Reiger, 1995; Imperial *et al*., 1993

into two types according to the overall goals. First, some projects address management of a valued biological resource . Such programs are implemented to prevent deterioration, or maximize sustainable harvests of a singular renewable resource. Examples of this type of application are the Rivers Inlet Sockeye Salmon project in British Columbia in the 1980s (Walters *et al.*, 1993) and the Columbia River Basin project (Lee and Lawrence, 1986; Lee, 1993), both of which targeted salmon stocks. Also in this category are plans for adaptive management of waterfowl harvests in the U.S. (Williams and Johnson, 1995) and of forest habitat for the preservation of the northern Goshawk in the Kaibab National Forest of the United States.

Other adaptive environmental management schemes have broader goals to improve environmental quality or ecosystem health in general. Projects which fall into this category include the Chesapeake Bay Program (Hennessey, 1994; Costanza and Greer, 1995) concerned with the viability of the ecosystem consisting of the Chesapeake Bay estuary and its drainage basin, water quality issues in the Latrobe River in Victoria, Australia (Grayson *et al*., 1994), management of the Florida Everglades for multiple uses such as agriculture, urban land use and water supply (Light, *et al*., 1995) and sustainable land management at the catchment and regional scale for the Murray Darling Basin, Australia (CSIRO, 2000).

In reviewing the literature, however, one finds that the distinction between targeting an ecosystem and targeting a particular biological resource *within* an ecosystem is merely a matter of starting points. For example, managers of projects with sustainable yield goals must define habitat and manage ecosystems, while those starting with ecosystem level objectives must identify key species and their habitats as indicators of ecosystem health. Whatever the starting point, it is the ecosystem which is managed.

The following four sections lay out the characteristics of AEAM following the framework presented by Mitchell (1991). Here a distinction has been made between characteristics of adaptive management approach and its components. *Characteristics* are understood to be theoretical aspects which underpin the approach. *Components* are technical tools associated with the adaptive management, such as workshops and simulation modelling, (which are described following a discussion of characteristics of AEAM).

Characteristics of Adaptive Environmental Assessment and Management

Ecosystems: A Systems Perspective

The concept of *"system"* is a heuristic device to aid understanding of the real world by structuring complex situations as an organized whole consisting of inter-related elements (Flood and

Carson, 1993:7).[7] An *ecosystem* is a type of system, commonly defined as a collection of biological and ecological interacting components, their interactions and their physical environment (Allen, *et al*., 1993:17-18). These interactions comprise ecosystem *process*, the functioning or operation of an ecosystem. The regularity and persistence of these interactions define ecosystem *structure*.[8] A representation of the structure of a system emerges from defining and bounding a problem situation in which key variables and relationships are exposed. The interactions of these sets of variables (processes) emerge in part because they operate at similar speeds, having for example, common turnover times and rates of matter-energy processing. Ecosystem structure can be defined according to processes which operate at similar speeds and with a distinct spatial scale (Allen *et al*, 1993:19).

Ecosystems are evolutionary in that they follow a cycle which is the manifestation of four evolving functions: *exploitation, conservation, release* and *reorganization* (Figure 2.2). There are nested sets of such cycles, as presented in Figure 2.3, each operating at a distinct spatial scale and with its own temporal attributes (Holling, 1995:23).

Adaptive management employs two key concepts related to the above information. First, ecosystem structure can be defined by relatively few variables. An important part of AEAM is discovering, defining, monitoring and managing these key variables (Holling, 1990:74). Second, because of complexity and uncertainty, ecosystem structure is not always correctly defined. Key variables or their interactions may be poorly understood or overlooked altogether. Practitioners of adaptive management should accept this possibility and be prepared to deal with resulting surprises by flexibility in defining ecosystem structure (*e.g.*, as regards spatial or temporal scale).

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[7] Defining systems characteristics include hierarchical organization (subsystems and wider systems), emergent properties (the whole being greater than the sum of its parts), and flows of materials, energy or information between elements, which constitute their inter-relationships. Flood and Carson (1993) provide a good introduction to systems science for those interested in further reading.

[8] Another way of thinking of processes is as activities that occur within a system, whereas the structure of the system provides a framework within which the processes occur, and defines how the elements are related to each other (Flood and Carson, 1993:13). Checkland (1981:316-317) associates processes with elements characterized by continuous change, whereas structure is provided by elements that change only slowly or occasionally.

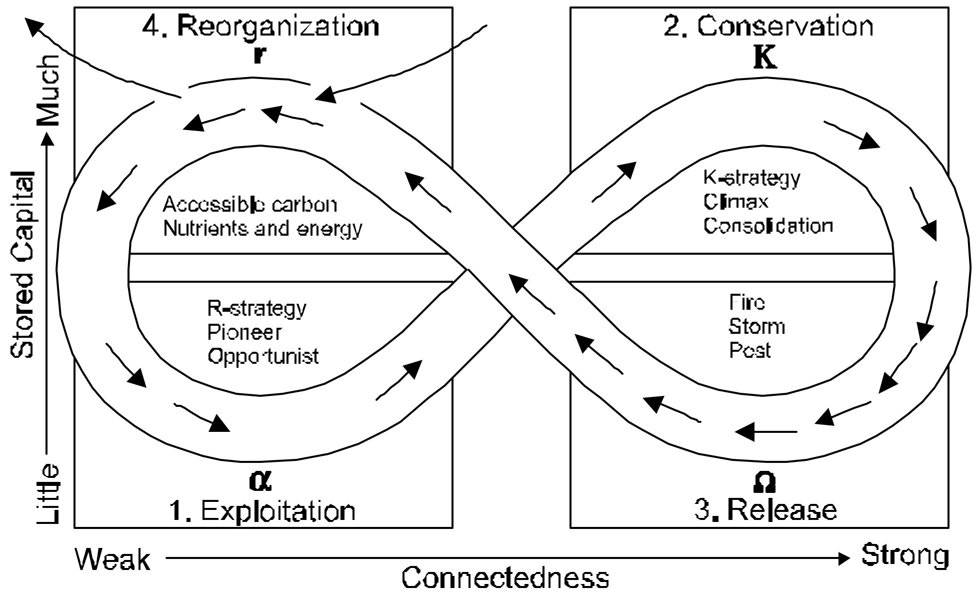

Figure 2.2: The four ecosystem functions and the flow of events between them. The arrows show the speed of that flow in the ecosystem cycle, where arrows close to each other indicate a rapidly changing situation and arrows far from each other indicate a slowly changing situation. The cycle reflects changes in two attributes; that is: (1) the Y axis -- the amount of accumulated capital (nutrients, carbon) stored in variables that are the dominant keystone variables at the moment -- and (2) the X axis -- the degree of connectedness among variables. The exit from the cycle indicated at the left of the figure suggests the stage where a flip is most likely into a less or more productive and organized system (*i.e.,* devolution or evolution as revolution). Source: Holling, (1995):22, Figure 1.2.

Kay *et al* (1999) describe another important set of characteristics of complex systems (such as ecosystems and human systems) – self-organizing behaviour. A simplified description of self-organization in open systems is that stable structures emerge in systems to dissipate flows of exergy[9] through the system. Such stable structures may, for example, be populations of aerobic bacteria or fish in a river such as the Cooum, having associated processes such as decomposition of organic nutrients, reproduction, digestion and other metabolic processes. If flows of exergy through a system are maintained within certain limits, a stable and coherent behavioural state can develop. Within this state space the system will be resilient. The system acts as if it is attracted to this

[9]High quality energy with regard to its ability to do work.

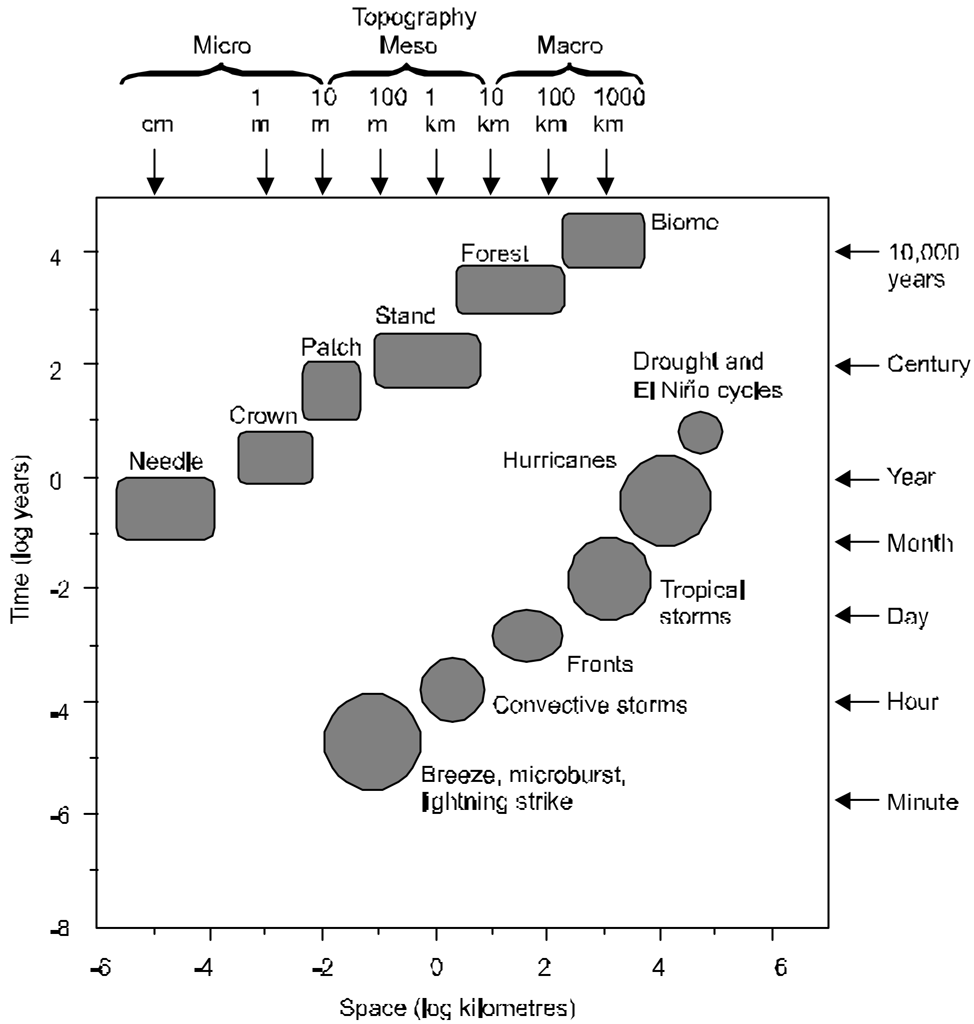

Figure 2.3: Space/time hierarchy of the boreal forest and of the atmosphere.
Source: Holling, 1995:23, Figure 1.3.

domain of behaviour, or *attractor state* (Kay *et al*, 1999:725). However, changing flows of exergy in the system can move the system away from equilibrium, and if a critical (catastrophe) threshold is reached, the system will spontaneously reorganize (or 'flip') to an new domain of coherent behaviour. For example, with large increases in domestic wastes (organic nutrients), the Cooum River system flipped from a system characterized by processes of aerobic decomposition of organic nutrients, to one in which anaerobic bacteria undertook decomposition of nutrients. Many other structures and processes in the system also changed, for example, fish species were no longer part of the system.

Thus, complex self-organizing open systems can have alternate stable states. This implies that if one can understand the cluster of important feedback loops and autocatalytic processes[10] that lead the system to organize within a particular domain of behaviour, such alternative states, if perceived as desirable, can serve as objectives for management. Propensities can be either reinforced or undermined so that particular configurations of the system (attractor states) are encouraged and others discouraged.

Although ecosystems have in the past usually been defined in biophysical terms, it is now commonly acknowledged that ecosystems are more than biophysical elements and their interactions. There are also human actors within such a system. Politics, management, multiple and conflicting uses, morals, intentions, societal goals and values overlay, are intertwined with and provide a context for the elements, interrelationships and operation of natural systems. It is, therefore, useful to conceive of ecosystems as consisting of both societal/cultural components and actors, and biophysical ones. Lee (1993:11) recognises this added complexity by referring to *large ecosystems.* He points out that "what makes the ecosystem "large" is not acreage but interdependent use; the large ecosystem is socially constructed." In a similar vein, this research will sometimes refer to such systems as *socio-ecological systems* so as to avoid the strong exclusively physical and biological connotations that the term *ecosystem* often evokes, and to emphasise the human components, including economic, political and cultural aspects, in the conception of ecosystems

One implication of this understanding of ecosystems is that it is not only the natural environment that should be the target of ecosystem management. As Kay (1994:68) pointed out, it is human interactions with the natural environment, not the environment itself, that need to be managed. If this line of thought is pursued, considerations of sustainability (in support of long term use of the natural environment), and participation in the management process (to accommodate the perspectives and activities of multiple stakeholders in the situation) arise. These issues correspond to Mitchell's "Balance" and "Teamwork" criteria, and are discussed below.

[10]Kay *et al* (1999:725), after Popper, labelled such feedback loops and processes *propensities* of the system, the cluster of these being its *canon*.

It is important to keep in mind that systems (ecosystems, large ecosystems, socio-ecological systems) are mental constructs – models or simplifications of reality to structure our understanding of the world.[11] Even though we often reify the concept, we should remember this to maintain flexibility in learning (which involves re-conceptualization) about a system. One way to do this is by recognizing the role of perspective in conceptualization of the system. This implies that, since a system is a conceptual construct, there can be better or worse 'systems' defined to aid our understanding of the real world. Indeed, multiple 'systems' can be defined to describe the same real world situation. Allen, Bandurski and King (1994:6) acknowledged this crucial concept by recognizing that different *types* of systems can be defined with regard to a single situation. The type of system is based on criteria or standards derived from one's perspective:

> Independent of scale, there are criteria that set the bounded system away from its background. The bounded system is the foreground and its boundary is a reflection of the type of system it is. One has to look at the appropriate scale to see an object, but which object one sees in the foreground at a certain scale comes from the standards that prescribe the type of system.

One's perspective, experience or interest in the situation, therefore, will influence the conceptualization of the system. Given the same information and situation, different people might decide to draw the boundaries of what they consider to be 'the system' differently, *i.e*., they might have different conceptions of what are the main components and interactions in the system as opposed to what is considered to be the environment of the system. For example, to an engineer at the Tamil Nadu Slum Clearance Board, a slum settlement along a river bank might be seen as a problematic situation in itself. However, to a slum dweller this may very well be perceived as the

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[11] There is a common confusion with the use of the word 'system.' In every-day usage, the word is often used to refer to a real thing or situation. However, in systems thinking (as in General Systems Theory and its descendent Complex System Theories, which underpin the concept of 'ecosystem'), a 'system' is a conceptual construct or tool which is mapped onto a real world situation. Systems concepts such as hierarchy and emergent properties are used to organize our observations of the workings of the real world and to define a model representing our understanding of the structure and functioning of part of the real world. We refer to this model as the 'system'. This entails a necessary simplification of the real world.

The confusion comes because not only do we refer to this conceptual construct which represents part of the functioning of the real world as "the system," but we also tend to apply this label to the actual real world situation itself. We should keep the concepts separate because we may incompletely or incorrectly understand the real world situation, and thus have an inadequate concept of the system. It is much easier to accept changes to our definition of the system, (especially if these involve drastic re-scoping and changes of scale), if we think of it as merely a conceptual map to aid in the understanding of the real world, and not as if it were a real thing in itself.

solution to a problematic situation. Conceptualizations of the same situation in the real world, built upon these two widely varying perspectives and sets of experience, are likely to be radically different. Similarly, human and bio-physical perspectives will generate different representations of a system. In Chennai, for example, one might draw important elements such as the river course and stormwater drainage system, and processes such as precipitation and tidal mixing to the foreground in the definition of the system. Another perspective might emphasis population, slum formation and the production of waste. The challenge is to integrate the different perspectives (Kay, 1997:67).

Recognition of the importance of system type implies that in managing an ecosystem a system definition/conceptualization must be undertaken for each relevant perspective, or else that a common understanding of 'the ecosystem' must be arrived at which incorporates the perspective of key stakeholders and actors in the situation. AEAM attempts to address this aspect of the management problem through stakeholder participation in a series of workshops and by stakeholder contributions to the development of simulation models which represent a common understanding of the ecosystem. These components of AEAM are discussed below.

Adaptiveness: Embracing Uncertainty

Walters (1986:162) describes three types of uncertainty which are usually distinguished in regard to natural systems. The first is background variation or "noise." This is not considered to affect management decisions except to obfuscate underlying trends and to necessitate monitoring and means of adjustment to changes in the environment of the system. Second, there exists statistical or "parametric" uncertainty. This is uncertainty about what has been defined as 'the system' for purposes of the management problem at hand. In particular, this is uncertainty about "what equations to use, how to estimate parameter values from noisy data, and how to assign probabilities to various hypotheses expressed as alternative equations and/or parameter values" (Walters, 1986:162). Finally, there is uncertainty in the definition of the structure of the system. Here the concern is that key variables and relationships may have been missed out. This implies that large and unexpected surprises in the functional responses of the system to management interventions may occur if its structural representation is incomplete.

An important principle of adaptive management is a recognition that all three kinds of uncertainty will always be present. Adaptive management attempts to use techniques that reduce uncertainty while also benefiting from the unexpected. In this way, surprises become opportunities to learn rather than failures in predictive models (Lee, 1993:56; Holling, 1978:9).

The three types of uncertainty, above, are an artificial partition of a continuum. For example, in defining a problem, distinctions must be made between system parameters and background variation, (*i.e.*, drawing a boundary between the system and its wider environment). This is largely a matter of temporal and spatial scale (Walters, 1986:163). The ability to match appropriate scales to the problem, and to understand processes that occur between scales, is crucial to successful adaptive management (Gunderson, *et al*., 1995b:531). Barriers to success include an orientation to past values and assumptions, and the inability to translate values and measures across scales, (*i.e*., to recognize processes operating at broader scales and to expand space and time scales, redefining the scope of the problem without losing touch with "local and fast dimensions") (Gunderson, *et al*., 1995b:528).

Walters (1986:163-164) found it heuristically useful to divide the process of adaptive management into three phases based on levels of uncertainty associated with environmental management problems. These are the *preadaptive phase*, the *adaptive phase* and the *certainty-equivalent* phase. The first phase is *preadaptive* because managers have little or no data on the response of the particular system with which they are dealing. Therefore, management decisions must be based on whatever existing data are available and the experience with "similar" situations in other systems. Choosing between management options may be difficult during this phase due to lack of information. However, almost any intervention in the system will increase knowledge and reduce uncertainty for management of the system in the future. Thus, recognizing uncertainty, AEAM uses management as a tool to reduce it (Williams and Johnson, 1995:431). The key policy issue in this phase is how much to invest in monitoring systems in pursuit of knowledge of system responses to development (Walters, 1986:163).

As knowledge about the system accumulates, managers can generate hypotheses, in the form of alternative models, to describe how the system will respond to various interventions. This is the *adaptive phase*. The key policy issue at this stage is "whether to act informatively with respect to hypotheses that imply opportunities for improved performance by moving outside the range of experience available" (Walters, 1986:163). During this phase, surprise remains unexceptional. This emphasises the importance of continual monitoring of key indicators.

The *certainty-equivalent phase* represents a situation in which sufficient information has been generated through experience and experimentation, and adequate understanding of the system has developed so that there is no further advantage in experimentation. Managers should act according to the best available model of the system as if it were based on certain knowledge. However, even allowing the (unrealistic) assumption that all knowledge previously generated pertains to the present state of an ecosystem, (that is, the system does not change over time), the certainty-equivalent phase may never be attained.

These phases in the evolution of the understanding of a situation also assume that the uncertainty to be reduced is either parametric or structural. There is a more fundamental uncertainty to consider in addition to these, which Wynne (1992) refers to as *indeterminancy*.[12] Indeterminancy is uncertainty about whether appropriate questions are being asked, whether problems are addressed with appropriate theoretical and methodological tools and within an appropriate paradigm. Ecosystem approaches have evolved in response to this kind of uncertainty. Recognition of the failure of "normal" positivist/reductionist science to deal adequately with environmental problem situations has led to such innovations as the application of systems concepts and participation of stakeholders in environmental planning and management.

Another useful way to characterize uncertainty is from the perspective of complexity and self-organization of systems (discussed in the preceding section). Kay (2000), for example, describes increasing levels of uncertainty associated with (1) systems whose behaviour can be described by mechanical Newtonian functional relationships, (2) systems characterized by

[12]Wynne (1992) identifies four types of uncertainty: risk, uncertainty, ignorance and indeterminancy. 'Risk' and 'uncertainty' correspond to degrees of parametric uncertainty discussed above, while 'ignorance' is structural uncertainty.

homeostasis about a single attractor, (3) systems having multiple attractor states where the attractors, and thresholds between them, are known, (4) systems in which the thresholds between attractors are not known, and (5) systems which have unknown attractors. Associated with this increase in complexity and uncertainty is a corresponding decline in the ability of management efforts which are based on anticipatory science to deal with the situation. As uncertainty and unpredictability increase, so does the need for adaptive management.

This implies that anticipatory management becomes less useful as complexity and uncertainty increase. This is an issue for caution in the application of AEAM. Despite the fact that the AEAM approach is explicitly adaptive, its application has traditionally employed anticipatory methods. That is, many of the tools employed by AEAM practitioners are rooted in traditional anticipatory science (*e.g.*, simulation modelling and forecasting) which attempts to predict the response of systems to management interventions. Learning is stimulated by comparison of actual and predicted system responses. These tools, based on the best available knowledge of the current organizational domain of the system, are most useful in the exploration and modelling of that single domain of organization. They will be inadequate to model system behaviour at catastrophe thresholds and within alternative attractor states unless those attractors and their thresholds are also known.

Teamwork: People, Communication and Organization

Adaptive environmental assessment and management is hailed as an interdisciplinary approach, involving policy people, managers, and scientists from various backgrounds. The AEAM process is also billed as participatory, involving multiple and conflicting interests. For adaptive management (and ecosystem approaches in general) to be successful in this way depends on the proper combination of people, communication and organization.

People are the key. For example, successful application of AEAM often depends on the participation of at least one *wise integrator*. This is “an individual with professional understanding who has an intuitive knowledge that the process will help and knows the institutional environment well enough to nurse the process through to completion" (ESSA, 1982:36; also see Gunderson *et al*., 1995b:505). The formation and influence of what Haas (1990) refers to as an *epistemic community* may also play a crucial role in providing insight and bridging conflict in environmental problem situations. Haas (1990:40-42) describes such a community as,

> ...composed of professionals (usually recruited from several disciplines) who share a commitment to a common causal model and a common set of political values. They are united by a belief in the truth of their model and by a commitment to translate this truth into public policy, in the conviction that human welfare will be enhanced as a result.

This informal network of experts or professionals shares a concern with, and a common approach to, the problem. This is the crux of their role in the process. That is, their advice is credible because "their understanding [is] scientific -- that is, open to revision by new information" (Lee, 1993:131).

In Chennai the network of 'credible' and 'legitimate' participants are primarily government planners, scientists and engineers, as well as local and international consultants. The paradigm which this group shares is rooted in normal reductionist science, engineering approaches to problem solving and master planning. NGOs and academic researchers are not seen by this group as making a credible contribution. They often do not share a "common causal model and a common set of political values."

For cooperation and participation to occur, open communication among decision makers, scientists, managers and the public is essential. Holling (1978:120) holds that communication is so important that it requires the dedication of at least as much effort as analysis. The main tool for communication among the various parties in AEAM is through participation in a series of workshops, and in the construction of (and gaming with) a dynamic system model. (Workshops and modelling are further discussed below). Another means of facilitating communication and participation occurs at the organizational level, especially in very large management programs. Practitioners are increasingly realizing the importance of flexibly structuring the organizational and institutional framework of environmental management programs to include all important contributors (Lee, 1993; Hennessey, 1994; Gunderson *et al*., 1995b). Public advisory committees are one way of doing this, and are typical in adaptive management programs.

AEAM has generally been found to be successful, but in those applications which have failed, lack of institutional support has been cited as a major cause (*e.g.*, ESSA, 1982; Rondinelli 1993a, 1993b). ESSA (1982:32) holds that the reason is "institutional inertia" resulting from two main sources:

(1) Large organizations strongly tend to worship stability and thereby attempt to maintain the status quo. Routine and imitative behaviour (*i.e*., mimicry) reduces the costs of decision making and creates (in theory) predictability.

(2) Related to the previous point is a lack of entrepreneurial spirit within organizations. Risks are feared and, therefore, immediate success is a requirement for any innovation.

Barriers such as this reflect an investment in, and inertia of, a mechanistic management style (Table 2.4). Rondinelli (1993a, 1993b) holds that, while an adaptive and experimental approach is needed in many developing country situations because of high levels of uncertainty, complexity and risk, the predominance of rigid bureaucracies, centralized and hierarchical control structures, operational biases toward programmed (not process-oriented) management styles, and failure to involve stakeholders in the management process are barriers to its implementation. These may be observed in the Indian context. For example, the Cooum situation is characterized by scarcity and poor quality of data, models of the situation constricted by jurisdictional and disciplinary boundaries, actors within government agencies that are paralysed by perceived lack of power to do so much as share information with other stakeholders, and a public which consistently complains of a closed and exclusive management process.

Such barriers should be expected and will require strategies to avoid or overcome them. For example, Brinkerhoff and Ingle (1989:491) suggest that a 'deliverables' mentality (which is characteristic of rigid bureaucracies and programmed approaches) may be appeased by incorporating short- and medium-term targets within an adaptive program.

Another possible way to overcome such barriers emphasises 'Teamwork' and the importance of key players in the adaptive management process. As discussed above, a respected proponent of the process within the institutional setting, or an objective and credible community of experts which endorses an adaptive ecosystem management approach, may be vital in overcoming

Table 2.4: Characteristics of mechanistic and adaptive management strategies in institutions.

	Management Strategy	
	Mechanistic	***Adaptive***
Environment	Certain	Uncertain
Tasks	Routine	Innovative
Management Processes		
Planning	Comprehensive	Incremental
Decision-making	Centralized	Decentralized
Authority	Hierarchical	Collegial
Leadership style	Command	Participatory
Communications	Vertical, formal	Interactive, formal and informal
Coordination	Control	Facilitation
Monitoring	Conformance to plan	Adjust strategy and plan
Use of formal rules and regulations	High	Low
Basis of staffing	Functions	Objectives
Structures	Hierarchical	Organic
Staff values	Low tolerance for ambiguity	High tolerance for ambiguity

Source: Rondinelli (1993b, Figure 2) after Rondinelli, Middleton and Verspoor, 1990.

institutional inertia.

The analytical approach employed in conventional applications of AEAM, (such as simulation modelling and management intervention formulated as scientific experimentation), can also be a barrier to the success of adaptive management programs. Gardener (1989:352) notes that the sophistication of such methods can compromise the potential for full community involvement in the process. Also, results of scientific studies in adaptive management programs are typically published in technical forums, and written for an academic and technical audience. As such they are not very accessible to the public (Smith *et al.*, 1998:676). Confusion can also be generated, and the perceived objectivity of the management process undermined when scientists (perhaps representing different interests in the situation) disagree on "facts" and assumptions associated with system models (McLain and Lee, 1996:443-444).

Additionally, scientific methods favour information and knowledge that can be quantified, and may exclude other kinds of knowledge (McLain and Lee, 1996:444). This presents a barrier to stakeholder participation and illustrates the danger that potentially enlightening understandings and perspectives of stakeholders in the situation may be ignored.

Such concerns arising from past adaptive management efforts, re-emphasize the earlier statement about the importance of communication. For this reason this research has attempted to avoid the use of scientific jargon in the conduct of workshops, and in the dissemination of information to participants in the program of research and stakeholders in the situation. This work also attempts to incorporate the knowledge of all stakeholders participating in the research in a shared conceptual model of the system, and employs the construction and use of a simulation model to express and explore aspects of that understanding.

Balance: Sustainable Development and AEAM

A central principle of sustainable development is the satisfaction of human needs in the long run (Gardner, 1989:340). This implies that trade-offs must be made between enhancing and preserving the resource base and the pursuit of economic growth. Trade-offs may be brought about, for example, where sustainable activities occur at lower levels or higher costs than previously was the case. Such (perceived) sacrifices will be easier to implement if public participation and communication have generated an awareness and sense of ownership of the problem situation and management program.

In addition, the systems perspective taken by adaptive management is conducive to recognition of environmental constraints on the economic system. The integration of human components and activity with biophysical elements and processes in the conceptualization of an ecosystem promotes the development of strategies to manage human interaction with the natural environment while highlighting the impacts of that interaction. This is in opposition to the historical trend in economic development in which the environment is treated as an external and everlasting source of raw materials and a bottomless sink for waste.

Lee (1993:8) argued that to achieve an environmentally sustainable economy we must enter into a process of social learning. He described social learning as a combination of adaptive management, (especially in the sense of explicitly operating the learning cycle while intervening in ecosystems), and the context of application within bounded conflict, (meaning politics), which result in the construction of institutions that can sustain civilization in the long term. Such institutions are likely to undertake management of ecosystems in the 'adaptive' manner described in Table 2.4.

Lee (1993:8) summarised the pertinence of adaptive management and social learning to sustainability nicely:

> Social learning explores the human niche in the world as rapidly as knowledge can be gained, on terms that are governable though not always orderly. It expands our awareness of effects across space, time, and function ... Human action affects the natural world in ways we do not sense, expect, or control. Learning how to do all three lies at the centre of a sustainable economy.

Components of AEAM

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

Workshops

Holling (1978:12-13) described adaptive management as a process involving two groups of people: (1) a small core group of analysts and support staff, 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 and mathematical analysis. 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 20-25 key actors; (*e.g.*, scientists, managers and policy people), to scope, define and focus the problem (ESSA, 1982:2). This workshop considers all elements of the project. This includes 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 (Holling, 1978:51). 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 (ESSA, 1982:2, 28).

Further workshops address more specific tasks. The participants involved in these workshops (*e.g*., decision makers, 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 the development of alternative management actions. Gaming sessions with public involvement may be organized to facilitate public participation and communication (ESSA, 1982:28). Between workshops, the core group consolidates information by way of model testing, evaluation of management policies, collection of data (Holling, 1978:56).

Models

Associated with the conventional process of adaptive environmental assessment and management is the development of computer simulation models as decision support tools to help develop and explore management options (Holling, 1978:14). This process requires the construction of symbolic models to represent the relationships between components of the system. Simulation comes from subjecting inputs to mathematical and logical operations to predict outputs. The term “dynamic” indicates simulations which are iterative, with each iteration representing a step forward in time and with the model state values changing with each iteration (Hettelingh, 1990:10). “Static” or “steady-state” simulations solve the model equations for a single period.

A major advantage of system modelling is that it creates a simplified laboratory world in which management actions can be tested (ESSA, 1982:43). This helps to alleviate the problem of reproducibility in complex real-world problem situations (as presented in Table 2.1). That is, simulation testing and experimentation can be performed with no irreversible adverse effects to the ecosystem. Extreme management actions and creative alternatives can be explored. In addition, the use of simulation models brings together integrated and inter-disciplinary teams, forces assumptions to be explicitly stated, and highlights further data and analysis needs (Gunderson *et al.*, 1995b:526, 528; ESSA, 1982:43).

Furthermore, computer models accelerate time and compress space, thereby allowing the user to experience results of 'management interventions' in the system being modelled. That is, this tool links the system's dynamics and the users' perception. Helping the user to experience a broader range of space and time can bridge a major barrier to adaptive management: the inability to recognize processes operating at broader scales and to expand the scope in space and time to match these processes (Gunderson *et al.*, 1995b:528).

The involvement of workshop participants in the development of simulation models also ensures that all understand its capabilities and limitations (Grayson, *et al.*, 1994:245), increasing the usefulness of the computer model to non-technical users. The visible results of a running model (in the creation of which both technical and non-technical users have contributed) generates a sense of ownership and acceptance. Graphical presentation of results, user friendly software and 'hands-on' gaming increase the utility of the models and the impact of modelling on decision making (ESSA, 1982:43). There is a danger, however, that users of the model will take its results as dependable predictions. To avoid their misuse, care should be taken to ensure that the accuracy of model results is understood. Risks and uncertainties associated with the model should be explained (ESSA, 1982:42).

Table 2.5: Some advantages and disadvantages of simulation modelling

Disadvantages	Advantages
▾ Requires computer facilities ▾ Requires expertise and time for development ▾ Results may be too easily believed by decision makers ▾ Results are usually complex (if there are many variables) and are therefore difficult to communicate to decision makers ▾ Fails to allow measures of degree of belief in data or in the assumptions to be reflected in final results ▾ Relations between variables usually assumed constant through time	▾ Promotes communication between disciplines ▾ User forced to clarify assumptions and causal mechanisms ▾ Any form of relationships can be handled - linear or nonlinear ▾ Can compare alternative management schemes ▾ Can include uncertainties of various types ▾ Graphics output a good way of communicating impacts ▾ Can utilize information about known processes that have not been investigated for the particular system of study but that have some generality (*e.g.*, predation, population growth) ▾ Can use detailed information concerning processes in the natural system ▾ Helps to identify key variables or relationships that need to be investigated or are sensitive

Source: Holling, 1978: after Table 5.5, 79.

Holling (1978) lists disadvantages and advantages of the use of simulation models in AEAM (Table 2.5). Note that many of the advantages correspond to the products of system identification exercises. The *process* of developing a simulation model may be seen as such an exercise. The product of that process, the model itself, is an expression of participants' conception and understanding of the system. (This is a large part of the role that simulation modelling and the development of GIS-based decision support system and database play in this research).

It has been mentioned above that one of the objectives of the first, and possibly subsequent, workshops in the AEAM process is the construction, modification and use of simulation models. Grayson, *et al*., (1994:248) described this process as follows:

1. Definition of the model scope including:
   - possible management actions;
   - indicator variables of the system that will test the efficacy of the management actions;
   - the required spatial scale for the model;
   - the simulation time step and overall period of simulation.

2. Formation of the modelling sub-groups; management actions and indicators are grouped into thematic sub-groups so that sub-models of the various components of the system can be developed and integrated at a later stage. People are assigned to each sub-group on the basis of knowledge and skills and the information requirements of the sub-groups are identified.

3. Development of the sub-models: within each sub-group, existing information is synthesized in order to model the behaviour of the indicator variables and to produce functional relationships between the management actions and the indicator variables. A sub-model of each component of the system is then developed by a modeller assigned to the sub-group.

4. Development of the integrated model: the sub-models are linked to form an integrated model of the system which is then tested and validated by the sub-groups.

5. Gaming: the model is used by the group as a whole to develop management scenarios and to compare the effects of the various management actions.

6. On-going development: the model is a dynamic entity which develops as further information becomes available or as different management options need to be evaluated.

AEAM in a Developing Country Context

Most applications of adaptive environmental assessment and management have been situated in more developed countries (MDCs). This raises a question: Is the approach suitable for less developed countries (LDCs)? Holling (1978) certainly thinks so. His review of the application of AEAM to the development of forestry, agriculture and hydroelectric power generation in the Rio

Caroni basin in Venezuela described the successful development of a rain-vegetation-soil-river simulation model to evaluate alternative intensities and combinations of land use within the watershed using various time horizons (Holling, 1978:246). However, successful modelling is only one component of AEAM, and does not constitute the approach itself. In reference to another project, Holling argued the universality of the adaptive management approach, citing a 2-day workshop for a regional planning project in the Bermejo River basin in Argentina as successfully "reidentifying the issues, promoting integration among disciplines, and producing a more global and coherent view of the problem and its solutions" (1978:19). However, he tells us no more about this project.

Another application of adaptive environmental assessment and management in the developing world was the Nam Pong Environmental Management Research Project. This project saw the successful development and evaluation of a management-oriented model of the Nam Pong River basin through the participation (and training) of Thai scientists in two month-long workshops in 1980 and 1981 (ESSA, 1982:102). It is not known how useful the model has actually been to institutions and managers in subsequent management of the basin.

These few examples hint at the suitability of the adaptive management approach in LDCs, but are far from conclusive. The question remains unanswered, but may be explored through yet another question: How is the context of environmental management in a developing country context different than in developed countries? Here, two categories may be identified: (1) differences in the or ecological setting.

Table 2.6 presents conditions in the first category, the international and historical setting. There are several implications of these for operationalizing adaptive management in developing countries. First, Sanderson noted that management options are more likely to be constrained due to urgent needs to maximize productivity of the system. However, this is no reason that adaptive management should not be attempted. Indeed, not only could AEAM prove useful to identify those options which do remain but, as discussed above, the process attempts to create an atmosphere in which creative management alternatives are generated.

Table 2.6: Differences in the context for environmental management between MDCs and LDCs.

Category	***Explanation***	***Implication for Environmental Management***
Structural Constraints	LDCs' macroeconomic environment is relatively fixed. They are confined in their range of motion by the rules of the international system over which they have little control.	Increased likelihood to be dominated by external management organizations with less "embeddedness" in the local environment. (Technical solutions and expertise, overriding of local knowledge)
International Economic Change	Politics in LDCs are structured by economics at a global scale to a greater degree than are MDCs.	Developing country ecosystems are more vulnerable to external cycles.
Colonial Legacy	LDCs are linked to a development design not of their making and outside of their control.	Imperatives of economic growth result in intensive management of resources, increasing the occurrence of brittleness in systems, surprise and catastrophe.
Persistence of the Current International Structure	The ability of LDCs to avoid the environmentally destructive consequences of the international economic system may depend on their ability to change the rules of the system.	The strategic focus of resource management must include the "overarching macrostructure," a goal undermined by the gap in power between LDCs and MDCs.

Source: Derived from a discussion of the case for developing country exceptionalism (Sanderson, 1995:377-383).

international and historical situation of LDCs, and (2) differences in the internal policy, bureaucratic

Second, the systems being managed in LDCs are likely to be more vulnerable to external shocks. For example, in systems which produce agricultural goods for export on the international market, a sudden increase in the price of beef or drop of grain prices might affect the dynamics of the system. External influences on such a system could be caused by changes in consumptive preferences in developed countries, new technologies, and war. Two aspects of adaptive management make this approach particularly appropriate in such a situation. One way is through a systems perspective. Part of the process of adaptive management is an attempt to bound problems in such a way that such external influences are considered (*i.e.*, defining appropriate spatial and temporal scales). Despite this, unforeseen events do happen. Adaptive management recognises (and expects) that surprises will occur, whether from misunderstanding of the structure of the system, or imposed from the (perceived) environment of the system. Managers and their programs are encouraged to be flexible and adaptive, learning from surprises and incorporating new information by, for example, expanding the scope of their spatial and temporal perspective.

Third, structural constraints in development projects (*e.g.*, as might be imposed by the IMF or World Bank) result in external experts and management consultants being parachuted into a situation often with little appreciation of local conditions and knowledge (Rondinelli, 1993a:96; Sanderson, 1995:380). Lonergan (1993:328) highlighted this problem, stating that along with the normal complex and multidimensional aspects of environmental problems, those in developing nations are also *conditional*,

> ... in that the state of a social system and the relationships which describe that system at any time are unique in time and space; poverty and environmental degradation are historically, socially, and politically, constructed -- only after assessing the significance of these forces can one understand the society and the relationships within.

This aspect of management in LDCs is alleviated by the emphasis on participation in AEAM. This is not merely information dissemination, but actual involvement in activities such as goal setting, and determination and evaluation of management alternatives. When outside management agencies and foreign ‘experts’ are involved, they should take the role of facilitators. This should mobilize and integrate local knowledge, perspectives and expertise. In the instance where local expertise is lacking, the facilitator’s role may also include training (Brinkerhoff and Ingle, 1989:494). Participation has the added advantage of building local capacity.

An important observation regarding the second category (internal differences) is that LDC institutions usually are more heterogeneous than those in MDCs. For example, there is likely to exist multiple means of governance of common pool resources, such as water, and the existence of indigenous institutions and tenure systems (Sanderson, 1995:383). This heterogeneity increases the incidence of politically fractious conflict-beset situations which frustrate efforts to manage fragile ecosystems. An example from India is the situation of squatter settlements (slums) on both public and private land along riversides in Madras. The rights of slum dwellers to occupy the land is officially recognized (Government of Tamil Nadu, 1971). This legal protection for squatters, legitimate claims to the land by the owners, and immediate proximity to a common resource add the complexity of multiple legitimate stakeholders to the situation. Jurisdiction over various aspects of the situation by agencies such as the Public Works Department, the Tamil Nadu Slum Clearance Board, the Chennai Metropolitan Development Authority, the Corporation of Chennai and the

Chennai Metropolitan Water Supply and Sewerage Board further complicate management issues.

Institutional inertia also may be greater in less developed countries. As a result, resource managers find that they are constrained in the approaches they may employ. Rondinelli (1993a:103) stated the problem as:

> What leads to success is the ability of managers to design and manage simultaneously; to test new ideas and methods continuously no matter what the circumstances in which they find themselves. This managerial flexibility, however, is often squashed by officials in the headquarters of international agencies or national ministries who insist on conformance to detailed plans and rigid management procedures.

According to this description, adaptive environmental management is a formula for success, but the implementation of such a program is unlikely in circumstances that demand a programmed approach. It may be possible to change this situation by incorporating some characteristics of a programmed approach into an adaptive management program. For example, Brinkerhoff and Ingle (1989:491) describe a structured flexibility approach that maintains characteristics very similar to those of adaptive management, but (among other things) satisfies the 'deliverables' mentality of inflexible bureaucrats by incorporating short and medium term measurable product or service targets.

Thus, adaptive management has the characteristics to address environmental management problems not only in the developed world but also in developing nations. A systems approach and emphasis on real participation make the approach transferable in the face of greater vulnerability to external influences, restricted management options and potential conflict. The greatest barrier to the implementation of the approach in developing countries may be an inflexible institutional and bureaucratic environment.

The Potential Role of GIS within AEAM

Geographic information systems (GIS) are "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" (Burrough, 1986:6). One set of purposes might be the support of the adaptive environmental assessment and management process. In particular GIS has relevance to the system modelling process that is such a central component of the usual AEAM procedure. Steyaert and Goodchild (1994:348) list four aspects for which GIS may make contributions to simulation in environmental management; as a preprocessor of data, storage and management of large spatial databases, analysis of data and model results, and visualization and presentation of simulations. Each of these will be discussed briefly below.

Preprocessing, Data Storage and Management

Large amounts and diverse sorts of data may be required for environmental modelling. Due to the nature of the environmental management problems, much of these data will have spatial characteristics. For example, land use and land cover data, digital elevation models and remote sensing imagery provide useful information to those attempting to model environmental and ecological processes. GIS provides a convenient means of storing and managing such data. Steyaert and Goodchild (1994:348) noted that GIS has automatic 'housekeeping' functions, such as documentation of data layers, and provides uniform access to diverse data that has been 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 program. 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 (Steyaert and Goodchild, 1994:348). Also significant is the ability to reformat and export data in formats useable to other packages, (especially, in this context, to simulation modelling packages).

Spatial Analysis

Spatial analysis is perhaps the most important contribution that GIS can make to the modelling component of adaptive environmental assessment and management. One opportunity is for GIS is to add a component of 'spatial specificity' 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 (Maidment, 1993:149). In contrast, distributed parameter modelling expressly considers spatially controlling parameters such as soils and land use (Engel, *et al*., 1993:232). Engel, *et al*. stated that 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 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. Such variables as runoff, erosion and chemical transport can be modelled and, for example, upland areas contributing to potential problems and areas in need of remedial action may be identified (Engel, *et al*., 1993:232).

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 has two other potential contributions to distributed parameter modelling. First, analysis in a GIS can 'parametize' the model.[13] For example, Blaszczynski (1992, as reported in Steyaert and Goodchild, 1994:341) derived the parameters required to apply a revised Universal Soil Loss Equation model (*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. In fact, GIS packages usually incorporate sufficient terrain analysis tools (such as the GRASS "Waterworks" package) that together with standard Boolean search and overlay functions, provide all the necessary

[13]"Parametize" "parametized" and "parametizing" are terms that are used throughout this work to refer to the process of developing parameters for input into an environmental model. This process could range from simple retrieval and transport of data to more extensive analysis to arrive at a set of data of the nature and form required by the environmental model.

capabilities for contemporary hydrologic modelling (Steyaert and Goodchild, 1994:339).

However, GIS as a stand-alone system is usually not used for environmental simulation modelling. Steyaert and Goodchild (1994:349) reported that simulations written as a series of GIS commands and operations are rare. It is more common that GIS are loosely coupled with modular system simulation software. However, such makeshift systems often result in cumbersome data conversion procedures (Steyaerd and Goodchild, 1994:347). One way that this, and other awkward technical tasks, might be relieved is by programming routines to automatically perform such procedures, and to provide access to these through a task-oriented form or menu driven interface (such as might be created using Arc/Info's Arc Macro Language).

Visualization and Presentation

A final 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 (*e.g*., Holling, 1978:124; ESSA 1982:43; Walters 1986:59).

GIS appear to be suited to use within the AEAM process. They can benefit the modelling process at all stages, from preprocessing of the data through data management, analysis and modelling to presentation of results. This work employs GIS, as part of a prototype decision support system, to construct and maintain a database of the study area, provide tools for query and visualization of datasets, and through simple analyses and retrieval of data, to parametize an environmental simulation model. This is discussed in detail in Chapter 4, and Appendix II.

Soft Systems Methodology

Overview

Another major influence on the approach taken in this research is the work of Checkland and his colleagues at the Department of Systems and Information Management, University of Lancaster, in attempting to make sense of, and intervene in, human activity systems. Soft System Methodology (SSM) provides a conceptual basis and a set of tools to address problem situations characterized by what Funtowitz and Ravetz (1994) refer to as emergent complexity. Allen, Bandurski and King (1993:45) in their report to the Great Lakes Science Advisory Board, recommended that Checkland's approach be employed in the execution of the general and specific recommendations in their report on the application of the ecosystem approach in the Great Lakes Basin.

Soft Systems Methodology was developed in the 1970s out of the failure of the systems engineering approach (which is used to solve 'hard' engineering type problems) to solve 'soft' human/social problems. 'Hard' problems in this context refer to problems which, although often difficult to understand and deal with, are definable. One can know what the problem is. Soft problems, on the other hand, are less focussed or structured and more 'fuzzy' or 'messy.' Soft problems are more usefully discussed as problematic situations in which the "same" problem may be perceived differently by various people (Flood and Carson, 1993:98). Soft or 'fuzzy' problems are typically encountered when attempting to deal with situations involving human or social 'real-world' situations. Hence, the term 'real-world problem' is often used by practitioners of Soft Systems Methodology. A real-world problem is a problem "which arises in the everyday world of events and ideas, and may be perceived differently by different people. Such problems are not constructed by the investigator as are laboratory problems" (Checkland, 1981:316; also see Flood and Carson, 1993:97-98). Note the similarities between this description of the type of problematic situations toward which SSM is oriented, and the discussion of the nature of environmental problems above.

Thus, soft systems methodology is

a general methodology which uses systems ideas to find a structure in apparently unstructured "soft" problems, and hence leads to action to eliminate, alleviate or solve the problem, or provides an orderly way of tackling "hard" problems" (Checkland, 1976:52).

An important aspect of Checkland's and others' work at the University of Lancaster is that the development of SSM, which applied systems thinking to ill-structured problems, was undertaken through interactions with real problem situations (Checkland and Scholes, 1990a:16). This type of research, labelled 'action research' in the soft systems literature, uses the experience of the research itself as a research object about which lessons may be drawn (in lieu of classical hypothesis testing). To undertake action research, an intellectual framework (such as hard systems engineering) for understanding the problem situation is adopted. The use of the framework is expected to lead both to insights into the problem situation and to a gradual improvement of the framework itself (Checkland and Scholes, 1990a:16).

The Basic Soft Systems Methodology

The idea that our perceptions of the world inform our conceptualizations of it implies that, as human beings, we endow our world with meaning. This is an important realization central to Soft Systems Methodology. That is, we deal with the "creation of an interpreted world, not merely an experienced world" (Checkland and Scholes, 1990a:2). Further, we can form intentions according to how we interpret the situations we experience, and act on these intentions. Such action is 'purposeful action' which is "deliberate, decided, willed action, whether by and individual or by a group" and taken in response to experience of the world to which humans cannot help but attribute meaning (Checkland and Scholes, 1990a:2). Human beings are continually taking purposeful action related to experiences of situations and the knowledge (interpretation of the real world) generated by such experiences. This experience-based knowledge informs purposeful action which in turn creates new experience of the world, yielding further experienced-based knowledge in a knowledge acquisition cycle which embodies the fundamental possibility of learning (Checkland and Scholes, 1990a:3).

Soft Systems Methodology is a methodology for "formally operating the learning cycle" in which learning from experience is directed to inform purposeful action in real world situations and is intended to improve the problem situation (as perceived by those taking the action) (Checkland and Scholes, 1990a:4). Thus, SSM involves the perception (and interpretation) of a real world problem situation which yields choices of relevant systems of purposeful activity. These conceptualizations are compared to the (perceived) problem situation, leading to debate about purposeful action to improve the situation. This action changes the situation, the perception of which leads to the conceptualization of relevant systems of purposeful activity ... and so on. This basic system of learning is demonstrated in Figure 2.4.

SSM also deals with a specific kind of system, a human activity system. The concept of a human activity system involves a set of interrelated human activities "which combine together to achieve the purpose attributed to the whole. One way to visualize a human activity system is to see it as the expression of a level of order (or purpose) higher than that contained in its component parts" (Woodburn, 1991:30). Thus, a house as a dwelling place, viewed as a system, is not merely a physical structure with people or a family living and performing daily functions and having particular interactions. It has meaning attributed to it by actors or observers of the system – it is a home, (*i.e.*, the whole is greater than the sum of the parts).

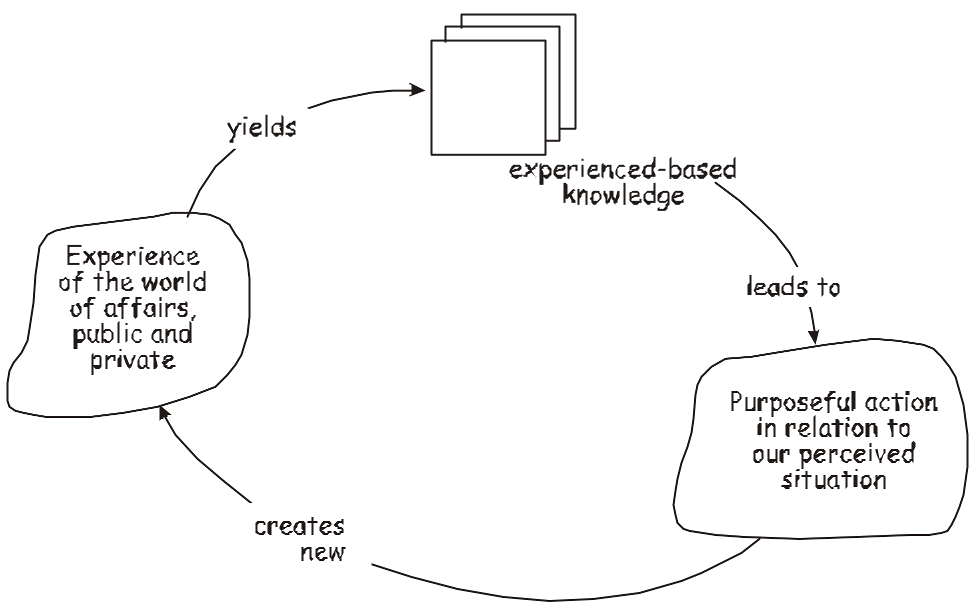

Figure 2.4: The experience-action cycle (Checkland and Scholes, 1990a:3).

The conventional SSM methodology developed by Checkland is described below. This methodology is presented because it is the most common form of the General Soft Systems Methodology. It is important to realize, however, that it is only one way to organize the learning cycle and that adaptation of the methodology may result from the learning experience of applying it, and that backtracking and iteration within the general methodology are a part of the learning process.

Figure 2.5 illustrates Checkland's general soft systems methodology. The basic methodology consists of seven stages; the problem situation unstructured, the problem situation expressed, root definitions of relevant systems, construction of conceptual models, comparison of conceptual models with the problem situation, debate about feasible and desirable change, and action to improve the problem situation. Checkland's seven stages to SSM can be condensed into three general phases. Woodburn (1991:29-30) presents these as:

(a) Building a "rich picture" of the problem situation (stages 1 and 2),
(b) Developing models of relevant human activity systems (stages 3 and 4), and
(c) Using those models to stimulate thinking about organisational change (stages 5, 6 and 7).

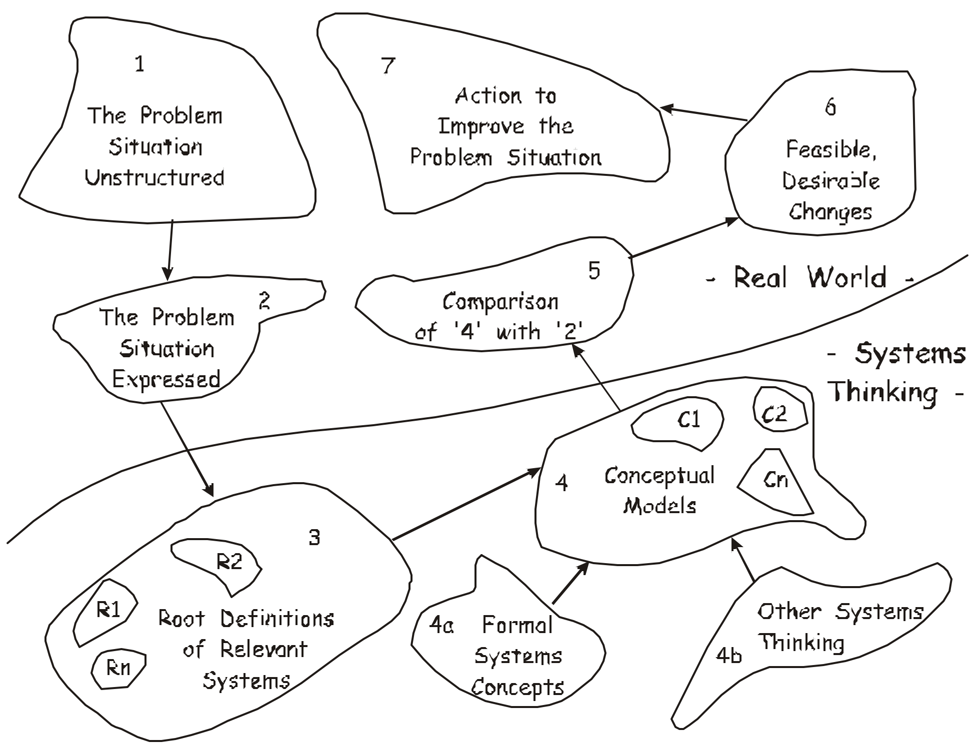

Figure 2.5: The original 7-stage Soft Systems Methodology (Checkland, 1981).

1. The Problem Situation Unstructured

The unstructured problem situation stage deals with the identification of a problem situation as it exists in the real world. This requires that an observer of or actor in the real situation perceives it as problematic. Thus, the identification of a 'problem' situation is always subjective. Once a problem situation is identified, it may be expressed.

2. The Problem Situation Expressed

At this stage a 'Rich Picture' of the problem situation is built. The 'Rich Picture' should be as neutral as possible while recognising the perspectives of various actors. This will lead to the development of non-neutral root definitions and conceptual models of relevant systems, (that is definitions and models base on explicitly recognized perspectives or world views), in the next phase of the methodology.

Expression of the problem situation involves identification, definition and measurement of various actors, components, interactions and relationships within the system. At this point, processes (who is doing what...) structures (within what organizational framework...) and climate (under what cultural norms, values...) may be identified (Woodburn, 1991:29). This is, thus, an analysis phase without necessarily employing systems thinking and concepts. In fact, analysis should not be in systems terms unless the problem situation is relatively unstructured (as there is a danger of becoming misled into identifying organizational groupings) (Checkland, 1976:60).

Rather, analysis needs to be addressed in terms designed to answer the question of "what?" (as opposed to "how") (Checkland, 1976:60). For example, the problem situation will be "turbulent" but elements of structure and process still may be identified. Structural elements are those which are relatively static. They act as a framework within which processes exist. Elements of process, on the other hand are dynamic. Examination of structure may, for example, be in terms of physical layout, hierarchy, reporting structure, patterns of communication (formal and informal), while examination of process may elucidate organizational contexts and basic activities such as planning to do something, doing it, monitoring how well it is done, and external effects, as well as taking action to correct deviations from the plan process (Checkland, 1976:60-61). Diagrams and pictures illustrating the situation are useful at this stage.

One must at some point move from analysis of the situation to the building of conceptual models. There is no rule for knowing when to stop the analysis, but Checkland (1976:61) notes that the analysis should be sufficient when one can answer at least the following questions:

1. What resources are deployed...
   ...in what operational context?
   ...under what planning procedures?
   ...within what structure?
   ...in what environments and wider systems?
   ...by whom?

2. How well is resource deployment monitored and controlled?

In general, the analysis is complete when it is possible to formulate a root definition (as described below). That is, when the function of the analysis phase "to display the situation so that a range of possible and, hopefully, relevant choices can be revealed" has been fulfilled (Checkland in Flood and Carson, 1993:110).

3. Root Definitions of Relevant Systems

At this point, the soft systems practitioner leaves the realm of thinking in real world terms and begins using systems thinking to construct models of relevant human activity systems. The purposefulness of each relevant human activity system may be expressed in a 'root definition' which is a "core description of purposeful activity taken from a specific point of view" (Flood and Carson, 1993:111). A root definition is "a condensed representation of the system(s) in its most fundamental form" and aims to capture insight into the situation (Checkland, 1976:62)

One technique for constructing well-formulated root definitions is to write a statement which reflects the aspects of the mnemonic CATWOE (Checkland, 1979:42). The components of this mnemonic are detailed below:

C	Customer	Who would be victims or beneficiaries of this system?
A	Actor	Who would perform the activities?
T	Transformation	What input is transformed into what output?
W	*Weltanschauung*	What view of the world makes this system meaningful?
O	Owner	Who could abolish this system?
E	Environmental Constraints	What in its environment does this system take as given?

The ‘Customer,’ ‘Actor,’ ‘Owner’ and ‘Environmental Constraints’ components of the CATWOE mnemonic are self-explanatory and will not be expanded upon here. The remaining components, (*i.e*., ‘Transformation’ and ‘*Weltanschauung*’) deserve some illumination. *Weltanschauung* is a German word meaning ‘world view’ and may be translated in this context to mean "what view of the world makes the situation meaningful?" (Flood and Carson, 1993:111). (Figure 2.6). *Weltanschauung* is linked to culture; it is a cultural viewpoint. Every actor or group of actors will have a different *Weltanschauung*. None is "better" than the other, and all are equally valid. A holistic approach, such as SSM, will take different Weltanschauungen into consideration.

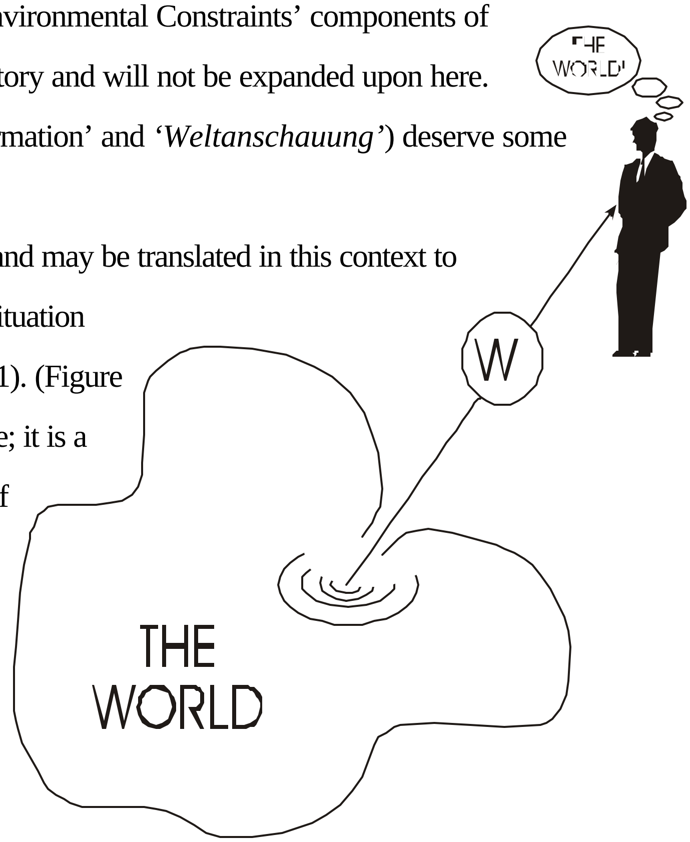

Figure 2.6: Weltanschauung – from CATWOE in Soft Systems Methodology. (Flood and Carson, 1988:120).

A transformation is also involved in a human activity system where the activity of the system transforms some input into an output. Generally, for a physical/abstract input a physical/abstract output is required. In constructing the root definition "it is important that the actual output is directly related to the input, so that the input is still there in some altered form" (Flood and Carson, 1993:112). It is useful to track both physical and abstract inputs. Also, consideration of how the transformation (T) could fail enables managers to think of measurements to monitor and control purposeful activity (Flood and Carson, 1993:113):

1. Measures of Effectiveness:	*e.g.*, T is correct/wrong activity to be doing
2. Measures of Efficacy:	*e.g.*, the way T is done does/does not work
3. Measures of Efficiency:	*e.g.*, T is/is not done with minimum resources (such as time)

It is important to note that measures of performance imply a structure for root definitions (Checkland *et. al.*, 1990:33). That is, statements of root definitions may be cast in the form:

either: do X in order to achieve Z

or: do X by Y in order to achieve Z

There can never be a demonstrably correct root definition because such a definition represents only one particular interpretation (*Weltanschauung*) of a real world situation. There may, however, be a range of possibilities of root definitions from glib and shallow to full of insight (Checkland, 1976:63). The root definition needs to be penetrating, derived from the richness of the analysis and "revealing to those involved in the day-to-day workings of the system concerned" (Checkland, 1976:63). Even an insightful root definition is only one possible interpretation of the purposefulness of the human activity system. It is, therefore, usually rewarding to explore the implications of several root definitions, (*e.g.*, from the perspective of what a participant wants a system to be as well as what an outside observer takes it to be) (Checkland, 1976:63).

4. Conceptual Models

Conceptualization uses systems thinking formally and involves a conscious break from the analysis stage (marked by the root definition). It is "the process of building conceptual models relevant to the problem situation but in a mood of detachment from it, something which can be compared, formally and specifically with the picture built up in the analysis phase" (Checkland, 1976:64). Conceptual models consist of "what the system *must do* in order *to be* the system named in the root definition" (Flood and Carson, 1993:114). A conceptual model here *is not* a representation of the "ideal" system or a representation of what "ought to be" in the real situation. It is a descriptive rather than a prescriptive model.

Checkland (1976:64) notes two main problems with which the researcher or manager is confronted at this stage:

1. finding a way to do the conceptualization, and
2. finding a way to validate the conceptual model which is the outcome.

It was discovered early in the development of soft systems methodology that, in conceptualizing human activity systems, it is useful to link a set of verbs, in the correct sequence, which identify the minimum activities necessary to the human activity system described in the root definition (Checkland, 1976:64). Verbs (or short action-statements) are selected as elements and these verbs/elements are ordered logically, reflecting sequences of activity in the system. These activities are linked by arrows, in a diagram indicating that an activity is 'logically dependent upon' or 'contingent upon' another activity. If an activity yields an output which is a significant input to another activity, then the latter is contingent, or dependent, upon the former (Checkland and Scholes, 1990b:42). Flows through the system which are absolutely essential and are reflected in the root definition may also be illustrated at this primary level of conceptualization.

In the early development of SSM, validation of the conceptualization was undertaken by comparing the conceptualized system with a formal model of a human activity system. As the methodology progressed, however, there was a realization that human activity systems are *abstract conceptualizations* which reflect a particular perception of the real situation and that it is impossible to represent the real world without involving subjective interpretation. Thus, it is inappropriate to attempt to validate these models. There is no such thing as a 'valid' or 'invalid' model, only models which are technically defensible or indefensible (Checkland and Scholes, 1990b:43; also see von Bülow, 1989:39-40).

5. Using Conceptual Models to Stimulate Thinking About Organisational Change

Stages 5, 6, and 7 are here discussed together because of the difficulty of generalizing about these stages of the process. In this phase, a comparison of the conceptual models to each other and to the 'rich picture' built during the analysis stage is intended to generate debate for desirable and feasible change. This comparison may come about in various ways. For example, Checkland and Scholes (1990a:43) noted that informal discussion, formal questioning, scenario writing based on operating models and attempting to model the real world into the structure provided by the conceptual models are all ways of generating debate. The most common practice, formal questioning, may proceed, for example, by asking of each activity in the conceptual model; Does it exist in the real situation? How is it done? and, How is it judged? (Checkland and Scholes, 1990a:43).

Regardless of how the comparison with the real world is undertaken, the aim is not to improve the models but to "find an accommodation between different interests in the situation, an accommodation which can be argued to constitute an improvement of the initial problem situation" (Checkland and Scholes, 1990a:44).

Such a debate, and hopefully the accommodation of interests, leads to the identification of desirable and feasible change. Change may, for example, be desirable on a structural level or an attitudinal level. Ideas for change, however, must be assessed for cultural feasibility and systemic desirability in the context of particular world views (Woodburn, 1991:30). Once the changes are implemented, the procedure does not stop. Soft systems practitioners emphasize that the situation should be under continuous monitoring and control. As Checkland (1976:72) states;

> the whole bias of the methodology is against the notion of once-and-for-all finite tasks and in favour of on-going purposeful maintenance of relationships.

SSM and the Cooum River Environmental Management Research Program

Soft Systems Methodology has been interpreted by some as a prescriptive functional methodology describing a series of stages to be followed (and tools to be applied) to undertake a system study and inform decisions for action in a problematic situation (*e.g.,* Naughton, 1981). This view is representative of the early development of SSM (in the 1970s and early 1980s). This is *not* how SSM was employed in this study. Although a discussion of the early form of the methodology, as above, is heuristically useful, more recent development and applications of SSM have expanded this methodology to be less prescriptive and more flexible. Checkland and Scholes (1990a) describe this dichotomy in the understanding and application of SSM in terms of *mode 1* (prescriptive use of the 7-stage model) and *mode 2* (a more pliant use of SSM to make sense of a problem situation).

By 1994, Krehler (1994:1296) found that many of the applications of SSM being undertaken by the 'inside group' of researchers and postgraduate students at the University of Lancaster (the originating school of SSM) were being undertaken in mode 2. Krehler (1994:1298) stated that mode 2 is used for reflection about the problem situation. It is a means to make sense of the complexity of the situation and the intricate multi-level approach to it (*e.g.*, systemic, systematic, cultural, logical, inclusive of a variety of perspectives). Differences between the two modes as ideal types are outlined in Table 2.7. It is within mode 2 that SSM is employed here.

Table 2.7: Differences between mode 1 and mode 2 of SSM.

Mode 1	**Mode 2**
Using SSM to do a study	Doing work using SSM
Intervention	Interaction
Mentally starting from SSM	Mentally starting inside the flux[†], providing a coherent way of describing or making sense of it
Stage by stage; logic-driven stream and cultural stream of analysis	SSM as a thinking mode, used in internalized form takes SSM itself as a framework; meta-level[‡] use of SSM compared with mode 1

Source: Kreher (1994):1300 (after Checkland and Scholes, 1990a).
[†]That is, starting with a problematic situation and using SSM techniques and tools as appropriate to organize observation and understanding, and to generate debate about it. More emphasis is placed on understanding the situation, than on prescriptive application of the methodology.
[‡]Use of the approach as a set of guiding principles within which tools and techniques are not prescribed.

Additionally, the 7 stage model and the specific tools used within these stages should not be seen, within mode 2 of SSM, as essential to the methodology. Modifications of the methodology in applications began to appear in the 1980s. For example, Atkinson (1986) selected 5 distinct modified applications of the methodology in a discussion of the emerging plurality of SSM. He concluded that "the actual methodologies used in soft systems projects are contingent upon the *context*, the *use* and the *users* of that methodology (1986:31). More specifically Atkinson

(1986:31) states,

> ...that if [Checkland's] SSM is an 'ideal type' of soft systems methodology, a distillation from a number of such methodologies evolved within a number of projects that, in turn, forms a point of departure from which other methodologies materialise in the context of a particular project and the *Weltanschauungen* of the inquirers themselves.

Thus, this research draws upon SSM to inform the approach to the Cooum River problem situation along the lines of a mode 2 application of the approach. Rather than an application of the 7 stage model, SSM influences this research by guiding inquiry into the Cooum problem as a learning process. The overall framework is influenced by SSM in the description of a socio-ecological system *via* the expression of the problem situation in real-world terms, the use of explicit systems thinking to conceptualize and operate relevant systems, and the use of these to simulate debate about desirable and feasible change. In the working sessions of the workshops SSM contributes conceptual tools and practical techniques, such as the development of a 'Rich Picture' and CATWOE analysis, to explore the Cooum situation – a complex problem situation in which human activity is involved.

Conclusions

This chapter has presented and discussed a general background for the approach and methods employed in this research. In light of characteristics of the problem situation such as complexity, uncertainty, multiple and competing interests in the situation, and the severity of the problem, a sectoral or disciplinary approach to the problem is inappropriate. A holistic approach grounded in systems thinking and which attempts to incorporate participation by stakeholders in the situation has been constructed. It is thought that this approach is more appropriate.

In brief, the approach taken here can be described as an ecosystem approach to the problem of rehabilitation and management of the Cooum River and its environs in Chennai. This draws mainly upon adaptive environmental management to operationalize the ecosystem approach framework, especially with respect to the use of a series of workshops oriented toward problem definition, system identification, the generation of goals and objectives for management of the system, the development of alternative possible management interventions, and scenario analysis using a computer simulation model.

This work is also informed by Soft Systems Methodology. SSM provides conceptual and methodological tools to understand human activity in the problem situation. It provides a way of modelling human activity and guiding learning through the application of the methodology itself. In Chapter 3, the methods and results of the first workshop in the Cooum River Environmental Management Research Program are presented and discussed.

3

A System Study for Environmental Management of the Cooum River and Environs

Introduction

In this chapter, a discussion is presented of the methodology and results of the first workshop of the Cooum River Environmental Management Research Program. This workshop, entitled *A System Study for Environmental Management of the Cooum River and Environs,* was held on 18-20 March 1998 at the Department of Geography, University of Madras. The workshop, which included both paper presentations and working sessions, initiated the problem analysis for the research program. It brought together key scientists, academics, managers, planners, and public representatives (*e.g.*, environmental NGOs) to scope, define and focus the problem. The workshop addressed issues such as definition and characteristics of the problem situation, identification of the social (cultural, economic, political) and biophysical system of interest, the determination of goals and objectives for management and rehabilitation of the Cooum River and its surrounding area, current management interventions in the system, possible future management actions, and the development of a framework for a system model.

In the context of the ecosystem approach framework presented in Chapter 2, this workshop was oriented toward identifying and developing a description of the system of interest, both in terms of ecosystem understanding (*e.g.*, structure and processes, hierarchy) and with regard to the cultural climate of the situation (prevailing attitudes, values, vision, institutional milieu). Less tangible, but very important, products of this first workshop included facilitation of communication between actors and the creation of an atmosphere conducive to the generation of creative management alternatives.

Practical matters (such as logistics, the cultural context, and access to data), associated with undertaking this program of research in Chennai are presented below. This is followed by a discussion of the organization of the first workshop and its results. The development of a GIS database and system model, and the second workshop will be reviewed in the fourth and fifth chapters, respectively.

Operationalizing the Approach

Logistics

Facilities

Several logistical matters relating to the conduct of research overseas are of critical practical importance in being able to undertake the research in Chennai. In particular, it would have been impossible to undertake this research without facilities such as an office, access to a telephone, fax facilities, a seminar or conference room in which to hold workshops, audio/visual equipment, and computer and printing facilities. Such facilities were generously provided, or otherwise arranged, by staff in the Department of Geography at the University of Madras. Affiliation with the Department of Geography, University of Madras was possible because this workshop series and related research were undertaken in association with the *Madras-Waterloo University Linkage Program*. The author has been associated with this linkage program since 1992.

The Madras-Waterloo University Linkage Program is a collaborative program between the Departments of Geography at the University of Madras and the University of Waterloo. This program, initially sponsored by the Canadian International Development Agency (CIDA), has involved the establishment of a Geographical Information Systems and Digital Mapping laboratory in Chennai, the offering of various workshops and seminars, as well as faculty, staff and student exchange and training programs. The linkage program has provided a venue and operational base in Chennai for research and training workshops, seminars and symposia such as those conducted for this research.[1]

Personnel

The considerable effort required for communication with potential workshop participants, and the organization of workshops, precludes undertaking these tasks without at least a minimal staff. The Department of Geography, University of Madras also arranged for two research assistants for each of the two workshops. These research assistants were employed part-time to help with communication and organization of the workshops and were allocated some data collection tasks. In addition, individual research associates, faculty, and staff at the department made contributions to the organization of workshops for this research. Tasks undertaken by the research assistants included;

- Phone contact with potential workshop participants to confirm participation
- Photocopying
- Purchase of items for participants' workshop materials packages
- Collation and mailing of pre-workshop communications (invitations, confirmation, *etc.*)
- Collating and construction of workshop materials packages
- Coordination of workshop catering services
- Delivery of workshop reports
- Accompaniment (of the researcher) to meetings/interviews at government agencies and NGOs, as representatives of the Department of Geography, University of Madras

Networks and Communications

The value of personal association with key individuals in the Indian context cannot be overstated. It has been this researcher's experience that to be able to successfully conduct research, a personal network of contacts at appropriate agencies, institutions and organizations must be cultivated. Without sponsors within various agencies, for example, participation in the research by some of these agencies might not come about.

I was able to draw upon an extensive personal network of professional acquaintances

[1]Although the funding period for the Madras-Waterloo University Linkage Program had expired part way through this research, research collaboration under the linkage program has continued, and funding for further collaborative projects is being sought.

developed during previous research in Chennai from 1993 onward (see Bunch, 1994 and 1996), and this network was expanded for this research. Also, the participation of individuals from the Department of Geography, University of Madras (especially Dr. S. Subbiah), provided access to their extensive personal networks.

Such contacts can dramatically decrease the amount of time and effort required for simple tasks such as meeting with various professionals or key informants at an agency, acquisition of data, and identification of potential participants in the research. If such a 'network' of associates in the study area does not exist, a considerable amount of time must be dedicated to developing one. As mentioned earlier in Chapter 2, communication in an adaptive management approach deserves at least as much attention as analysis (Holling, 1978:120). This happens through bringing together a variety of stakeholders, professionals and scientists at a series of workshops, and through the development and facilitation of informal networks based on common interests and cooperation.

Cultural Context

Institutional Setting

Several considerations deserve mention regarding the societal and institutional culture within which this research is undertaken. One of these issues, briefly discussed in Chapter 2, relates to the dominant strategies for management in Indian institutions. These were described in general in Table 2.4 under the column labelled "mechanistic management strategies." Characteristics such as an orientation toward programmed approaches, rigid hierarchical authority and structural organization, vertical communication channels, and centralized control are typical. Rondinelli (1993a:92-93) argued that such an organization is typically incapable of effectively dealing with complex and uncertain situations:

> One needs only cursory review of evaluations conducted by national governments and international agencies to discover that attempts at comprehensive analysis and control-oriented management generated adverse and often unintended results: costly but ineffective analysis; greater uncertainty and inconsistency; the delegation of important development activities to foreign experts who were not familiar with local conditions; inappropriate interventions by international assistance agency and central government planners; inflexibility; and unnecessary constraints on managers. In addition, serious implementation problems have

> been created by failure to include intended beneficiaries in the design and implementation of projects and by managers' reluctance to engage in error detection and correction.

Such concerns have arisen in discussion with planners, engineers, and other officers at various agencies in Chennai with regard to planning and intervention in the problem situation of the Cooum River and environs, (*e.g.*, Ranganathan 1999, regarding foreign consultancy reports and Gonzaga, 1999, regarding slum clearance and relocation programs). Related to the institutional cultural environment is a larger societal bias towards traditional scientific, positivistic and engineering approaches to understanding, problem solving, intervention and planning. This is reflected in many government agencies by the dominance of engineers in the institutions, and orientations toward systematic analyses and programmatic planning. The inertia associated with this kind of institutional culture has already been discussed in Chapter 2 as a potential barrier to the implementation of adaptive management programs.

One must be sensitive to the fact that individuals who can make a difference in the situation must work within such a cultural environment. Testing an adaptive approach in the context of a research program which is outside of, and (hopefully) non-threatening to these existing institutions, and in which government agencies may participate, may be one way to circumvent this barrier.

Perceived Legitimacy of the Research Program

Another issue associated with the cultural context is the perceived legitimacy and position of the researcher and research by potential participants and cooperators. It has been my experience that the status as a researcher from overseas, and position outside of the Indian cultural and institutional hierarchical structure, accorded access to individuals and data that an Indian researcher undertaking dissertation work may not have had. This perception has been confirmed in discussion with Indian researchers (*e.g.*, Vasantha Kumaran, 1999). However, while this status may open some doors, it is another matter altogether to ask senior planners and managers, and other potential participants with already full schedules, to attend workshops for 3 and 5 days, and to take time to prepare materials for those workshops. For this, the research must be perceived as (1) potentially useful and informative to them in their professional capacity, and (2) undertaken by a legitimate and culturally acceptable authority.

This issue was dealt with in the following manner:

- The research was undertaken within the context of the Madras-Waterloo University Linkage Program, a program sanctioned by the Government of India and based locally in India at the Department of Geography, University of Madras. All correspondence to potential participants was co-signed by the coordinator of the linkage program in India.

- The researcher was presented not only as a research scholar from the University of Waterloo, but also as a research associate with the Madras-Waterloo University Linkage Program. The latter was emphasised.

- Much effort was directed towards personal face-to-face communication with potential participants and co-operators, so that the research could be described in detail and queries about it addressed. This also served to coordinate a network for the researcher, and to operate and expand a network for the potential participants.

Data and Information

Availability and Accessibility

There are two main issues associated with data and information employed in this research: availability/accessibility, and quality. As indicated in the previous chapter, much information has been generated by government agencies and consultants engaged by these agencies, with regard to various aspects of the problem situation. However, much of this data is not generally available to researchers without serious effort devoted to navigating bureaucratic labyrinths. This would involve an extensive campaign of formal letters of introduction, requisition, and repeated visits to agencies. It was found that the most effective means of acquiring data was through personal relationships with those having access to such information. Even so, some data known to exist were not forthcoming. Even when data had been acquired, it has been the experience of this researcher that conditions such as the confidentiality of the provider of the data, the masking of the source of the data where it is printed on maps, and the speedy return of clandestinely loaned materials are preconditions of access to the information.

A related problem is that access to some types of information is controlled through a system of military classification. Access to this data is difficult for researchers. Such materials as aerial photographs and topographic maps for the Chennai region fall into this category. Fortunately, the Department of Geography at the University of Madras is a regional repository for topographic sheets and this basic information was readily available to researchers associated with the Madras-Waterloo University Linkage Program.

Quality

Data quality is also an important issue in undertaking research in Chennai. It was certain that error would be present in the data sets employed for the Cooum River project (*e.g.*, for incorporation into a GIS database and in support of system modelling). One might anticipate problems such as missing values in various data sets, inconsistent administrative district boundaries and changing variable definitions between census years, as well as poor quality, incomplete or not-to-scale maps of basic information such as administrative districts, sewerage details and topography. However, as Lee (1993:179) indicated, in adaptive management, alternatives posed as hypotheses to be tested through simulation modelling need to be tested at a level of significance relevant to *managers*, not necessarily to scientists.

> Management decisions often involve judgments that something is more likely than not to occur. That kind of judgment asks for information that reduces the probability of error to under 50 percent. This is drastically different from the conventional scientific one, which seeks to avoid Type I errors at a statistical level of assurance of more than 95 percent. (Lee, 1993:179)

Thus, the research making use of such data is still likely to be useful from a management perspective even if there is a fairly large error component. Adaptive management is intentionally designed to deal with this sort of issue by expecting error, uncertainty and surprise, and preparing its practitioners to learn when this is encountered.

On the other hand, this issue highlights the need to be aware of error and the quality of data being employed. Participants in the program of research should be aware of the limitations of analyses undertaken with data which are lacking, of questionable quality, or where "best guess" estimates have been employed. This issue will be further discussed in Chapter 4 relating to the construction of a GIS database, decision support system and simulation model for the Cooum system.

The First Workshop

Objectives

There were five main objectives of this initial workshop: (1) problem identification; (2) system identification; (3) generation of objectives for management and rehabilitation of the Cooum River; (4) development of a framework for a system model; and (5) facilitation of communication among stakeholders in the problem situation.

First, this workshop was intended to identify "The Problem" or constellation of problems associated with the Cooum River. In general, this objective is pursued in exercises oriented toward expressing the problem situation. This includes the identification of actors, elements, activities and processes in the situation, as well as a description of their relationships. System Identification begins to occur with the focus on particular aspects of the problem situation and their description in systems terms, and in the overall conceptualization of 'the system.' The third workshop objective, the generation of goals and objectives for management of the situation, are closely linked with the system identification. System identification in this research included the development of an understanding of desirable future states of the system. Objectives for rehabilitation and management of the Cooum system help to express such visions. Objectives also provide a focus for discussion about possible interventions in the system, and this helps to illustrate the feasibility of visions of the potential future states of the system to which the objectives are tied.

Together the paper presentations, working sessions, discussion and debate at the first workshop were also oriented toward the generation of a framework for a computer-based system model. By "framework" is meant the identification, within the larger context of the problem situation, of the fundamental elements of the system, actors within the system, and relationships among these. Such relationships may be expressed in terms of inputs, outputs, flows, transformations, activities and/or processes. Indications of spatial and temporal scope associated with these system characteristics are also necessary. This information is used to develop a working system model focussed on the problem situation. The construction and operation of the simulation model re-informs the conceptualization of the system.

The fifth objective, the facilitation of communication and the generation of a cooperative and participatory atmosphere, depends on three factors: the skill of the workshop facilitator, the mix and attitudes of workshop participants, and the appropriateness of the methodology to the problem situation being addressed and within the particular cultural context in which it is applied. The attainment of this goal is important not only for the success of the workshop, but is necessary if a continued research program and stakeholder process are to make any contribution to efforts at management and rehabilitation of the Cooum River and environs in the future.

Participants

At the outset of organizing the workshop, potential participants who were thought to be appropriate because of their professional role, expertise, experience or interest were identified by personal knowledge and through consultation with academics at the Department of Geography, University of Madras. The distribution of general information about the workshop, as well as provision of letters of introduction, and invitations to this group to participate in the workshop were followed by personal visits. During such visits, the set of potential participants was expanded through discussion with the interviewees. Letters were also sent to heads of departments, agencies and NGOs so that participants could be deputed to the workshop. Approximately 80 potential participants were contacted by mail, phone or personal visit to inform them of the workshop. A notice of the workshop was placed in *The Hindu* newspaper.[2]

A total of 49 persons registered for the workshop and attended the formal opening session, while a core group which fluctuated between 25 and 30 persons remained to participate throughout the 3 day workshop. Of the participants registered and who participated on at least one of the days of the workshop, 8 represented NGOs, 18 were from

[2]Notification of the workshop was given to several English and Tamil language newspapers in Chennai. It is known that the workshop was announced in at least one of them (*The Hindu*).

Table 3.1: Representation at the first workshop in the Cooum River Environmental Management Research Program

Academic Institutions

- Centre for Water Resources, Anna University
- Department of Geography, University of Madras
- Institute for Ocean Management, Anna University
- Regional Institute of Education (RIE), [N.C.E.R.T.]
- Madras Institute of Development Studies
- Department of Zoology, University of Madras (Guindy Campus)
- National Law School of India
- Ocean Engineering Centre, Indian Institute of Technology (I.I.T.) Madras

Government Agencies

- Tamil Nadu Pollution Control Board
- Tamil Nadu Slum Clearance Board
- Tamil Nadu Public Works Department (Water Resources Organization), Chennai Region,
- Tamil Nadu Public Works Department (Water Resources Organization), Plan Formulation
- Tamil Nadu Public Works Department (Water Resources Organization), Araniar Basin Division
- Directorate of Public Health and Preventative Medicine, Government of Tamil Nadu
- Department of Environment and Forests, Government of Tamil Nadu
- Storm Water Drainage Department, Corporation of Chennai
- Chennai Metropolitan Development Authority
- Chennai Metropolitan Water Supply and Sewerage Board

Consultants, Private Industry

- Tamil Nadu Rubber Corporation
- T.T. Maps & Publications Ltd
- Environment & Rural Development Planning, Ltd.
- New Tirupur Area Development Corporation Ltd.

NGOs, Citizens and others

- unaffiliated private citizens (3)
- Sustainable Chennai Support Project, United Nations Centre for Human Settlements (Habitat)
- Madras Editorial Services (Press)
- The Hindu (Press)
- WAMP (Citizens' Waterways Monitoring Programme)
- Public Utility Sanitation Centre (Regd.)
- PROBUS (Professional and Business Club)
- Exnora International and Exnora Naturalists' Club
- INTACH (Indian National Trust for Art and Cultural Heritage)

government agencies, 18 identified themselves as academics, 5 were from the private sector, and 4 were interested citizens or representatives of the media.[3] Table 3.1 lists the agencies and organizations represented by the participants at the first workshop, and Appendix I includes a participant list. A comparison and further breakdown of the workshop participants

[3]Two participants represented more than one category.

of both the first and second workshop are presented in Chapter 5.

These participants represent a wide spectrum of stakeholders in the problem situation. The participation of scientists, academics, engineers, planners, private sector stakeholders, NGOs, and citizenry provided a foundation for meaningful dialogue and participation in the workshop. Of particular note is the participation in this setting of key government agencies and departments. Several times during the workshop participants indicated that, despite past interventions to improve the condition of the Cooum River by various agencies, this was the *first time* that all of the pertinent government agencies had gathered at the same table to discuss this issue. All of these agencies had continued representation throughout the workshop, with the exception of the delegate from the Chennai Corporation and from the Department of Environment and Forests who attended the first day and final sessions only.

One group that was not represented, on the other hand, was lower income groups (especially slum dwellers) living in proximity to the Cooum River. This is an important group to consider because they are both affected by the environmental condition of the river and its environs, and are commonly seen as part of the problem. During the workshop, some effort was made by participants from the TNSCB and several of the NGOs to speak for slum dwellers. Future work should incorporate the perspectives and knowledge of this group, and attempt to provide a vehicle for their participation in research and management programs.

Sequence of Working Sessions and Paper Presentations

Workshops in India generally have a standard format. That is, they consist of a series of paper presentations, each followed by a short period for questions and discussion. Typically such workshops begin very formally with a Welcome, an Inaugural Address by a dignitary and a Vote of Thanks. Workshops are closed in a similar manner, with a Valedictory Address, Closing Comments and a Vote of Thanks. Workshop reports, when produced, usually consist of a compilation of the papers presented at the workshop, and a list of recommendations, usually generated at an open discussion on the final day of the workshop.

Workshops undertaken in association with this research were different from the

Indian norm. The methodologies employed here require a more interactive style of meeting. That is, the workshops needed to have working sessions in order to undertake the activities necessary to achieve the workshop objectives outlined above. However, it was expected that most or all of the participants in the workshops would not be familiar with this more Western style of workshop. To avoid alienation of participants, certain characteristics of workshops as normally operated in India were incorporated. In particular, the workshops were operated formally with opening and closing sessions that included Inaugural and Valedictory Addresses by prominent persons, and a series of paper presentations were interspersed among the working sessions.

Aside from providing workshop participants with an anchor to familiar terrain, papers presented at the first workshop served to inform working sessions. The papers provided valuable general and specific background information and baseline data which were reorganized, expressed and revisited during the working sessions. Table 3.2 lists the papers presented at the first workshop.

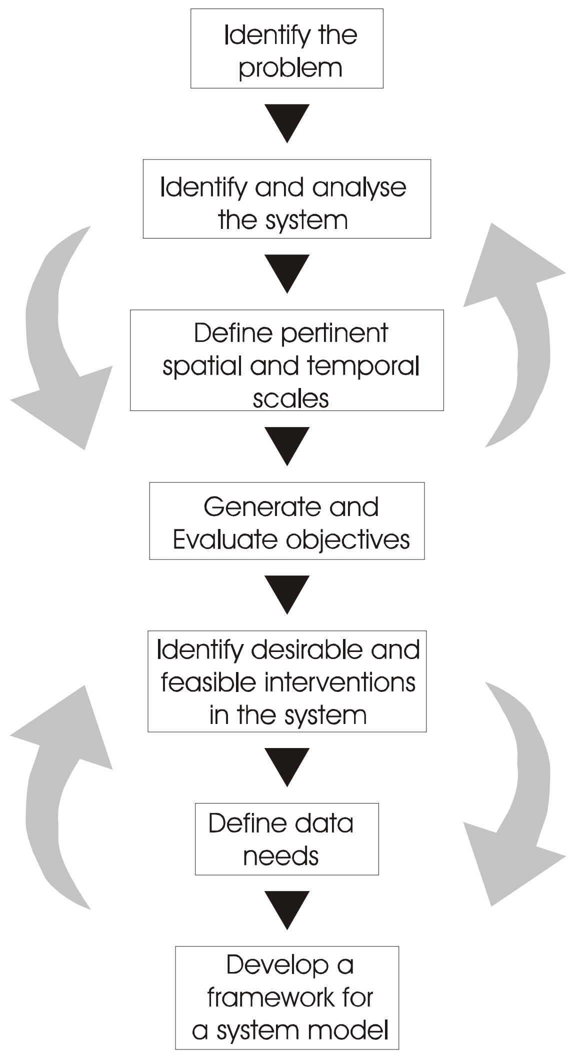

Figure 3.1: Sequence of working sessions in the first workshop. The arrows in this diagram are intended to indicate that the process is not necessarily linear – topics addressed in working sessions may be revisited and their products modified based on new information or insight generated in later sessions, paper presentations, discussion and debate.

Working sessions were developed which progressed from the more general problem definition, through identification of the system, generation of objectives and means for intervention, to discussion of data and modelling the system in a simulation model. Figure 3.1 and Table 3.3 present the overall sequence of workshop activities and working sessions.

Table 3.2: Papers presented at the first workshop in the Cooum River Environmental Management Research Program, March 1998. (A workshop schedule is provided in Appendix I).

	Paper Topic	*Presenter*
18 MARCH	Inaugural Address	**Dr. S. Ramachandran** Director, Institute for Ocean Management, Anna University
	Workshop overview and methodologies	**Martin J. Bunch** Research Associate, Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
	Rehabilitation and Sustainable Maintenance of Chennai Waterways – How Should We Go About It?	**Er. P.V. Sahadevan** Deputy Chief Engineer Plan Formulation, Water Resources Organization, Public Works Dept.
	Intercepting Sewers for Sustainable Maintenance of Waterways in the City	**S. Ananthapadmanabhan** Superintending Engineer Chennai Metropolitan Water Supply and Sewerage Board
19 MARCH	*The Vectors and Parasites of Public Health Importance in the Cooum River and Environs*	**C. Rajendran** Chief Entomologist Directorate of Public Health and Preventative Medicine, GOTN
	Modelling and Scenario Analysis for the Construction and Comparison of Management Scenarios: The Development of a Prototype Cooum River Environmental Management Decision Support System	**Martin J. Bunch** Research Associate, Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
	Slums on the Banks of the Cooum and Programmes to Address Them	**K.R. Thyagarajan** Superintending Engineer, Tamil Nadu Slum Clearance Board
20 MARCH	*Basic Information for Cleaning of the Waterways*	**G. Dattatri** Project Advisor UNHCS (Habitat) Sustainable Chennai Support Project
	Biological Treatment of Waste Water – A low cost alternative	**Sangeetha Sriram** Project Officer, Exnora International, Exnora Naturalists' Club Citizen's Waterways Monitoring Programme
	Selected Population Issues	**Dr. S. Sivarajasingham** Consultant, Environment & Rural Development Planning
	Valedictory Address	**Dr. T. Sekar, I.F.S.** Director of Environment Department of Environment and Forests, GOTN

Table 3.3: Working sessions in the first workshop of the Cooum River Environmental Management Research Program. (A workshop schedule is provided in Appendix I).

Working Session Timing	Session Title
1 - Day 1 at 11:30 - 12:00	An exercise in problem definition
2 - Day 1 at 2:00 - 3:45	Identifying the system of the Cooum River and environs – system components, linkages and relationships
3 - Day 2 at 10:45 - 11:45	Scoping the problem situation – spatial and temporal scales
4 - Day 2 at 11:45 - 1:00, 2:30 - 3:00	Setting goals for rehabilitation and management of the Cooum River
5 - Day 2 at 4:00 - 5:30	Group sessions – generating management alternatives for use in scenario analysis
6 - Day 3 at 10:30 - 11:45	Data requirements, sources, availability and quality: matching available knowledge and data to possible management interventions
7 - Day 3 at 11:45 - 1:00	Linking data, knowledge and models: what we can and can not do
8 - Day 3 at 2:00 - 3:15	Discussion of further steps and the second workshop Review and evaluation of the workshop

Throughout all of the working sessions, and also for discussion following paper presentations, the researcher acted as facilitator. In this role, he attempted to guide discussion, debate, and activities so as to achieve the objectives of the workshop and of individual working sessions, without influencing the actual outcome of the sessions in terms of the content of materials produced or the specifics of information generated and debated in discussion. Thus, in a working session dedicated to generating objectives for management and rehabilitation of the system, the facilitator guided participants through the process of generating objectives, but endeavoured not to influence participants' decisions regarding what those objectives should be. A detailed discussion of working sessions in terms of their immediate objectives, intended products, methods employed and results is presented below.

Working Sessions of the First Workshop of the Cooum River Environmental Management Program

Working Session 1: Problem Definition

Immediate objectives and intended product

The first working session was oriented toward problem identification. This was a simple session – a set of tasks consisting of written responses to 8 questions provided in the participants' workshop materials package. Each participant at the workshop already had an idea of the problem situation. Indeed, many of them had been working directly with a situation that they considered problematic for some time. However, there was a wide range of experience and perspectives among participants. One of the objectives of this exercise was to capture that variation before there had been much group discussion to colour the responses.

Another objective was to stimulate participants to take a fresh look at the problem, to start them thinking about it, and not to go into the workshop without a new consideration of what the root problem or problematic situation was that, in their opinion, needed to be addressed.

Finally, this exercise was intended to generate materials to serve as input into later working sessions on the first and second days of the workshop when activities were directed toward identification of actors, components and relationships in the system, and to scoping or bounding the system and subsystems in time and space.

Method

Box 3.1 presents the questions given to workshop participants in the first working session. This material, and some of the material from later working sessions, was taken from a UNCHS (1991) action research publication entitled *Guide for Managing Change for Urban Managers and Trainers*. The exercise papers with printed questions and reserved space for responses were distributed to participants in workshop material packages at the beginning of

1. What is the problem? (Start with a rough description and underline the key words and phrases)

2. Why is it a problem? What would the problem look like if it were solved?

3. Whose problem is it? Who owns it? (Once you have determined who the problem belongs to, go back and underline all those you believe are willing to invest in its solution and, finally, circle the individual, group or organization you believe is the most important in the problem solving venture).

4. Where is it a problem? Is it localized and isolated, or is it widespread and pervasive?

5. When is it a problem? (*E.g.*, every Monday morning at 8a.m.? Once every full moon? Continually?) As with other questions be as specific as possible in your answer.

6. How long has it been a problem? If it is a long standing problem, this may say something about the ability, will or priority to solve it.

7. Really now, what is the problem? Go back to your statement in task one and determine whether: (a) the problem you defined is a symptom of a bigger problem; or (b) a solution to what you think is the problem. If you decide you are dealing with either symptoms or solutions, go back to Step 1 and try to identify the real problem.

8. Finally, what would happen if nobody did anything to solve the problem?

Box 3.1: Problem identification tasks (from UNCHS (Habitat), 1991).

the workshop. Participants were briefed on objectives and intended products of the working session, and instructed to complete individually the eight question exercise. One half hour was allocated to do this, but the session was able to start early and participants completed the exercise in forty minutes.

The exercise papers were collected immediately after the working session, and the results were collated and summarized for presentation over the following lunch break and paper sessions. The summary was transferred to poster-sized paper and displayed in the seminar room for convenient reference for the duration of the workshop.

Results

This exercise generated a large amount of basic information about the problem situation. This basic collection and expression of data is the first step in expressing the problematic situation (as in the first stage of SSM). The variety of responses and large number of individual items ascribed to each question are an indication of the complexity of the situation.

Workshop participant responses to the first working session questions are presented below (Table 3.4 to Table 3.8). These are reported as direct quotes or paraphrased responses. An attempt has been made to retain original wording. However, to minimize repetition, multiple responses with the same meaning have been represented with a single statement.

1. WHAT IS THE PROBLEM?, 2. WHY IS IT A PROBLEM?, AND 7. REALLY NOW, WHAT IS THE PROBLEM?

Responses to Questions 1 and the first part of Question 2 addressing the "What" and "Why" of the problem situation, respectively, are reported here together (Table 3.4). This is done because a high level of cross-over occurred in the participant responses between these two questions. For example, the mosquito menace and health risk associated with the river was indicated by several participants in response to both the questions "What is the problem?" and "Why is it a problem?" as were various indications of pollution such as odour and the presence of sewage. This and the wide range of aspects (more than 70 distinct items) of the problem given by participants in response to these questions demonstrate a situation in which the problem is not a single, simple or well defined one. This is another indication of the complexity and uncertainty in the problem situation. This is typical of what are often referred to as “wicked,” “soft” or “fuzzy” problems.

A categorization is employed to present this part of the exercise. Participant responses fell into categories of: (1) sensory aspects (in which three different problem issues or items were identified), (2) health hazards (eleven items), (3) objectionable land and land use (six items), (4) hydrology (eight items), (5) pollution and related factors (nineteen items), (6) population (four items), (7) tourism and recreation (four items), and (8) political, social and management aspects (fifteen items). Of these, almost all of the problems were identified in response to the first and second questions (and these were primarily physical, observable manifestations of the problem). However, question 7 (“Really now, what is the problem?”) was more important in defining the final category, that of ‘political, social and management aspects’ of the situation.

Question 7 was intended to narrow the identification of the problem down to its core. That is, to identify the root problem(s) by asking whether the items previously identified were merely symptoms of a larger problem, and if so, what that larger problem is. When asked to reconsider the problem, participant responses reinforced several of the categories just described (especially the hydrology and pollution categories). The 8th category, on the other hand, was not only reinforced by responses to this question, but also was considerably augmented with new input. This category had to do with items identifying the problem as, for example, lack of political and public will, poor coordination and communication of agencies, inappropriate models for environmental problem solving and basic uncertainty about the situation. The political, social and management aspects category, in the end, consisted of 15 distinct items that were identified as “the Problem.” This was the second strongest set of problem items, after the pollution category, which had 19 items.

It is interesting that this category should show so strongly. These are issues which have almost never been addressed in either academic studies, or government reports having to do with the condition of the Cooum River. Thus, while many reports make reference to the problem of the Cooum as caused by, for example, untreated sewage being routed to the river, and to physical and hydraulic complications, none mention issues such as problems of

Table 3.4: Questions 1, 2a and 7 responses: "What is the problem?," "Why is it a problem?" and "Really now, what is the problem?"

1 *Sensory Aspect*
- A visual hazard; Eyesore
- Image of the city for future investment and development is threatened
- Foul smell; Foul/bad odour; Stench; Stink

2 *Health Hazard*
- Mosquito breeding (disease vectors, *e.g.,* filaria, malaria)
- Habitat for rodents
- Mosquito nuisance - sleeplessness
- Fly breeding, cockroaches
- Unhygienic atmosphere
- Communicable diseases
- Breeding ground of intestinal parasites
- Life growth and nourishment of children growing along the river side are hampered
- High in health risks (*e.g.,* heavy metal, cyanide poisoning)
- Fishing and direct contact (children playing)
- Population in vicinity of the river also disseminates disease

3 *Objectionable land and land-use*
- Illegal (and legal) encroachments along banks of the river, and upstream on tanks, ponds, agricultural and forest lands
- Location of slum developments
- Paving/cementing land surrounding houses
- Indiscriminate felling of trees in upstream areas
- Densification/Intensification of land use
- Non-coverage by the sewerage system of approximately 30% of the population along the banks of the Cooum

4 *Hydrology*
- Retardation of flood flowing potential
- Stagnation during rains
- Slow flow – no flow, Water flow is slow in inter-monsoon periods (leads to health hazard)
- Flooding and overflowing
- Clogged most of the stretch
- Reduction of base flow
- Blockage by sandbar at the mouth, no free flow to the sea
- Together with storm water drains, blockages cause inadequate disposal of monsoon rains

5 *Pollution and Related Factors*
- Sewage carrier of both treated and partly treated water – septic, anaerobic conditions, organic wastes
- Illegal dumping of building rubble, debris
- Solid waste dumping
- Non-point source pollution by slum areas
- Inadequate solid waste removal
- Inadequate sewerage system (liquid waste removal and treatment)
- Industrial waste carrier
- Trade (commercial) waste carrier
- Domestic sewage carrier
- Heavy silt from storm water drainage
- Degradation of ground water quality
- Degradation of river water
- Degradation of air around the river
- Degradation of land along the river banks
- Marine environment – Pollution of seawater during flushing; Coastal water is getting polluted.
- Natural flora, fauna and river ecology are lost due to the anaerobic condition
- Heavy pollution load: High BOD, low or nil DO, High suspended sediment concentration
- Sewage outfalls need to be stopped
- Partly treated sewage is let into the river
- Open air defecation

6 *Population*
- Population growth, densification
- Slum development
- Encroachments
- Urbanization and industrialization (increasing demand for water, increasing pollution load)

7 *Tourism/Recreation*
- Stench, odour, eyesore repellant to tourism
- Denial of, unsafe for pleasure boating, bathing, swimming, fishing
- No walkways, lawn, gardens, parks on the slopes
- Denial of a sustainable tourism asset

8 *Political, Social and Management Aspects*
- Communities, citizens and government inaction, neglect, lack of political will
- Lack of communication and coordination among institutions concerned with rehabilitation and development along the Cooum
- Inability to solve environmental problems, improper/inadequate management, poor planning
- Failure of previous management attempts
- Lack of a multi-disciplinary approach to the problem
- Inability to approach things with integrated efforts
- Inability to take a holistic approach to problems
- Unauthorized occupants *i.e.*, occupation of objectionable land, encroachment –> lack of will to enforce regulations
- Budget starvation and day-to-day management based local bodies = insufficient management and upgrading to keep up to the problem in the past, leading to the current crisis
- Not a small problem with implications for level of conflict, no. of stakeholders, no. of overseeing agencies
- Polluting & flood aspects = symptoms of a larger problem
- Lack of consensus on contemporary studies
- Lack of public co-operation due to lack of transparency in Government bodies
- Lack of knowledge – no large scientific database of parametric variables; absolutely no information at mass level for action
- Lack of public awareness

coordination and communication among government agencies, data sharing, and inadequate approaches to dealing with environmental problems as part of the problem itself.[4]

Also of interest is the way that different groups responded to this question. Of the 13 delegates from government agencies and departments, 10 of them (77%) indicated that the items identified in their response to questions 1 and 2 were really indications of a larger problem. Three of these respondents specifically indicated poor cooperation, coordination and management of the situation by agencies as the root problem, while two related the problem to physical, hydraulic aspects of the system, and one indicated unauthorized occupation on the banks (slums). Of the six NGO responses to question 7, four indicated that the 'real' problem had in some way to do with inability of agencies to deal effectively with environmental problems, and one indicated that lack of political will was at the root of the problem. (Government and NGO participants made the strongest contribution in question 7). Only three of the 9 academic respondents re-focussed their understanding of the problem situation in response to question 7. These cited lack of inter-agency cooperation, weak political and public will and inadequate approaches to environmental problem solving as the root problem. Similarly, two of the six respondents from the private sector, media and others made a contribution here, indicating that lack of political commitment, and basic lack of support of the population (*e.g.*, to raise standards of living, provide education and basic urban services) are the problem.

3. WHOSE PROBLEM IS IT? WHO OWNS IT?

Responses to this question resulted in a list of actors in the problem situation as well as those who might take part in a solution to the problem. These have been categorized into four groups: *Government and Government Agencies, NGOs, Academic Institutions and Researchers*, and *Citizens and others*. Where workshop participants elaborated on the actor, (for example, stating a possible role), those remarks have been summarized and listed (Table

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[4]Examples include a recent "Hydrographic and Pre-feasibility Study" by the Inland Waterways Authority of India, (1998), the Terms of Reference for the development of a waterways rehabilitation and reclamation plan by the Public Works Department (Government of Tamil Nadu, 1997) and the sludge disposal consultancy report undertaken by Mott McDonald Ltd for the Government of Tamil Nadu (Mott McDonald, 1994). One exception is an academic work (Appasamy, 1989) which includes a discussion of the need and potential for public participation and the role of NGOs in pollution control measures for Chennai waterways.

Table 3.5: Question 3 responses: “Whose problem is it?” “Who owns it?”

Government and Government Agencies	***Citizens and others***
• An inter-departmental problem	Communities
• No one agency is more important	Society
	All citizens of Chennai*
Corporation of Chennai	1. Not the problem of any specific individual but of
1. Especially the storm water drainage department	the whole of the city, common property
CMWSSB	2. Must pressure government and canvas for support
1. Must ensure that overflow from pumping stations	3. Polluting role
does not discharge into Cooum	4. Need to be educated
2. Ensure functioning of treatment plants	Slum dwellers along the Cooum
CMDA	Public representatives of citizens of Chennai *
1. Plan city development (*e.g.,* proper drain design)	1. Governmental sector
2. Mobilize resources, organization & political clout	2. Non-Governmental sector
PWD*	Private sector
1. Maintain river course	Industries located along the Cooum
2. Remove sludge and silt	1. Polluting role
3. Plug outlets	CBOs
4. Ensure free flow (control of constricting	Interested experts
structures, removal of shoals, sand bar)	Citizens’ committees
5. Store floods and flushing	Residents adjacent to the river
Members of Parliament of Chennai*	International institutions
TNSCB	Potential Integrated Group
1. Plan and prepare proposals to rehabilitate the	1. A group composed of scientists, government
river (regarding the nearly 40 000 hut dwellers along	agencies, private & public organizations, NGOs, *etc.*
the Cooum within the city)	
2. Ensure provision of sewer systems in slum areas	***NGOs***
TNPCB*	Citizens’ Waterways Monitoring Programme (WAMP)
Government of Tamil Nadu	Voluntary organizations
1. Because Chennai is the capital	Exnora
Department of Environment and Forests (State)	Citizens’ groups
Central Government	International organizations
	1. Involve people at large
Academic Institutions and Researchers	2. Provide a forum where people can speak freely –
IIT	NGOs can be useful in the preposition forming stage
Anna University	3. Have a societal role of “egging on” “encouraging”
University of Madras	and “challenging” the government and its agencies
Individual Researchers	4. Fulfill the role of educating the public about
Public Administration Departments of Universities	environmental and civic issues.
Consultancies	

3.6). The presence of an asterisk (*) after the name of an actor indicates an explicit statement about that particular actor being the “most important” in the problem situation in some way or other.

As with questions 1, 2 and 7, the responses to the third question also demonstrate the complexity of the Cooum problem situation. This is indicated by the numerous agencies, organizations and other groups which are perceived by participants to be in some way central to the problem ("Whose problem is it?") or having some responsibility toward it ("Who owns it?"). In response to question 3, participants identified 10 government bodies, 6 research entities (or groups of these), 5 NGOs or categories of NGOs, and 13 organizations and groups such as industry, slum dwellers, citizens at large, and Commercial Business Organizations (CBOs), as having some sort of ownership of the problem.

It is interesting to note, in light of responses to this question, that a main item of concern expressed in this working session, and in later sessions and discussion in both the first and second workshops, was the lack of public consultation and involvement in current and historical efforts at rehabilitation and management of the Cooum River. This has been expressed yet again by one of the NGO participants (in a communication involved with activities following on from this series of workshops).

> It is encouraging to know that the Government is doing 'something' about [rehabilitating the waterway]. But it is as discouraging to know that that 'something' which is being done is not being done the right way. And we don't even have enough information on what has been happening. The Government is not consulting with the people on any of its action plans... (Ramkumar and Sangeetha, 2000).

In contrast with the rather closed way that government agencies in Chennai have historically operated, the identification of so many 'co-owners' of this problem suggests that planning and managing for the Cooum River and its environs should be (1) open with regard to both information relating to the state of the situation and plans to address it, (2) inclusive of pertinent stakeholders and (3) participatory in nature. Not to do so may cause important contributions of these stakeholders to be missed, and may alienate groups which could facilitate rehabilitation and management efforts.

4. WHERE IS IT A PROBLEM?

Responses to the question "Where is it a problem?" indicate that, in general, participants considered the problem to be widespread and pervasive. (One government and one academic participant did not respond to this question). Most thought that this was so for stretches of the river in the urban area. Where participants indicated that the problem was localized, they did this in the context of the problem being contained within the city limits (only 3 respondents made reference to the river or catchment outside of the city limits). Several participants indicated that the intensity of the problem varied at different points within the city, and some considered this intensification in particular areas to be a localized problem. In this context, riverside slums, point source pollution outlets into the Cooum River, and the Koyembedu Sewage Treatment Plant were mentioned. Participant responses are summarized in Table 3.6 and divided into two general categories: *Widespread* and *Localized*.

Responses to this question proved to be important in a later working session which attempted to conceive of a 'system' pertinent to the problem situation and to identify its spatial scale. Responses to question 4 identified the location of the problem as places proximate to the river within Chennai city limits. Although only one respondent alluded to the locations of polluting activities within the city away from the river, this description of the scale of the problem influenced the later conception of the system as a primarily urban one, and the identification of its spatial scope as encompassing the Cooum River's urban drainage catchments and the sewerage collection zone of the Koyembedu STP which empties into the river, while explicitly excluding the upper catchment to the west of Chennai.

Table 3.6: Question 4 responses: "Where is it a problem?"

Widespread	***Localized***
• Everywhere in the watershed where activities contributing to the problem occur (*e.g.,* deforestation in the upper reaches, encroachment and dumping in the lower reaches, *etc.*) • Widespread and pervasive within the city limits 1. Slums along the banks/illegal habitation 2. Organic pollutants 3. Sewerage 4. Latrines 5. Stench and clogging • Problem is widespread but intensity varies from place to place • In general it is widespread and pervasive • Widespread and pervasive along river stretches 1. For a distance of 18 kilometers upstream 2. From the Koyembedu treatment plant to the sea 3. Originating at the source of the river in terms of flow of water 4. "A problem all through the terrain it flows" • Along coastal areas of the city	• At point sources of sewage and industrial effluents • Localized and isolated 1. Inorganic pollutants (point sources) 2. Sand bar at mouth of the river 3. Dumping locations of construction debris and concrete materials 4. Stagnation at the mouth of the river • Localized to the city limits in terms of pollution load (no water flow in many places beyond city limits) • Worst stretch is from Poonamalee High Road to the sea

5. WHEN IS IT A PROBLEM? AND 6. HOW LONG HAS IT BEEN A PROBLEM?

Question 5 and 6 addressed participants' perceptions of time in relation to the problem situation. (For question 5 one NGO and one academic respondent did not answer and for question 6 one NGO participant did not respond). The intention of these questions was to first place the problem in its historical context (*e.g,* has it been a longstanding problem?) and second, to explore any temporal aspects of the problem situation that might later illuminate the operation of processes in the system. Regarding the former, all participants considered the problem to be longstanding (all but one indicated that it has been a problem for more than twenty years). Table 3.7 presents these results (numbers in the margin indicate frequency of the response). 38% of participants cited lack of political will as the main factor in the lack of success in addressing the problem situation.

Some participants, without direct prompting by the questions, indicated that the problem was becoming more acute over time. The distribution of responses in this case is notable. 60% of NGO respondents (3) to question 6 and more than two thirds of the 'other' respondents (4) indicated a worsening situation. Only one each of the 9 academic and 13 government respondents indicated that this was so. This may indicate a difference in perception of the problem between the public on the one hand, and government planners, scientists and researchers on the other. However, this perception of a worsening trend was later strengthened in participant discussions which included anecdotal reports of historical figures being able to perform daily ablutions in the 'clean' Cooum waters around the turn of the 19th century, and reference to studies which indicate that while 49 species of fish were supported by the Cooum in 1949, this had declined to 21 species in 1975-79, and none in 1998 throughout most of the river (only a very few varieties of the hardiest fish exist at the periphery of the city where some dissolved oxygen may still be observed) (see also Ganpathy, 1964; Azariah and Azariah, 1987; Gowri, 1997: 44).

Not surprisingly, in the responses to question 5 "When is it a problem?" a seasonal variability in relation to the northeast monsoon emerged as an important process in the problem situation. 41% of respondents made note of the monsoon, indicating a yearly cycle in which the situation is dominated during the dry season by low flow, stagnant water and blockage of the mouth of the Cooum River by a sand bar, and during the northeast monsoon, by a river with greater flow, no stagnation, a clear river mouth but also characterized by flooding. Later discussion in the workshop would see this understanding expressed as different states of the same system, between which the system ‘flips’ in response to seasonal variation in storm water input.

Tidal variation was also indicated (by 21% of participants) regarding its effect on diurnal and monthly cycles of flushing of the river in response to high and low tides. This identification of tidal flushing sparked discussion throughout the workshop regarding the

Table 3.7: Questions 5 and 6 responses: “When is it a problem?” and “How long has it been a problem?”

When is it a problem?	***How long has it been a problem?***	
• Continually	• At least for the past 10-15 years	1
1. Especially when the river mouth is blocked by a sand bar	• For the past 20 years (or more)	6
	• For the past 30 years (or more)	4
2. Except when tidal waters enter the Cooum	• For the past 40 years (or more)	3
3. The problem is not time-bound	• For the past 50 years (or more)	4
4. All through the day and night	• For the past 100 years	2
5. Daily variation due to tides	• Long standing problem/decades	10
6. Slums are a continuous aspect	• Ever since city development	1
7. Silt deposition is gradual and continuous		
8 Inorganic effluents are worse on working days of industries	• Change in the problem over time: 1. It has grown along with population in the city 2. It is growing more intense 3. 1960s - noticed; 1970s - pronounced; 1980s - acute; 1990s extreme	
• All the year through but the problem is different for Monsoon and Non-monsoon seasons		
MONSOON SEASON		
1. Problem is diluted due to the rain water relocated to the sea	• Since the time that the pollution load exceeded the regeneration/assimilation capacity of the river	
2. Flushed out silt causes heavy metal contamination of the marine ecosystem	• Most participants have identified lack of political will or priority to solve the problem as a reason for the problem being long standing.	
3. Flooding of surrounding areas		
4. River discharge breaks open the sand bar formation near the mouth		
NON-MONSOON SEASON		
1. Stagnant water causing problem to residents living in the area		
2. Perpetual stink		
3. No adequate storm water to dilute the pollution load and flush out polluted water, suspended material and sediments		
4. Problem is concentrated during the summer		
• Early in the morning		

potential of tidal processes to alleviate the pollution problem if the sandbar could be kept clear of the mouth of the river. (By the end of the workshop a consensus was reached that tidal variation was insufficient to make a qualitative difference in the condition of the river).

2B. WHAT WOULD THE PROBLEM LOOK LIKE IF IT WERE SOLVED? AND 8. WHAT WOULD HAPPEN IF NOBODY DID ANYTHING TO SOLVE THE PROBLEM?

The second part of Question 2 and responses to Question 8 provide two contrasting visions of the future generated by workshop participants; one looking toward a desirable future state (similar to a 'visioning' exercise), and one projecting the current situation with no solution to the problem. In each case, the variety and flavour of participant views are demonstrated by quotes from the working session sheets (Table 3.8). Question 8 generated a series of responses that demonstrated the character of the situation and projected its overall trends in the system. Thus, the participants saw the situation as continuing to be a highly polluted and degraded environment, and one which will continue to deteriorate with regard to flooding, spread of pollution to the Bay, increased risk to health, possible catastrophe, increased difficulty to control the situation, and a decline aesthetic characteristics. Note that these trends reinforce the participant responses to questions 5 and 6 which indicate that, historically, the situation has been deteriorating.

Question 2b asked participants to envision a future in which there was no problem. This elicited statements[5] about the aesthetic beauty of the river and the city (10), the river as a resource for tourism (5) and recreation (11), a freely flowing and navigable river (10), the absence of slums (2), a healthy environment (5), absence of sewage (6) and solid waste (2), flood protection (3) and an environmentally friendly city (10). The responses, however, did not come equally from the government, NGO, academic, and 'other' groups. First, several participants (four from government agencies, one academic and one in the 'other' category – a reporter) did not respond to this question. Second, 34% of these partial visions of a problem-free future came from NGO representatives, who accounted for only 18% of those participating in the exercise (including those who did not respond to the question). 'Other'

[5]The frequency of these statements is indicated in parentheses.

Table 3.8: Questions 2b and 8 responses: "What would the problem look like if it were solved?" and "What would happen if nobody did anything to solve the problem?"

What would the problem look like if it were solved?

- "...the aesthetic glow of Cooum will [be a] mark of beauty on the geography of Chennai"
- "The river will be pleasant, attracting tourism."
- "People will be free from the mosquito menace."
- "The city will look beautiful."
- [The river] "itself could become a positive parameter and facilitate storm water drainage, rain water harvesting and ground water recharged, and navigation and recreation."
- "Serious flooding problems can be avoided and spreading of epidemics will come under control."
- "the clean waterway ... will be a greenway *cum* tourist spot for the Chennai inhabitants. It also serves as a[n] open space/living space for the highly dense city."
- "...the river or river bed could be free from flow of sewage and the entire area serve as a[n] open space to provide free flowing fresh air and add to the acceptability of the city as a city of people who are prepared to solve environmental problems."
- "Environment friendly Cooum water front with surface mobility and flood defenses."
- "... a legacy regained and restored."
- "An open watershed of adequate environmental status contributing to additional living space."
- [The river] "might provide an inland waterway system."
- "A place for fun, frolic and recreation. [It will] make Chennai one of the graceful, beautiful cities in India."
- "Slum dwellers will feel healthier."
- "... a cleaner, stench-free waterway, perhaps even permitting navigation."
- [After removal of the sandbar there will be:] "... free flow of water into [the] sea. [The river] will facilitate inland transport and recreating facilities, fishing activities, [and] parks along the banks."
- "The river Cooum will have more fresh, clean water."
- "The Cooum will become a fresh water, healthy river pleasant for boating, swimming, bathing, *etc.*."

What would happen if nobody did anything to solve the problem?

- "Cooum will continue to be an open stagnating sewer flushed occasionally during the monsoon flood flows."
- "May lead to higher flooding in future if sand bars are not cleaned."
- "A beautiful recreational facility within the city will be lost forever."
- "Environmental degradation [will] occur at the Bay of Bengal"
- "The [river] will become a bigger sewer and eventually create health problems and a stench thought the northern part of the city."
- "It'll worsen, endangering peoples lives."
- "We may experience [a] real catastrophic event."
- "A major resource of monsoon drainage [in] the city ... would be lost."
- [The] "city will be exposed to furthermore health hazards and environmental hazards."
- The pollution to the adjacent residents will be more and more, and [the] problem could not be controlled."
- "Due to non-flushing from [the] sea, the development of mosquitos could be more."
- "It'll cause an environmental disaster for the city. If the river is not made functional and to carry flood water, there will be severe inundation in and around the city during rainy season."
- "It will be a permanent eye sore to those who wish to live in a better environmental surrounding."
- [The problem] "will lead to the eventuality of a permanent environmental damage, leading to long term health effects."
- "This may cause health hazards to the public in large and may cause damage to the aquatic life of the sea."
- "The problems will [be] aggravated and ... [the situation of] flooding, unhygienic, unhealthy environment [will deteriorate] still further.
- "Nothing will happen! People will live, not bothering to do anything about it."
- "The problem will remain unsolved. It is simple as that. The consequences as time progresses would be severe. I personally feel this problem should be solved on a war-footing."
- "'HELL' will become a reality, and it will of course be Chennai city."
- "The 'river' would become a gutter and serous health problems would arise which could be difficult to solve as the investments would become heavy and patience of citizens would run out. This could lead to migration, flight of capital and slow lingering death for the city and its people."
- "Outbreaks of filariasis ... leptospirosis may occur."
- "...the flora and fauna that is existing will disappear."
- "Since the arterial drains are connected with Coovum river, at one point the city will be flooded with polluted water due to blockages."

citizens made 19% of the statements while accounting for 18% of participants. However, government delegates (38% of participants) and academics (27% of participants) were under-represented in their responses, accounting for only 33% and 14%, respectively, of these statements.

One might speculate that NGO delegates can more easily remove themselves from the context of the problem to envision a desirable future state than can government representatives who must deal with the day to day management of the problem, or academics concerned with understanding, and developing ‘solutions’ to, specific aspects of the present problem situation. Also, certain NGOs are in the business of expressing and promoting visions of desirable futures. For example, one of the participant NGOs in this research was “Exnora” whose name stands for “EXcellent NOvel and RAdical ideas” and which has the stated goal of “the generation of innovative ideas and implementing them, [to] help transform the society” (Exnora International, 2000). This is also an indication of the importance of including such groups in management efforts, especially at the stage where an understanding of the future states to be targeted, and objectives for management, are developed. It is possible that an overemphasis on the current situation and the use of techniques which project from this state, can lead to targeted futures which are merely projections of the present state. What needs to be identified are desirable and feasible future states, and not the most probable ones (Robinson 1990: 823).

Working Session 2: Toward a System Identification of the Cooum River and Environs – System Components, Linkages and Relationships

Immediate objectives and intended products

The second working session was oriented toward expressing the problem situation. The main tool employed to do this was the development of a ‘Rich Picture’ showing components and actors in the situation and their interrelations. Also, the second working session initiated the shift to from simple description of the real world to systems thinking.[6] The Rich Picture of the problem situation was intended to provide a reference and guide for further exercises, such as scoping the problem situation in terms of time and space, identifying and prioritizing objectives, and especially developing a framework to model this system dynamically in a computer-aided decision support system.

Once the Rich Picture had been developed, the second working session was designed to begin organizing participants' understanding of the problem situation in systems terms. In fact, the second and later iterations in the construction of the Rich Picture proceeded with some systems-based orientation. Systems understanding was furthered by the use of the Rich Picture as the context from which important "themes" in the problem situation were extracted, discussed and contextually developed in a systems-oriented manner.

The immediate objectives of the second working session were:

- To identify and define various actors, components, interactions and relationships within the problem situation.
- To develop a 'Rich Picture' of the problem situation (a graphical representation of elements, actors and relationships).
- To understand the "climate" in which elements and actors within the problem situation interact (*e.g.*, culture, values, norms).
- To identify themes seen as important by workshop participants within the Rich Picture.
- To begin to understand these themes in systems terms.

Method

The second working session built upon and organized the material developed in the first working session. It was undertaken in a one hour and forty-five minute session immediately following lunch on the first day (during which time the first working session

[6]If one were to compare these working sessions to the traditional 7-stage SSM, this exercise together with the first working session corresponded to stage 2 of Soft Systems Methodology, while the explicit break from description of the problem in 'real world' terms and the use of systems thinking to structure the problem situation moved the workshop into stage 3 of the methodology.

results were being collated and recorded). The second session started with a brief presentation of results of the Problem Identification exercise. These results were put on white sheets posted around the room and included (1) underlined key words from question 1 of the Problem Identification exercise, (2) circled key actors in solving the problem in question 2; and (3) other underlined actors in question 2.

From this context the Rich Picture was developed, and then used to focus debate on key themes in the problem situation. Guidelines followed in constructing the Rich Picture and using it to focus discussion in the second working session are presented in Box 3.2.

1. Begin to focus on the problem in terms of physical elements and then start building up a Rich Picture:
   a) Place the river on a large drawing sheet or board as the initial element. This will act as the anchor to relate the other components to.
   b) Choose another key component as directed by workshop participants and place it pictorially on the drawing sheet. Ask how it is related to the river? Is there a transformation involved? What is the nature of the transformation, if so? (What is the input, what is the output?). Represent these in the diagram.
   c) Ask participants if this component is relatively static, providing a structure for the system, or is it dynamic, that is a process which undergoes change?
   d) Is this a component which can be considered as acting to alleviate the problem situation or to exacerbate it?
   e) Ask what other actors or components influence or impact on this component? Illustrate this as well.
   f) Repeat this for all components.
   g) For actors in the situation, ask what activity or transformation is involved, but also, what is the value, norm or world view that makes this meaningful. *I.e.*, what is the purpose of the activity undertaken by the actor?

2. When no more components are being put forward by participants, begin to extract themes from the diagram:
   a) From the participants, draw out the components or set of components which they feel are most important within the situation and discuss what influence the activity or processes represented by these has on what is happening within the system.
   b) Ask questions related to these components as systems themselves. Use the CATWOE mnemonic to guide these questions.
   c) Try to identify different and multiple wider systems (of which the current system may be considered a subsystem) and environments.
   d) Try to identify subsystems within the system.

3. If time allows, and if it is judged that the participants would be receptive to such an exercise, develop root definitions and basic, verb-oriented conceptual models based on the extracted themes.

Box 3.2: Guidelines followed in constructing a Rich Picture of the problem situation.

Results

The Rich Picture of the problem situation is presented in Figure 3.2. The diagram was initially built up by operating steps outlined in 1 of Box 3.2 above. The development of the diagram proved to be an effective means of organizing the material generated in the first working session into a more coherent expression of the problem situation. The first working session had already stimulated participants to think about various aspects of the problem situation and the construction of a diagrammatic representation progressed from this naturally.

The Rich Picture, and the participatory manner in which it was developed, resulted in the diagram representing a common and agreed understanding of the problem situation. Each element and actor, and its interconnections and relationships, were open to discussion and revision in the open forum of the working session. After further development of this understanding, with the aid of systems-based concepts, the Rich Picture acted also as the common focus or symbol of the 'system' central to the problem situation. This was a product of the workshop that workshop participants could feel they had made a contribution to, but was also a team effort.

Throughout the workshop, the Rich Picture performed the role of a living and changing conceptualization – something that could be modified in a participatory manner whenever new information and understanding of the situation arose. Thus, once the Rich Picture was developed in the second working session, it took on a dual role: (1) to provide a flexible means of expression for the common understanding of the problem situation and system of interest, and (2) to stimulate and provide for participatory interaction among workshop participants.

Item 2 in Box 3.2 above describes the process followed to draw themes from the expression of the problem situation. Supplementary exercises described in Item 3 in Box 3.2 were not attempted due to insufficient time, and also because, in the judgement of the facilitator, the introduction of these explicit root definition and conceptualization exercises would not have worked well with this group of participants (as the exercises would have been too alien to them). The themes extracted from the expression of the problem situation were, however, explored through facilitated discussion which was heavily influenced by these SSM tools (although this would not have been obvious to anyone not familiar with SSM). In particular, elements of the CATWOE mnemonic were intentionally drawn out in discussion of various themes. These themes were: slum dwellers as polluters in the system; slum

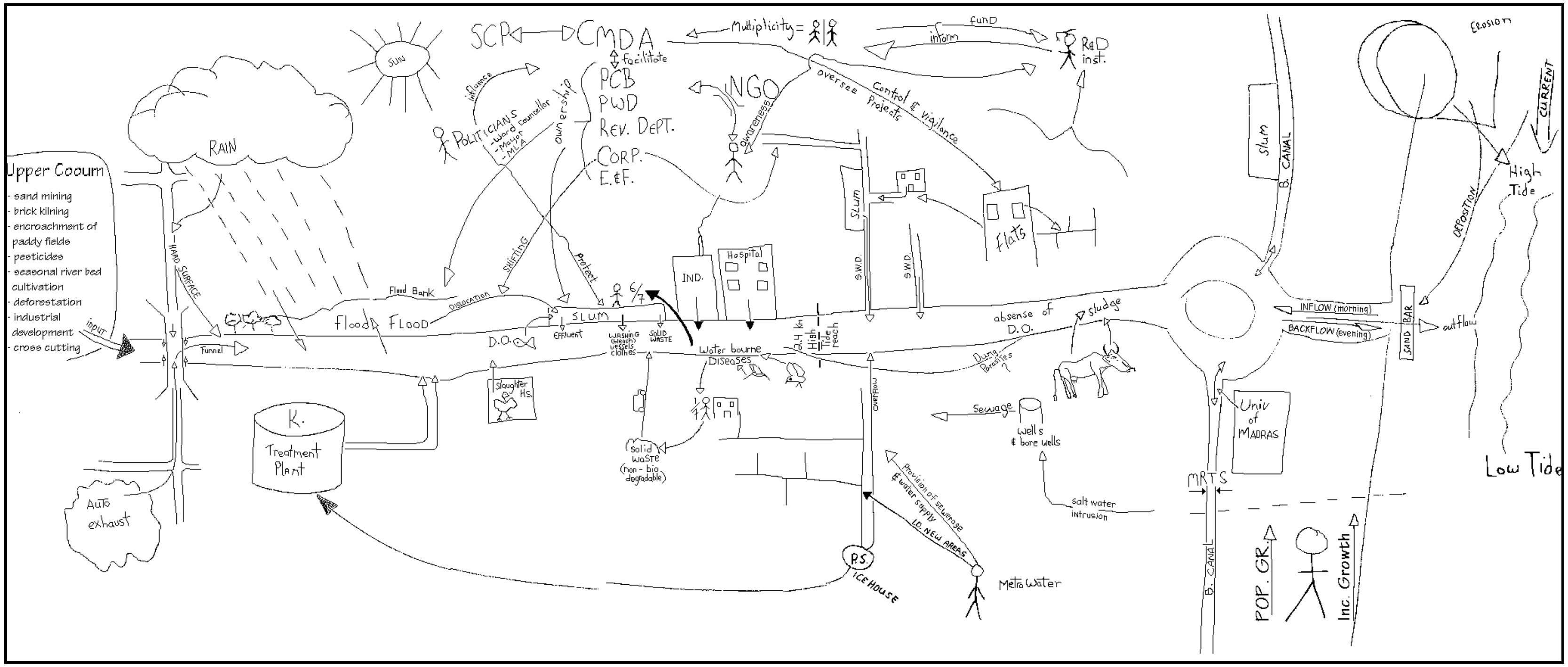

Figure 3.2: A Rich Picture of the Problem Situation.

This diagram is a Rich Picture of the problem situation developed by participants at the workshop (this version is a 'cleaned up' scanned image of a photograph of the original). The building of this diagram was facilitated by an interactive session and discussion on the first day of the workshop which was intended to provide an overview of the main components, actors and interrelationships within the problem situation. The diagram was transferred from whiteboard to paper after the working session and presented to workshop participants for a second time early in the second day of the workshop. At that point, some modifications were made by workshop participants. The diagram provided a reference to workshop participants and an aid to the holistic approach employed in the workshop.

This diagrammatic tool was not constructed as an explicit system model, but as its construction progressed, and especially later on throughout the workshop, it began to be used as a representation of a 'system' in the sense of a bounded whole with a particular spatial and temporal scope, and having an environment which influences and is impacted upon by the system. The representation of the upper Cooum as another system (or perhaps a subsystem within the same watershed as the system of the lower Cooum River and its urban environs) which provides inputs into the lower Cooum system exemplifies this. Representations of the moon having influences on tidal activity, which in turn has some flushing action in the river system, the sun, with relevance to rates of evaporation and periodic drought, rain clouds representing the impact of monsoons, and a population figure indicating population growth and changing levels of income in the population at large are examples of important influences from the environment of the system as perceived by workshop participants.

dwellers as squatters; the provision of sewerage services by the CMWSSB; the provision of water supply by the CMWSSB; the population of Chennai as polluters in the system; animal husbandry; the stormwater drainage system (SWD) as flood protection; the SWD system for sewage disposal; political protection of slums; agency intervention and control of activities; the hydraulic operation of the river; and tidal action.

Recall from Chapter 2 that CATWOE analysis is used to capture the essence of a human activity system by focussing on a Transformation occurring due to human activity, identifying victims or beneficiaries (Customers) of that transformation, recognizing the Actors involved in the Transformation and the *Weltanschauung* that makes it meaningful in the context of the system, specifying the Owner of the system who has the power to stop the Transformation from occurring, and indicating the Environment of the system which is taken for granted, *i.e.*, the context in which the Transformation occurs. Since CATWOE analysis was employed to draw out the themes, and it captures their root characteristics, the mnemonic is used to present a summary of the discussion of these themes below. Themes (that can be modelled as Human Activity Systems) that were extracted from the Rich Picture are:

- slum dwellers as polluters
  - C slum dwellers
  - A slum dwellers
  - T waste in need of disposal –> waste disposed of
  - W it is convenient and acceptable to discard solid waste and wastewater on the banks of the river, directly into the river, and into storm water drains
  - O Tamil Nadu Slum Clearance Board
  - E un-serviced slum hutment areas as the location of household activity

- slum dwellers as squatters
  - C slum dwellers
  - A slum dwellers
  - T unoccupied land on river banks –> occupied land (as "objectionable land use")
  - W in the absence of affordable housing, any unoccupied land may be settled
  - O Tamil Nadu Slum Clearance Board
  - E cities as the location of employment, economic constraints of the economically weaker section of society

- provision of sewerage services by the CMWWSB
  - C citizens of Chennai
  - A Chennai Metropolitan Water Supply and Sewerage Board
  - T areas in need of service by a sewerage system –> properly serviced sewered areas
  - W sewage should be properly treated before release into the environment
  - O Chennai Metropolitan Water Supply and Sewerage Board, legislators
  - E limited budget, some areas are inaccessible (*e.g.,* objectionable lands)

- provision of water supply by the CMWSSB
  - C citizens of Chennai
  - A Chennai Metropolitan Water Supply and Sewerage Board
  - T areas in need of adequate water supply –> properly serviced and supplied areas
  - W households in Chennai should be provided with at least the Indian minimum standard of water consumption
  - O Chennai Metropolitan Water Supply and Sewerage Board, legislators
  - E limited budget, some areas are inaccessible (*e.g.,* objectionable lands), local sparsity of water during non-monsoon season

- the population of Chennai as polluters
  - C citizens of Chennai
  - A citizens of Chennai
  - T waste in need of disposal –> waste disposed of
  - W waste should be disposed of in the most convenient and least costly manner to the household
  - O Chennai Metropolitan Water Supply and Sewerage Board, Chennai Metropolitan Development Authority, Corporation of Chennai
  - E inefficient sewerage system (with connection charges), storm water drainage accessible in many areas

- animal husbandry
  - C citizens of Chennai (tea shops, hotels/restaurants, middle and lower class citizens)
  - A cattle and buffalo owners
  - T fodder and organic waste –> milk and dung
  - W cattle and buffalo (and their waste) are acceptable hazards in the streets so as to have locally produced milk
  - O Chennai Metropolitan Development Authority, Corporation of Chennai, legislators
  - E existing milk distribution system and tradition of animal husbandry in Chennai

- the storm water drainage system as flood protection
  - C citizens of Chennai
  - A Corporation of Chennai, Tamil Nadu Public Works Department
  - T_1 un-routed rainfall runoff –> runoff routed to waterways and the ocean
  - T_2 flood-prone areas –> flood protected areas
  - W flooding should be averted
  - O Chennai Metropolitan Development Authority, Corporation of Chennai, Tamil Nadu Public Works Department
  - E climate (monsoon), topography of the Chennai region (flat, low-lying)

- the storm water drainage system for sewage disposal
  - C citizens of Chennai, commercial enterprises and small-scale industries
  - A citizens of Chennai, commercial enterprises and small-scale industries
  - T waste in need of disposal –> waste disposed of
  - W it is convenient and less costly to dispose of wastes into the storm water drainage system
  - O Chennai Metropolitan Development Authority, Corporation of Chennai, legislators
  - E lax regulatory environment relating to the disposal of waste, inefficient and more costly sewerage system

- political protection of slums
  - C slum dwellers
  - A politicians, government agencies
  - T slums in danger of clearance –> slums protected from clearance
  - W slums and the economically weaker section of the population constitute a strong potential voting constituency
  - O legislators, state high court
  - E larger political and societal systems

- agency intervention and control of activities
  - C government agencies, citizens of Chennai
  - A officers at government agencies
  - T problem in need of action –> problem defined and addressed within agency's jurisdiction
  - W problems falling within the jurisdiction of the agency should be addressed by the agency without interference or sharing of control with outside bodies
  - O legislators, government agencies
  - E institutional culture, sectoral and areal jurisdictional divisions

The identification of these themes, which can also be seen as subsystems of the Cooum system, helped workshop participants to focus on key activities and components of the situation – that is, to begin to deal with the complexity of the problem through systems thinking (using such concepts as hierarchy, transformation and control).

In addition to identifying some structure in such a complex situation, this exercise also generated new information. This not only has to do with new insight into the various subsystems or themes that participants discussed, but the process of drawing themes out of the Rich Picture also contributed to its further development. For example, in singling out and discussing slums as a component and slum dwellers as actors within this context, new information emerged regarding the relationship between slums and the protective actions of politicians, (such as ward councillors, the mayor, members of the legislative assembly). Politicians as actors within the problem situation had previously been missed. This new information was, therefore, incorporated into the Rich Picture diagram.[7]

This modified application of CATWOE analysis, on the other hand, proved insufficient to deal with themes that could not be modelled as Human Activity Systems. Thus, discussion of the two ‘physical' themes were structured around a description of the main process(es) involved, its characteristics and factors or system elements which affect its operation. Primary characteristics of the two physical themes identified by workshop participants during the second working session are;

- the hydraulic operation of the river
  - the topography of the region (being very flat) leads to low rates of flow
  - non-monsoon flow is from treated and untreated wastewater (upper Cooum is dry)
  - there is a blockage by a sand bar at the mouth of the river which restricts outflow
  - stagnation due to the previous 3 points occurs in the lower reaches
  - due to low flow and stagnation, large amounts of sludge are deposited in the river
  - the river is subject to monsoon flushing during the north-east monsoon
  - there are numerous constrictions of the river, *e.g.*, due to bridges and debris dumping
  - the river sometimes overflows its banks during the north-east monsoon, especially near the city limits

[7] In the traditional 7-stage SSM model, this would be seen as an iteration between stage 2 and stage 3.

- tidal action
  - some tidal flushing occurs from inflow and backflow of seawater into the mouth of the Cooum
  - tidal flushing is impeded by the accretion of sand bars at the mouth of the river
  - the limit of tidal influence is 2.4 km upstream
  - mixing of seawater occurs at low velocity

The identification of the theme of tidal action also led participants to discard it as a critical subsystem. During discussion about the theme there was some debate about the potential for tidal flushing to clean out the lower reaches of the Cooum river. The general consensus that came about in this discussion was that (1) the sand bar usually blocks the mouth of the river, so that tides are not an issue, and (2) if the sand bar were to be removed, then the tidal variation is small, and the rate of change in elevation of sea level so slow, as to result in very low velocity mixing of sea water. Thus, tidal flushing has minimum effect on the problem.

Identification of the other physical subsystem, having to do with hydraulic aspects of the river itself, was seen by participants to be much more central to the Cooum system. This acted as a main subsystem to which participants related all the others. While the Cooum 'system' began to be understood in this session as much more than a physical system (as evidenced by the themes drawn out in the CATWOE analysis), the river itself provided a core structure to it. Also, it was the quality of the water in the river that participants perceived as a main indicator of the condition of the larger Cooum system.

Working Session 3: Scoping the Problem Situation – Spatial and Temporal Scales

Immediate objectives and intended products

The third working session consisted of a scoping exercise. This was directed toward bounding the system in time and space. The idea of scoping in this context was not to fix upon some physical boundary and planning horizon, beyond which the research would not focus. Rather, the exercise was directed toward developing a qualitative understanding of the spatial and temporal extent of components, activities and processes associated with the system (although representing the system in a simulation model would eventually force a more operational definition of these). As with other working sessions, this process was informed by debate and a series of papers presented throughout the workshop.

Building from a review of Day 1 analyses, the first objective of the working session was to delineate the spatial extent of the system and outline its spatial hierarchy. Similarly, the temporal dimensions of the system were to be debated to set time horizons for goals and objectives to be modelled for scenario analysis. Accordingly, the working session was intended to produce an evaluation by workshop participants of (1) the spatial extent of individual components of the system, (2) the temporal extent of processes of the system.

Also, out of this working session would come a set of descriptive labels for the system which might present a simple description of the basic nature of the system, and which defined the observers' perspective of it. This exercise was intended to capture the root meaning of the system – its function, purpose or role.

Method

Participants were briefed by the facilitator about bounding the system and were asked to note on working sheets (from the workshop materials package) the 'footprint' of components or elements of the system, and the extent in time of processes and activities occurring within the system. In addition, workshop participants were asked to consider critical processes within the system which could be used to characterise it. They were then to label the system.

Box 3.3 provides general guidelines followed in undertaking this session. Also, in briefing participants at the beginning of this working session the following points were made:

1. What is the boundary of the system in physical space?
   If we were to "draw a line" between what we consider aspects of the "system" and what we view as its environment, where would it be drawn?

   Consider this for;
   (1) Physical components of the system.
   (2) Human components of the system.

2. What is the extent of time that we should be consider with regard to this system?
   (1) Identify rates at which processes operate within the system.
   (2) Identify rates at which the system as a whole might change.

3. Identify the system:

What kind of a system is this? *E.g.*, Is it a river system? Is it an urban system? Consider all of the components and relationships in the system as it has been defined so far in this workshop and give it a label which defines what is of interest to the observer of this system.

This labelling:

(1) Will define our perspective in relation to the system.

(2) Is likely to illustrate an emergent property of the system.

1. From the first working session problem identification exercise, post and review:
   a) a list of locations of the problem (from question 4)
   b) indications of when it is a problem (from question 5)
   c) indications of how long it has been a problem (from question 6)

2. List main components and actors within the system and define their spatial extent. Using the 'Rich Picture' of the system as a reference, have workshop participants identify main components of the system. Itemize these on the working sheet provided. For each component, describe the physical extent of the component within the system. Note that boundaries do not necessarily have to coincide with each other (the system as perceived and defined by its observers does not necessarily map neatly onto the physical reality in space).

3. Identify rates at which processes and activities operate within the system. Using the Rich Picture of the system as a reference, have workshop participants identify main processes and activities within the system. Itemize these on the working sheet provided. For each process and activity describe the time period involved in undertaking the activity or cycle lengths of process, *etc*.

4. Systems are often identified in terms of "emergent properties," that is properties of the system evident for the system defined as a whole, but absent in its individual components. Can we define this system in such a way? Have workshop participants consider whether there is an activity or process which characterizes the system – then answer the following question:

What kind of a system is this? *I.e*, Is it a river system? Is it an urban system? Is it a waste disposal system? (You don't have to restrict yourself to these labels – be creative!). Consider all of the components and relationships in the system as it has been defined so far in this workshop and give it a label which defines what is of interest to the observer in this system.

Box 3.3: Guidelines for working session 3 - scoping exercises.

Results

The results of the scoping exercises in Working Session 3 are presented in Table 3.9. As with the previous results, these are a summary and categorization of statements made by workshop participants as recorded in the working session response forms. Participant responses in this exercise describe spatial and temporal characteristics of components and actors of the system.

The identification of spatial and temporal scales related to the components of the Cooum system helped to further define the system. For example, this exercise led to the identification, in debate following the session, of some elements as existing outside the main

Table 3.9: Results of spatial and temporal scoping exercises.

System Component	*Extent in time and/or space*
Water supply and sewerage system/ Infrastructure	• Daily: peak flow • Seasonal: dry weather flow/flow during rains • Pressure at delivery point [areal variation], Network within the city, supply zones • Treatment, effluent discharge (collection, point source outfalls at treatment plant and pumping stations and non-point source outflow) • Along the Cooum River, both sides • Continuous process of accretion and deterioration of the system
Citizens of Chennai/population	• Ongoing problem, not time bound • Non-point source addition of effluent to the city [non-sewered areas] • Effluent addition to sewage component [in sewered areas] • Within city limits • Pattern of land utilization (changes on an 80 to 100 year time scale) • Generation of solid waste (daily disposal)
Industry/Slaughterhouses	• Ongoing problem, not time bound • Effluent point sources within city limits • Environmental impacts in city and beyond, coastal area
Slum dwellers/Hutments	• Ongoing problem, not time bound • Can have very fast process associated: settlement, clearance • Within sewerage and storm water catchment areas • Along banks, especially (non-point source pollution)
Storm water drains	• Catchment areas along both sides of the Cooum • Network of drains within the city
Bio-system (*e.g*., mosquitos, frogs, pigs, dogs, buffalo/cattle)	• Within about 1km of the river • Insects/Water bourne disease: entire stretch of Cooum • Vectors: seasonal (pre/post monsoon), occupies entire city • Cattle menace: Concentrated in hutment areas, worse during rains • Within river course: aquatic weeds, nutrients, parasites
Sewage	• Throughout the city where it is generated
Solid waste	• Within city limits; At locations of Slum, Hospitals
Hydrological component (surface water)	• From the source to the sea, along the river reaches, within river channels • Daily hydrological processes, seasonal peaks of flow (annual) • Flood/Drought cycles are stochastic
Encroachments/Debris	• Along banks of the river, Building materials from within city dumped in Cooum
Context/External Influence	
Tidal flow	• Daily: spring tide, reap tide • Full, New moon/Monthly variations • Yearly: minimum and maximum variations • Effect at the mouth and up to 2.4 km upstream
Rainfall and flooding	• Yearly (also 5, 25, 50, 100 year events) • Extent falling within city limits affects the system • Damages [inundated areas] • Flood dams, flood defences [localized constructions]
Sandbar	• Slow process of accretion • Influencing effect reaching upstream (blocking flow, spread of water upstream) • Effect of bounding (preventing entry of tidal water)
Institutional Arrangements P.W.D., CMWSSB (Metrowater) CMDA, TNSCB, Corporation	• Annual, perennial time scale, (sometimes periodic) • Reaches of river within city limits • City limits [jurisdictional boundary]; CMA
Government/legislation	• Legislative affects to have same spatial extent as the component/actor that it affects
Economic (production/employment)	• 25-30 year time scale
Ground water	• 1km on either side of the river

focus of interest in the situation. These should be treated as part of wider systems or environment of the lower Cooum system. They were: the climate (monsoon and dry season), coastal currents and interaction with the Chennai port, areas and activities outside of the sewage collection area and urban stormwater catchments in Chennai. Other aspects of the situation were identified as having a long temporal scale, and so were considered to belong to wider systems. For example, economic activity in the city was identified as operating on a 25-30 year time scale. In general, participants identified processes and activities in the system which operated on daily, seasonal, and yearly scales, and indicated associated structural components and actors that exist within the city limits.

Additionally, it was noted that future studies might treat the lower Cooum (urban) watershed as a subsystem together with other subsystems (*e.g.*, the Adyar watershed) within the Madras basin. Thus, this scoping exercise contributed to further conceptual structuring of the situation, identifying a hierarchy of relevant systems at the same level as the Cooum system, which together comprise a wider system one level up from the system of interest.

The scoping exercise also led participants to discuss differences between the upper part of the Cooum catchment and the lower system within the city limits. This would later (in working session 5) lead them to exclude the upper part of the Cooum River catchment (outside of the city proper) from their notion of the 'Cooum system.' The upper Cooum was identified as a separate system having unique characteristics quite different in nature from the lower Cooum system. Participants argued that it should, therefore, be addressed separately. The relationship of the upper and lower Cooum systems was considered to be defined by the quality and quantity of input to the lower Cooum at their joint boundary (the city limits). Appropriate modifications were made to the Rich Picture to reflect this.

In addition to the identification of spatial and temporal scales associated with components of the system, participants were asked to provide a label for the system as a whole. Systems are often identified in terms of "emergent properties," that is properties of the system which are evident for the system defined as a whole, but are absent in its individual components. One part of the scoping exercise was directed to defining the system in such a way. In this exercise, participants were asked if there was an activity or process which characterizes the system, and then to state in a short phrase what kind of a system it is. That is, they were to consider all of the components and relationships in the system as it had been defined so far in the workshop and give it a label which describes what is of interest to the observer of this system. After reducing repetition among responses, the labels for the system were as presented in Box 3.4 below:

Urban	River system *cum* sewer system
Urban system	Water supply and drainage system for the city
Urban river system	Waste disposal system
Metropolitan Ephemeral River System	'Recycle' system involving natural & human-use systems
River system	'Undefined ecosystem' in an ecologist's viewpoint

Box 3.4: System labels from working session 4.

Most participants saw the system as being defined by its urban characteristics and/or its urban waste carrying role. More participants (67%) saw the system as an 'urban system' or some sort of urban waste disposal system than as a 'river system' or system defined only by its storm water drainage function. This is significant. It is an indication that workshop participants had begun to expand their conception of the system from a primarily physical one, to a system which includes integral human characteristics. It is also important in determining on which of the identified components, actors and relationships to focus to model the essential structure and processes of the system, and in generating objectives and interventions for management.

Working Session 4: Setting Goals for Rehabilitation and Management of the Cooum River

Immediate objectives and intended products

The fourth working session was intended to generate a set of goals and objectives to guide intervention in the system. These were informed by debate and discussion during working sessions and paper presentations, by expression of the problem situation and visions of the problem solved, and also by conceptualization of the problem situation which represents the system in its current state. Goals and objectives drawn out in this session were intended to express aspects of workshop participants' vision of how they would like the system to be. These were related to variables (indicators) which may be used to monitor and evaluate management intervention effectiveness in achieving the stated objectives.

Thus, intended products from this working session were (1) a set of objectives for management and rehabilitation of the Cooum River and environs, (2) a corresponding set of indicators for these objectives which could be used to evaluate management scenarios, and (3) a prioritization of the various objectives.

Method

Objectives for rehabilitation and management of the Cooum system were generated by a facilitated 'brainstorming' exercise. The generated objectives were then discussed with participants in terms of (1) specificity, (2) measurability, (3) results orientation, and (4) obtainability. The purpose of this facilitated discussion was to narrow the list of objectives, and to associate objectives with indicators. Workshop participants examined objectives along these same lines before prioritizing them by way of pair-wise comparison. Working sheets were provided for these last 2 exercises, which were undertaken individually by

1. Facilitate a "Brainstorming" session to generate a set of objectives for rehabilitation and management of the Cooum River and environs. Record these on large paper sheets.

2. Narrow the list of objectives by facilitating a discussion of each, having participants consider the following questions:
    Is it specific – can it be stated in a more concise way?
    Is it measurable? How might attainment of the objective be indicated?
    Is it results-oriented? (As opposed to stating an activity?)
    Is it realistic and attainable (within what time frame: Immediate? 5, 10, 15, 20, 50, 100 years? Never?)

3. Assign an indicator variable for each objective (this may be done in connection with 2 above).

4. In preparation for comparing and ranking objectives, have participants individually reassess each objective by answering the following questions as indicated on the sheet provided:
    Is it specific – can it be stated in a more concise way?
    Is it measurable? What is the variable measured?
    Is it results-oriented? (As opposed to stating an activity?)
    Is it realistic and attainable (within what time frame: Immediate? 5, 10, 15, 20, 50, 100 years? Never?)
    Who will do it?
    Who will benefit?
    When will it happen?
    How will you know if it has been successful?

5. Have workshop participants prioritize the objectives using the pair-wise comparison matrix provided for this purpose. The scores in these matrices will be tallied, summarized and presented to the participants.

Box 3.5: Guidelines followed for facilitation of the fourth working session (after UNCHS, 1991: 69-71).

workshop participants. Box 3.5 presents guidelines followed in conducting the fourth working session.

Results

The brainstorming exercise, which was undertaken as the first activity during the fourth session, produced a list of both indicators and objectives. There was some confusion among workshop participants about the distinction between objectives and indicators. The distinction had to be sorted out during the facilitated discussion intended to reduce the objectives and to associate indicator variables with them. Objectives and their indicators have been separated below, and clarifications made based on participant discussions and debate. In all, 15 objectives and associated indicators were generated. These are presented in

Table 3.10: Objectives and associated indicators for rehabilitation and management of the Cooum system.

	Objective	***Indicator***
1.	Improved land use and enforcement of zoning regulations	% of land with best designated use (interim measure)
2.	Construction of recreational facilities to make use of the Cooum as a recreational resource	Construction of walkway (metres of pathway)
3.	Maintenance of the river course as an operational waterway	Presence of water in channel to 20 km upstream
4.	Increase recreational use of the Cooum and environs	No. of people using
5.	Ground water recharge	Water table change
6.	Prevention of encroachment, Beautification and Ecological enhancement	No. of trees planted (particular species)
7.	Improvement of surface water quality in the lower Cooum system (within city limits)	D.O., incidence of pollutants: heavy metals, BOD, S.S., pH, salinity, chlorine, pathogens
8.	Inland water quality [improvement of surface water quality in the upper Cooum system]	D.O., incidence of pollutants: heavy metals, BOD, S.S., pH, salinity, chlorine, pathogens
9.	Improve flood defences	Flooded area from overflowing
10.	Decrease in water- born disease	Incidence of malaria, filariasis, *etc*.
11.	Increase public awareness and political will regarding rehabilitation and maintenance of the Cooum river and surroundings	Resources to Cooum programmes
12.	Increase in physical quality of life	Longevity
13.	Vector control	Mosquito density
14.	Make the river navigable	Maintenance of water depth [depth of water along the course of the river]
15.	Environmental improvement of slum areas	Metres of road/drain, # of street lights in slum areas

Table 3.10.

An attempt to prioritize objectives through the use of pair-wise comparison matrices, in which workshop participants systematically compared objectives to each other, and indicated whether the current item was more important, less important or equal in importance to the compared objective, was not successful. Workshop participants seemed to find this exercise extremely abstract or complex, and most did not complete the exercise. Dr. Subbiah (Department of Geography, University of Madras) commented about the exercise that "some [participants] may not have understood the relevance of using a logical method like the comparison matrix to rank objectives." It is the researcher's own observation that most participants found the pair-wise comparison exercise to be unfamiliar and perhaps even intimidating. It is possible that this exercise would have been more successful if it had been presented in a more participatory manner (such as a facilitated comparison exercise), or if a different method of attaining relative weights was tried.

Because of the failure of this part of the working session, a prioritization of objectives for management interventions was not obtained. However, the session still produced useful information. The list of objectives in particular provide insight into preferences and values of workshop participants. These can be used to illustrate aspects of the vision that workshop participants had of desirable future states of the Cooum system. For example, objectives 2, 4, 6, and 7 have to do with beautification and development of the river for recreation, indicating a vision of a Cooum system that attracts residents as a resource for recreation. Similarly, objectives 3 and 14 in Table 3.10 express a vision of a navigable river. Aspects of desirable future states which these objectives express include: a healthy population; a safe and health-promoting environment; an aware and involved population; the river as a recreational resource; the river as a navigable waterway; and, the Cooum as a clean river.

Working Session 5: Group Sessions – Generating Management Alternatives for Use in Scenario Analysis

Immediate objectives and intended products

The fifth session was designed to itemize possible management interventions in the system. It was also intended to allow for some exploration of these through small group discussion among participants, and also in the larger workshop context. Thus, the main intended product of the workshop was a description of possible changes and interventions in the system, described in terms such as (1) physical description of the intervention (or other change), (2) effect on the system (direction and estimated magnitude), (3) temporal scale of implementation and operation, (4) actors: beneficiaries, implementing agencies, regulators, *etc*., and required resources.

The possible interventions generated by participants in this working session were intended to inform the development of a computer simulation model. The interventions could then be further explored through scenario analysis. The fifth working session, therefore, sets the stage for operationalization of the conceptual model.

Method

Workshop participants were divided into four groups, each of which was to discuss several interventions (or other changes in the system) oriented toward objectives in one of the areas of:

- Hydrology
- Urban Infrastructure
- Regulatory Environment
- Population

Workshop participants were given some control over group topics, but the originally suggested set of topics was acceptable to them. Participants divided themselves among the four groups according to their interests. Each group consisted of 6 to 8 workshop participants.

Each of the groups was asked to suggest several interventions. Each of the interventions should be associated with a particular objective for the intervention. Interventions were also to be discussed in terms of indicators, affected components of the system, implementing agencies or actors, time frames for interventions, and resources necessary for implementation. Working sheets were provided to guide the group discussion. Guiding questions included on the working sheets are presented in Box 3.6.

Working Sheet for group discussions on system interventions and evolutionary changes

Instructions to workshop participants on working sheets:

Describe the intervention (or other change) in the system using this sheet as a guide. Please be as specific as possible. Use another sheet for other comments and elaboration if necessary.

Guiding Questions:

Describe the intervention/change.
Which objective(s) previously discussed will this intervention address?
What indicator variables will be used to measure its progress or effectiveness?
What components of the system will this intervention/change or affect? How?
Who will implement this intervention?
What will be the time frame of this intervention/change?
What resources will be required to implement this intervention?

Box 3.6: Guide for group discussions on system interventions and evolutionary changes.

Once the groups had been given time to generate and briefly discuss several interventions, participants presented their interventions to the entire group. Comments and debate on the proposed interventions followed.

Results

Possible management interventions in the Cooum River system identified by workshop participants are listed in Table 3.11. These interventions and others were discussed throughout the workshop. Those listed below were generated specifically in the context of interventions which might be usefully modelled in a decision support system. Also listed are non-intervention changes in the system which should also be considered when modelling the Cooum River and environs. The interventions identified by participants are all physical interventions in the system. For example, participants indicated that the potential for recreation in the system might be bettered by greening and landscaping the river channel, and that water quality should be improved by upgrading sewage treatment plants.

The discussion of aspects associated with the interventions described above served mainly to reinform the system conceptualization to clarify some relationships between elements of the system, and to refine the overall conception of the system itself. The discussion of interventions in the system was a step toward operationalizing the system

Table 3.11: Interventions generated during the fifth working session

Possible management interventions in the system to achieve stated goals and objectives

- Upgrading of sewage treatment plants
- Linking of industries, commercial enterprises, houses, *etc.,* to the existing sewerage collection system
- Provision of collection systems to un-sewered areas
- Biological treatment of waste water (*e.g.,* autodigestives, grasses, weeds, mangroves, chromium bacteria)
- Clearance of slums
- Improvement of slums
- Construction of flood defences
- Proper collection and disposal of solid waste
- Removal of encroachments (*e.g.*, shops and other commercial enterprises, slums)
- Regulation of flow, *e.g.*, at Kesavaram Anicut and through barrages (also, desilting, re-sectioning)
- Removal of the sand bar at the mouth (to facilitate tidal flushing to 2.4 km upstream)
- Alteration of physical interventions in the river channel (such as constricting bridges and causeways)
- Greening/landscaping of river channel, banks and berms
- Vector control on the water surface

Other changes in the system which should be taken into account in a system model

- Increase in population density
- Settlement of new areas on the periphery of the city
- Increase of income of urban dwellers (corresponding increase in use of water)
- Increase in the water supply (*e.g.,* from the Krishna project)

conceptualization. For example, it was during discussion of interventions in the system (what interventions, where, and toward what end) that the upper Cooum system was separated from the lower Cooum system. The upper Cooum was seen as distinct from the lower Cooum, and the consensus was reached that it should not be considered in detail at this stage in the research. It was to be treated as an input to the system of interest.

Thus, the interventions which participants generated in this session were intended to inform management of the lower (urban) Cooum system. Similarly, participants indicated that the GIS database and simulation model should apply to the lower Cooum only.

Working Session 6: Matching available knowledge and data to possible management interventions

Immediate objectives and intended products

This session was intended to generate an outline of data requirements and assumptions associated with the potential changes and interventions generated in the previous session. It was also intended, time permitting, to outline the means of incorporation of these into a Geographical Information System database, and hydraulic and water quality simulation system. This session was, however, somewhat curtailed due to the incorporation of two short paper presentations by workshop participants on the final day, which were not originally scheduled. The working session was accommodated by combining the session with the first paper presentation of the day entitled "Basic Information for Cleaning of the Waterways" (Dattatri, 1998).

This paper by Mr. Dattatri addressed directly the issues of the working session. It discussed data availability and quality in the context of several "areas of information," including the Cooum River system, particular problems associated with the system, causative factors related to those problems, slum settlements, stakeholders and non-government sources of information, past projects and monitoring indicators. The paper and discussion also built upon Mr. Dattatri's experience in developing a project for a Community Information System (CIS) in association with the UNCHS (Habitat) Sustainable Chennai Support Project (INTACH, 1996).

Results

Although no significant new information directly related to data issues arose from this session and paper presentation, two important contributions were made. First, the working session played a key role in keeping workshop participants informed about the quality and accessibility of data upon which the GIS database and environmental simulation model are built. Recall that even though Lee (1993) stated that a larger error is acceptable in modelling in support of management than in traditional scientific work, it has also been stressed that users should have an idea of the error of simulation results, so that model output is not mistaken for accurate prediction.

Second, it was expressed during the working session discussion, and generally agreed upon by participants, that the operation of an information system such as that being developed for this program of research should be operated by a body outside of government agencies (such as an NGO). This idea has largely to do with data availability and accessibility issues, and is a double edged sword: Such an operation would provide more easy, open and free access to the data. However, there may be significant difficulty in acquiring data from government agencies, when it is known that the data will be freely distributed.

Working Session 7: Linking data, knowledge and models – What we can and cannot do, further steps in the research program, and workshop evaluation

Immediate objectives and intended products

As with the previous session, this one was somewhat modified to allow room for 2 additional paper presentations on the final day of the workshop. As a result, the seventh working session was combined with the final session. These are presented here together. Objectives of the seventh (combined) working session included the determination of further steps in the research, and a workshop evaluation. Other objectives had to do with linking data, knowledge and models with a framework for a system model. These latter objectives require brief discussion. One of the purposes of the workshop was to support the development of a simulation model and the construction of a Geographic Information System database focussed on the Cooum River and environs. This system was developed, following the first workshop, as a prototype decision support system for environmental planning and management of the Cooum system. Users of the model were expected to perform 'scenario analysis' with the system model to compare and evaluate the effect in the system of different management interventions, growth scenarios, and various sequences and timings of interventions in the system. A prime objective of this working session was to review the workshop in terms of how the framework for such a model had evolved over the previous three days, and to solidify the basic structure of such a model through discussion with workshop participants.

Method

Review and further development of the framework for a system model were undertaken by (1) a brief review of the work undertaken in the workshop, and (2) discussion of how this information supports the development of a computer simulation model of the system. A very basic structure for the working model was presented to participants for discussion. Workshop participants had already been introduced to the concept and development of the simulation model during a paper presentation on the second day of the workshop (Bunch, 1998). Following this, some of the main components and activities in the system were identified in facilitated discussion. This was to form the core of the prototype simulation model of the Cooum system.

Further steps in the research program were also addressed by way of facilitated discussion in the final working session. The workshop evaluation was undertaken by participant response forms which had been distributed to participants in their workshop materials package. Also, comments and discussion about the workshop and research program in general were invited during the final session prior to the valedictory address.

Results

Initially, the final working session discussed how the workshop had supported the development of the system model. From this discussion, several items can be identified, including:

1. The workshop provided for the development of a definition of a conceptual model of the 'system' to be simulated, as presented in the preceding sections of this chapter.

2. It allowed for input from a wide variety of professionals, managers, academics, representatives of the public (*e.g.,* in the form of NGOs) and government agencies, which has the effect of
   - ensuring that the system model was developed on the basis of expertise and experience of parties working and living with the problem situation,
   - giving legitimacy to the model (and a sense of ownership of it to participants), through a participatory process to build the foundations for the model.

3. It provided for the discussion of desirable and feasible interventions in the system, which may be incorporated into the simulation system and employed in scenario analysis.

4. It provided for the discussion of possible non-intervention changes in, and influences on, the system which may be incorporated into the simulation system and employed in scenario analysis.

5. From the definition of the 'system' and discussion of possible changes to the system, and from paper presentations and facilitated discussion, the workshop provided an indication of the data required to develop the simulation model and GIS database.

Thus, the activities in the workshop provided an indication and understanding of the main components and actors to be modelled, which in this session were identified as 'types' of systems relevant to the Cooum problem situation. These were defined as the population of the city, the sewerage system, the stormwater drainage system, the river system, and slums, with precipitation and the upper Cooum system acting as systems providing major inputs to the Cooum system. It also developed (1) a delineation of the spatial and temporal scope of these systems, (2) an indication of the data required to represent them in a GIS database and environmental simulation model, and (3) a set of potential interventions and changes to the system that should be modelled. It is this information, generated by workshop participants during this 3-day workshop, which gave shape at a fundamental level to a simulation model and decision support system for environmental management of the Cooum River and environs.

The components and activities identified as a framework for the system model are those which were seen by participants to be critical for the operation of the system, and without which the system could not be said to represent that which had been conceptualized throughout the workshop. Each of these may be conceived of as a system in itself and represents a particular perspective on the Cooum situation.. For example, the population system consists of the population of Chennai within the urban catchment basin of the Cooum, and within the sewage collection area (Zone III) of the Koyembedu STP. This population is involved in a transformation of water and food (inputs) into sewage and solid waste (outputs). Factors that affect how this process happens include the per capita water supply, and the level of income of members of the population. These system 'types' are outlined in Table 3.12. (They will be discussed in more detail in Chapter 4). The items in this table have been expanded with material from discussion in this and previous working sessions, and the paper presentations.

A discussion of further steps to be taken in the Cooum River Environmental Management Research Program led workshop participants to note the general focus and direction they thought the program should take. These were simply expressed as four overarching goals. The first three relate to direct support for efforts at management and

Table 3.12: Types of systems identified in the Cooum problem situation which serve as a framework for the Cooum River Environmental Management Decision Support System.

Type of system	*Processes*	*Factors Affecting Process*	*Data Required*
Population	Generation of sewage	Water supply Level of income Water consumed	Population by ward Income levels / income class by ward Water consumption by income class
Sewerage System	Treatment of sewage Routing of sewage	Capacity of STPs Efficiency of STPs Efficiency of sewerage system Area served and unserved by sewerage system	STP details (*e.g.,* capacity, efficiency) Sewerage catchments Sewerage network Sewerage network details (indication of efficiency, state of repair, *etc*.)
Storm Water Drainage System	Routing of rainfall runoff Routing of sewage (from overflow, illegal connections)	Capacity of storm water drainage system Area served and unserved by storm water drainage system Precipitation intensity, duration and frequency	Storm water drainage catchments Storm water drainage network Meteorological data
River System	Transport of storm water runoff Transport of STP treated effluent Transport of sewerage from overflow and SWD system Aerobic and anaerobic decomposition	River reach characteristics Upstream input water quality and quantity Outfall water quality and quantity	River network (reaches, distances, *etc.*) River reach cross-sections Flow measurements Water quality data
Slums	Generation of sewage	Water supply Level of income Water consumed Slum size (% of ward)	Population by ward Slum locations Slum size (population) Income levels or income class of slum population Water consumption by income class

rehabilitation of the Cooum River and environs. The fourth has to do with the management process, and the manner in which this research program operated. They were defined by workshop participants as:

1. Improve water quality
2. Assure free flow of water in the lower stretches (of the city)
3. Improve aesthetics of the system
4. Continue the stakeholder process and methodology

The participants' evaluation of the workshop was very favourable. However, only thirteen of the workshop evaluation sheets were returned. Scores were assigned by participants to 6 questions on which they could scale their opinions of aspects of the workshop from "not at all" effective, useful or appropriate (1) to "very much" effective, useful or appropriate (5). All questions had mean scores between 3.9 and 4.5 out of 5. Table 3.13 details this evaluation of the workshop. Of favourable comments by workshops participants, the most common was the successful participatory approach, especially regarding the success of bringing together the various stakeholders. Of concerns voiced by the participants, the possible problem of acquiring sufficient and appropriate data for construction of the GIS database was prominent.

Table 3.13: Participant responses to workshop evaluation questions.

Evaluation Question	Mean score (max 5)
Workshop effectiveness in stimulating thinking about the problem situation	3.9
Usefulness of the workshop working sessions in relation to this problem situation	4.4
Usefulness of systems concepts as employed in this workshop in relation to this problem situation	3.9
Appropriateness of papers presented in the workshop	4.2
Potential usefulness of a Geographic Information System database to support decision making about the Cooum river and environs	4.5
Potential usefulness of simulation modeling and scenario analysis to support decision making about the Cooum river and environs	4.5

Conclusions

The first workshop in the Cooum River Environmental Management Research Program was, overall, successful. All five of the workshop objectives, *i.e.*, (1) problem identification; (2) system identification; (3) generation of goals and objectives for management and rehabilitation of the Cooum River; (4) development of a framework for a system model; and (5) the facilitation of communication among actors in the problem situation were accomplished.

An important conclusion that may be drawn from the experience of this first workshop has to do with the usefulness of a diagrammatic representation of the problem situation. It was observed that the construction of this diagram, in a participatory manner, was very effective in expressing a common understanding of the problem situation. It served to organize all of the elements and actors which were itemized in the first working session and provided a coherent picture of the problem for reference and comparison throughout the workshop. Expression of the problem situation is the role of the Rich Picture within Soft Systems Methodology, so it is not surprising that this proved to be such a successful technique for identification and expression of the problem in this research.

In addition, the use of this technique served to draw participants together – all participants having cooperatively contributed to the development of the Rich Picture. In this way it facilitated the fifth objective of the workshop, that is, the generation of an atmosphere conducive to communication and cooperation. In fact, verbal feedback from participants indicated that this was a successful aspect of the workshop. Similarly, the fact that a wide range of key government agencies (who for the first time came together to discuss the Cooum issue at this workshop), as well as academics, NGOs and other citizens, all contributed equally from the beginning of the process, generated enthusiasm for what the participants referred to as the "stakeholder process."

Beyond expression of the problem situation, the Rich Picture also acted as a tool for conceptualization of the Cooum system. This use of a Rich Picture goes beyond its normal application in SSM. In this research the diagram evolved to represent the 'Cooum system' as systems thinking was applied to the problem situation throughout the workshop. This occurred because the Rich Picture was employed as a convenient reference to the problem situation by workshop participants throughout the workshop, and was continually modified as new information arose during working sessions and discussions. This representation, in the context of all of the discussion, debate and working session products, became not merely an expression of the problem situation, but as a conceptualization of the system of interest developed, it became "the Cooum system."

Not all exercises in this workshop worked as well as the Rich Picture. For example, the identification and prioritization of objectives for rehabilitation and management of the Cooum system were problematic. In particular, the use of a pair-wise comparison matrix is cautioned. A facilitated pair-wise comparison session, or a more simple ordering exercise, may work better. This did not prevent, however, the achievement of the more basic workshop objective of development of objectives for rehabilitation and management of the system.

A major product of this workshop has been the development of a framework for a system model. This framework, based on the conceptualization of the Cooum system, consisted of the minimum set of primary subsystems (population, sewerage system, SWD system, the river system and slums) which are required for the computer-based model to represent the 'Cooum system' conceived of by workshop participants. This GIS database and environmental model was developed following the first workshop in 1998, and prototyped at the second workshop in February 1999. The development of the Cooum River Environmental Management Decision Support System is addressed in Chapter 4.

4

A Prototype System Model – The Cooum River Environmental Management Decision Support System

Introduction

In this chapter, an overview is presented of the prototype *Cooum River Environmental Management Decision Support System* (also referred to here as the "Cooum DSS"). This loosely-coupled GIS and simulation model makes operational the conceptual model of the Cooum system generated in the first workshop in the Cooum River Environmental Management Research Program. It was intended to provide the facility for participants in the second workshop to explore the problem situation, and their vision of future states of the system, through scenario analysis. Both the process of developing the DSS and its use in exploratory scenario analysis contributed to the further development of a description of the socio-ecological system. (See Figure 2.1 to place this in the context of ecosystem approach employed in this work). Although this tool is currently oriented toward exploration and learning with regard to the study area and problem situation, it also involves the development of an extensive database, parts of which may have immediate utility for planners, managers, researchers and others in Chennai.

Developed on the basis of the framework generated in the first workshop, the Cooum DSS represents key components and processes of the Cooum system. It consists of a loosely-coupled GIS and environmental simulation model, with a custom graphical user interface

(GUI) and decision support module that ties them together. The Cooum DSS produces water quality indicators to reflect the state of the system. This reflects the primary and original concern of workshop participants with the environmental condition of the Cooum, especially the pollution of its waters.

The fundamental principles of the Cooum DSS, some of the more technical aspects of its development, the GIS database, the three modules which comprise the Cooum DSS, and the primary functions and calculations which are undertaken in operating the system are described below.

A Framework for a System Model

Primary subsystems and processes

A framework for a system model of the Cooum River system was developed during the first workshop. This framework is derived primarily from the conceptual model of the system which is represented by the Rich Picture of the problem situation and informed by working sessions, debate, discussion and paper presentations during the first workshop. The conceptual model identified the main elements, actors and interrelationships in the problem situation, and provided an indication of the spatial and temporal scope of the system to be modelled. It brought to the fore those elements and interactions which were perceived as most important in describing the system. Other output from the first workshop, which contributed to the development of the framework for a system simulation model, included an indication of preferred future states (or 'vision') of the system, related to objectives for management and rehabilitation of the system, and the generation of various interventions in the system which might achieve those objectives. Together these provide a general guide in the construction of the system model and decision support system by laying out system structure and process, and indicating changes to, and interventions in, the system that must be explored.

The first workshop also produced a set of themes which may be modelled as systems. The most important of these themes have been operationalized in the prototype

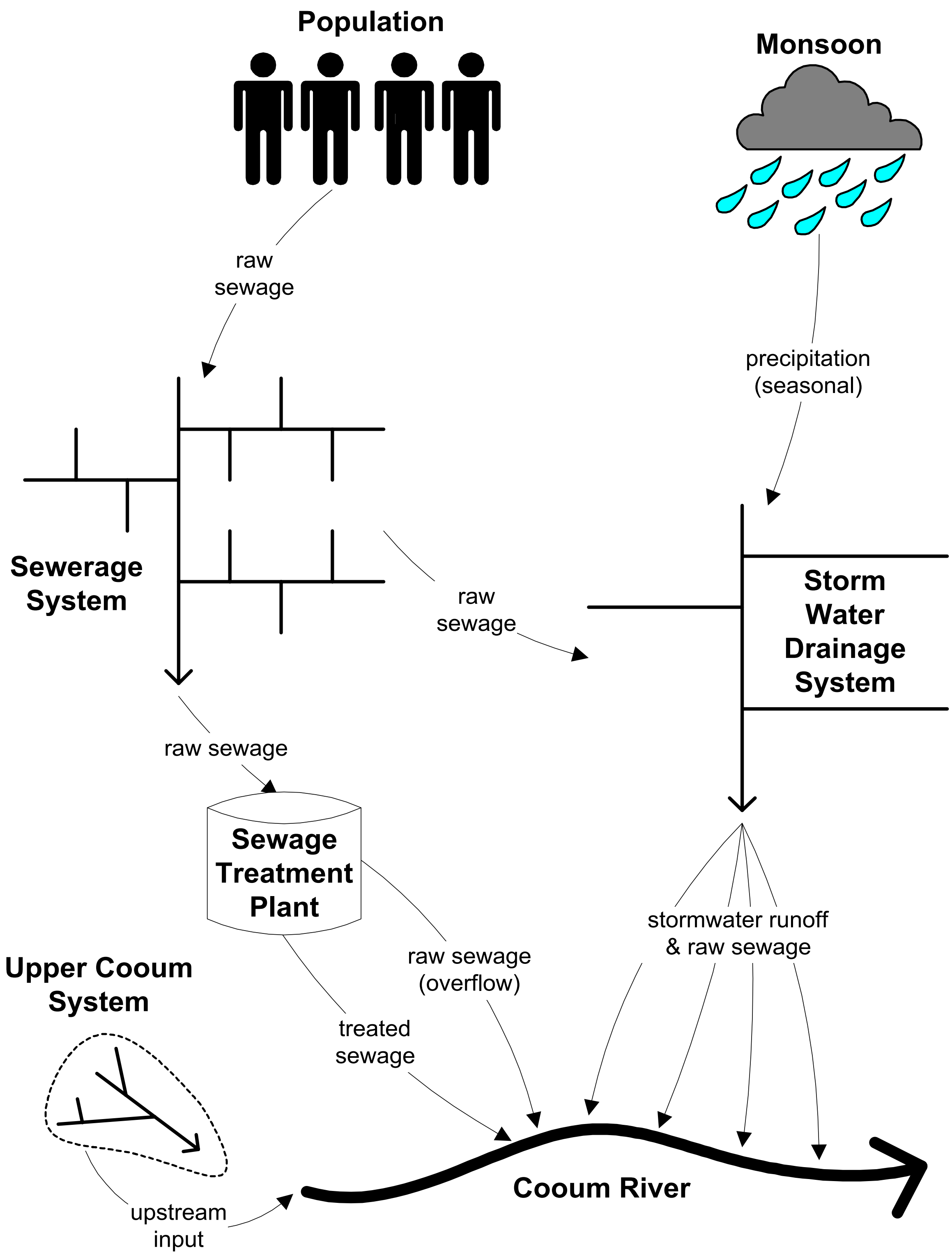

Figure 4.1: Core structure of the Cooum system as it emerged from the first workshop of the Cooum River Environmental Management Research Program. This provides a framework for the construction of a computer simulation model of the system.

system simulation model. These key themes include (1) the production of sewage by the population of Chennai, (2) the routing and treatment of sewage by the sewerage system, (3) the routing of runoff, (and sewerage overflow and diversions), by means of the storm water drainage system, and (4) the transport of stormwater runoff and sewerage effluent by way of the Cooum River. Another theme, slums, also arose as an important theme in the first workshop. The slum theme has to do with the production and disposal of sewage and solid waste in locations not serviced by the sewerage system. Although this theme was not seen as absolutely crucial for the basic functioning of the system, because of its persistence in discussion and debate among workshop participants it was deemed important enough to try to incorporate into the model. These key themes are represented in Figure 4.1.[1] A description of how they have been operationalized in the prototype Cooum DSS is presented later.

Flow of Data and Architecture of the Simulation Model

Figure 4.2 presents a conceptual model of the flow of data through a loosely-coupled GIS and environmental simulation model such as the prototype Cooum River Environmental Management Decision Support System. From the perspective of data flow, a core component of a coupled GIS and environmental simulation model is a GIS data library. This is a store of spatially referenced data, (in raster, object or attribute form), which may be queried and manipulated to produce parameters for input into an ecological or environmental simulation model. These site-specific parameters, as well as fixed parameters which are treated as unchanging for the purpose of model simulation, are input to an environmental simulation model which produces new data as output. The simulation results may be incorporated back into the GIS data library, where it can be used for visualization of data layers or model

[1]Economy is often represented as a key subsystem in models such as this one. However, in this research, economy did not emerge as a distinct subsystem. Participants in the first workshop discussed economic characteristics of the system (*e.g.*, income distribution, income growth) with regard to population. They also explicitly downplayed the importance of commercial and industrial activity in the context of the Cooum system. For this reason the framework that the participants generated does not contain an explicit economic subsystem. In this model it is mostly subsumed by the participants' understanding of the population subsystem. Use of the Cooum DSS, and further work in the second workshop resulted in participants more strongly emphasizing economy, primarily in the context of urban growth, employment as a 'pull-factor' for rural-urban migrants and tourism.

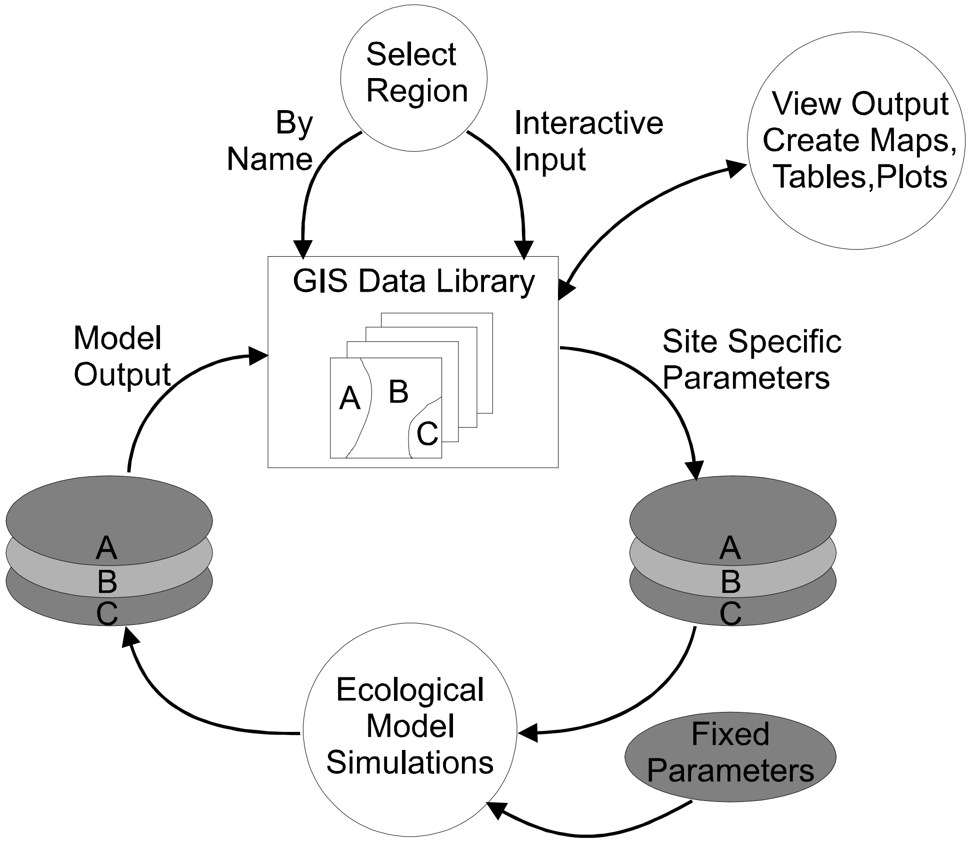

Figure 4.2: Conceptual design of the flow of data in an integrated GIS/ecological simulation model. (Source: Coleman *et al.*, 1994:406, Figure 24.4).

results, generation of map output, and further development of new scenarios.

Data flow in the prototype Cooum DSS fairly closely parallels the conceptual model of data flow described in Figure 4.2. The Cooum DSS consists of 3 loosely coupled modules linked together with data transport and parameter calculation routines. The GIS employed is GRASSLAND which provides the primary means of storing, maintaining and manipulating the data library. GRASSLAND also provides tools for visualization and query of data for exploration of the GIS data library by users of the system. The GIS data library consists of raster data layers, vector data layers and attribute files in ASCII text format.

Additional spatial attribute files are created and modified by way of the decision support module. The decision support module presents the user of the system with a graphical user interface (GUI) through which scenarios for management of the Cooum system may be manipulated (*e.g.*, opened, saved, created, modified). In terms of data flow, the decision support module provides a means to collect information from the user which affects how the environmental simulation model is parametized. Some spatial attribute files may be entirely constructed from user input in this module.

The third module in the system consists of the water quality simulator DESERT. Data from the GIS data library, prepared using the GIS and decision support modules, is placed into DESERT data (dBase III) files, together with fixed parameters of the system, and the model is run. This produces model output in terms of water quality and hydraulic data to an excel spreadsheet, to a text file, or to a computer monitor. It is possible to incorporate this information back into the GRASSLAND database (although automated routines to do this have not yet been developed by the researcher).

Although the loose-coupling of GIS with other software specific to a particular type of task such as statistical analysis or environmental modelling is not uncommon, there are some unique features about this particular combination. Certainly there is no evidence in the literature that GRASSLAND and DESERT have been used together, and this research demonstrates such a application. More interesting is the use of GRASSLAND GIS at all. This GIS is based on GRASS (Geographic Resource Analysis Support System) code. GRASS is a very powerful (primarily raster-based) GIS which runs on UNIX platforms. In the past UNIX platforms have been considered "high-end" workstations (though this is becoming less so as x86-based machines increase in power). They have been relatively expensive, and the use and maintenance of the operating system difficult, compared to typical Windows-based machines. Thus, despite the fact that GRASS if free, it has been denied to users who lack the resources or UNIX expertise to run it. This work, in employing a PC-based port of the GRASS code, demonstrates the accessibility and utility of GRASS code on low-end machines.

The modular design of this system provides flexibility for expansion and modification of the system. For example, if one wished to use a different GIS than GRASSLAND, it would be relatively easy to replace the whole GIS module. Similarly, one could "plug in" additional or alternative environmental simulation modules. Figure 4.3 presents a schematic

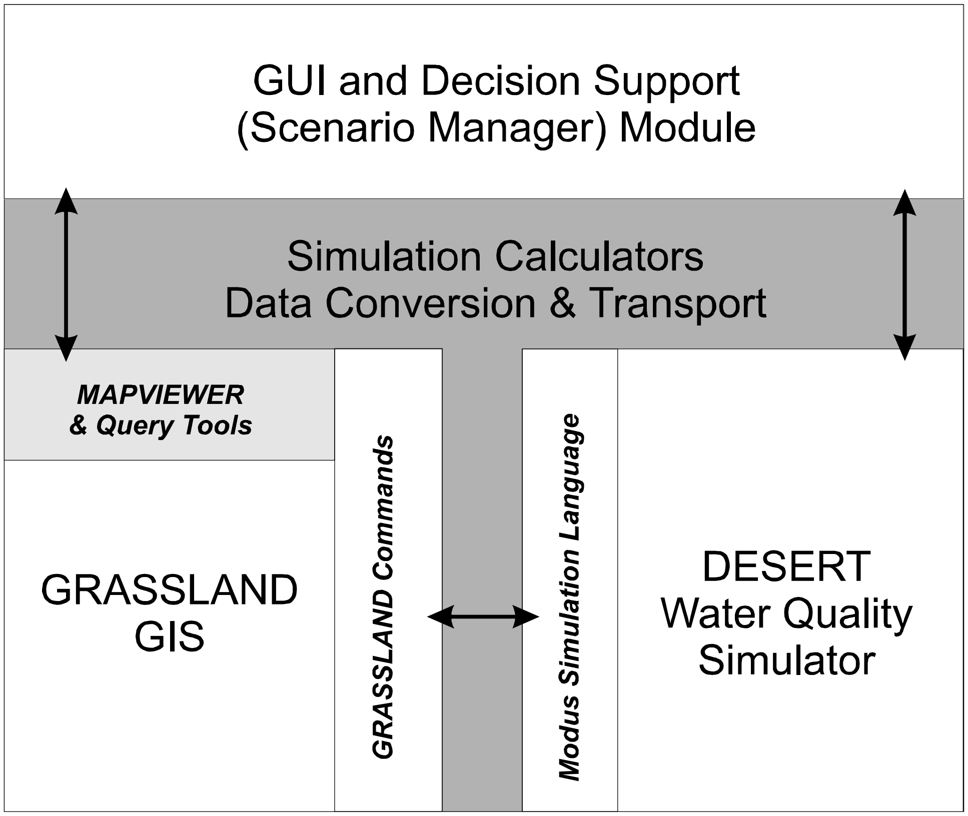

Figure 4.3: Coupled and modular architecture of the prototype Cooum DSS

representation of the coupled and modular architecture of the Cooum DSS. Each of the modules represented will be more fully detailed below. First, however, the software itself and the tools used to develop the system are described.

Software and Development Tools

The primary software and development tools employed for the Cooum DSS were chosen for a combination of their capabilities, affordability, and ability to run on 'low-end' computers. The development tools (Tcl/Tk and C/C++), for example, are powerful and versatile development languages. Tcl/Tk is free, and although the particular C/C++ tools used for the development of the Cooum DSS are commercial, many free or affordable ones are available and could be used to maintain or continue development of the system. These are discussed below following a description of GRASSLAND GIS and the water quality simulator DESERT.

The two pre-compiled software packages that were incorporated into the Cooum DSS as modules were GRASSLAND GIS version 1.1, and DESERT version 1.1. These were chosen because;

- They are low-cost software – DESERT was free, while GRASSLAND was available at a relatively affordable price to the researcher and to users of the Cooum DSS (CDN$510).

- Both programs will run under MS Windows 95/NT, or later versions, which is common, affordable and easily accessible in India, where the system will be implemented.

- They require only a minimal hardware configuration on which to run (486 processor, 8MB RAM, 16 MB disk storage for GRASSLAND and a 386/486 processor, 4MB RAM, 10 MB disk storage for DESERT). This will keep the cost of implementation down for potential users of the system.

Additionally, GRASSLAND provides a graphical user interface developed in Tcl/Tk (a fourth generation interpreted macro language) which makes GRASSLAND easily customizable, and allows for development of the system in the spirit of the open source movement (Tcl/Tk is an open source development environment). The Tcl/Tk combination with GRASSLAND also provides a scripting language and interpreter for automation, customization and extension of the GIS, which may be used to develop customized GIS applications and graphical user interfaces. (This provided the facility to develop much of the decision support module of the Cooum DSS). Furthermore, GRASSLAND allows for data connectivity to a wide range of spatial database formats through the Open Geospatial Datastore Interface (OGDI) and to other common formats through Object Database Connectivity (ODBC) capabilities, and provides a full suite of GIS functions (*e.g.*, database management, spatial analysis, map output, data visualization).

DESERT also has several other attributes that make it attractive for use in this context. In particular, it provides several variants of hydraulics and much flexibility in water quality modelling (both pre-programmed and through the MODUS simulation language). It can be linked to OLE servers such as MS Excel, Corel Quattro Pro, *etc.* for output of model results, and has standard format data files (dBase III) which may be easily accessed and modified with common commercial software or through the use of a database engine.

GRASSLAND GIS

The prototype Cooum DSS incorporates the geographic information system GRASSLAND version 1.1. GRASSLAND is a Windows 95 and Windows NT version of the UNIX public domain GIS software GRASS (Geographic Resources Analysis Support System). GRASS was developed by the US Army Corps of Engineers (Army Construction Engineering Research Laboratory) and is "Open Source" software. That is, the source code for the software, as well a manual for programmers and other similar information, are distributed freely to the user community. Users may easily modify the software for their own purposes, and generate new and modified code which contributes to the continued development of the software. As of February 1996, the US Army Corps of Engineers was no longer developing and distributing GRASS for the public domain. UNIX based GRASS development is now based at the Center for Applied Geographic and Spatial Research, Baylor University in Texas, and Windows 95/NT porting and GUI development has been undertaken by Global Geomatics Inc. (formerly Logiciels et Applications Scientifiques, Inc.) in Montreal (CERL, 1999).

The GRASS Development Team (1999) at Baylor University describes GRASS as "a raster-based GIS, vector GIS, image processing system, graphics production system, data management system, and spatial modelling system." GRASS is a powerful, flexible, customizable raster-based GIS, with a full suite of support, analysis and output routines, as well as some vector capability. The GRASSLAND version of this GIS is based on GRASS 4.1, and has incorporated almost all of the GRASS functions except for the map representation and output functions, which it has replaced. GRASSLAND provides a graphical user interface to GRASS built in Tcl/Tk (see below) and provides several features not available in GRASS, such as the ability to access a wide variety of data formats in their native form (*via* the Open Geospatial Datastore Interface, or OGDI), the capability to link to data files using Object Database Connectivity (ODBC) functionality in the Windows environment, and a visual object-based programming environment to automate sequences of

GRASS functions. Within the Cooum DSS, GRASSLAND provides GIS analysis, visualization, map output, and database management functions.

Arc/Info GIS

Arc/Info versions 6.1 and 7.1.1 were employed to construct and edit the primary spatial datasets that were imported into the GRASSLAND GIS database for use in the prototype Cooum River Environmental Management Decision Support System. Arc/Info is a high-end commercial GIS developed and distributed by the Environmental Systems Research Institute (ESRI) and has a full suite of both vector and raster capabilities. Arc/Info was used to construct the datasets because versions of Arc/Info were available at both the University of Waterloo (ver. 7.1.1) and Madras University (ver. 6.1) in labs that included large format digitizers. (Data could also have been developed in GRASSLAND if Arc/Info had not been available). Also, GRASSLAND, *via* OGDI, can access Arc/Info coverages in their native format, providing an easy and convenient means of incorporating of Arc/Info coverages into the Cooum DSS.

DESERT Water Quality and Hydraulic Simulator

The environmental simulation model employed by the Cooum DSS is DESERT version 1.1. DESERT (which stands for *DE*cision *S*upport system for *E*valuation of *R*iver basin s*T*rategies) was developed at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria.

DESERT provides a self-contained hydraulic and water quality simulation modeller that allows for flexibility of modelling decisions by users of the Cooum River Environmental Management Decision Support System. This is important because, even though hydraulic and water quality modelling are not the expertise of the researcher who has incorporated DESERT into the system, informed and expert knowledge may be incorporated into it at any time without further development.

DESERT incorporates hydraulic models based on mass continuity and momentum equations of fluid mechanics, and it models rivers through one-dimensional shallow water equations (Ivanov, *et al.*, 1996:11). The user of the system is presented with 6 options for hydraulic modelling of river reaches. Box 4.1 describes these alternatives. Similarly, for water quality simulation the user is offered 6 options for solving mass transport equations. These alternatives, which are described in Box 4.2, may be applied on a reach-by-reach basis. For three of these, reaction processes may be described using an interpreted command language called MODUS. This allows the user the freedom to formulate the model in whatever way seems most appropriate, and to incorporate as many variables as required by the situation, even if DESERT does not have these model formulations or variables pre-programmed into the system.[2]

> *The hydraulic models used in DESERT for rivers and open channels are based on mass continuity and momentum equations of fluid mechanics. It models river hydraulics through the one-dimensional shallow water equations*
>
> **None –** No hydraulic simulation is performed. Therefore, the reach is considered as non-existing
>
> **Water balance** – This alternative uses a simple steady state water balance between consecutive points along the reach. The reach is subdivided into equal segments of length specified by the user, and the water balance is applied from mesh point to mesh point.
>
> **Power-hydraulic approximation –** With this alternative, discharge is calculated according to [the equation used for the water balance option], while water velocity and depth are computed with a power function approximation.
>
> **Uniform flow depth –** With this alternative, the reach is subdivided into a series of segments, the lengths of which are specified by the user through a dialog box. Within each segment the flow is considered spatially uniform and in steady state.
>
> **Steady state (diffusion wave) –** For a steady state situation, typical of low-flow periods, the momentum and continuity equations can be simplified by omitting terms responsible for the dynamic behavior of the flow... Because of the solution procedure used, the model is valid only for rivers which are controlled by downstream conditions, that is backwater curves are computed.
>
> **Non-steady state (diffusion wave) –** Since this software is oriented primarily toward water quality management, complex hydraulic models are usually not needed. For dynamic situations (non-stationary in time), the diffusion wave approximation strikes a good balance between complexity, accuracy, and computation speed.
>
> *Source*: Ivanov *et al.*, 1996:11-14

Box 4.1: Options for computing river hydraulic characteristics in DESERT's hydraulic unit (Excerpts from Ivanov, *et al.*, 1996: 11-14).

DESERT represents a river system as a binary tree system. That is, the river system is modelled as a one dimensional series of branches progressing from the headwaters of tributaries, through a series of confluences to a single root. There are several restrictions imposed by this model: it does not permit bifurcations of reaches,

[2]The reader is referred to the DESERT user's manual (Ivanov, *et al.*, 1996) for further details.

confluences of more than 2 reaches at a single point are not allowed, and, thus, it is unable to model systems (cycles) of reaches. (Figure 4.4 demonstrates these models).

There are 2 main implications for the use of DESERT to model the Cooum River system that arise from its binary tree representation of rivers. First, since bifurcations and systems are not allowed, the flow of the river around an Island in the lower reaches cannot be properly represented. As will be described below, a somewhat awkward workaround was attempted to overcome this problem. Second, the binary tree structure is one dimensional. Thus, layer representation and mixing of tidal waters with river waters – as a process helping to ameliorate the condition of the Cooum waters – cannot be represented.

None – No water quality simulation is performed and the reach is considered as non-existing from a water quality view point.

Mass balance (no mesh) – Simple steady-state mass balance is performed on the segments of the reach delimited by structural objects. The concentration of each water quality constituent adopted by the user is described by the continuity equation alone.

Mass balance (mesh) – This alternative uses the same kind of mass balance performed for the no-mesh method. The difference is that the reach is subdivided into segments.

Mass transport (no mesh) – With this alternative, no differential or transport equation is solved. The user directly specifies the water quality constituent concentration as a function of other water quality constituents or of external inputs (like temperature, light, or oxygen).

Mass transport (mesh, steady state) – The steady-state approximation of the transport equations [is solved using] a fourth order Runge-Kutta scheme. The reach is subdivided by mesh points.

Mass transport (mesh, non-steady state) – The full set of transport equations is solved at mesh points... Initial values are determined either by interpolating input data values or by running the Mass transport (mesh, steady-state) alternative with the initial boundary conditions. The solution of the system of equations is obtained by an Implicit First-Order Method.

Source: Ivanov *et al.*, 1996: 17-20

Box 4.2: Options for modelling water quality in DESERT. (Excerpts from Ivanov, *et al.*, 1996: 17-20).

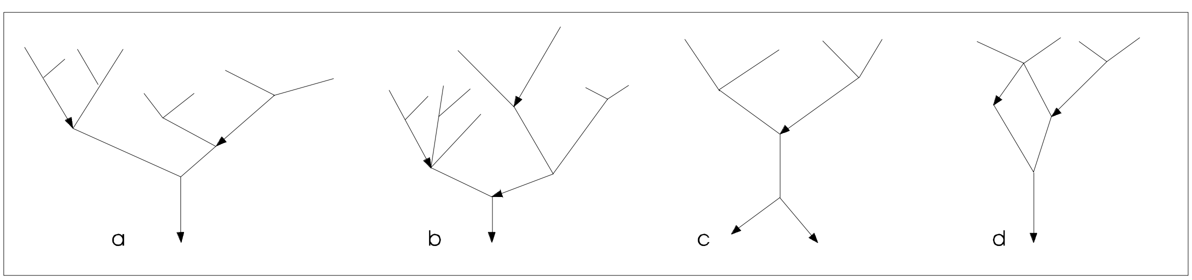

Figure 4.4: Possible river systems. DESERT will not accept b) , c), and d) due to the presence of confluences with multiple merging branches, multiple roots, bifurcations, and cycles within the trees. a) is a binary tree and is acceptable. (Source: Ivanov *et al.*, 1996: Figure 2.1.1).

Discussion during the first workshop, however, indicates that participants believed that this process is not important, as the tidal variation over time is small and the inflow and outflow of sea water into the river is too slow to provide for significant flushing.

'Structural objects' which may be represented in the DESERT module include river reach separations (beginning and ends of reaches), reach confluences, headwaters of the system, and the end or root of the system. In addition, DESERT provides for the representation of 'river objects' (that are associated with structural objects as attributes), such as lateral flows into reaches, water abstraction (withdrawal) from reaches, water quality measurement points, reach cross sections, water quality constraints, point source effluent inflows, weirs, and treatment plant discharge locations. These objects and associated attributes, such as various water quality parameters, are stored in dBase III files. These are the files which are modified by the Cooum DSS when generating and loading parameters for the system model.

The Development Environment

The graphical user interface (GUI) and decision support module of the Cooum DSS were developed in Tcl/Tk and C/C++. Tcl stands for "Tool Command Language." This is a string-based interpreted command language designed for use in building applications from various software "building blocks" (Welch, 1997:3). This is a large part of its role in the Cooum DSS. The language is "C-like" in its syntax, but simpler and easier to learn. Tk is a tool kit for Tcl intended to facilitate the development of graphical user interfaces. Tcl/Tk is part of the open source movement and is distributed free of cost. The interpreted language was used to develop the GRASSLAND GUI and acts as a macro language for automation and customization of the GIS. Tcl interpreters are available for Windows, Unix and Macintosh platforms, so the code is portable among operating system platforms.

C/C++ code is also a easily ported among platforms. The 'calculators' described below, and the data transport routines used to populate the DESERT database files, are developed in this language. C/C++ is both a structured language (from the 'C' legacy) and an object-oriented programming (OOP) language in its C++ manifestation. C/C++ code is compiled into executable programs which are much more efficient at performing calculations than an interpreted language (such as Tcl) in which code is read and executed one line at a time.

The C++ code deployed in the Cooum DSS was developed using a commercial development environment: Inprise's (formerly Borland) C++ Builder 3. An attempt has been made to avoid the use of libraries and capabilities of C++ Builder that are non-standard, so that if desired, the code may be ported to other development environments. However, one aspect of the code that is Borland-specific has to do with data transport. In populating the DESERT dBase III files with parameters generated by the calculators, use is made of the Borland Database Engine (BDE). Because of this feature, the BDE has to be installed on computers running the Cooum DSS for it work properly.[3]

Data and the GIS database

Fundamental Spatial Units and GIS Data Layers

Modelling the workshop participants' conception of the Cooum system in a coupled DSS capable of undertaking scenario analysis required the development of an extensive database. Required data included information associated with Cooum system elements such as population, sewerage and stormwater drainage infrastructure, climate, land use, water supply and consumption. Except for hydraulic details of the river system, (which is handled by DESERT in the water quality module), the Cooum DSS stores these data in one of two locations and formats: as a GRASS format GIS (raster or vector) data layer in the 'chennai' GRASSLAND dataset, or as an ASCII format data file in a Cooum DSS scenario directory. Detailed description of these data is provided in Appendix II. An overview of the data is offered here, along with a general description of the database development. As with the description of the data, a more detailed description of the GIS database development is presented in Appendix II.

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[3] Installation of some products such as Corel WordPerfect, Paradox or dBase automatically install the Borland Database Engine. If these are not available, the BDE may be distributed from C++ Builder.

One objective of this work is the incorporation of spatial data in, and the use of, a GIS for the exploration of possible management scenarios for the Cooum system. Toward this end, datasets representing four fundamental spatial units were identified. These were crucial to the operation of the Cooum DSS if it were to model the system as conceptualized by workshop participants. The spatial units were (1) wards (corporation divisions) with which data such as population, population growth rates, income distribution, water consumption and sewage generation could be associated, (2) sewerage catchments, which have to do with routing of sewerage to treatment facilities, and with data representing the efficiency and coverage of the sewerage system in various parts of the city, (3) stormwater drainage (SWD), or urban runoff catchments, which collect runoff and sewerage not directed to the sewerage system, routing it to nearby drains, canals and rivers, and (4) slum locations which are linked with population data, physical characteristics of slums, and unsewered areas in Chennai.

Analogue maps of each of these spatial unit datasets were acquired from various agencies in Chennai (Shaw Technical Consultants (P) Ltd. and Hyder Consulting Ltd., 1997 [sewerage catchments]; Tamil Nadu Slum Clearance Board, 1986 [slum locations]; Mott MacDonald Ltd. 1994a [SWD catchments]; Corporation of Madras, 1991 [wards]). The quality of these data, however, is poor. These maps are typical of the type of data available in Chennai – all of them are without indication of a coordinate system, in several instances there are obvious omissions and errors, and linework for features such as roads and boundaries are often little better than a sketch. They are, however, the best available data. These four map sheets were digitized as Arc/Info coverages using table coordinates.

In order to improve the quality of these basic data, and to reconcile boundaries and internal features among maps, a process of geometric correction and projection to a common coordinate system was undertaken. For this, Survey of India topographic sheets (Survey of India, 1971a-b, 1976c-d) were employed to create a base map to which the required data could be corrected. Even the topographic sheets, however, were not of very good quality. Despite the fact that the Department of Geography, University of Madras, (which provided logistical support for field work undertaken for this program of research), is a repository for Survey of India topographic sheets, not all the pertinent area was available at 1:25000 scale, and part of the area had to be patched with a 1:50000 scale map, as indicated in Table 4.1.

Table 4.1: Index and spatial arrangement of topographic sheets used to construct the master base map for the GIS database.

66 c 4 1:50000	66 c 8/2 1:25000
66 c 4/6 1:25000	66 c 8/3 1:25000

These maps were well used and several were missing small parts of the paper. Furthermore, the Survey of India maps did not indicate projection information and represented data that were last updated in 1970-71. The poor quality of data available with these maps illustrates a level of uncertainty about the basic situation. This was expected to be the case, and the database was constructed with the best available data, with the intention that it could be updated in the future when better information becomes available.[4]

As there was no projection information included with the topographic sheets (in the marginal information or elsewhere), and general inquiries failed to illuminate the question, the topographic sheets were treated as if they employed a simple spherical system measured in degrees of longitude and latitude. As a defined projection was required, (*i.e.*, for a GRASS format database), a projection environment (based on a simple conic projection and the Everest spheroid), which seemed to be the most likely for these maps was chosen, and the database developed on that basis.[5] The four basic data layers from the GRASSLAND GIS

[4]Some agencies do in fact have better data. For example, aerial photographs of Chennai are in the possession of the Chennai Metropolitan Development Authority. However, access to these for the purposes of research was out of the question as they are considered to be militarily sensitive.

[5]If this projection information is incorrect, some information derived from the GIS database may not be directly comparable with external data. This would not affect comparison and analysis of data in this research however, as that data is internally consistent.

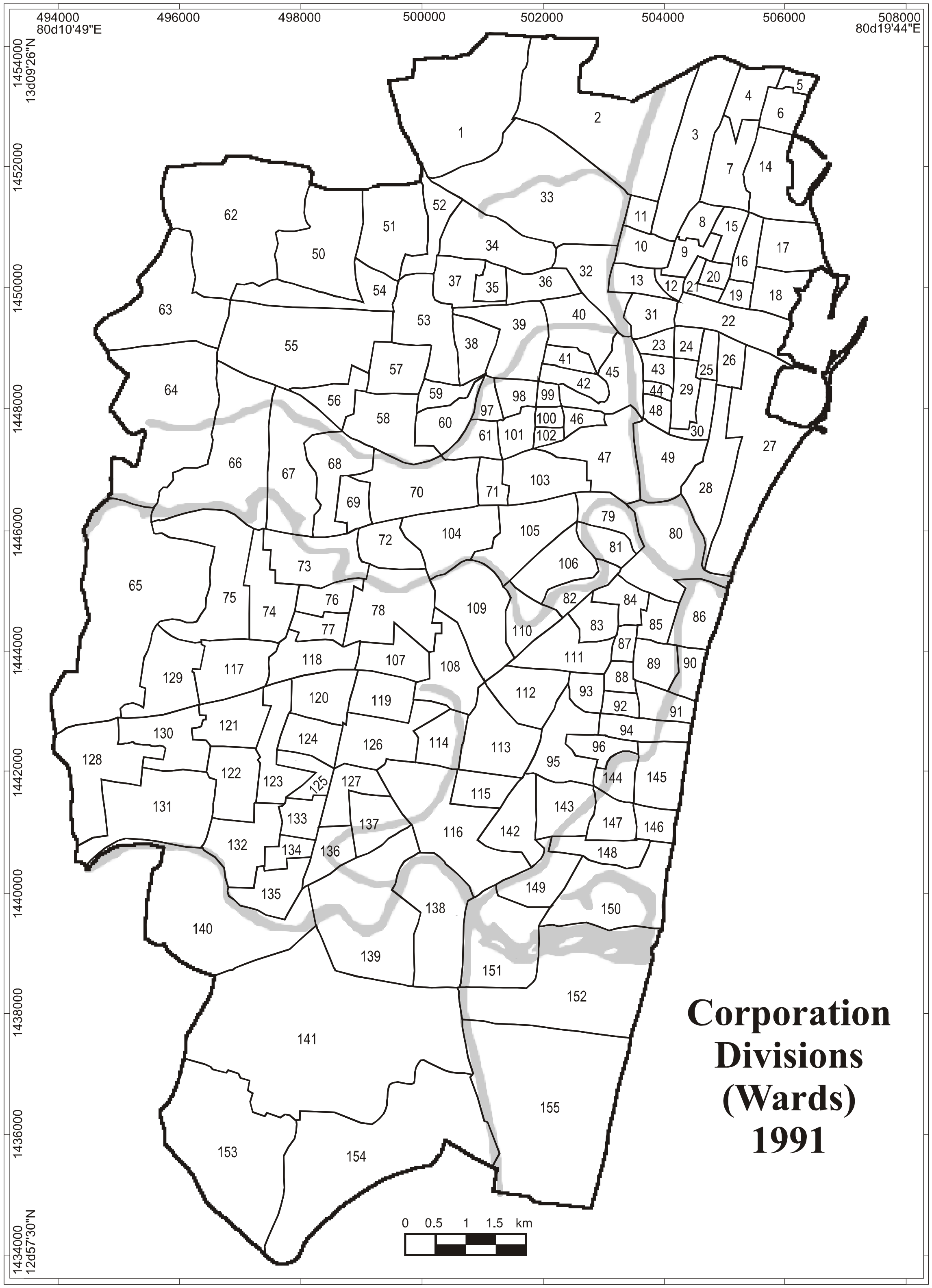


Figure 4.5: Corporation divisions, as of 1991, from the GIS database. The waterways layer is also from the database and is intended for use as a visual reference.

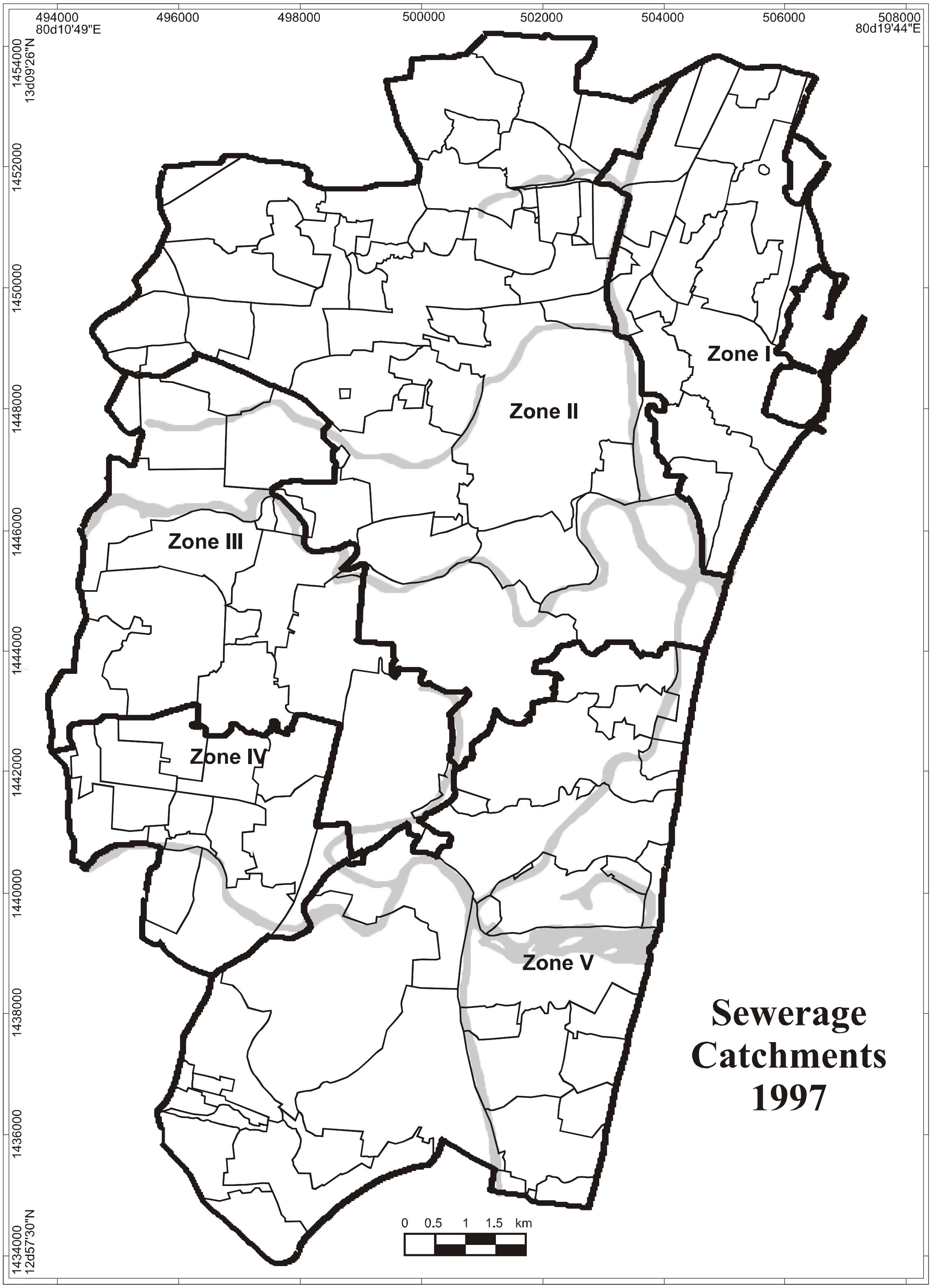


Figure 4.6: Sewerage collection areas, or catchments (in 1997), from the GIS database.

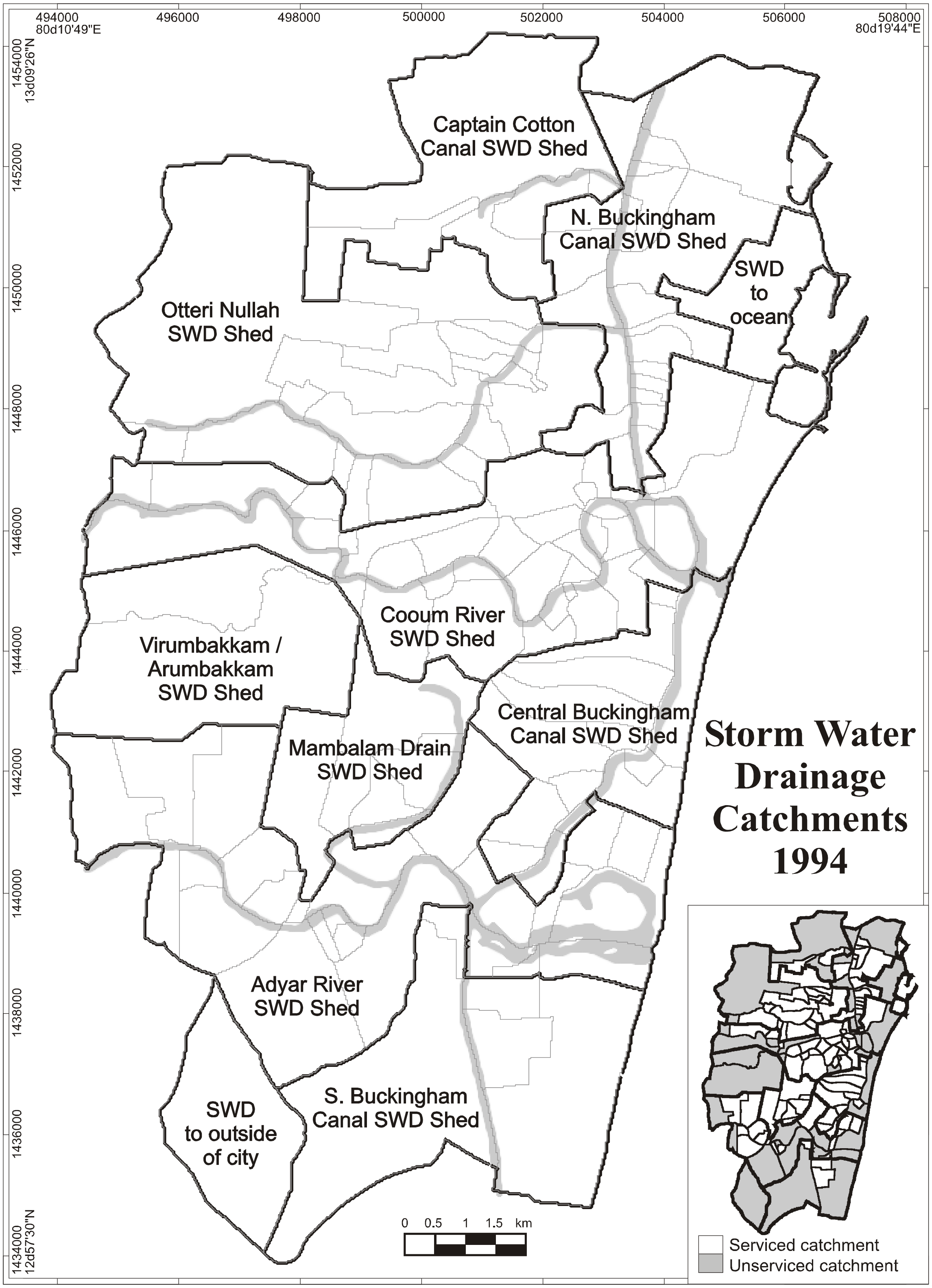


Figure 4.7: Storm water drainage catchments, from the GIS database. The inset indicates SWD-serviced areas (in 1994). Unserviced areas are estimated for overland flow.

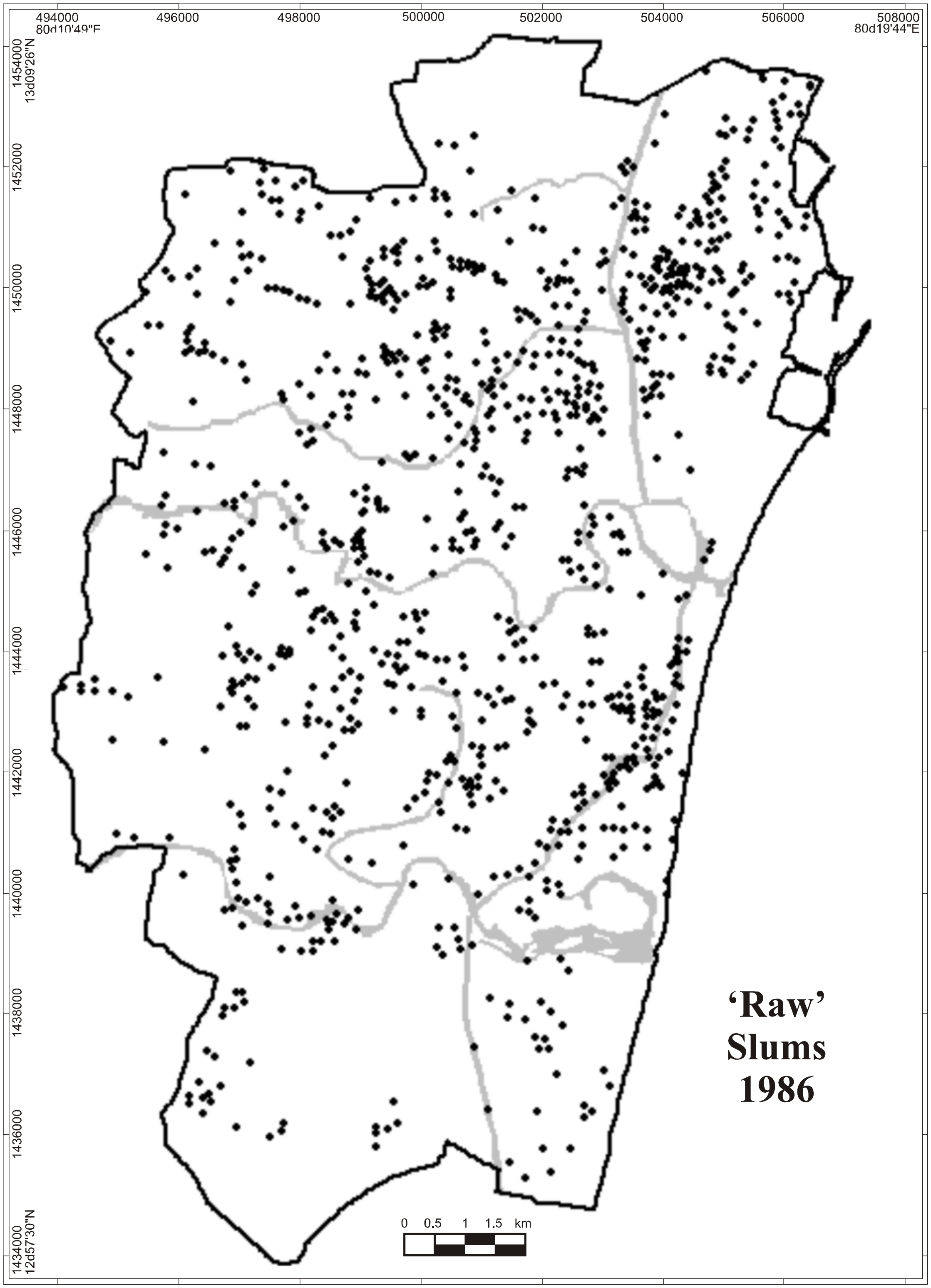


Figure 4.8: Slum locations, from the GIS database (in 1986). These are slums that have not been previously addressed by a government scheme. They range in size from 5 to 901 huts (with a mean of 90) (MMDA 1987) and a mean population of 653 (Bunch, 1994).

database are presented in Figures 4.5 to 4.8. These represent corporation divisions (wards), sewerage collection areas, stormwater drainage catchments and slum locations. Development of this database represents the most accurate and complete spatial dataset of this form and relating to these themes of which the author is aware.

The first three of these datasets, *i.e.*, wards, sewerage catchments and SWD catchments, are areal units which were employed to construct "routing units" which are the smallest units common to all three. These routing units are used in the Cooum DSS to assign portions of sewerage generated by population in a ward to be routed *via* either the sewerage collection system to a treatment plant, or *via* stormwater drains to nearby canals and rivers. (This process is described in the calculator section below). Data layers in the GIS database representing several other derivations of the primary datasets were also generated. A list and brief description of data layers in the spatial database is presented in Appendix II.

Attribute and other data

Primary Datasets in ASCII Format

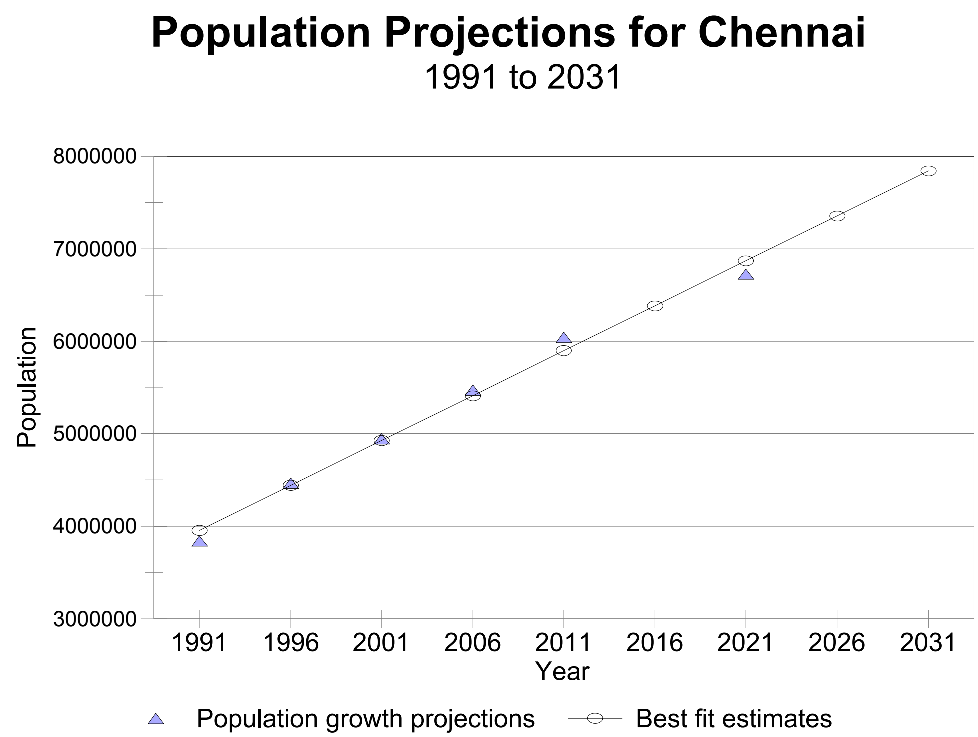
In addition to data stored as raster or vector layers in the GIS database, several sets of data were developed which represent attributes of point or areal units used in the Cooum DSS, and parameters of the system as a whole. For example, while basic spatial units, such as wards, are stored in the GRASS format database, population data are stored as attributes of wards in a text data file. These datasets were employed to construct a "default" scenario in the Cooum DSS, and may be customized by the user of the Cooum DSS in developing new scenarios. (For example, the default scenario in the decision support system assumes no change in the relative proportions of population among wards over time. In building a new management scenario, this may be altered by the user). The basic ASCII data files employed by the Cooum DSS are presented in Table 4.2.

Estimation of Population and Population Growth Rates

Population data are the most fundamental attribute dataset employed in the Cooum DSS. Figure 4.9 presents a plot of estimates for population growth in Chennai from 1991 to 2031. The various population projections from 1991 to 2021 published by several

Table 4.2: Primary data stored as ASCII format datasets. (Intermediate data files generated by the Cooum DSS are not presented here. More detail regarding both primary and intermediate data files is presented in Appendix II).

Dataset	Description	Source
population.dat	population of wards in Chennai, 2001 to 2031	Calculated from the following sources: 1. 1991 Ward population for Chennai: Census of India 1991 (Government of India, 1991) 2. 1996 - 2011 city population projections based on figures from the "Second Master Plan for MMA - 2001: Extracts from MMDA's Monograph on Demography" (MMDA, 1991). 3. 2021 estimate is from a CMWSSB estimate (CMWSSB, 1998). See below for more information on the generation of population figures.
popGrowthRates.dat	growth rates of ward populations, 2001 to 2031	Annual Population Growth Rates (AGR) have been calculated individually from the estimated populations in each ward. See below.
efficiency.dat	proportion of sewage routed *via* the sewerage system to a STP. (This is an indicator of the overall efficiency of sewerage collection in ward)	These data are estimated, hypothetical data for the purposes of the default scenario in the Cooum DSS. They may be modified by users of the system.
proportion_lig.dat	proportion of population in wards that are in the low income group	These data are estimated, hypothetical data for the purposes of the default scenario in the Cooum DSS. They may be modified by users of the system.
proportion_hig.dat	proportion of population in wards that are in the high income group	These data are estimated, hypothetical data for the purposes of the default scenario in the Cooum DSS. They may be modified by users of the system.
rainfall.dat	average rainfall (mm) in SWD catchments	Figures for Chepauk station in Chennai were obtained from Mott McDonnald (1994b). For the default scenario, no variation is indicated among SWD catchments. This may be modified by the user.
runoffcoef.dat	coefficient (from 0 to 1) describing the proportion of rainfall which runs off of a SWD catchment	These data for the Chennai urban area are estimated with reference to other typical runoff values, for purposes of the default scenario. For the default scenario, no variation is indicated among SWD catchments. This may be modified by the user.
slums.dat	physical characteristics of Chennai slums	Unpublished data from the *Survey of Slums in Madras Metropolitan Area* (MMDA, 1986).
parameters.txt	miscellaneous model parameters including STP capacity and effluent quality, sewerage and stormwater characteristics, hours of rainfall, water consumption, average slum household size	Treatment plant capacity and water consumption figures: Times Research Foundation (1991) Effluent/Sewerage characteristics: TNPCB (1989) Rainfall: Mott McDonald (1994b) Slum data: MMDA (1987)



year	**1991**[1]	**1996**[2]	**2001**[2]	**2006**[2]	**2011**[2]	**2016**	**2021**[3]
population	3 841 396	4 469 000	4 947 000	5 471 000	6 045 000		6 730 001

[1] 1991 Chennai ward-wise population in 1991 are from the Census of India 1991 (Government of India, 1991).
[2] 1996 - 2011 figures are estimates based on the UU,RGD estimates for the Chennai growth rate from *Second Master Plan for MMA - 2001: Extracts from MMDA's Monograph on Demography* in (MMDA, 1991). (Medium growth rate estimates, *i.e.*, averages of rates from 1901-81, were used to generate these figures).
[3] 2021 figure is a CMWSSB (1998) estimate from *Chennai Sewerage Project, 21.2.98, Table 1: Zone wise Population for the year 2001*, (This figure has been corrected for the inclusion of the year figure in the total)

Figure 4.9: Population projections and population estimates employed in the Cooum DSS.

government agencies in Chennai. A plot of these figures describes a straight line (a least squares regression of the data produced an R^2 of 0.99). Thus, for the purposes of constructing a population data file for the default scenario in the Cooum DSS, the population for the city was estimated from these data using a (linear) least squares regression method to determine the equation of the line representing the expected population of Chennai in the years 2001 to 2031. Individual wards (corporation divisions) were assigned a proportion of the total estimated city population for a particular year by multiplying the total population figure by the proportion of the total population accounted for by that ward in 1991:

$$\hat{W}_t = \frac{W_{1991}}{P_{1991}} \times \hat{P}_t \tag{4.1}$$

where;

W_{1991} is the ward population reported in the 1991 census,

P_{1991} is the city population reported in the 1991 census,

$\hat{P}_t$ is the estimated city population for year *t*, and

$\hat{W}_t$ is the estimated population of the city for year *t*.

For the initial default scenario, annual population growth rates (*AGR*) were calculated from the estimated populations in each ward in the following manner:
For an estimated ward population, $\hat{W}$, at year *t*,

$$AGR = \left(\frac{\hat{W}_t}{\hat{W}_{t-1}} \times 100 \right) - 100 \tag{4.2}$$

The data file of calculated ward-wise annual growth rates for the years 2001-2 to 2031-2 may be modified by the user and used to calculate new population figures.

Unavailable Data

Some of the data required to construct the data files presented in Table 4.2 (*e.g.*, efficiency coefficients for the sewerage system and the relative proportions of different income groups in the various wards) were either not accessible or available, or simply not in existence at the time that the data base for the Cooum DSS was being developed. In these cases, the files were constructed using estimated data, with the expectation that the datasets would be improved when the data become available. The Cooum DSS provides tools so that users of the system may easily update these data. It was expected that estimated and/or hypothetical data would have to be used in instances where reliable data are not available. In keeping with an adaptive approach, it is expected that such data will be incrementally improved as knowledge about the system is generated, or as data become available in some other way. This is one way to deal with uncertainty in the situation.

The data representing the efficiency of the sewerage system in wards are an example. Efficiency refers to the proportion of sewage generated by a ward's population that is transported *via* the sewerage system to a sewage treatment plant. In the absence of complete data on the efficiency of the sewerage system in the various sewerage collection areas, all the areas were set to have an initial efficiency of 0.6. (That is, 60% of sewage produced in an area was assumed to be routed *via* the sewerage system to an STP for treatment). The actual data depends on many factors, such as the proportion of the ward's population which lives in sewered areas, the operational condition of the sewerage system, the frequency of cross-connections to the storm water drainage system, regulations, citizen compliance and agency enforcement regarding connections of residences and enterprises to the sewerage system.

The collection of such information is problematic, as it brings to the fore sensitive issues such as corruption of agency officials in the enforcement of by-laws and regulations, lack of service to vulnerable groups, and substandard provision of services by the responsible agencies. It is likely that an agency such as the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) has a good idea of, if not detailed information relating to, the overall efficiency of the sewerage system throughout the city, but it would be politically unwise, from their perspective, to make this information available. Nevertheless, the CMWSSB was quite cooperative in providing basic information about the sewerage system in Chennai, including a plan of areas in need of improvements and repair to the sewerage lines (Shaw Technical Consultants (P) Ltd. and Hyder Consulting Ltd., 1997).

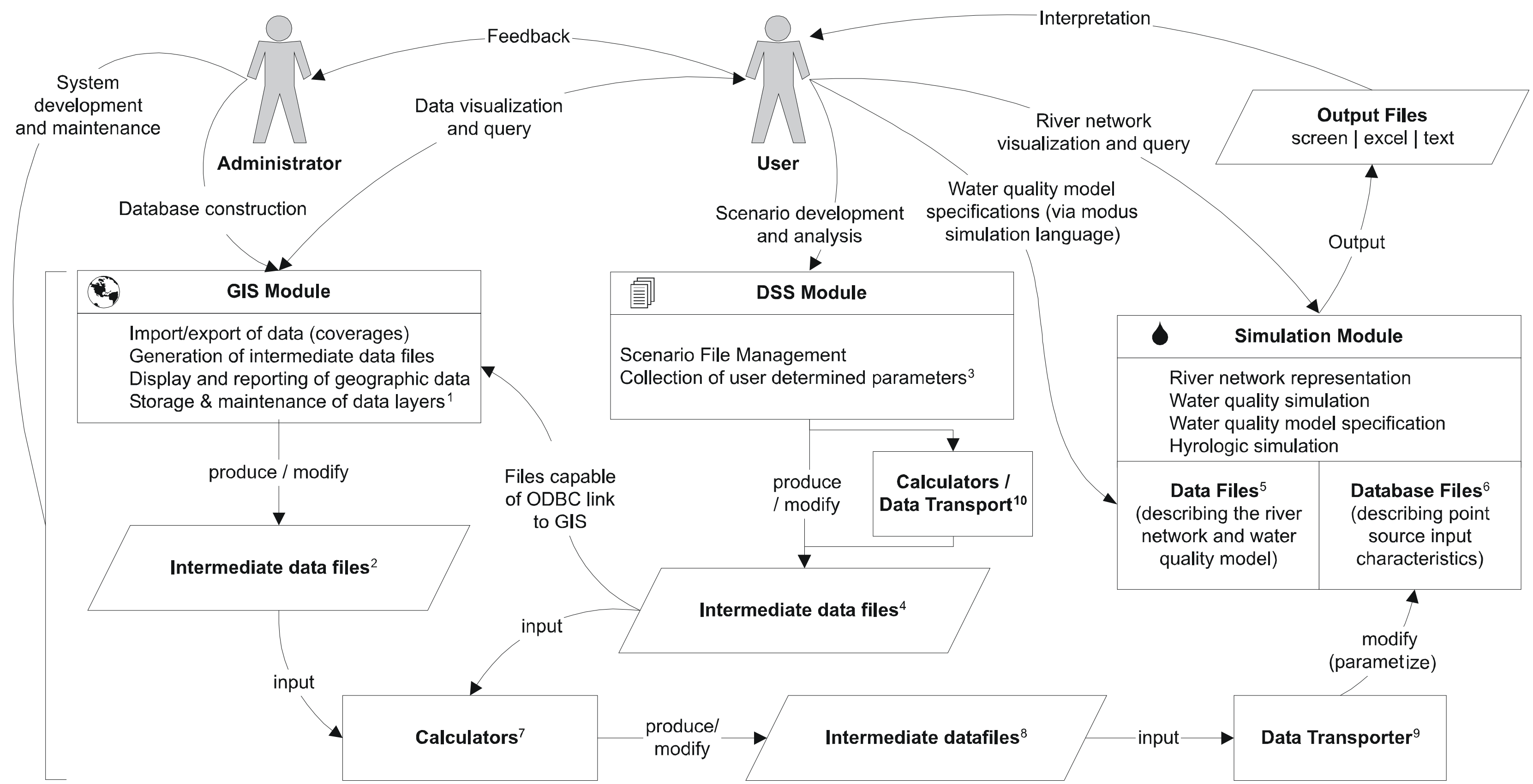
Similarly, the data describing income distribution (proportion of population in high and low income groups) throughout Chennai are hypothetical. This is due to the unreliability of data in Chennai, and India generally, regarding household income. Where data are available they are notoriously inaccurate due to untruthful reporting of income. For this reason, income figures in India are not reported in the published census (Bhavani, 1998). One possibility for generating income distribution data is to impute income information from other data reported in the census. However, the author is unaware that any published attempt to do this for Chennai. For this research, the proportion of high income group citizens in each ward was set to a default value of 0.1 (which is the proportion of this group for India as a whole) and the proportion of the low income group was set to 0.35 (the approximate proportion of the population in Chennai living in slums) for all wards. As with other basic data, the user of the Cooum DSS is easily able to update or speculate regarding this information.

Other estimated values involve runoff coefficients. The calculation of storm water runoff from urban drainage catchments requires an indication of the amount of rainwater that runs off catchments, as opposed to seeping into the ground. For the initial setup of the Cooum DSS this figure was estimated to be 95 percent of rainfall for all catchments. This rather high figure was chosen because of the large areas of land in the city which are paved or covered with structures. For comparison, open land with stiff clay soil and slopes of 0 to 5 percent can be expected to have a runoff coefficient of 0.6 (Singh *et al*, 1990:30). For the default scenario it is assumed that there is no variation across the city with regard to runoff coefficients in storm water drainage catchments.

Cooum River Environmental Management Decision Support System

Organization of the Cooum DSS

The prototype Cooum River Environmental Management Decision Support System consists of three main software modules, (the GIS, DSS and Water Quality modules), plus programs to perform calculations and transfer data between the modules. The Cooum DSS is used to generate and explore scenarios for management of the Cooum System. A user of the system may visualize and query data in the GIS database, construct scenarios in the DSS module by speculating about change of system characteristics (such as population growth, water consumption, slum improvement and others), and explore the effect of such changes with the water quality and hydrology simulation module. (In this way the Cooum DSS is intended to act as an adaptive learning tool). For each scenario developed in the system, a



[1] Wards or Corporation divisions
Stormwater drainage catchments
Sewerage catchments
Slum locations

[2] swdcatch.index
runits.index

[3] population and population growth
population income characteristics
management of groups
water quality parameters
precipitation parameters
slum improvement/clearance
simulation model specifications

[4] popGrowthRates.dat & .doc
population.dat & .doc
proportionLIG.dat & .doc
proportionHIG.dat &.doc
groups.txt; history.txt
rainfall.dat; runoffcoef.dat
seepage.dat; slums.dat
parameters.txt

[5] maptab.bna
mastab.dbf
proftab.dbf
<filename>.mod

[6] infotab1.dbf
infotab2.dbf
infotab3.dbf

[7] population.exe
r_sew.exe
sewerage.exe
rain.exe

[8] infotab1.dat
infotab2.dat
infotab3.dat

[9] ParamInfo1.exe

[10] slums.exe
slum_improve.exe
slum_clear.exe
dbmod.exe

Figure 4.10: Structure and operation of the Cooum River Environmental Management Decision Support System.

unique set of data files is generated, so that it may be revisited or modified. (The organization and role of these data files is explained above, and in Appendix II). Operationally, these modules, calculator and data transport programs, and data files are organized as presented in Figure 4.10.

Figure 4.10 portrays two actors who interact with the Cooum DSS: the system 'administrator' and the 'user.' The administrator is responsible for the development and maintenance of the system. This involves tasks such as improvement and debugging of automated routines and programs, the creation of new automated functions to facilitate the operation of the system and routines to support scenario development by the user. The administrator is also responsible for construction and update of the GIS database and river network representation. Skills required from the administrator include the capability to undertake basic system maintenance, as well as facility with GIS, database management software, and programming (in Tcl/Tk and C/C++).

The user of the Cooum DSS interacts with each of the three modules, but is generally not aware of most of the intermediate data files, the structure or formats of databases, or the internal workings of calculator and data transport programs. Each of the three modules is self-contained and may be accessed separately by the user. Generally, a user would interact with the modules in the order (from left to right) that they are displayed in Figure 4.10. It is recommended that a user of the Cooum DSS first use the GIS module to display and query the GIS database so as to improve understanding of the spatial units involved, and the spatial distribution of variables in the Cooum system. Then the DSS module is employed to construct or modify a scenario by modifying the characteristics of the system in an attempt to achieve a vision of a future state or evolution of the system. This sets the parameters for the water quality module, which may be employed to investigate the results of modifications specified in the DSS module.

Each of the three main modules, plus the calculators which, in effect, operationalize some of the relationships conceptualized as part of the Cooum system, is described below. Most of the attention is given here to the DSS and the calculator programs, as particulars regarding the GIS and water quality simulator software and their usage are available publicly (*e.g.*, Ivanov *et al*, 1996; L.A.S, 1996; Byers and Clamons, 1997), in contrast to the other components which were developed specifically in conjunction with this work.

GIS Module

The Geographic Information System module serves several purposes. First, it serves a fundamental role as a tool for database development and storage, and provides standard "housekeeping" functions to help maintain and administer the database. In addition, the GIS provides for development of a Graphical User Interface and for the automation of routines through an interpreted macro programming language. The GIS also provides the capability to undertake analysis of the data stored in its database. For example, in this research, overlay operations have been employed to produce a set of spatial units which are basic subunits of wards, stormwater catchments and sewerage catchments. These may be used in determining the value of a variable in one set of spatial units, that is originally associated with another. For example, using the "smallest common denominator units" created with such an overlay procedure, one may break down the amount of sewage produced in wards, and re-build the information based on stormwater catchment areas. In this way, the amount of sewage produced in a stormwater catchment can be estimated using data associated with wards.

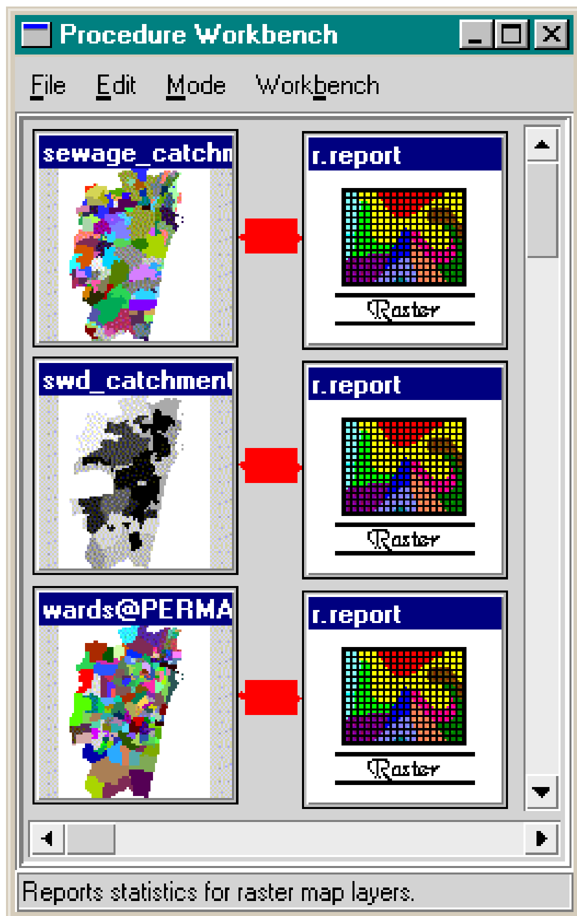


Figure 4.11: The 'Procedure Workbench' in GRASSLAND, loaded with a procedure which automates area reporting in 3 data sets and writes the report to a text file.

Some of the most important data derived from the GIS database have to do with the generation of simple spatial characteristics

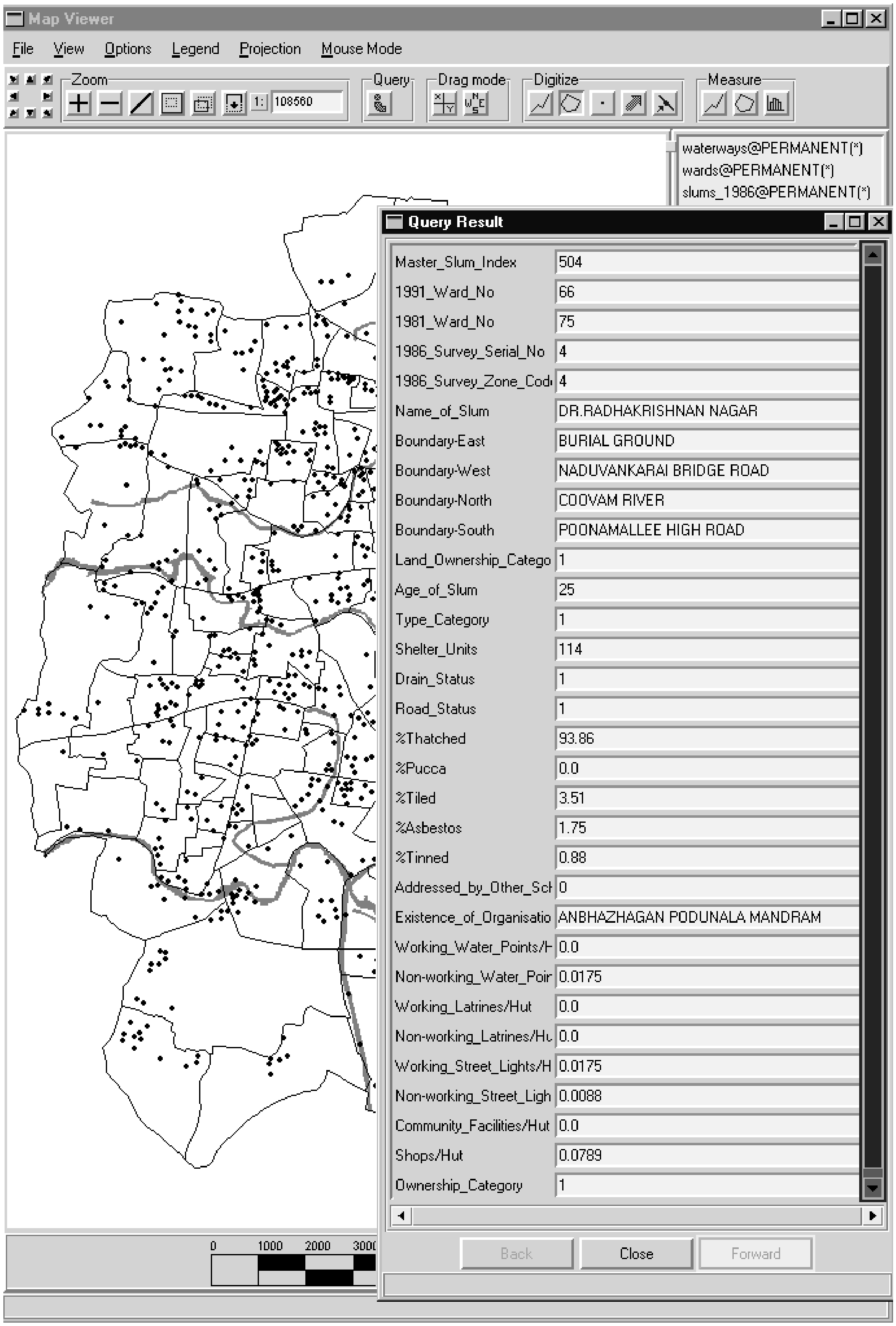


Figure 4.12: Query result on a GRASSLAND vector point layer that returns data obtained from a comma delimited text file which has been related to the map layer *via* ODBC.

of data layers. In particular, area values associated with wards, stormwater catchments and sewerage collection areas are used in many of the calculations performed in the Cooum DSS. These figures may be derived from reporting functions in the GIS module and written to a text file, which serves as input to calculation procedures in the Cooum DSS. Area figures may be produced through manual interaction with the GIS, through a visual programming environment such as portrayed in Figure 4.11, or the calculation of areas may be entirely automated with a Tcl script. The later two methods allow the storage and re-use of such procedures as necessary when the database changes.

Finally, the GIS module provides a means to query and visualize the data. This is a powerful tool in developing an understanding the problem situation and the study area as portrayed in the GIS database. GRASSLAND provides a full suite of GIS database reporting tools in its 'Spatial Analysis Toolbox,' and interactive query tools in its 'MapViewer' component. These allow a user to explore dataset profiles, to measure areas and distances and query database attributes. Such data exploration is not limited to attributes of raster and vector data in the GRASS format database itself. GRASSLAND has the capability of connecting to other datasets which can be associated with vector area and point data. Data files in the Cooum DSS which contain information related to areal units and points in the GIS database have been specifically constructed to allow such a connection. A query of this sort is demonstrated in Figure 4.12, where slum attributes stored in an ASCII format data file are accessed *via* a vector point layer in the GRASSLAND 'MapViewer.' Furthermore, GRASSLAND has the capability to access a wide range of other spatial data formats in their native state (L.A.S., 1996). In this way, new datasets may be quickly and easily accessed by users of the system.

Decision Support Module and GUI

The decision support module of the Cooum DSS provides a graphical user interface (GUI) which is designed to facilitate development of management scenarios for the Cooum River system. The decision support module allows the user to explore "what if" scenarios and to express a 'vision' of a future state of the Cooum, or evolutions of the system to achieve that vision. Thus, it acts as an adaptive learning tool in the development of a socio-ecological system description – a description which represents a continually deepening understanding of both the current organization and dynamics of the system, and its potential futures.

Upon starting the Cooum DSS, the user is prompted to open a scenario or start a new one. Once the user's choice is made, a scenario is loaded. (Choosing to start a new scenario copies the default scenario to a new name which the user supplies). The user is then presented with the main window of the Cooum DSS. This consists of a window containing a text box for presentation and editing of meta information, (stored in the scenario's 'history.txt' file), which relates to the scenario under development, and a main application menu bar with menu items: File, Explore, Tools, Run and Help.

Items under the file menu allow a user to manage scenarios (create, open, import, export), to manage scenario history or metadata files (save, save as, print), and to exit the program. These 'housekeeping' functions for scenarios will not be described in detail as their role and operation should be obvious to any user familiar with Windows 95/98/NT.

Items under the 'Explore' menu are not yet enabled. These represent a close coupling of the DSS and GIS modules that is envisioned for future development of the system. In the meantime, the user interacts directly with the GIS module to perform these operations, as described above.

The 'Tools' menu presents the user with tools to build or modify a scenario. These tools are what the DSS module is designed to support. They are the means by which a user expresses a vision of the state of the Cooum system, or expresses a design for interventions directed at achieving that 'vision.'

The choice of which tools to develop for the Cooum DSS is a reflection of the importance of various processes and relationships among system actors and elements, as represented in the conceptual model of the system and expanded during discussion, debate and in the various working sessions in the first workshop of the research program. The following, represented earlier in Figure 4.1, are the most important of these that have provided a framework for, and directed the development of, the Cooum River Environmental

Management Decision Support System:

- The ultimate primary source of pollution in the Cooum River (about 90%) may be attributed to the residential population of Chennai. This involves processes of water consumption and transformation of consumed water into sewage. Thus, there must be some way for users of the Cooum DSS to modify population characteristics, as well as water consumption and sewage generation parameters.
- The most important sources of input, accounting for the flow (quantity of water) of the Cooum River, are (1) treated effluent and untreated overflow from the Koyembedu sewage treatment plant, (2) point source effluent of untreated wastewater from areas adjacent to the Cooum River along its course within the city, (3) flow from upstream (output from the Upper Cooum System), and (4) input of stormwater during the monsoon season. This indicates a need for tools allowing interaction with STP capacity and climatic variables.
- Two system elements (which may also be seen as subsystems) of the Cooum system are involved in the transportation of waste and storm water from its location of production or collection to the Cooum River: the sewerage system (which transports sewage), and the storm water drainage system (which transports storm water and wastewater not routed *via* the sewerage system). The operation of these subsystems in the Cooum DSS requires tools to modify efficiency characteristics of the sewerage system.

Thus, the Decision Support System must be able to operationalize this basic structure of the system, and if scenario analysis is to be undertaken, the DSS must provide for some way for change to be introduced into this basic setup due to human intervention or evolutionary changes in the system. The various tools developed for this purpose are described below.

The Point Plotter Tool

The 'Point Plotter' tool (Figure 4.13) provides a simple way for a user of the Cooum DSS to modify some of the primary data sets which describe the characteristics of the Cooum system. Such data include population of wards, population growth rates of wards, and the proportion of population of wards which are in high or low income groups, all of which affect the amount of sewage produced in the system, and the efficiency of the sewerage system, which impacts on how sewage is routed. Data sets which may be modified using the 'Point Plotter' are those with a ".doc" extension which provides information about how to load the file into the 'Point Plotter' (*e.g.*, how to set up the y-axis, metadata, *etc.*).

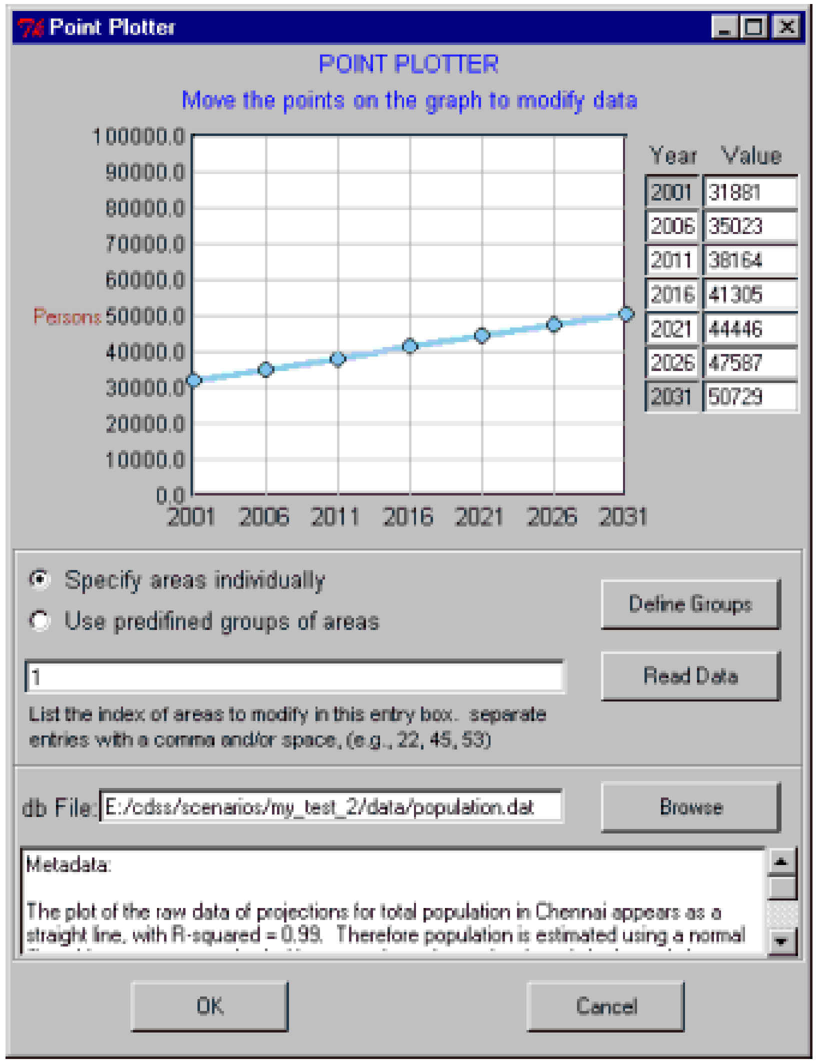


Figure 4.13: The 'Point Plotter' tool in the Cooum DSS.

When the 'Point Plotter' tool is run, it prompts the user to choose a data file, using a standard 'open file' browser and selection window. The point plotter sets up a graphical display and loads the selected dataset into it. The user modifies data by either specifying an x and y value (*e.g.*, year and population) in the text entry boxes next to the graphical display, or by using a mouse to "drag and drop" data points on the graph to new positions. Modifications are immediately reflected in the graph of the data.

These modifications are applied to the area(s) listed in the text box below the graphical display of data, when the user selects the 'OK' button. In populating records in the data file with the new information, data values (the y-axis) for particular fields (the x-axis) are determined linearly between adjacent points on the graph (and also represented in the data text entry boxes).

By default, the data loaded into the graphical display of the ‘Point Plotter’ corresponds to the unit in the first line of the selected data file. The user may change the area index to another one by deleting the area index in the text box and typing in a different number. (The ‘Read Data’ button will load data for the new area into the graphical display). The user may also specify multiple areas in this text box (separating them with a comma or space), and any changes will be applied to all areas listed. Predefined groups of areas may also be listed in the area selection box (the user indicates this mode by clicking on the appropriate radio button). The ‘Group Manager’ tool (see below) may be called from the ‘Point Plotter’ to define these groups.

The ‘Point Plotter’ also displays metadata about the currently loaded data set in a scrollable text box. The user may enter further information in this box, and it will be recorded to the dataset’s “.doc” file when modifications to the file are made. Also, when changes are made to the dataset, a record of this is entered into the scenario’s history file in which is loaded in the main application’s text display.

The ‘Point Plotter’ is designed primarily to facilitate the modification of data having to do with population characteristics which are based on wards (corporation divisions). This reflects an understanding that population is the primary source of pollution in the Cooum system and that the quantity of sewage produced is a function of population size, growth and income distribution.

The Group Manager Tool

The ‘Group Manager’ tool (Figure 4.14) does not make any changes to actual data in a Cooum DSS scenario. Rather, it modifies the “groups.txt” file associated with a scenario. Groups defined in this file are used by the ‘Point Plotter’ to modify multiple areas in a data set more quickly than if new data values were specified for each area individually.

The ‘Group Manager’ loads a data file, displaying an index listing of the spatial units (records in the data file). From these, a user can construct a list of areas to treat identically, give this group a name, or add it to the list of defined groups in the “groups.txt” file. The ‘Group Manager’ also provides for some basic management of defined groups such as removing groups from the file, importing groups from group files in other scenarios, and importing new group files to replace the one in the current scenario.

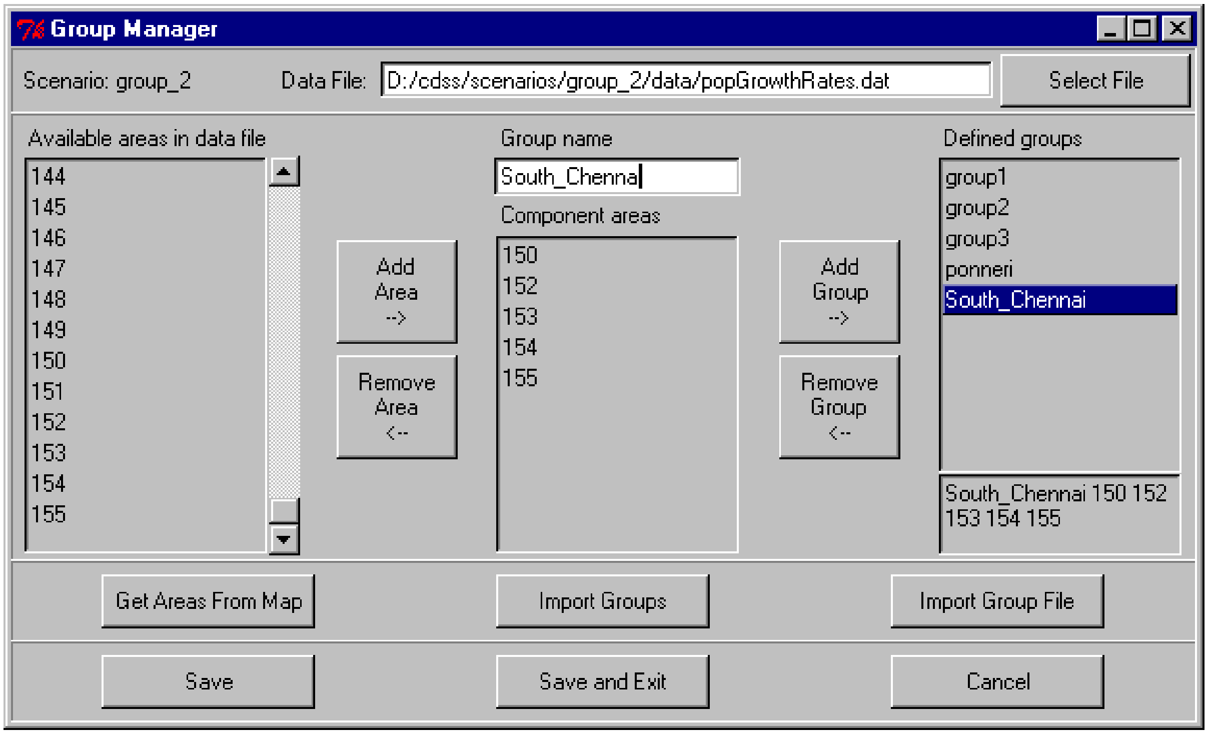


Figure 4.14: The ‘Group Manager’ tool in the Cooum DSS.

The Precipitation Manager Tool

The ‘Precipitation Manager’ tool provides the facility to modify the rainfall characteristics of the study area. For mean hours of rainfall per month, these attributes are based on the study area as a whole. For mean rainfall per month, the system is intended to apply changes to specified storm water drainage catchments. However, although the data file is set up to facilitate spatial specification among SWD catchments, the DSS currently applies these figures to the entire study area.

The user of the Cooum DSS may specify the mean hours of rainfall and the mean amount of rainfall in the study area by entering values in the entry boxes displayed in Figure 4.15. A list of storm water drainage catchments to which the mean rainfall data will be

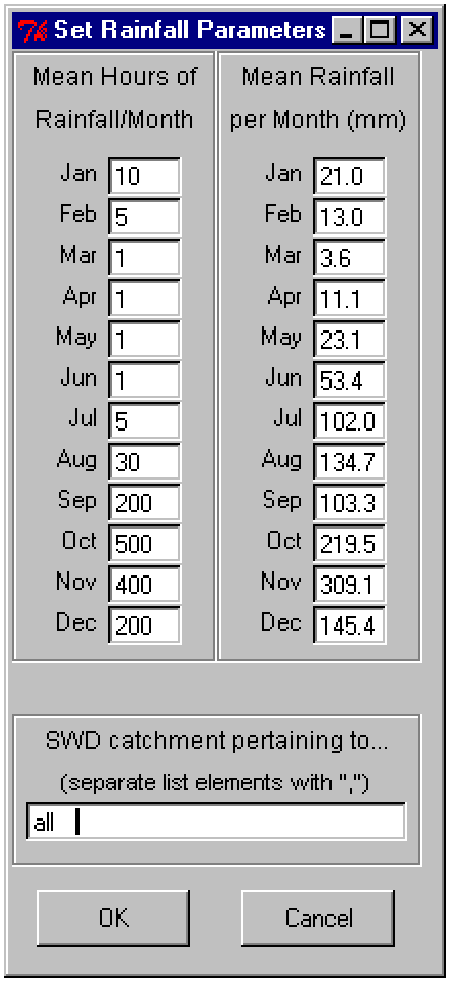


Figure 4.15: The 'Precipitation Manager' tool in the Cooum DSS.

applied may be specified in the text box below the entry box lists for mean hours and mean amount of rainfall. The DSS is currently set to apply changes in mean rainfall to all storm water drainage catchments. Selecting the 'OK' button will call the Tcl procedures which implement the specified modifications to the data files.

The precipitation manager is designed to adjust rainfall inputs to the system. The stormwater runoff calculator uses the input data to determine the impact of rainfall on the Cooum River. The primary assumption that this implementation rests upon is that these inputs will be distributed evenly throughout the city. Provision has been made, however, to allow for spatial specificity in the distribution of rainfall (*i.e.*, the data sets and the precipitation manager are set up so that this facility may be easily incorporated in the next stage of development of the Cooum DSS – currently, such changes must be made using a text editor).

The Water Quality Characteristics Tool

The 'Water Quality Characteristics' tool allows for the specification of attributes of raw sewage, treated effluent from the Koyembedu sewage treatment plant, and storm water runoff. A set of text entry boxes for each of these three items is provided to allow the user to enter new values of water quality parameters (Figure 4.16). Water quality characteristics which a user may adjust are the 5-day biochemical oxygen demand (mg/l), chemical oxygen demand (mg/l), suspended solids (mg/l), total dissolved solids (mg/l), nitrogen (mg/l), phosphorous (mg/l), dissolved oxygen (mg/l) and temperature (°C). The Cooum DSS in its current form is set up to make use of the BOD_5, N, DO and T variables in the simulation of water quality.

The 'Water Quality Characteristics' tools also provide the user with the capability to adjust the capacity of the Koyembedu sewage treatment plant. In this way, actual and speculated improvements to the capacity of the STP may be represented.

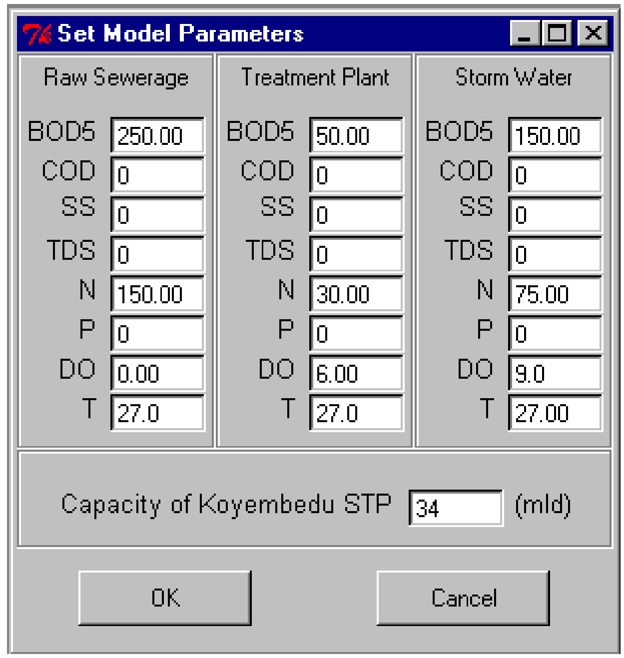


Figure 4.16: The 'Water Quality Characteristics' tool in the Cooum DSS. (Some values were are not specified as they were not modelled in the water quality simulation)

The way in which these water quality parameters are used in the Cooum DSS rest on several assumptions. First, it is assumed that water quality characteristics of raw sewage and storm water are consistent over space (*e.g.*, sewage will have the same quality in north Chennai as in the south of the city). However, discussions raised by participants during the second workshop indicate that some spatial specificity is appropriate. This is because population of different income groups consume different amount of water. Thus, their sewerage output will vary, as will its concentration of pollutants. (This is discussed further in Chapter 5). The way that sewage is treated by the Cooum DSS has an averaging effect of pollutant loads among wards. This will not greatly affect the results of the model unless the representation of income groups in a ward is significantly different from the average distribution.

Second it is assumed that sewage and stormwater characteristics will be consistent over the duration of the simulation, (*e.g.*, storm water will have the same characteristics from one day to the next), and that water quality characteristics of sewage and stormwater will not be affected by such factors as the size or income distribution of a population. In the current configuration of the Cooum DSS (with a steady state, not a dynamic model) this is a reasonable assumption. Where these characteristics might in fact vary (in the first flush of storm water from city streets, for example) appropriate modifications may be made when designing the scenario.

The Income Dependent Variables Tool

Water consumption (in litres per capita per day), and the proportion of water consumed that is transformed into sewage, are variables which may also be modified in the Cooum DSS. Each of these variables may be adjusted for high, middle and low income groups in Chennai using the 'Income Dependent Variables' tool (Figure 4.17).

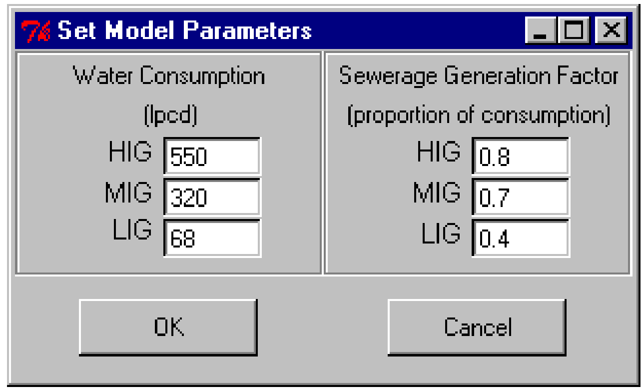


Figure 4.17: The 'Income Dependent Variables' tool in the Cooum DSS.

The provision of capability to adjust these variables is based on an understanding expressed by participants in the first workshop that the amount of sewage produced by population is related to income. In particular, the higher income groups will consume more water than will middle and lower income groups. Also, a larger proportion of water consumed by wealthier sections of the population will be converted into sewage than will be the case with the less well-to-do groups (*e.g.*, from wastage).

In accounting for these income-dependent characteristics, it has been assumed that income-dependent characteristics are determining factors in the quantity of sewage produced, and that they do not impact on other characteristics (*e.g.*, water quality) of sewage. The experience of the second workshop (see Chapter 5) indicates that, although this does not cause a large problem with model results, the latter assumption may not hold. Future development of the Cooum DSS should incorporate the ability to represent spatial variation in quality characteristics of sewage.

It has also been assumed that water consumption variables incorporate water availability or supply characteristics of the city, so the relationships between water supply and demand need not be represented. Finally, it is assumed that water consumption and sewerage generation characteristics (and this has also to do with the availability of water) do not vary spatially throughout the city. These assumptions were supported by participants' perceptions of water consumption throughout Chennai in the second workshop.

The Slum Treatment Tool

The 'Slum Treatment' tool (Figure 4.18) in the Cooum DSS allows the user to design scenarios which incorporate slum improvement and slum clearance interventions in the system. These interventions are aimed at affecting population characteristics (clearance from, and relocation to, wards) and improving sewerage system efficiency characteristics (by providing sewerage service to previously unserved slum dwellers).

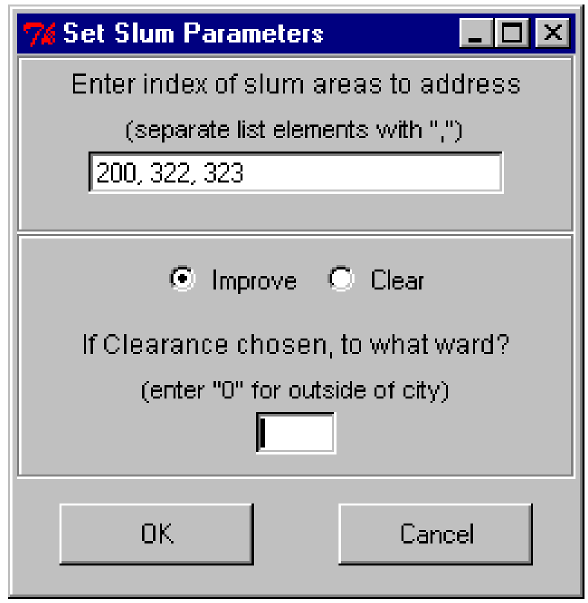


Figure 4.18: The Slum Treatment Tool in the Cooum DSS.

The inclusion of a tool specifically aimed at addressing slum dwellers in the system reflects the importance given to slums by workshop participants in discussions during the first workshop. Aside from one participant's comment that slums may not account for much quantity of untreated effluent into the river compared to other domestic sources, slums were a recurring theme in the context of being a primary problem in the Cooum system.

The implementation of a tool to allow for impacts of slum clearance and slum improvement is based on the assumptions that slums that are cleared will be destroyed, and their population relocated to serviced (sewered) sites in the specified ward, and that slum improvement involves the provision of sewerage service to all slum dwellers. This reflects the typical clearance and improvement models in Chennai.

The General Model Parameters Tool

The 'General Model Parameters' tool allows the user to set some basic parameters of the environmental simulation that will be passed on to the Water Quality and Hydraulic Module. These are portrayed in Figure 4.19. The starting and end date define the duration for dynamic simulation of the system. As the Cooum DSS currently handles only steady state simulations, only the starting date (together with the starting time of the simulation) need to be specified. This dialogue box also allows the user to choose a descriptive name for the simulation, and to select from a set of radio buttons, the simulation period (from hourly to yearly).

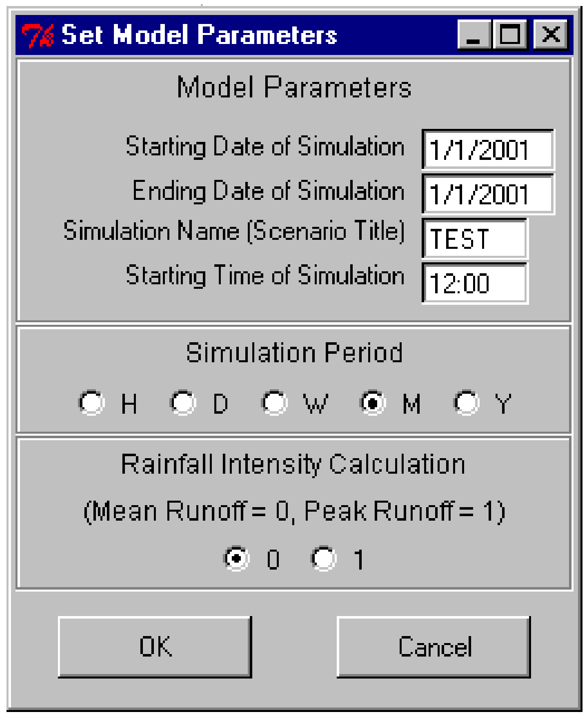


Figure 4.19: The 'General Model Parameters' tool in the Cooum DSS.

Executing the Calculators and Loading Parameters into the Environmental Model

The tools of the Decision Support Module described above modify a scenario's basic characteristics such as the size of ward populations, income distribution, the efficiency of the sewerage system, the inputs of storm water, and water quality and treatment characteristics. Once these changes have been specified, and the user is satisfied with the scenario as it has been constructed, these fundamental changes in the data must be subjected to a series of calculations which ultimately produce a set of data files for the water quality simulation model, which specify the sources, quantity and water quality of inputs to the Cooum River. The details of these calculations are reviewed below in the section on "Calculators and Data Transport Programs." In order to initiate the "calculators" which perform these operations the user calls them from the "Run" menu in the main Cooum DSS window. This menu's items are:

- Run Slums Calculator

- Run Population (sewerage generation) Calculator
- Run Storm Water Routing Calculator
- Run Sewage-to-Routing Units Allocation Calculator
- Run Sewerage Routing Calculator
- Build Model InfoTable...
- Run DESERT Simulator...

The first five of these menu items call 'Calculators' which take as input, the basic data and parameters stored in a scenario's data directory, and produce intermediate data files necessary for the environmental simulation model. Depending on the changes made to a scenario, not all of these calculators will be required. For example, if no modifications are made using the 'Slum Treatment' tool, the 'Slums Calculator' will not need to be run. Presently, there is no automated way in the Cooum DSS to keep track of which of these calculators should be called after modifications to a scenario are made, although a reporting tool for this purpose will be developed in the future. If a user is unsure of which calculators to call, or does not wish to keep track of this manually, it is recommended that all calculators be called, in order, starting from the top of the 'Run' menu and working down.

The 'Build Model InfoTable' item in the 'Run' menu is the final stage in preparing the environmental simulation model. This model presents the user with a set of buttons which correspond to "InfoTable" database files in the DESERT water quality simulator (Figure 4.20). Two sets of buttons are presented: one for steady state models and one for dynamic models.

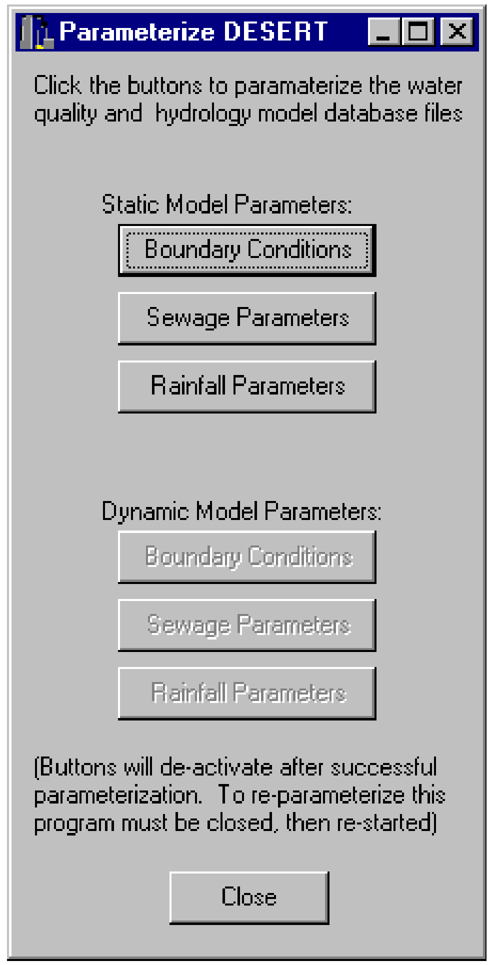


Figure 4.20: The parametization window in the Cooum DSS. This is used to populate the DESERT database files with new parameters for the simulation.

As the Cooum DSS does not yet support dynamic modelling, the second set has, for the time being, been disabled. Depressing these buttons populates the appropriate InfoTable with data prepared by the 'Calculators.' As with the 'Calculator' menu, and depending on the scenario design, a user may not need to select all of these buttons.

Once the calculators have been run, and the DESERT database has been populated with new values, the stage is set to run a simulation in order to explore the behaviour of the system under the new management scenario, as indicated by water quality in the Cooum River. The DESERT water quality modeller may be called from the Cooum DSS 'Run' menu, or in the standard way from the 'Start' button in Windows 95/98/NT.

Water Quality Simulation Module

Structural Representation of the Cooum River Network

DESERT version 1.1, (described above in the "Software and Development Tools" section), undertakes water quality and hydraulic simulation for the prototype Cooum DSS. (Box 4.3 presents a basic procedure for operating this module). The Decision Support Module (above) in the Cooum DSS parametizes DESERT's 'InfoTable' database files. These are required files in DESERT, as they contain information on quantity and quality of flows at point source effluent locations along the Cooum and its tributaries. However, DESERT also requires a structural representation of the river system. In order to provide such a representation, a database was constructed which described 'structural objects' such as reaches, confluences, headwaters, and the end or root of the system, as well as river objects such as point source effluent locations, sewage treatment plant effluent locations, reach cross-sections and abstractions. Figure 4.21 presents a representation of the Cooum River system, referred to as a 'rivernet', in DESERT.

The Cooum system as it was constructed for the DESERT simulator consists of the Cooum River and several tributaries. The Cooum itself is represented in the centre of the rivernet schematic (Figure 4.21), running from west to east. The headwater at the west end is actually a false headwater, as the Cooum is only represented within the city limits. (This point is treated as a headwater, but it is allocated a base flow which represents input from the

Upper Cooum system). The Buckingham Canal is represented in the schematic above as stretching from the city limits in the north to south of the Cooum. The headwaters of the Buckingham Canal are treated in the same way as is the Cooum. (The Canal actually stretches for hundreds of kilometres along the coast). In the past, the flow of the Buckingham Canal was from north to south throughout Chennai, but it is here represented as flowing south (to the Cooum) only in the northern part of the city. Due to neglect and siltation of the canal, which has changed its hydrologic characteristics, in the late 1990s it flowed north within the central city to the Cooum. Cross-sections indicate that there is actually a divide which splits the flow of the Central Buckingham Canal between the Cooum River in the north and the Adyar river in the south.[6] The other tributaries are the Arumbakkam/Virugambakkam Drain which empties into the Cooum in the west end of the city, Otteri Nullah (drain) and Captain Cotton Canal, both of which

1. Start DESERT (either from the 'Run' menu in the Cooum DSS, or in the normal way in Windows).

2. Under the 'File' menu, choose 'Open.' Use the dialogue box to navigate to the scenario's "data" directory. Select and open the river sytem universe file (.unv) in the directory (*e.g.*, test.unv). A representation of the river system will load in a 'Universe' window.

3. With the selection tool (the scissors icon on the tool bar), select the portion of the river system that will be subject to simulation. (*E.g.*, clicking around the outside of the river system representation, and double clicking to finish, will select the entire system).

4. Under the 'Edit' menu, set the default model (spatial step) for the simulation. ('Set Default Model (Mesh)' with a spatial step of 100 metres or less is recommended).

5. Under the 'Edit' menu, choose 'Copy Rivernet.' Under the 'File' menu chose 'New Rivernet.' Under the 'Edit' Menu chose 'Paste Rivernet.' A copy of your "Universe" representation of the river system will appear in the new rivernet window.

6. In the terminal window, type "init." This will initalize your river system for simulation. If errors appear in the terminal window, you may have to go back to step 4 and reduce the spatial step.

7. Under the 'File' menu, choose 'Import'. Select the MODUS (.mod) file that contains the scenario's water quality model specifications.

8. [Optional] To set up an Excel spread sheet to receive output: Under the 'File' menu choose 'Connect to Table'. Select 'Plottab.xls' in the scenario's "data" directory. Indicate that this is an excel worksheet in the dialogue box that appears. Double-click on the datasheet when it appears.

9. Run the model, using the "print" or "plot" commands in the terminal window, sending output to either the terminal window (*e.g.*, "print DO") or the spreadsheet (*e.g.*, "plot BOD").

Box 4.3: The basic procedure for running a simulation in DESERT, which acts as the Cooum DSS's water quality module.

[6] The Adyar River is not part of the Cooum River network.

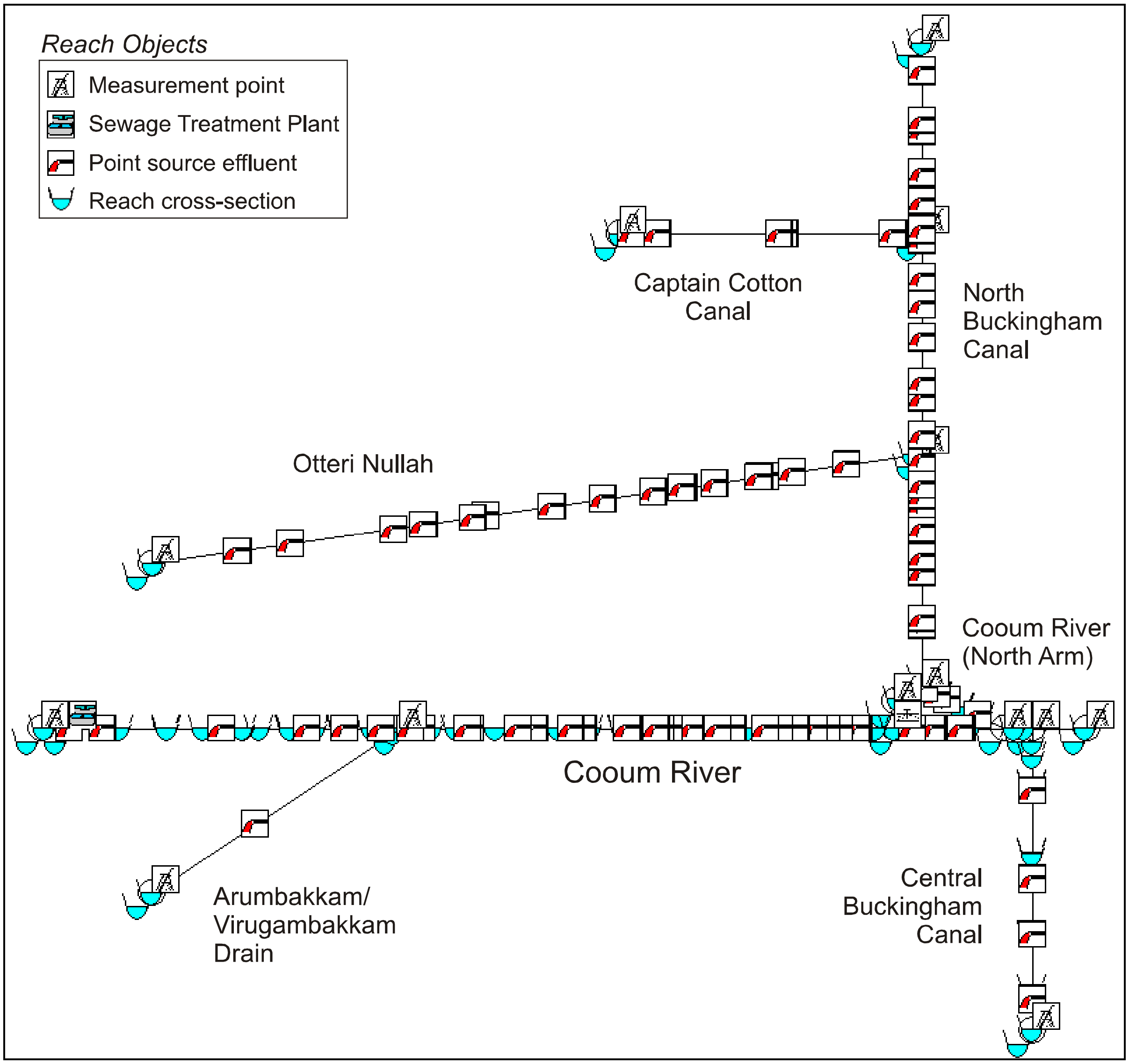


Figure 4.21: The Cooum River system binary tree 'rivernet' representation in DESERT. (This schematic represents the approximate orientation of the Cooum River and its tributaries within Chennai. North is toward the top of the diagram).

drain into the North Buckingham Canal.

In developing this structural representation of the Cooum River network, a problem was encountered in representing the Island in the lower reaches. As discussed above, DESERT does not allow bifurcation of reaches. Because of this, Islands cannot be represented. A "work around" was used which involves treating the northern arm of the Cooum, which is a minor branch that creates the Island, as if it were a tributary, and allocating a base flow to it, while at the same time withdrawing the same amount of water from an abstraction point on the main reach where the bifurcation point would have been. This situation is not ideal, but it is a better representation than altogether ignoring the Island. Table 4.3 presents the main branches in the river network.

Table 4.3: Main branches of the Cooum 'rivernet' representation in DESERT

Waterway	Length within the city (m)
Cooum	16 000
Cooum (North Arm)	2 050
Otteri Nullah	10 400
Captain Cotton Canal	2 850
North Buckingham Canal	6 900
Cental Buckingham Canal	2 350
Arumbakkam/Virugambakkam Drain	5 500

Source: Estimated from Mott McDonald (1994a) *Madras City – Urban Drainage Catchments.* [1:20000]. Chennai: Madras Metropolitan Development Authority.

Associated with structural objects such as headwaters, confluences and the end of the river network, are basic information about water quantity and flow, and water quality. These set the initial conditions for simulation of the network, and in the Cooum DSS, are stored in the "InfoTab1.dbf" file. These initial conditions may be changed by modifying this dBase file, or in the Cooum DSS, by modifying the corresponding ASCII format file ("InfoTab1.dat"), then using the "Build Model InfoTables" tool under the Cooum DSS 'Run' menu to transport the data to the dBase file. This may be easily accomplished with a text editor.

Representation of Objects in the River Network

In addition to representation of the basic structure of the river network, river objects must be specified in order to provide information on river reach characteristics. For the Cooum River network in DESERT, 69 reach cross-sections, 88 storm water outlets for rainwater, 88 outlets for untreated sewage, 1 sewage treatment plant effluent (treated) outlet, 1 sewage treatment plant overflow (untreated) outlet, and 1 water abstraction point (which

Table 4.4: River objects for branches of the Cooum River network, as defined in DESERT.

Waterway	Cross-sections	Stormwater point sources	Sewerage point sources	STP effluent point sources	Abstrac-tions
Cooum	45	33	33	2 (1 treated)	1
Cooum (North Arm)	6	4	4	-	-
Otteri Nullah	2	18	18	-	-
Captain Cotton Canal	2	5	5	-	-
North Buckingham Canal	2	22	22	-	-
Cental Buckingham Canal	10	4	4	-	-
Arumbakkam/Virugambakkam Drain	2	2	2	-	-

has already been discussed, above), were defined (Table 4.4).

The cross-section information used to construct cross-sections for the DESERT database (see Figure 4.22) were obtained from the *Stormwater Drainage Master Plan for Madras City, and Pre-Feasibility Study for Madras Metropolitan Area: Final Report – Appendices* (Mott McDonald, 1994c). These provided cross-section descriptions for the Cooum River, the Central and South Buckingham Canal, Mambalam Drain, and the Adyar River. It is almost certain that other appendices associated with the Mott McDonald report contain cross-section descriptions for the Otteri Nullah, North Buckingham Canal, Captain Cotton Canal and Arumbakkam/ Virugambakkam Drain. However, attempts to acquire these were unsuccessful. As a result, the river reach descriptions for the Cooum, Cooum (North Arm) and the Central Buckingham Canal are

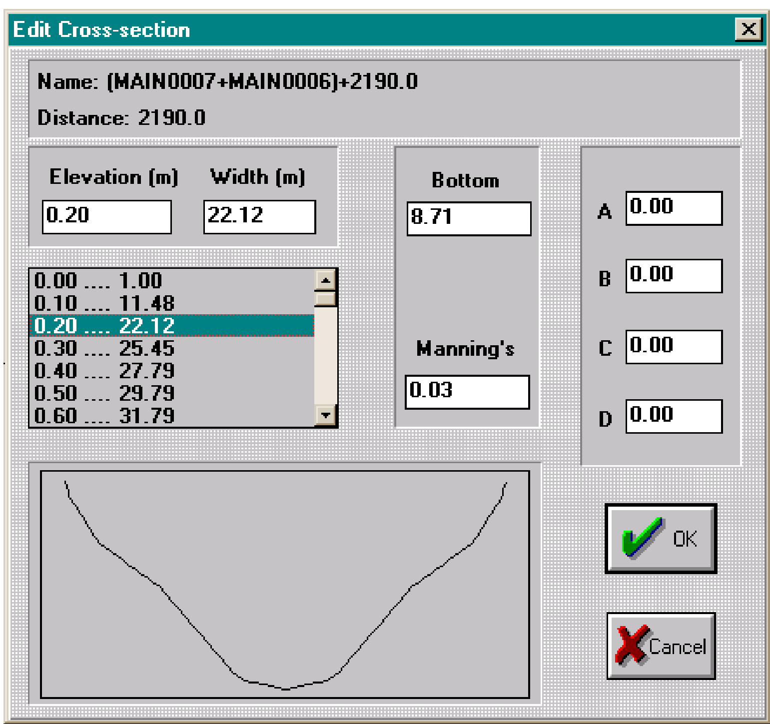


Figure 4.22: A river reach cross-section object on the Cooum system 'rivernet' in DESERT.

based on cross-section data from the Mott McDonald (1994c) report, while the remainder are modelled off the Central Buckingham Canal cross-sections with reference to elevations on the Survey of India topographic map sheets (Survey of India, 1971a, 1971b, 1976a, 1976b).

The cross-sections of the Cooum River indicate that bottom elevations in the downstream reaches of the system are below sea level. As DESERT cannot handle negative numbers in its calculation of river hydraulics, the entire river network was "raised" by 10 metres in the 'rivernet' representation to allow DESERT to function properly. In addition, the Manning's Roughness Factor, N, associated with cross-sections to describe reach roughness, was estimated to be 0.03 for all reaches of the system. This is a reasonable estimate for rather sluggish streams and canals with little vegetation on their banks (Mitchell *et al*, 1997: Appendix E2E; Raffensperger, 1997: Table 4.1).

Point source locations of effluent from the storm water drainage system in Chennai were modelled in the DESERT 'rivernet' representation of the system by taking the midpoints of stormwater catchment boundaries on either side of waterways, as indicated on the map of *Madras City – Urban Drainage Catchments* (Mott McDonald, 1994a). Stormwater drainage catchments are used as units to collect and route to waterways both stormwater and sewage that are not routed *via* the sewerage system. However, in the DESERT model, two outlets for each SWD catchment are indicated, 10 metres apart at the midpoint of the SWD boundary along the waterway. One outlet represents stormwater point source effluent, and the other corresponds to sewerage point source effluent. In this way DESERT is able to handle the mixing of sewerage and storm water, and removes the need to model this outside of the simulator.

Two other point source effluent river objects were constructed for the 'rivernet' representation of the Cooum system. These have to do with effluent from the Koyembedu sewage treatment plant, which is located just south of the Cooum River, near the city limits. Similar to the outlets from SWD catchments, one of these is allocated flow rate and water quality characteristics of treated effluent, while the other is dedicated to untreated effluent which is released into the Cooum River when the STP exceeds its maximum capacity.

Water Quality Modelling in DESERT

The water quality model specified as the default for use in the prototype Cooum DSS is based on the standard model used as an example in the DESERT software manual (Ivanov *et al.*, 1996:26-7). This model simulates the coupled reactions of the 5-day biochemical oxygen demand, ammonia as nitrogen, and reaeration of dissolved oxygen. To support such a model, the Cooum DSS loads the DESERT dBase files with the BOD_5, DO, N, and temperature data. An attempt to specifically customize the water quality model to more closely represent the Chennai situation has not been made here. However, if desired, the user of the Cooum DSS may customize the model file easily with a text editor. It is hoped that

```
#----------------------Hydraulic variables declaration------------------------------------------------------------
var flow
var width
var crossect                                          # Cross sectional area

#----------------------Input Data variables-----------------------------------------------------------------------
var T                                                 # Temperature
var DO                                                # Dissolved Oxygen
var BOD                                               # Biological Oxygen Demand
var N                                                 # Nitrogen (treated same as NH4-N)

#----------------------Constants declaration----------------------------------------------------------------------
daysec=86400.0                                        # Number of seconds in one day
Kr=0.8/daysec                                         # BOD removal rate (1/s)
Kn=0.8/daysec                                         # N removal rate (1/s)
ka0=2.0/daysec                                        # Reareation coefficient (m/s^0.5)
Ksod=0.0/daysec                                       # Sediment Oxygen Demand (g/m^2/s)

#----------------------Local variables declaration----------------------------------------------------------------
subst u=flow/crossect                                 # Velocity (m/s)
subst hydepth=crossect/width                          # Aeration depth
subst fta=(1+ 0.014*(T-20.0))                         # Temperature dependence of reaeration
subst ka=ka0*fta*sqrt(u/hydepth)                      # Oxygen exchange at water-air interf.
subst ftl=1.047**(T-20)                               # Temperature dependence of BOD removal
subst ftn=1.072**(T-20)                               # Temperature dependence of N removal
subst Osat=14.652-0.41022*T+0.00799*T**2-0.000077774*T**3  # Saturation O2 concentration

#----------------------Initialization of components (setting of boundary conditions)--------------------------
component L=BOD                                       # Biological Oxygen Demand
component OX=DO                                       # Dissolved Oxygen
component NG=N                                        # Nitrogen

#----------------------Equations of DO-BOD reaction schemes-------------------------------------------------
equation L=-Kr*L*ftl                                  # Exponential decay
equation NG=-Kn*NG*ftn                                # Exponential decay
equation OX=ka*(Osat-OX)/hydepth-Kr*L*ftl-Kn*NG*4.57*ftn     # Reaeration - BOD consumption -
                                                             # N consumption -SOD consumption
```

Box 4.4: The default water quality model (after Ivanov *et al.*, 1996) in the Cooum DSS.

further development of the water quality model will be undertaken in conjunction with other researchers in the near future, and that users of the Cooum DSS in Chennai will undertake continued development of the system.

Water quality model specifications and modifications may be imported from an ASCII file with a ".mod" extension (as in Box 4.4), or typed at the command line into the terminal window in DESERT. Once the user is satisfied with the water quality model specifications, model output may be generated by printing to the terminal window, or plotting to a spreadsheet.

Calculators and Data Transport Programs

Calculators and data transport programs are executable programs developed specifically for the Cooum DSS. They undertake the work of calculating new data from the various input data files and parameters, and also populate database files with the new data for use by the environmental modelling module. These programs were developed as binary executable modules in order to improve the efficiency and speed at which they perform operations such as file access, string manipulation and mathematical calculations.

The main compiled programs, or "calculators" described here, may be run from the 'Run' menu in the Cooum DSS. These programs involve:

1. Calculations of changes to ward populations and sewerage system efficiency coefficients due to improvement or clearance of slums,
2. Calculation of the amount sewage generated by population in wards,
3. Calculation of storm water runoff in urban drainage catchments,
4. Calculation of the proportion of sewage generated in wards which is allocated to the smaller routing units,
5. Calculation of sewage routed *via* the sewerage system, of sewage treatment plant overflow, and of sewage routed *via* the storm water drainage system to SWD catchment outlets, and
6. Transportation of the data products of the previous calculators into binary database files compatible with the water quality simulator.

The Slums Calculator

The slums calculator, compiled in the executable file "slums.exe", calculates changes to ward populations and ward sewerage efficiency coefficients when the user of the Cooum DSS specifies a scenario in which slums are either cleared (slum dwellers are relocated) or improved (the specified slums are sewered). There are several calculations that this program may perform. These are associated with user specifications for clearance or improvement of one or more slums that are passed from the GUI to the calculator as arguments to the program.

One of the functions of this calculator is to recalculate ward sewerage efficiency coefficients. If a slum is cleared from a ward, the efficiency rate must be re-calculated. (The efficiency rate is an indicator of the proportion of sewage generated in a ward which is routed *via* the sewerage system and, in part, represents the proportion of population in a ward which is serviced by the sewerage system). There is a basic assumption here that slum dwellers live in non-serviced areas.

The calculation of the efficiency rate for a ward from which a slum is cleared is stated by the equation:

$$e_2 = \frac{e_1 \times p}{p - (s_c \times h_z)} \tag{4.3}$$

where:

e_1 is the original efficiency rate for the ward,

e_2 is the new efficiency rate for the ward,

p is the original population of the ward,

s_c is the number of shelter units in the slum being cleared from the ward, and

h_z is the average household size for slums in the 1986 survey zone, z, in which the slum is located (as specified by the 1986 *Survey of Slums of Madras Metropolitan Area* (MMDA, 1987)).

This equation divides the population of a ward which has its sewage routed to an STP by the new total population of the ward once the slum population has been relocated.

A corresponding equation describes the calculation of the efficiency rate for wards receiving the cleared slum population, when the receiving area is specified as a ward within the city. The calculation of the efficiency rate for a ward which receives slum population cleared from another ward is:

$$e_2 = \frac{(e_1 \times p) + (s_r \times h_z)}{p + (s_r \times h_z)} \tag{4.4}$$

where:

s_r is the number of households (huts) of rehabilitated slum population that are being moved to the new ward, and

e_1, e_2, p, *and* h_z are as defined above.

This equation assumes that relocated slum dwellers are always provided with serviced sites in the new (destination) ward. The new efficiency is the weighted average (by population) of the efficiencies of the original population (e_1) and the relocated slum dwellers (1.0)

The calculated results of the two equations above are used to update the ward sewerage system efficiency coefficients data file. The population figures must also be updated. New population figures for wards from which slum dwellers are moved, and to which they are relocated, are also calculated very simply. The new population figures for wards in which slums are cleared is calculated as;

$$p_2 = p_1 - (s_c \times h_z) \tag{4.5}$$

where:

p_1 is the original population for the ward,

p_2 is the new population for the ward, and

s_c and h_z are as defined above.

Similarly, the new population figures for wards receiving slums are calculated as;

$$p_2 = p_1 + (s_r \times h_z) \tag{4.6}$$

where:

p_1, p_2, s_r, and h_z are as defined above.

These calculations are simply the original ward population plus or minus the incoming or outgoing slum population. There is an underlying assumption that the whole of the slum population will be relocated if a slum is indicated as cleared, and that they will be relocated all to the same destination. This is typical of clearance schemes in Chennai, which ordinarily relocate the entire population of a cleared slum to serviced sites outside of the city.

A final calculation that the slum calculator may undertake relates to the calculation of the efficiency rate for wards in which slums are improved, rather than cleared. This involves no recalculation of population figures, and only requires updating of the ward sewerage efficiency coefficient file. The calculation of the efficiency rate for a ward in which the slums are improved is stated by the equation:

$$e_2 = \frac{s_i \times h_z}{p} + e_1 \qquad (4.7)$$

where:

s_i is the number of shelter units (huts) in slums that are being improved *in situ*, and

e_1, e_2, p, and h_z are as defined above.

This equation is the incremental proportion of a ward's population (the slum dwellers) whose sewage is routed to a STP, added to the original efficiency rate of the ward. This relationship between improvement of slums and proportion of population served by the sewerage system rests on the assumption that slum improvement involves provision of sewerage to the slum population and the improved slum is considered as a sewered area with 100% coverage. (Improved slums are usually provided with communal latrines that are either sewered or have a septic tank. However, these are not always fully utilized by the slum population, especially if they are not well maintained).

The Population Calculator

The population calculator generates figures representing the amount of sewage produced by a ward's population. This involves an expression of the relationship between level of income (broken into three categories, high, middle and low), water consumption, and proportion of water consumed that is transformed into sewage. The calculations involved are expressed as follows;

$$q_s = \frac{s_{HIG} + s_{MIG} + s_{HIG}}{1000} \quad (4.8)$$

where:

q_s is the quantity of sewage generated (m^3/day) by population in an area (wards), and

s_{HIG}, s_{MIG}, and s_{LIG} are the sewerage generated (l/day) of the respective high, middle and low income groups which comprise the ward population. These income group sewerage figures are calculated as:

$$s_x = p(i_x \times c_x \times g_x) \quad (4.9)$$

where:

s is the sewage produced by income group *x* in a ward,

p is the population of a ward,

x indicates an income group (HIG, MIG, or LIG),

i is proportion of ward population which is in income group *x*,

c is the average consumption of water (litres/capita/day) of income group *x*, and

g is the sewerage generation factor describing the proportion of water consumed by income group *x* that is transformed in to sewage.

This relationship among income, water consumption and sewage generation assumes that sewage generation factors and water consumption figures for each group will not vary spatially across the city. That is, spatial variation in the amount of sewage produced by a given population is determined by income distribution alone. (As previously indicated, this assumption was though to be a reasonable one by participants in the second workshop). In designing scenarios, the user of the Cooum DSS is able to modify the sewage generation factors and water consumption figures associated with each income group, but these correspond to global changes which affect population equally throughout the study area.

The Stormwater Runoff Calculator

The stormwater runoff calculator is designed to calculate the rate of flow of stormwater from urban drainage catchments into the river, canal or drain into which they empty. The calculator updates the figures in the intermediate data table which describes the flow of water at an effluent point from each stormwater drainage catchment.

For this calculation, the "Rational Method" of calculating runoff rates is used. This method is simpler and more robust (having stood the test of time in the face of new understandings in soil science), compared to the two primary alternatives (*i.e.*, Cook's Method and the Hydrologic Soil Cover Complex Method) (Singh, *et al*, 1990, 30). The rational method is expressed in the equation:

$$Q_r = \frac{C \times I_h \times A}{360} \tag{4.10a}$$

where,

Q_r is the peak runoff rate in cubic metres per second (m^3/s),

C is the runoff coefficient (the proportion of stormwater which does not seep into the ground),

I is the intensity of rainfall (millimetres per hour), and

A is the area of the catchment in hectares.

This method assumes that rainfall occurs at a uniform intensity both temporally over the specified period, and spatially across an individual catchment. In the Cooum DSS, the capability to describe spatial variability across the city is provided through access to spatial attributes of the SWD catchment areas (rainfall and the runoff coefficient), in their ASCII format data files.

This method, however, calculates *peak* runoff which uses a rainfall intensity calculated using the actual number of hours of rainfall in a month, and the amount of rainfall. But even during the monsoon there will be periods of no rain. Stormwater runoff will usually be less than that calculated by equation 4.10a. For simulations with a longer period, or that do not model maximum intensity of rainfall, the equation has been modified to derive rainfall intensity using the number of hours in a month (I_m) to calculate the *mean* rate of runoff:

$$Q_m = \frac{C \times \mathrm{I_m} \times A}{360} \tag{4.10b}$$

The user of the Cooum DSS may choose from either equation.

The Routing Unit Sewage Allocation Calculator

The routing-unit sewage allocation calculator retrieves information relating to the amount of sewage produced by city ward populations (which is generated by the population calculator) and area data for wards and routing-units (produced by the GIS module).[7] It makes a simple calculation of the proportion of sewerage generated in wards which are allocated to each routing-unit in the study area. The formula is:

$$q_{ru} = q_s\left(\frac{a_{ru}}{a_w}\right) \tag{4.11}$$

where:

q_{ru} is the quantity of sewage (m^3/day) produced in a ward which is allocated to a routing unit,

q_s is the quantity of sewage generated (m^3/day) by population in a ward,

a_{ru} is the area (m^3) of the routing unit, and

a_w is the area (m^3) of the parent ward within which the routing unit is located.

The routing-unit sewage allocation calculator allocates sewage produced within a ward to its "child" routing-units without consideration of spatial variation within the ward. That is, the Cooum DSS assumes that sewage is produced homogeneously within a ward and does not consider spatial variation of population density within the ward.

The Sewerage Calculator

The sewerage calculator reallocates a portion of sewage associated with routing-units (produced by the routing-unit sewage allocation calculator) to storm water drainage catchments, and allocates the remainder to the Koymebedu sewage treatment plant. It also calculates overflow from the STP when its capacity is exceeded. (This is set to its current capacity of 34 mld for the default scenario). Sewage routed to the treatment plant *via* the

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[7]Since population (which is ultimately used to calculation the quantity of sewage) is a continuous variable, but is represented using arbitrary areal units (wards) which do not necessarily correspond to natural breaks in the data, the data may be subject to the modifiable areal unit problem. That is, changing the boundaries of the units, *e.g.*, disaggregating the data to create routing units, may change characteristics of the variable as observed in the data set. Future work will test this dataset to determine if this is a concern.

sewerage system is calculated in the following manner:

$$q_{STP} = \frac{\sum_{i=1}^{n} (e_i \times q_i)}{t} \tag{4.12}$$

where,

q_{STP} is the quantity of sewage (m^3/s) directed to the sewage treatment plant,

n is the number of routing-units in the study area,

i is the index of the routing-units,

e_i is the sewerage efficiency coefficient of the routing unit (derived from the parent ward),

q_i is the quantity of sewage (m^3/day) allocated to the routing unit (calculated by the routing-unit sewage allocation calculator), and

t is the number of seconds in a day.

The sewerage calculator checks to see if q_{STP} exceeds the capacity of the sewage treatment plant, (as specified in the management scenario and passed to the calculator as an argument). If it does, q_{STP} is capped at the capacity level, and the treatment plant overflow is calculated as:

$$q_{OVR} = \left(\frac{\left(\sum_{i=1}^{n} (e_i \times q_i) \right) - (c_{STP} \times 1000)}{t} \right) \tag{4.13}$$

where,

q_{OVR} is the quantity of sewage (m^3/s) routed to the STP overflow, and

c_{STP} is the capacity of the Koyembedu sewage treatment plant (mld).

The sewerage calculator also routes a portion of the sewage allocated to the routing-unit, (*i.e.,* that part not routed to the STP *via* the sewerage system), to storm water drainage catchments. The equation below represents this operation. For each storm water drainage catchment, *i*;

$$q_{SWD} = \frac{1 - (e_i \times q_i)}{t} \qquad (4.14)$$

where,

q_{SWD} is the quantity of sewerage routed to a storm water drainage catchment, and

e_i, q_i, and t are as defined above.

The main assumption to be aware of here, is that all sewage which is not handled by the sewerage system, is assumed to make its way to the main waterways *via* the storm water system.

The Data Transport Program

The data transport program does not produce any new data. Rather, it loads data from the ASCII format intermediate data files produced by the calculators, *via* the Borland Database Engine, into the binary dBase III format InfoTables required by DESERT. The user must invoke the data transport program from the "Run" menu in the Cooum DSS after any of the calculators have been run.

Conclusions

The prototype Cooum River Environmental Management Decision Support System attempts to operationalize the conception of the Cooum system, which was generated in the first workshop of the Cooum River Environmental Management Research Program (Chapter 3). The Cooum DSS itself consists of a loosely-coupled GIS (GRASSLAND) and environmental simulation model (DESERT), together with a graphical user interface and decision support module developed in Tcl/Tk and C/C++.

The development of the Cooum DSS involved the construction of an extensive database which consists of GRASS format spatial data, and associated ASCII format attribute files. The development of this database highlighted data needs to support research associated with Chennai and the Cooum system. The poor quality of much of the data, and total absence of some information to construct the database, is one example of uncertainty associated with environmental problems in India. However, the database was constructed with the best available data, and likely constitutes one of the most accurate and comprehensive databases of this nature available in Chennai. In addition, the Cooum DSS has been designed to facilitate the incorporation and upgrading of data when new or better information becomes available.

The operationalization of the conceptual model of the Cooum system also forced a narrowing of focus to primary relationships in the system. A common criticism of holistic and comprehensive approaches is that studies and projects which adopt such an approach try to take on too much, getting bogged down in the details of system interactions and relationships that, in fact, do not account for much variability in the system. Attempting to model the system simply, with limited resources, and with a basic framework for the system provided by participants of the first workshop, resulted in a more direct and focussed approach, in which only those actors, elements and relationships in the system perceived by participants as critical to the functioning of the system were modelled.

Additionally, attempting to express relationships and processes in mathematical or logical terms fostered another kind of focussing. In order to do this, such relationships have to be very explicitly defined. This forces assumptions about those relationships to also be stated explicitly, fostering yet further understanding, and clarity in representation, of the system. The assumptions discussed in this chapter are all part of attempts to express a situation mathematically, so as to represent reality as closely as possible. However, the representation of relationships in the real world as mathematical expressions is necessarily a simplification. There is likely to be some variability in the relationship that is not modelled. Stating assumptions in a way of expressing this.

Each of the relationships modelled in the Cooum DSS, and their associated assumptions, has been based on the collective knowledge and experience expressed by participants at the first workshop in the Cooum River Environmental Management Research

Program. For this reason the assumptions are likely to be realistic. Also, for assumptions relating to default values of data in the Cooum DSS, these values are accessible to the user, and may be modified as desired.

Finally, this system is a prototype. It has limitations, and further development of the GIS database and the decision support system will occur. This is part of an adaptive learning cycle in which the use of the Cooum DSS (and new experience in the real world) will generate new knowledge of the system and improved data, which will lead to improvement in the tool and inform action in the real world problem situation, and so on.

The next step for the Cooum DSS was to bring it back to workshop participants to see if it actually operationalized what they had originally conceived of as "the system," whether they found it useful in exploring the problem situation through scenario analysis, and whether participants felt that the Cooum DSS (and the whole approach within which it fits) continues to be useful to them in facilitating learning about the problem situation, and in potentially supporting decision making about rehabilitation and management of the Cooum system. This was the role of the Second Workshop of the Cooum River Environmental Management Research Program, which is discussed in Chapter 5.

5

Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs

Introduction

This chapter presents a discussion of the methods and results of the second workshop of the Cooum River Environmental Management Research Program. This workshop, entitled *Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs*, was held on 24-28 February, 1999 at the Department of Geography, University of Madras. It continued the problem analysis initiated during the first workshop. Once again, key actors and interested parties (*e.g.*, scientists, managers, planners, and others) came together to address the problem of rehabilitation and management of the "Cooum system." The second workshop addressed issues such as refinement and further development of the conceptual model of the Cooum system, implementation of interventions in the system, the design of simple exploratory scenarios for management of the situation, and the testing and use of the Cooum River Environmental Management Decision Support System (Cooum DSS) for exploration of aspects of the problem situation and sensitivity analysis.

As with the first workshop, there were intended to be some intangible products. These included the facilitation of communication among workshop participants, the creation of an environment in which creative solutions could be generated, and the development of a sense of ownership of the process. The second workshop consisted of both paper presentations and working sessions, but in contrast to the first workshop, it also included a component of ‘hands-on’ work with the Cooum DSS. The goals and objectives, participants, methods and results of the second workshop are discussed below.

The Second Workshop

Goals and objectives

The second workshop in the Cooum River Environmental Management Research Program had five primary objectives. First, it was intended to continue the systems-based problem analysis begun in the first workshop. Toward this end, the workshop employed system-based methods and continued the use of the ‘Rich Picture’ of the Cooum system as a focal point for discussion, and as a representation of common understanding of both the problem situation and the system of interest. Also, to provide continuity from the first to the second workshop, it was important that as many as possible of the original participants of the first workshop attended, and that as many as possible of the agencies, organizations and departments represented at the first workshop had continued representation. (Participation and representation are discussed in the section below).

Second, it was an objective of this workshop to continue dialogue on the Cooum system in an attempt to provide a source of information, ideas and participatory input to inform management and planning efforts. This was attempted through a series of presentations and associated discussion related to various aspects of the pollution and management of Chennai waterways, and through interactive working sessions oriented toward the development of a systemic understanding of the problem situation, prioritizing objectives, investigating interventions and undertaking scenario analysis of the Cooum system.

The second workshop was also intended to provide validation, refinement, and further development of the conceptual model of the Cooum system developed by participants at the first workshop in March 1998. This is a continued development of the conceptual understanding of the Cooum system in the context of a further year of reflection and new knowledge gained by returning participants, input of fresh ideas and understandings by new participants, new information presented during sessions, and clarifications arising from the attempt to operationalize this conceptualization in a computer simulation model. This third objective also included an intention to further develop an understanding of desirable possible future states of the system as expressed by the workshop participants. These were expected to emerge both in general discussion and in various working sessions in which participants prioritized and further developed alternative interventions in the system.

A fourth objective of the workshop had been to evaluate the prototype computer simulation model and decision support tool based on the framework provided by the initial workshop (see Chapter 4). This was to be done in part through responses in a formal workshop evaluation, but primarily through informal dialogue and interaction during the working sessions which employed the Cooum DSS

Finally, a fifth objective of the second workshop in the Cooum River Environmental Management Research Program was to use the Cooum DSS to: (1) identify aspects for which relationships between elements and actors in the system had not been correctly identified, or were in need of clarification (*i.e.*, to identify particular areas of uncertainty with regard to processes occurring within, or the structure of, the system), (2) to identify aspects for which data required to operationalize relationships and processes within the system were lacking (*i.e.*, parametric uncertainty), and (3) to perform sensitivity analysis with regard to various system components to determine if they affect the system as expected, and to learn from those analyses.

Participants

Participants for the second workshop were sought from the same group who attended the first workshop, from agencies and organizations to which they belonged, and from original invitees who were unable to participate in the first workshop. In addition, a few potential participants were identified who had not been identified for the first workshop (*e.g.*, academics at the Centre for Environment Studies at Anna University, and scientists from the Department of Oceans working on an Integrated Coastal and Marine Area Management project). Participation was solicited by a written invitation to potential participants, and their heads of department/agency, followed up by telephone and personal visits. Also, as with the first workshop, notice of the workshop was sent to, and posted in, several English and Tamil language newspapers.

Fifty-two individuals participated in the workshop (excluding the workshop organizers and some MSc candidates who sat in for part of the workshop), although many of these were present only for certain sessions such as the Inaugural Address. Participation numbers generally fluctuated between 20 and 28 for the working sessions and presentations, and about 20 participants were involved in working with the Cooum River Environmental Management Decision Support System on the fourth and fifth days of the workshop. Table 5.1 presents an overview of participation in both the first and second workshops of the Cooum River Environmental Management Research Program. As this table demonstrates, core agencies and NGOs were represented at both workshops, although in the case of government agencies, actual representing participants were fewer in the second workshop [12] than in the first [18]. Representation from private sector enterprises (such as developers and consultants) remained about the same in both workshops, while participants from academic institutions[1], and the those in the 'Other' category (comprised of interested citizens and the media) both increased. This increase in the 'Other' category from 4 to 10 is mainly due to media attention at the workshop.

Continued representation at the second workshop, especially from key governmental agencies and NGOs represented at the first workshop, provided for continuity in the program of research. Deputation of individuals to attend the second workshop, after the experience of the first, is an indication that those organizations and departments found the program of research, at least potentially, useful. In this case, 6 of the 8 government agencies that participated in the first workshop (those identified as the key agencies in the situation) also deputed individuals to participate in the second workshop. All of the participating NGOs were represented in both the first and the second workshop.

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[1]The figures for participants from Academic institutions are somewhat inflated by over-representation of geographers from the Department of Geography, University of Madras (10 in the first workshop, and 8 in the second).

Table 5.1: Outline of participation in the first and second workshops of the Cooum River Environmental Management Research Program.

Categories of Participant Representation	Workshop 1	Workshop 2
Number of Workshop Participants	49	52
Participant vis Stakeholder Counts		
Participants representing NGOs	8	9
Participants representing Government Agencies	18	12
Participants representing Consultancies/Corporations	5	5
Participants from Academic Institutions	18	22
Other (*e.g.*, private citizens, representation from the media)	4	10
Representation Count Total	53	58
Participants represented in more than 1 category (above)	2	4
Agency Representation		
Chennai Metropolitan Water Supply and Sewerage Board	✔	✔
Tamil Nadu Pollution Control Board	✔	✔
Chennai Metropolitan Development Authority	✔	✔
Tamil Nadu Slum Clearance Board	✔	✔
Tamil Nadu Public Works Department	✔	✔
Corporation of Chennai	✔	✔
Directorate of Public Health and Preventative Medicine, Govt. of Tamil Nadu	✔	✗
Department of Environment and Forests, Government of Tamil Nadu	✔	✗
Department of Ocean Development, Government of India	✗	✔
NGO Representation		
Public Utility Sanitation Centre	✔	✔
UNCHS (HABITAT) Sustainable Chennai Support Project	✔	✔
Indian National Trust and Cultural Heritage (INTACH)	✔	✔
Citizens' Waterways Monitoring Programme (WAMP)	✔	✔
Exnora International	✔	✔
Exnora Naturalist's Club	✔	✔
Professional and Business Association (PROBUS)	✔	✔
Chennai 'Local Environmental NGO'	✔	✔

Aside from representation of stakeholder groups and actors, it was also important for continuity of the program of research that as many *individuals* who participated in the first workshop also participated in the second. In all, the program of research saw continued participation by 26 individuals.[2] Continued participation of individuals was strongest in the NGO, Private sector and Academic categories (Table 5.1). The Government Agency and 'Other' categories had less continuity in participants between workshops (Table 5.2). Presumably, in the case of Government Agencies, this is because heads of agencies designate participants to the workshop according to their availability. The 'Other' category, in contrast, consists almost entirely of representation from the media, only two of whom were registered as participants at the first workshop.

Table 5.2: Stakeholder/Actor categories with representation by returning participants, as a proportion of all participants in their category in the second workshop of the research program.

Participant Category	**% of individuals at Workshop II who also participated in Workshop I**
Non-governmental Organizations	89
Government Agencies	33
Consultancies/Corporations	80
Academic Institutions	59
Other	20
Overall	50

Sequence of Working Sessions and Paper Presentations

The second workshop was organized in a manner similar to the first workshop. That is, it consisted of an inaugural session, working sessions and paper presentations, and a valedictory session[3]. As described in Chapter 3, workshops in this research program were a combination of the Indian 'paper presentation' style of workshop, with a more interactive

[2]This represents 50% of individuals participating in the second workshop. This number, however, downplays the 'real' level of returning participation in the second workshop, as those who did return tended also to be those who participated throughout the workshop, rather than merely provide a token presence (*e.g.*, at the Inaugural or Valedictory sessions).

[3]A valedictory session is a formal final session that includes an address by a notable person and a vote of thanks to the participants.

style designed to accomplish specific tasks. These tasks included a recommencement of the problem analysis, continued development of the conceptual model of the Cooum system, an investigation of selected potential interventions in the Cooum system, and the design and modelling of exploratory management scenarios. Figure 5.1 presents the sequence of working sessions oriented to these tasks. Table 5.3 presents the topics of paper presentations and discussions at the workshop and Table 5.4 details the timing and titles of the working sessions throughout the workshop.

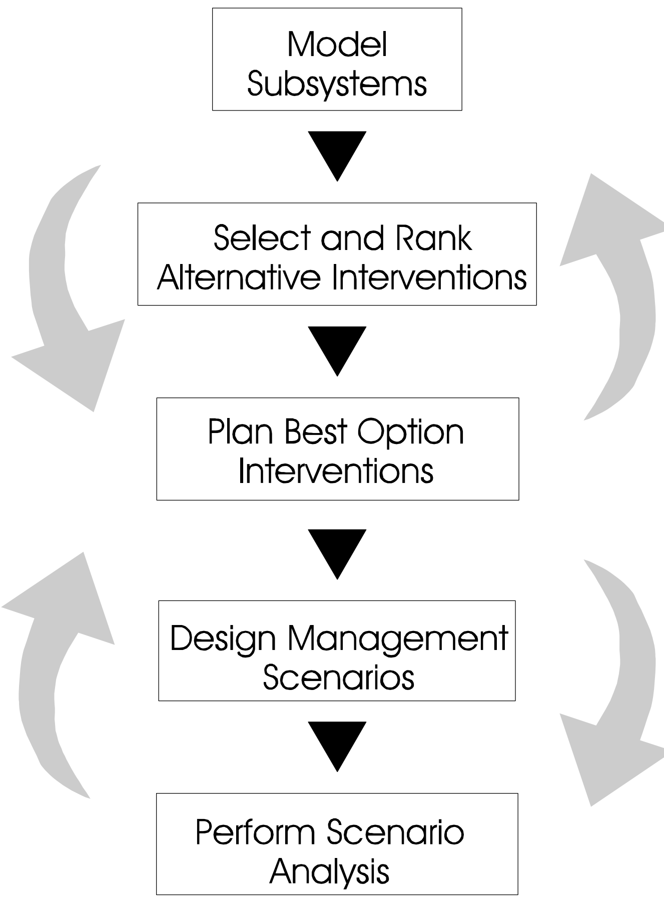

Figure 5.1: Sequence of working sessions in the second workshop of the Cooum River Environmental Management Research Program. The arrows in this diagram are intended to indicate that the process is not necessarily linear – topics addressed in working sessions may be revisited and their products modified based on new information or insight generated in later sessions, paper presentations, discussion and debate.

One major difference of the second workshop from the first was the provision of one and one-half days of "open lab" in which workshop participants were encouraged to work with the Cooum River Environmental Management Decision Support System at their convenience. The open lab was held in the Reprographic Laboratory of the Department of Geography, University of Madras, at which several workstations were provided for that purpose. The immediate objectives, intended products, methods employed and results of working sessions in the second workshop are discussed in detail below.

Table 5.3: Papers presented at the second workshop in the Cooum River Environmental Management Research Program.

	Paper Topic	*Presenter*
24 FEB	Inaugural Address	**Mr. S.A. Subramani, I.A.S.** Vice-Chairman, Chennai Metropolitan Development Authority
24 FEB	*Workshop overview and methodologies Review and Presentation of Workshop I Report*	**Mr. Martin J. Bunch** Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
24 FEB	*An Overview of Programmes to Address Waterways in Chennai*	**Er. P.V. Sahadevan** Deputy Chief Engineer Plan Formulation, Water Resources Organization., P.W.D.
24 FEB	*Are Long-Term Management Programmes Beneficial?*	**Dr. R. Ramanibai** Reader Department of Zoology, University of Madras (Guindy)
24 FEB	*Environmental Management of the Cooum River and Environs – Holistic Solutions*	**Mr. K. Thangavelu IRSE** President, PROBUS Chief Engineer, Ministry of Railways (Rtd)
24 FEB	*Waterways Restoration – Ecological and Social Dimensions*	**Ms. Sangeetha Sriram** Project Officer, Citizens' Waterways Monitoring Programme, Exnora International, Exnora Naturalists' Club
25 FEB	*Water Supply and Sewage Production in Chennai: Implications for Pollution of the Cooum River*	**Mr. S. Ananthapadmanabhan** Superintending Engineer Chennai Metropolitan Water Supply and Sewerage Board
25 FEB	*Chemical and Biological Characteristics of the Cooum River*	**Dr. V.S. Gowri**, Technical Assistant and **Dr. S. Ramachandran**, Director Institute for Ocean Management, Anna University
25 FEB	*Control of Mosquito Vectors in the Cooum River*	**Mr. B. Dhanraj** Senior Entomologist, Corporation of Chennai
25 FEB	*Modelling Hydrology and Water Quality in the Cooum using DESERT*	**Mr. Martin J. Bunch** Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
25 FEB	*Extempo: Critical Comments on the Programme of Research*	**Mr. S. Muthiah** Indian National Trust and Cultural Heritage (INTACH) President Emeritus, T.T. Maps & Publications Ltd. Publisher, Madras Editorial Services
26 FEB	*Rehabilitation of Slums Along Waterways for Better Environment –Myth or Realty?*	**Mr. Benjamin Gonzaga** Senior Planner Tamil Nadu Slum Clearance Board
28 FEB	Valedictory Address	**Mr. V. Rajagopal** Chief Engineer Chennai Metropolitan Water Supply and Sewerage Board

Table 5.4: Working sessions in the second workshop of the Cooum River Environmental Management Research Program.

Working Session Timing	Session Title
1 - Day 1 at 3:00 - 5:00	Re-examining the Cooum System – Sub-systems within the Cooum System
2 - Day 2 at 11:45 - 1:00	Action oriented objectives – Management Scenarios Part I
3 - Day 2 at 3:45 - 5:00	Operationalizing objectives – Management Scenarios Part II
4 - Day 3 at 10:30 - 1:00†	Introduction to the Cooum River Environmental Management Decision Support System
5 - Day 3 at 2:00 - 4:30† Day 4 all day (open lab) Day 5 morning (open lab)	Sensitivity and Scenario Analysis using the Cooum River Environmental Management Decision Support System
6 - Day 5 at 2:00 - 3:00	Presentation and discussion of model results Future directions for the programme of research

†These sessions were pushed back by 1.5 hours due to presentations to complete working session 3 from the previous day, and rescheduling of a paper presentation to the morning of Day 3.

Working Sessions of the Second Workshop of the Cooum River Environmental Research Management Program

Working Session 1: Re-examining the Cooum System – Sub-systems within the Cooum System

Immediate objectives and intended product

The first working session of the second workshop was intended primarily to re-initiate the problem analysis, and to stimulate further thinking about the problem situation associated with the Cooum River in 'systems' terms by addressing subsystems and relating them to the conceptualization of the Cooum system represented by the 'Rich Picture' (Figure 3.4). This was to provide an opportunity for new participants to contribute to the development of the conceptual understanding of the Cooum system that was initiated in the first workshop, and to share in a sense of ownership of it. It was also intended to facilitate further insight into the situation by looking at important subsystems of the Cooum system.

Tangible products of the working session were a series of written responses, generated during group discussion in answer to a series of questions (Box 5.1), and the production of schematic diagrams representing participant groups' conceptions of the operation of several subsystems.

Method

Several subsystems of interest within the Cooum system were identified through a facilitated discussion. Once this task was accomplished, participants were asked to divide themselves into groups based on mutual interests in analyzing particular subsystems. For this session, participants were provided with a exercise sheet in their workshop materials package. (The substantive content of this sheet is presented in Box 5.1). Each group worked through the exercise and presented its common understanding of the subsystem to other workshop participants at the end of the working session.

Conceptualizing Subsystems

1. What is the single main **process** (for natural systems) or **activity** (for human activity systems) that occurs within this subsystem?
   Note: This process/activity should make the subsystem "important" to the larger system as we conceived it earlier. Refer to the 'Rich Picture' generated in the first workshop to place the subsystem in context.

2. For human activity systems:
   Who are the main actors undertaking the activity described above in 1.?
   For natural systems:
   What are the main natural forces which operate the processes described above in 1.?
   List: (i) Actor/Force
   (ii) How does it act on the subsystem?

3. What are the inputs required for the activity/process described above to occur?

4. What are the outputs of the activity/process?

5. Who or what can change the way that this system operates?

6. Draw a schematic of the subsystem that represents its operation. The schematic should contain only the minimum number of actors and components to make the system operate the process described in 1.

Box 5.1: Working sheet guide for the first working session.

The guided exercise presented in Box 5.1 is strongly influenced by techniques in Soft Systems Methodology (Checkland 1981; Checkland and Scholes, 1990a) for developing root definitions and conceptualizing systems. In particular, this guide attempts to lead group members to identify actors in the subsystem, and activities or processes that are occurring that make the subsystem important in the context of the larger system, transformations involved in these activities/processes, and 'owners' of the system (who have power or ability to change them).

Results

Several subsystems of interest were identified. However, workshop participants organized themselves into only three groups, having to do with (1) Physical Hydrology, (2) Slums, and (3) Population (excluding slums). This resulted in large groups (7 in the Hydrology group, 8 in the Slums group and 8 in the Population group), a pattern that was to persist throughout the workshop.[4] Each of the groups was mixed, having representatives from government agencies, academia, and NGOs. The group results in this working session are discussed below in the context of the subsystems which each group addressed.

1. HYDROLOGY SUBSYSTEM: This group had some difficulty with the exercise, despite some guidance from the facilitator (researcher). This was primarily due to the internal dynamics of the group and the insistence of a senior and respected participant to express the subsystem in terms of a vision of how it might be, rather developing an understanding of how it is. This group produced an interesting product, but the reader should be aware that it is not entirely consistent with the products from the other groups in this working session.

The Hydrology group identified its subsystem in terms of a desirable system state for the future. They expressed it as: "Water Front for a length of 20 km." The main process identified for the 'envisioned' system was a "nominal flow" of water in the Cooum River. They further specified that the flow of water in the Cooum should have characteristics of surface mobility (no stagnation) and a minimum depth of 1.5 to 2 metres throughout the year. The main forces identified as operating the key process of the subsystem were:

- Rains and floods (which recharge neighbouring areas),
- Storm water drains (which provide for improved water quality of runoff), and
- Treated sewage effluents from the Koyembedu STP (which introduce flow to surface waters near the city limits).

The inputs required for the activity/processes to occur were identified by the Hydrology group as (1) funds, (2) resection (reshaping) of the river and removal of silt, (3) flood banks, and (4) course interventions such as mini barrages. Outputs of the primary process were seen to be (1) clean water, (2) landscaping, berms and bands (3) an eco-friendly system, and (4) revenue to government from recreational parks. Government agencies and

[4]Groups were originally intended to be 4 to 6 participants in size.

the Corporation of Chennai were seen to have the capability to change or affect the system, particularly in terms of implementing and managing interventions to achieve the vision.

The extensive discussion of the Hydrology group did not allow time for this group to complete the final part of the exercise, that of expressing their understanding of the subsystem in a schematic or pictorial representation. The 'vision' expressed by this group is something that had been addressed earlier in the first day of the workshop during paper presentation periods, and had also been expressed in the first workshop a year earlier. It is centred on the idea of a navigable waterway with year-round unobstructed flow, having flood protection for adjacent areas, and providing the location for recreational activities for the Chennai population. A series of objectives oriented toward this vision were generated in the first workshop, and several interventions designed to achieve those objectives were discussed (see Chapter 3). Some of these were revisited in the Hydrology group's conception of the hydraulic subsystem.

One of the contributions made by the Hydrology group related to the Cooum system and tourism. In discussions surrounding this vision during the first working session and earlier, the Cooum system and support of recreational and tourism activities were discussed. (This specific issue arose out of discussion about whether the river should be made and maintained as navigable). When the Hydrology group made its presentation, the issue of the potential for the Cooum to contribute to the draw of tourists to Chennai was again raised and discussed. A general understanding arose among workshop participants that, due to its repugnant character, the Cooum and surrounding areas currently act as a repellent for tourism and help to suppress a potentially large domestic tourism industry. This was seen as an important characteristic of the Cooum and later led to a refinement of the 'Rich Picture' so that this aspect of the situation was included as part of the 'official' conceptualization of the Cooum system.

2. SLUMS SUBSYSTEM: The Slum subsystem group identified the main process or activity involved in its subsystem as "Unauthorized Occupation of the River Banks (Habitation)." The main actors seen to be involved were slum dwellers and livestock, which acted within the system to pollute the Cooum waters, primarily by producing polluting

outputs by way of defecation, sullage, disposal of cattle and other wastes, household waste disposal (discharge), and blocking of free flow of water. This group discussed inputs to the slum subsystem largely in terms of the context of location and formation of the slums. In particular, they listed proximity to job opportunities, availability of free land, push and pull factors of migration, and natural increase of population as 'formative' inputs (or more

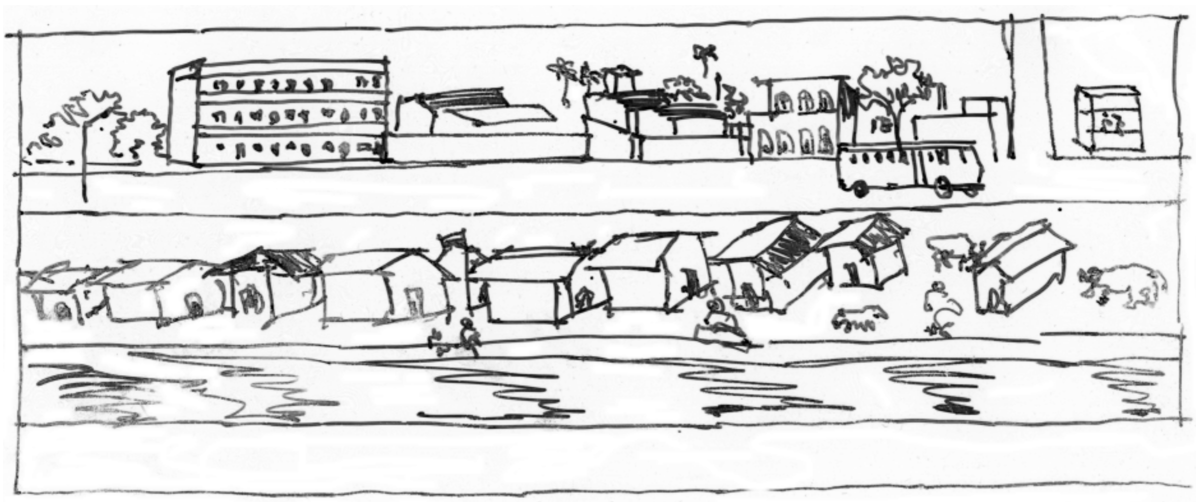

Figure 5.2: Diagrammatic representation of the slum subsystem in the Cooum system generated by workshop participants in the second workshop of the Cooum River Environmental Management Research Program. The diagram depicts a linear slum between a road and the river, and various activities associated with the slum such as washing and animal husbandry.

correctly, processes) important to the system. Government and NGOs were seen to be the 'owners' of the system, and that they could change it. The Slums group listed social education, empowerment of youth groups and women's groups, leadership training, policing, safeguarding of the land by the appropriate land-owning departments, and social and physical improvement in slums by NGOs as some ways in which the functioning of the subsystem might be altered.

The slum subsystem was represented in a sketch by this group (Figure 5.2). This representation illustrates many aspects of the slum subsystem discussed by the Slums group, not all of which were presented formally to the larger workshop group. In particular, note the location of the slum on objectionable land between the river and a road (subject to both flooding and traffic hazard), but at the same time proximate to the location of employment, and to public transportation. Also, open air defecation is represented, as are household activities and animal husbandry. There is also a flag (flying on a flag pole) represented, which in Chennai indicates a slum which has been politically organized.

The most interesting contribution of the Slums group was to highlight processes involved in slum formation, such as population increase, in-migration, "push" and "pull" factors of migration, availability of unoccupied land along watercourses, and the location of employment opportunities as important determinants in lower income group location decisions. These processes and relationships were noted in the presentation of the Slums group, and also came up throughout the workshop, particularly in the discussion following a paper dealing with slums along the banks of the Cooum (Gonzaga, 1999). These discussions enhanced participants' understanding of this aspect of the problem situation and led to modification of the 'Rich Picture' to incorporate an indication of in-migration and push and pull factors acting on rural-urban migrants and slum formation.

3. POPULATION SUBSYSTEM: The group that looked at the population component specified the subsystem they were interested in as "Population (excl. slums)." This group indicated two main processes or activities which characterize this subsystem: (1) the production of wastes (sewage, domestic, hospital, animal, commercial, industrial), and (2) frequent violation of civic responsibility. It would probably be more appropriate to characterize the latter of the two as a contributing factor or influence on the former, but the group felt that this aspect was so important that it deserved to be highlighted as a prime characteristic of the system. The main actors identified in the Population subsystem were "all humans." The group went on to emphasize this with examples of doctors, dairy farmers, restauranteurs, and factories. They further characterized humans in the subsystem as indifferent to the environment and to the increase of pollutant load which they caused. Humans were described as affecting the system, and the river in particular, through pollution resulting in the deposition of sludge, introduction of toxic waste and unauthorized solid waste, heavy metals and the creation of a "bad odour."

Inputs to the system were described as food, clothing, building materials, medicines, needles, straw, and foodstuffs. These were transformed by actors in the system into building debris, human wastes, domestic wastes, animal dung, food wastes and factory wastes. The operation of this system was seen by the group to be subject to control by the sewerage board (CMWSSB), (for example in the treatment of wastes), by factories which could undertake the separation of toxic chemicals, by NGO's which could engage the population in civic responsibility, and by government in enforcing the rule of law, through pricing policy and other incentives and penalties.

Figure 5.3 is the schematic from the Population subsystem group to represent its system. The figure depicts some very straight forward relationships between the Cooum River as a carrier of waste and several human institutions and activities. In this depiction the production of sewage and domestic waste is portrayed as subject to interception by the CMWSSB, hospital wastes are seen as potentially treated through high temperature incineration, and industrial waste through separation of toxic waste and treatment by a chemical effluent treatment plant. Garbage collection, composting and burning are portrayed as potentially acting to alleviate pollution from dairy farming and domestic waste. An interesting aspect of this schematic is the portrayal of the Cooum as a disposal and conveyance system for waste, and all human activity as waste producing. Contrast this to the 'vision' of the hydrology group, which saw the Cooum as a resource for recreation, tourism and transportation.

Throughout the Population group's discussion, and in its presentation, the issue of civic responsibility arose. This topic repeatedly came under discussion throughout the workshop. By civic responsibility, this group was referring to the attitudes and related behaviour of the citizens of Chennai. The basic idea was that people did not care if they polluted in Chennai. They did not see that their individual behaviour would make a difference to the situation, so they did not modify their behaviour. Furthermore, they did not expect others to modify their behaviour either. Polluting behaviour, such as public urination, spitting, indiscriminate tossing of domestic waste, construction rubble, and indeed, anything else, had become commonplace and socially acceptable. The premise was that behaviour could be modified if the citizen were motivated to do so.

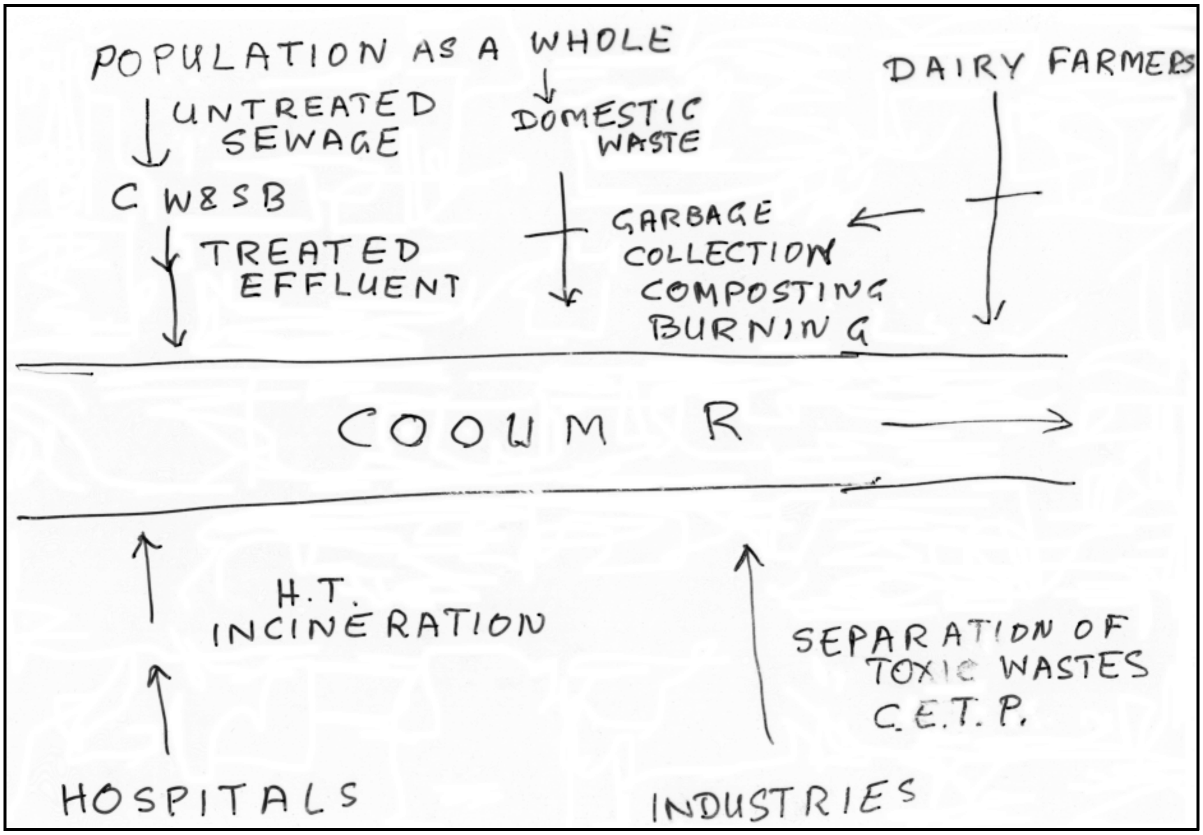

Figure 5.3: Schematic diagram of the Population subsystem belonging to the Cooum system generated by workshop participants in the second workshop. The schematic depicts components of the system and associated processes which act to pollute the Cooum River, as well as elements and processes which potentially alleviate polluting activity.

Several times during the workshop, the anecdote of a Chennai traveller was used to make this point. The Chennai traveller, a terrible polluter in Chennai – spitting, tossing rubbish, *etc*. – will board an aircraft and travel to Singapore. The same person's behaviour will be unrecognizable in Singapore because they know there that polluting behaviour is not socially acceptable and anti-polluting laws are strictly enforced. The same individual, after concluding their business in Singapore, will fly back to Chennai and immediately resume the polluting behaviour that they had just consciously abandoned. Hence, this group's comments regarding the potential of NGO's to initiate change in the system by fostering civic responsibility in the population, and of governments through enforcement of regulations and bylaws, pricing policy and various other incentives and disincentives.

Working Session 2: Action Oriented Objectives – Management Scenarios Part I

Immediate objectives and intended products

One of the products of the first workshop was the generation of a set of options or alternative interventions (Table 3.11) linked to objectives for rehabilitation and management of the Cooum system. An objective for this working session was to revisit possible interventions, and narrow the options to a few out of the 18 identified in the first workshop. Interventions discussed in this working session were directed at what participants in the first workshop indicated as the primary goal of the Cooum River Environmental Management Research Program – improvement of the Cooum system measured by water quality in the river.

While many of the interventions discussed by participants in the first workshop could help to attain this goal, some might have greater effect, be more politically feasible, or be easier and cheaper to implement, than others. Managers of any program to address the Cooum problem must decide which option(s) to pursue and there may not be an obvious choice. This working session borrowed from material in the UNCHS (Habitat) publication *Guide for Managing Change for Urban Managers and Trainers* (1991) to ask fundamental questions about the various proposed interventions. This exploration of options was intended to support reasoned judgement about which interventions to implement. It was intended both to contribute to efforts of managers to improve the situation of the Cooum and surrounding areas, and to guide workshop participants in the construction of management scenarios which explore the most potentially effective interventions in the Cooum system.

Thus, this working session was to produce fewer alternatives for intervention in the Cooum system than had been generated in the first workshop. It was also intended to produce scores for each of those options which could be used to compare and rank them.

Method

Workshop participants were presented with a review of the objectives and potential interventions for rehabilitation and management of the Cooum system developed in the first workshop. After a brief discussion, participants were broken into groups. Each group was asked to discuss and select what it considered to be the four most important options or interventions which would help to achieve the goal of improving the quality of water in the Cooum River. (In this, participants were not restricted to interventions generated in the previous workshop).

Groups then evaluated each option by way of directed critical questions (as outlined in UNCHS, 1991, 84). These were:

(a) Will this option clearly help us reach our objective? (In other words, is it goal directed?)

(b) It is feasible? Can we do it? Will it work?

(c) Do we have the resources to carry it out? People? Funds? Equipment? Time? Leadership? Organizational Capacity? Motivation?

(d) Is it adequate to meet the challenge? Given the size of the problem, will this option result in change to make pursuing it worthwhile?

Workshop materials were provided for participants to undertake the exercise (Box 5.2), and scores were allocated to the various options based on a discussion of the questions above. The results of the exercise were summarized, recorded, and displayed. Each of the groups made a brief presentation of its discussion and the results of the exercise.

Results

Once again, 3 groups were formed. These had size and composition similar to the groups in the first working session. Groups were tasked to choose what they considered to be the four interventions which had the most potential for leading to improvement in the system. They then, through consensus, awarded a score to each option in the manner presented in Box 5.2. (One group evaluated five interventions, as they felt they could not reduce the most important options to only four). Alternatives evaluated by the three groups are discussed below.[5]

GROUP1: Tables 5.5, 5.6 and 5.7 summarize the alternatives and scores awarded to

[5]Because groups compared and scored alternatives within, not between, participant groups, the actual scores will not be compared from one group to another. An option's relative position, or rank, within a group's evaluation of alternatives, however, may still be an indicator (even between groups) of its relative importance.

Narrowing the Options – Working Sheet

The OBJECTIVE to be achieved is: The OPTION to be achieved is:

Assessment Criteria: Check one numerical response for each of the following criteria:

(1) FOCUS:
- __ 4 - option is focussed directly on achieving the objective
- __ 2 - option is focussed more on another issue but will help achieve the stated objective
- __ 0 - option is not focussed on achieving the stated objective

(2) FEASIBILITY:
- __ 4 - option is very feasible to implement
- __ 2 - option is questionable in terms of its feasibility of implementation
- __ 0 - it is highly doubtful that we could implement this option

(3) RESOURCE AVAILABILITY:
- __ 4 - option can be implemented with the resources already available
- __ 2 - resources could be garnered to implement this option but it would be difficult
- __ 0 - it will be impossible to get all the resources required to implement this option

(4) ADEQUACY:
- __ 4 - option is very adequate in meeting the challenge stated in the objectives
- __ 2 - it is barely adequate to meet the challenge
- __ 0 - option will not meet the challenge

(5) COMMITMENT:
- __ 4 - top leadership will commit immediately to this option
- __ 2 - getting leadership commitment is questionable
- __ 0 - top leadership will not make commitment to this option

Potential Consequences: This option if implemented, will have the following consequences (circle appropriate number):

		Favourable	Hard to say	Disastrous
Economic	Short-term	2	1	0
	Long-term	2	1	0
Social	Short-term	2	1	0
	Long-term	2	1	0
Political	Short-term	2	1	0
	Long-term	2	1	0
Environmental	Short-term	2	1	0
	Long-term	2	1	0
Cultural	Short-term	2	1	0
	Long-term	2	1	0

Box 5.2: The exercise (excluding summary) employed to compare alternative interventions intended to improve water quality in the Cooum River. (After UNCHS (Habitat) (1991) *Guide for Managing Change for Urban Managers and Trainers*, 85-87).

them by the groups. The first Group described its four options (in italics) in the following manner:[6]

[6]Group 1 did not evaluate and score the alternatives in terms of short-term consequences (Table 5.5).

G1, Option 1: Increase in Storage Capacity of the reservoirs (dams) from the monsoon rain, etc. (flushing).

This option is related to an intervention described in the first workshop involving regulation of flow, but more directly refers to a plan put forward by one of the workshop participants, Mr. (Er.) Sahadavan of the Tamil Nadu Public Works Department (Water Resources Organization) (1994, 1995, 1996, 1998:7), to use tanks (reservoirs) to store water during the monsoon and use them to periodically flush out the Cooum during the dry season when the problem of pollution of the river is most obvious and severe (as evidenced by odour, colour, stagnant water, *etc.*).

Flushing of the Cooum was ranked lowest among the four alternatives, scoring only 53%. In presenting their evaluation of alternatives, participants in this group indicated that, in particular, they believed that it would be difficult to reserve fresh water for flushing the river, especially in a region and season of water scarcity. Some would even consider it extremely wasteful of a valuable resource. They also believed there would be great difficulty removing encroachments to restore "dry" tanks, and to maintain them in proper order. Such things as construction works for reservoirs, dams and connecting canals were viewed as expensive, while only providing for a periodic and temporary relief from symptoms of the problem.

G1, Option 2: Rain water harvesting should be made mandatary (Lower BOD)

This alternative (not included as a possible intervention in the first workshop) describes the extension of a recent initiative by the NGO 'Exnora International' to encourage construction practices for buildings which include measures to trap, and collect or direct, rainwater for the purposes of storage for private use, and for groundwater recharge. In the context of an option for alleviating the condition of the Cooum, this initiative is expected to increase the supply of water to households, even during the non-monsoon season (because of the greater availability of groundwater). This will increase the input of wastewater into the system. The waste in the water will be diluted (as there will be the same amount of pollutants, but more water), and the flow will be increased, which will correspond to less polluted water overall, and an improvement in the hydraulic characteristics of the river.

This alternative was tied for the highest score (87%) among the four alternatives evaluated by Group 1. It is a low-cost initiative that is seen as being easily implemented. There was, at the time of the workshop, a well publicized and recently initiated pilot project in Chennai to undertake rainwater harvesting measures. It addresses a well known problem (scarcity of water) that affects most of the population of Chennai (who acquire a large portion of their daily water needs from wells and pumps). However, the participants pointed out that the ultimate effect on the Cooum system was uncertain, and that this option is directed primarily at ground water recharge and water supply, and not at improving the condition of the Cooum.

G1, Option 3: Public Participation ... (high level management, NGOs, Voluntary Organizations ... in an active manner [including] follow up action)

Group 1 discussed as an intervention in the Cooum system the development of a participatory program of management. This option was not discussed in the first workshop, although the continuation of a participatory research program was identified as a main goal. Such an option would include important stakeholders, especially representatives of the public, in the governance, management and monitoring of programs to address the Cooum. This group thought that this would be a way to mobilize the public in working toward a healthy environment, and helping to ensure public cooperation with specific initiatives (such as bylaw compliance) to clean the Cooum.

This alternative ranked third of four, scoring a total of 83%. Participants in Group 1 believed that a participatory management program had very great potential to improve efforts to rehabilitate the Cooum system, primarily through the modification of polluting behavior of citizens. They also indicated, however, that they were skeptical that government agencies would be open to non-token participation, which might entail agencies relinquishing some of their control over resources, jurisdiction and decision making as well as requiring the sharing of data and information, and generally operating in a more open manner. A summary of the scores given to management options by Group 1 in the second working session are presented in Table 5.5.

Table 5.5: Scores given to management options by Group 1 in the second working session.[†]

Criteria	1. Storage and Flushing	2. Rain Harvesting	3. Public Participation	4. Preventing Sewage Disp.
Focus	2	2	4	4
Feasibility	0	4	4	4
Resources	2	4	2	2
Adequacy	0	2	4	4
Commitment	4	4	2	4
Consequences				
Economic				
Short Term	-	-	-	-
Long Term	2	2	2	2
Social				
Short Term	-	-	-	-
Long Term	2	2	2	2
Political				
Short Term	-	-	-	-
Long Term	2	2	2	2
Environmental				
Short Term	-	-	-	-
Long Term	2	2	2	2
Cultural				
Short Term	-	-	-	-
Long Term	0	2	1	0
Total Points	16	26	25	26
Percentage Score	53	87	83	87

[†] Group 1 did not evaluate options for short term consequences. Thus, the Percentage Score is calculated with a total possible score of 30 points instead of 40 points.

G1, Option 4: Prevention of waste getting into water bodies, should be taken seriously & modern methods should be adopted to tackle this problem

The fourth option was to stop all untreated domestic sewage from entering the river. The specification of modern methods refers to the collection and treatment of sewage *via* sewers, pumping stations, holding tanks and treatment plants. This alternative would entail upgrading of the sewage collection system (*e.g.*, sewering un-serviced areas, construction of intercepting sewers, improved maintenance and repair) as well as increasing the capacity of the sewage treatment plant. This option is a combination of two alternatives discussed in the first workshop.

Option 4 was also ranked (tied) as the highest score for Group 1 (87%). The primary difficulty with this option, for the group participants, was the great expense involved, and the difficulty in acquiring (clearing) land for expansion of the STP and construction of intercepting sewers.

GROUP 2: Group 2 evaluated five options. These included prevention of solid waste dumping in the system, increase in the capacity of the sewage treatment plant, the conduct of educational/awareness campaigns, diversion of storm water for the regulation of flow in the river, and periodic flushing of polluted waters from the river (Table 5.6).

G2, Option 1: Banning all dumping of garbage and untreated sewage into the river

This option involves the implementation and/or enforcement of bylaws to ensure that both solid waste and sewage are disposed in an acceptable manner. The option is partially related to two interventions discussed in the first workshop: (1) proper disposal of solid waste, and (2) linking sewage producers to the sewage collection system.

This option, ranked fourth out of five (60%), was stimulated by earlier discussion of the polluting behavior of Chennai residents, and the rampant non-compliance with laws stipulating proper disposal of wastes. Participants in Group 2 were, however, somewhat skeptical about the capacity to enforce laws banning improper disposal, citing issues such as the attitudes of citizens and corruption. It was also indicated that this alternative would not be enough, in itself, to make a very large impact on the system. There would also have to be the capacity to deal with the waste directed to dumps and treatment plants.

G2, Option 2: Strengthening treatment plant's capacity of treatment units, pumps & standby electricity

This option describes an increase in the capacity of STPs to treat sewage. It also indicates improvement to the collection system – specifically the pumps and power supplied to pumping stations, so that power failures would not result in overflows of sewage to the SWD system and the river. Ranked second of the options considered by this group (75%), this intervention was seen as critical to the success of other measures (such as provision of sewerage services and infrastructure to new areas and bylaw enforcement). However, as with Group 1, this group identified potential difficulties in land acquisition for upgrading of the STP, and also flagged high implementation and maintenance costs.

G2, Option 3: Educational campaigns to create awareness

'Educational campaigns' was an intervention in the system not formally identified at the first workshop, yet this option was ranked highest (83%) of the five considered by Group 2. In presenting this option, this group indicated that it was oriented primarily toward modification of the behavior of citizens of Chennai by helping to stimulate a common belief that polluting behaviors are socially unacceptable. (Again, the example of the Chennai resident modifying his/her behavior when traveling to Singapore was invoked).

Group 2 did not identify very many specifics of what this option might entail, but did indicate that they believed that NGOs could play a vital role in educating and mobilizing the public-at-large, and that an important target group would be school-age children. Once again, this option was identified as not sufficient by itself to deal with the problem, and would have to be combined with other interventions (*e.g.*, enforcement, dredging of sludge, upgrading of the collection system) to be effective. However, it was thought that other interventions would not be successful in the long term if this option was not pursued. The importance placed on this intervention by Group 2 entails a recognition that behavior of city dwellers, embedded in culture and values, is a key aspect of the situation. This must be addressed if the 'problem' is to be alleviated.

G2, Option 4: Storm water to be diverted through detention tanks

This intervention is intended to deal with a particular hydraulic aspect of the river, namely overflowing of the banks along certain reaches during particularly heavy monsoon rains. This is an issue that arose during the first workshop in March 1998 due to flooding of some areas adjacent to the Cooum River in November 1997 during the northeast monsoon. Use of detention tanks and diversion of storm water would regulate the flow of the Cooum so that the maximum water surface elevation during peak flow periods could be lowered.

This intervention was ranked 3rd of 5 (73%) by Group 2. Participants in Group 2 indicated that this intervention would have a direct effect on the objective (improving water quality in the Cooum), but did not indicate how this would occur, except to argue that it could be linked with a plan for reserving water for later flushing of the Cooum (as in option 5). This would provide for dilution of heavily polluted water when the water depth (and flow) of the Cooum was less, thus improving water quality. Participants were uncertain whether this plan would be adequate in itself to meaningfully address the objective – and suggested that it required integration in a larger management plan with a series of related interventions. They also questioned the feasibility of acquiring land for detention tanks within both the urban storm water catchment of the lower Cooum system, and the peri-urban and rural areas of upper Cooum.

Table 5.6: Scores given to management options by Group 2 in the second working session.

Criteria	1. Ban on Dumping Solid Waste	2. Increase STP Capacity	3. Awareness Campaigns	4. Storm Water Diversion	5. Flushing of the River
Focus	2	4	4	4	4
Feasibility	2	2	4	2	2
Resources	4	4	4	4	2
Adequacy	2	4	2	2	2
Commitment	2	2	2	2	0
Consequences					
Economic					
Short Term	0	1	1	1	1
Long Term	2	2	1	2	1
Social					
Short Term	1	0	2	1	1
Long Term	2	2	2	2	1
Political					
Short Term	0	0	1	0	1
Long Term	1	2	2	2	1
Environmental					
Short Term	2	2	2	2	1
Long Term	2	2	2	2	2
Cultural					
Short Term	0	1	2	1	2
Long Term	2	2	2	2	2
Total Points	24	30	33	29	23
Percentage Score	60	75	83	73	58

G2, Option 5: Cleaning and flushing of river

The intervention of cleaning and flushing the river is the same as the first option evaluated by Group 1 (above). It involves the storage of monsoon rains in restored or improved tanks (by the PWD), primarily in the upper reaches of the Cooum outside of the city limits, and the use of this water to periodically (once or twice per dry season) flush out the polluted water from the lower Cooum River. As with Group 1, Group 2 also ranked this alternative the lowest (58%). In their presentation of the interventions, Group 2 cited cost and land acquisition as issues of concern. They also pointed out that this option did not address the root of the problem of the production and treatment of pollution, but merely moved the polluted water from one location to another, and would be likely to threaten Marina Beach and coastal fisheries.

GROUP 3: Group 3 evaluated four options: collection and treatment of sewage, solid waste disposal, flushing of the Cooum, and slum clearance. These are described below. Group 3's scoring is summarized in Table 5.7.

G3, Option 1: Prevention of untreated sewage into river water and into treated effluent water

This intervention is the same as that evaluated by Group 1 (option 4). It was ranked very high (2nd out of 4 at 90%, compared to Group 1's first place tie). The intervention, which describes measures to ensure that all wastewater and sewage produced are collected and treated, involves upgrading of the sewerage system in the city. The emphasis placed on this option is due to a belief by Group 3 that the basic cause of the poor water quality in the Cooum River is that the population produces sewage which is then let into the river untreated. Collect this waste (*e.g.,* with intercepting sewers), and properly treat it (with increased capacity of the sewage treatment plant), and the problem would be greatly improved. Group 3 considered that this was widely recognized as a feasible solution, and that both resources and political commitment for its implementation were not insurmountable obstacles.

G2, Option 2: Eviction of unauthorized occupants

Eviction of unauthorized occupants refers to clearance of slums along the banks of the Cooum River. Both clearance and improvement of slums *in situ* were identified as potential interventions in the Cooum system during the first workshop. Typically, clearance of slums requires a declaration of a slum area as located on "objectionable" land (*e.g.*, locations hazardous to the occupants due to flooding).[7] The slum dwellers are then removed from the area and are typically relocated to the periphery of the city and provided with basic services (*e.g.,* as in a sites and services scheme). Clearance of slums is generally thought to improve the situation of water quality in the Cooum because slum dwellers living on its banks dispose of their household waste (both solid and liquid) into, and on the banks of, the Cooum. Slum dwellers are also known to dispose human wastes (through open air defecation), either on the banks of the river or in adjacent storm water drains which flow directly to the Cooum. However, relocation typically removes slum dwellers from proximity to their place of employment, and to areas which provide fewer opportunities for employment.

This group ranked slum clearance last out of the four alternatives, giving it a score of 88%. Group 3 felt that slum clearance would make a significant contribution toward improving the quality of water in the Cooum, despite the fact that clearance of slums was more likely to occur in the pursuit of goals other than Cooum River maintenance (such as housing rehabilitation of slum dwellers). Removal of slums was indicated by Group 3 as likely to remove obstacles to flow of the river and allow resectioning and lining in areas previously occupied by slum dwellers.

G2, Option 3: Periodical flushing of Cooum River flow

Once again, the option of flushing the Cooum was examined (this alternative is the same as described for Groups 1 and 2, above). Group 3 ranked this option 3rd out of the four options. As with the other groups, it cited cost as an issue, particularly in relation to the construction of connecting canals, and land acquisition in the Upper Cooum system. Group 3, however, indicated by its ranking that it considered this intervention to be more directly applicable to the objective of improving water quality, and more feasible than did the other two groups.

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[7] Definition and legal issues associated with slums are laid out in the The Tamil Nadu Slum Areas (Improvement and Clearance) Act, 1971, (Government of Tamil Nadu, 1971). Chapter VII of this act deals with protection and eviction of slum dwellers.

Table 5.7: Scores given to management options by Group 3 in the second working session.

Criteria	1. Preventing Sewage Disposal	2. Slum Clearance	3. Flushing of the River	4. Ban on Dumping Solid Waste
Focus	4	2	4	4
Feasibility	4	4	4	4
Resources	4	4	2	4
Adequacy	4	4	4	4
Commitment	4	4	4	4
Consequences				
Economic				
Short Term	1	1	1	2
Long Term	2	2	2	2
Social				
Short Term	1	1	2	2
Long Term	2	2	2	2
Political				
Short Term	1	1	1	1
Long Term	2	2	2	2
Environmental				
Short Term	2	2	2	2
Long Term	2	2	2	2
Cultural				
Short Term	2	2	2	2
Long Term	2	2	2	2
Total Points	37	35	36	39
Percentage Score	93	88	90	98

G2, Option 4: Stoppage and prevention of garbage dumping into the Cooum River

This option is similar to the option of banning the dumping of solid waste and disposal of sewage identified by Group 1, except that this alternative deals with solid waste alone. Solid waste is seen as contributing both to the poor water quality of the Cooum River, and also to creating significant hydraulic obstacles which may block the path of the river and cause the flow to meander and slow,[8] or stagnate. To illustrate, in presenting the score for this alternative, Group 3 cited an example of widespread dumping of construction and demolition debris on the banks. Comments from workshop participants at this point

[8]Mr. Danraj, Senior Entomologist at the Corporation of Chennai, demonstrated in his paper at this workshop (Danraj, 1999) that such obstacles in the river create breeding habitat for mosquitos, increasing annoyances (such as lack of sleep) caused by mosquitos, and exacerbating diseases in the nearby population for which mosquitos are vectors.

indicated that solid waste throughout the system (not just on the banks) was considered important, as it causes clogging of and flooding from sewers, contributes to the "system shock" of the first flush of water from polluted streets in the monsoon, and is generally unsightly, harmful to health and is representative of the lack of environmental consciousness of the population at large. These factors led this group to rank this intervention highest among the four, with a percentage score of 98%.

Table 5.8 presents the ranks given to the various alternatives by the three groups. Even though these ranks are not strictly comparable, because groups evaluated different sets of options, two trends are still evident. Two alternatives were evaluated by all three groups: flushing of the Cooum River, and upgrading the coverage and capacity of the sewage collection and treatment system. The former was ranked low by each group, while the latter was ranked high. It is likely that the river flushing scenario was considered by all groups because it is a proposal that has been circulating since at least 1994 (*e.g.*, Sahadavan, 1994), and came to the attention to workshop participants again through its proponents at the workshop (primarily from the PWD, including Mr. Sahadavan, the scheme's originator).

From the discussion surrounding this alternative, it seems that the low rankings may be attributed in part to anticipated high costs and logistic difficulties. More importantly, this alternative was not perceived to address the root of the problem for the pollution of the river, (although there are other multiple benefits to the scheme, which are especially evident when the scope of the system is expanded to include the regional scale river, canal and reservoir network). In contrast, the alternative proposing that all sewage produced in the city should be collected and treated before letting it into the river was seen by participants to directly address the problem.

Some alternatives in the second workshop had not been formally identified in the first workshop. These were rain water harvesting, public participation in management programs, educational campaigns, and diversion of storm water to detention tanks. The latter aside (it is related to the river flushing scenario, identified early in the first workshop), these options are qualitatively different from those put forward by the first workshop participants in March 1998.

Table 5.8: Relative ranks to alternative interventions by groups in the second working session. (In interpreting these ranks, remember that groups did not compare the same sets of alternatives, even though some alternatives were considered by two or more groups).

	Rank		
Intervention	**Group 1**	**Group 2**	**Group 3**
1. Flushing of the Cooum	4	5	3
2. Rain water harvesting	1		
3. Public Participation	3		
4. Proper collection and disposal of solid waste		4	1
5. Upgrade capacity of sewerage collection and treatment system	1	2	2
6. Educational campaigns		1	
7. Diversion of storm water through detention tanks.		3	
8. Slum Clearance (eviction)			4

The difference has to do with the nature of the management interventions proposed. In the first workshop, all of the options could be labeled 'traditional' in that they could (and have been) implemented by government agencies in their normal operating mode. For example, the TNSCB might clear slums from objectionable land along the banks of the Cooum, the PWD would be involved in regulation of flow and the construction of flood defenses, and the Corporation of Chennai would implement vector control or garbage collection and disposal programs. These types of interventions are influenced by aspects of their implementing agencies: centralized control of the project, vertical and formal communications within a hierarchical organization, conformance to plan, and very little tolerance for uncertainty (*i.e.*, mechanistic management strategies as presented in Table 2.3).

Some of the interventions identified by participants in the second workshop were of the same variety (and were in fact identified in the first workshop). The three options (rain water harvesting, public participation in management programs, and educational campaigns) identified above, however, are innovative in that they involve the public. In the case of rain water harvesting, private dwellings are renovated or constructed to catch and conduct rain water to local recharge wells, and to private water storage tanks. The success of such a scheme depends upon the participation of the population-at-large.

The option of public participation in management programs addresses change in the way management interventions are planned and implemented. These have to do with aspects such as coordination, communication, control, leadership and monitoring of projects, moving them away from a mechanistic to a more adaptive management style, as described by Rondinelli (1993b). Educational campaigns are similar in that they target the population-at-large, who are expected to become the main actors, through voluntary action, in maintaining and rehabilitating the Cooum system.

This difference in interventions from the first to the second workshop (where 3 of the 8 primary potential management interventions were of a participatory nature) may be evidence of the evolution of understanding of the system. In general (and this is a simplification), participants in the first workshop described and understood the Cooum system in a primarily physical, tangible manner. Progression from the first to the second workshop saw the focus shift to consideration of the cultural, societal context in which the behavior, attitudes and related activities became more important aspects. The second workshop, in its revisiting of the Cooum system in this context, can be seen as an active operation of a learning cycle, bringing a qualitatively different understanding of the system, as reflected by the new management interventions which it generated.

Working Session 3: Operationalizing Objectives – Management Scenarios Part II

Immediate objectives and intended products

Once the options have been narrowed, an alternative may be chosen (one which satisfies the criteria in the previous exercise). This working session was intended to provide an opportunity for small groups of participants to discuss a single alternative intervention in depth. In particular, it picked up where the second working session stopped, taking up the most promising interventions, as identified by workshop participants, and identifying and discussing issues associated with their implementation. An intended product of this session was the development of a basic understanding of activities, actors, allocation of responsibilities, resources, and time frames likely to be involved in such interventions.

Method

This session began with a brief discussion to identify the options to be further pursued by the workshop participants. Participants in the session were again allocated into groups. Each group was asked to begin to sketch out issues and activities associated with an important alternative management intervention that arose as a "best" option in the previous working session. Participants were to do this through group discussion guided by the questions presented in Box 5.3. Each group was to make a brief oral presentation of its discussion to workshop participants as a whole.

(1) What are the activities involved (steps to be taken) in implementing this option? (Consider a single option only).

(2) Who will take the primary responsibility for each action? (Someone needs to be in charge).

(3) Who else needs to be involved?

(4) What resources will be needed (people, materials, money, equipment, skills)?

(5) When will each action be complete? (Not only how much time will be required, but a realistic date of completion).

(6) How will we know progress is being made toward carrying out our option and meeting our objectives? How are we going to evaluate success? What are our verifiable indicators?

(7) What other options need to occur in conjunction with this option in order for it to be effective (or to support the effectiveness of other options)? (What options comprise the management scenario or plan?)

(8) Where does this option fit in the sequence of options to be implemented in the management scenario (plan)?

Box 5.3: Guiding questions for exploration of management alternatives. (These questions are a continuation of the previous exercise drawn from the UNCHS (Habitat) (1991) publication *Guide for Managing Change for Urban Managers and Trainers)*.

Results

Before breaking into groups (the same as in the previous session) to discuss a plan for implementing a "best" option, consensus was reached about which alternatives from working session 2 would be addressed by each group. Two of the groups wished to pursue more in-depth discussion about the option of preventing untreated sewage from entering the Cooum.

It was decided that these groups would look at different aspects of this option. Group 1 addressed the improvement of sewage collection so that untreated sewage would not be let in to the river. Group 2 looked at optimizing and increasing the capacity of the sewage treatment plant. Group 3 chose to look at prevention of solid waste dumping in the system.

This session was slightly abbreviated due to some rescheduling of papers and working sessions, and because a previous session had overrun. As a result, by the time the groups had discussed their chosen option in light of the questions above, participants were ready to leave for the day. Workshop participants preferred to make brief presentations of their results early the following morning. Table 5.9 summarizes the points that the groups presented early on the third day of the workshop.

These options are not presented in depth here, as the plans at this stage were little more than outlines. However, some interesting points were raised in the presentation of these scenarios. These had to do with uncertainty and the need for information. For example, Group 1 presented as part of its outline plan the required activity for identifying unauthorized sewage and stormwater outfalls into the river. It complained that, despite some previous work (*e.g.*, Mott McDonald, 1994b), these were still not entirely known. This kind of situation demonstrates a simple lack of information. Such a situation is not insurmountable, as evidenced by Groups 1's prescription. However, some information may be known, but not accessible. This is exemplified by a comment by Mr. Dattatri (a retired Chief Planner of the CMDA, Project Adviser of the Chennai Sustainable Support Project, and an Urban Consultant), a participant in Group 2. He stated that, in discussing the upgrading of the treatment plant, we were missing even the most basic of information. For example, it is not known outside of “Metrowater” (*i.e.*, CMWSSB) whether the STP has the capacity to treat all of the sewage that would potentially be delivered to it. Thus, the group could not know if it merely needs to be optimized in its use, or if upgrading the capacity of the plant is called for. The implication here is that agencies keep this kind of information to themselves, and that outsiders, even other government agencies, may sometimes not be privy to this information when needed. It is also a comment on the institutional climate and

Table 5.9: Outlines of plans to implement "best" options for management of the Cooum system.

Activity	Primary Actor	Who else would be involved?	Required Resources	When Complete	Progress Indicator	Complementary Options	Where does it fit in the plan?
Group 1: Preventing untreated sewage being let into the Cooum							
Identify unauthorized outfalls	PWD	CMWSSB, NGOs	Money, Personnel	4 months	chainage surveyed (km)	STP must have the capacity to treat additional sewage routed to it	First
Eviction of river (slum) dwellers	TNSCB	CMDA	Money, Land	unknown	land free of occupants		Second
Construction of intercepting sewers along river (to catch and re-route sewage)	CMWSSB	PWD, CMDA	Money, Land	1 year	no. of drains intercepted		Third
Group 2: Optimizing and upgrading STP							
Land acquisition	CMWSSB	CMDA, Chennai Corporation	Money, Land	unknown	land acquired	Electrical power supply stabilized (failsafe), pumping station upgrades	First
Facility construction	CMWSSB	PWD	Money, Land, STP equipment	unknown	increased capacity of the STP		Second
Group 3: Stoppage of solid waste dumping							
Public awareness and education	NGOs	Sustainable Chennai Support Project, CMDA	Money	ongoing	compliance, participation	Enforcement of bans on dumping	all through
Incineration at household level on the outskirts of the city	NGOs	Sustainable Chennai Support Project, CMDA	Money, kilning bricks	unknown	no. of households incinerating		all through
Dustbin solid waste collection	Chennai Corporation		Money, Trucks, Drivers, Land	unknown	tonnage of waste collected		all through

cultural context that a less established and well respected individual probably could not have made such a criticism of a government agency.

Working Sessions 4 and 5: Sensitivity and Scenario Analysis using the Cooum River Environmental Management Decision Support System

Immediate objectives and intended products

Working sessions 4 and 5 are presented together as they both relate to the use of the Cooum River Environmental Management Decision Support System by workshop participants. Working session 4 had to do with some elementary training of participants in the use of the Cooum DSS, while session 5 saw workshop participants work with the Cooum DSS to explore various management scenarios in the Cooum system.

The objectives of this session were several. First, it was desired that workshop participants would evaluate the representation of the Cooum system by the Cooum DSS. This representation was intended to be the operationalized version of the conceptual model generated in the first workshop. Thus, it was hoped that the following question could be asked of participants "Does this represent the situation that you conceived of as the Cooum system?" Second, the general usefulness of being able to visualize data, to modify parameters of the system to explore its sensitivity to various changes, and to construct representations of the system that illustrate potential future states, was to be explored. Also, although the Cooum DSS was still a prototype for this working session, it was thought that some interesting results might arise from actually running the model using scenarios developed by workshop participants. Finally, improvements to the model were sought, both in terms of how the Cooum system had been operationalized in the DSS, and in the form of the DSS itself (*e.g.*, window layout, ease of use).

Thus, the intended products of this session were an evaluation of the Cooum DSS itself, of the representation of the Cooum system it is based upon, the generation of a set of simple management scenarios with which to perform sensitivity analysis, and the results of running the model with those scenarios.

Method

For the “hands-on” use of the Cooum DSS, an open “drop-in” lab was run for one and one-half days. This occurred on Saturday, 27 February, 1999 (all day) and the following Sunday morning. The training session (session 4) was conducted on the preceding Friday afternoon. Workshop participants were encouraged to drop in for several hours to develop exploratory management scenarios for simulation using the Cooum DSS. This researcher (who is also the developer of the system) was present to provide technical support for workshop participants, and to receive feedback from them regarding the Cooum DSS and its representation of the Cooum system.

In developing scenarios for the Cooum system, workshop participants were instructed to establish a scenario describing a “Baseline” or normal situation for the Cooum at a particular time of year. They then were asked to design at least one scenario that represented a single large-scale deviation from that Baseline. The scenarios constructed using the Cooum DSS could then be subjected to hydraulic and water quality simulation to explore the effect on the system of that single intervention.

Results

About 20 workshop participants joined in the Cooum DSS working session. Participants came to the lab throughout the day and morning, and placed themselves in groups which jointly explored the Cooum DSS and developed exploratory management scenarios. Four groups of 4-6 participants each were involved. Feedback from these groups dealt primarily with the Cooum DSS itself, the representation of the system in the Cooum DSS, and data issues. Each of the groups developed a variety of scenarios which explored simple interventions in the system. Some of these were pure exploration of the DSS. Others were more organized scenarios aimed at exploring a single or very few management interventions. A discussion of these is reserved for the presentation of exploratory management scenarios later in this chapter.

With regard to the GRASSLAND GIS and Tcl/Tk Graphical User Interface of the Cooum DSS, the workshop participants uniformly indicated to the researcher that they were very enthusiastic. Visualization and query of the spatial units and data using the GIS module generated much discussion from participants. In part this may be because GIS is a new technology, particularly in many developing areas, and the new experience of using a sophisticated and somewhat "flashy" technology can be exciting. Also, however, use of the GIS module brought to the attention of workshop participants issues about the accuracy of the data in the GIS database, the maps used to create that database, the availability of maps of high quality and accuracy, the reluctance of government agencies to share information, and the classification of materials such as maps in coastal areas and other places perceived to be militarily sensitive. It impressed the group that they were working with a database that was properly spatially referenced, a characteristic that, in Chennai, is usually only evident on restricted access topographic sheets. Participants in several groups broke off for animated discussions on this issue.

The general consensus was that the restricted availability and access of such basic information was an important hindrance to development efforts. Participants considered the development of an extensive GIS database outside of the institutional climate of the government agencies to be a potential means of developing and disseminating key information. (The importance of data of high quality which may be freely distributed is underscored by the "scramble" for the four large format hardcopy maps from the GIS database that were used during the workshop. Nearing the end of the workshop claims on the maps were entered by various groups. *E.g.*, a participant from the Slum Clearance Board requested the map of slum locations in Chennai, and a participant from 'Metrowater' asked for the map of sewerage catchments. All the maps were spoken for).

Similar animated discussions occurred when participants began to design scenarios using the DSS module. The structure of the system had been explained in the first workshop, and the nature of the relationships among actors and elements of the system discussed. However, when it came time for participants to actually provide values for parameters in those relationships, they were often stymied. Participants expressed the desire to develop information on such things as the spatial distribution of water consumption and sewage generation throughout Chennai, the value of the runoff coefficient in the various urban drainage catchments, the relationship between income and water consumption, and among water consumption and the water quality characteristics of sewage produced. Several participants expressed the belief that the relationships in the conceptual model of the Cooum system, and operationalized in the Cooum DSS, were sound, but that the data to parametize them did not yet exist, so "best guess" data had to be used.

In their exploration of the GIS and DSS modules of the Cooum DSS, workshop participants identified several aspects that could be improved. In the GIS module, some participants expressed the desire to be able to visualize information such as marginal land uses, water consumption and characteristics of the river system, such as flow and water quality parameters. More data related to the study area such as zoning and vegetation were requested. For the DSS it was noted that it would be useful to break the income groups down from three (High, Middle and Low Income), to include a specific category for the "Economically Weaker Section" of the population, whose marginal existence results in different characteristics of water consumption and sewage production than even the other members of the Lower Income Group. Some capability to deal with spatial variation in the quality of sewage was indicated as being needed as well. Both of these comments point to a possible refinement of not only the DSS, but more importantly, of the conceptual understanding of the system that was generated in the first workshop.

Throughout the full day drop-in lab and part of the following morning session, participants worked at exploring the Cooum River Environmental Management Decision Support System, and in developing exploratory management scenarios. They did not, however, progress to the point at which water quality simulations were run to see what would be the effect on the system of the various alternatives. This is significant. Despite attempts to guide (corral?) participants back to the workstations (so as to be able to produce some simulation output before the end of the workshop), on the morning of the last day "animated discussions" about data and understanding of the relationships expressed in the Cooum DSS and the 'Rich Picture' reached a peak. At this point, the participants broke off working with the Cooum DSS to carry on an impromptu meeting about the program of research.

It was evident from the comments of workshop participants, and from the discussions throughout working session 5, that exploration of the available data and of the conception of the Cooum system as operationalized in the DSS, had demonstrated to the participants the potential power of these tools, while at the same time illustrating some very real needs for reducing uncertainty in the system. The development of the GIS database of Chennai that was available to workshop participants, for instance, was enough to spark excitement over the potential for the development and dissemination of data outside of the restrictive government environment. In contrast, dismay at the extremely poor quality of data generally available from government agencies which could be incorporated into the database was expressed. Several participants communicated the desire to pursue immediately continued development of the database. Similar discussion was oriented toward improving the understanding of the relationships among actors and elements of the system that were drawn out in the workshops, expressed in the 'Rich Picture', and operationalized in the Cooum DSS.

Part of the enthusiasm over the Cooum DSS may be attributed to the demonstrated move from conceptual discussions, paper presentations, and working sessions, to the development of a potentially useful and "real" tool. Participants could relate their own contribution in the development of a conceptual understanding of the Cooum system to the DSS module that they were using, and they could use the GIS module to visualize data that might not normally be available to them. The use of the Cooum DSS also highlighted the extent of uncertainty in the system, partly in terms of structure and processes of the system itself, but more prominently in terms of parameters in the decision support model which were related to these. It was obvious from discussions in this session that participants felt it was quite a different thing to conceptualize a relationship or process in the system (*e.g.*, the population consumes water and food and produces waste), versus operationalizing that relationship (*e.g.*, How much water do persons of various income groups consume? What is the supply and how is that related to consumption? How much of that input is transformed into sewage and waste water? What are the water quality characteristics of that sewage?). Attempting to specify values for some of the basic parameters in the system led participants to reflect on underlying relationships and the associated assumptions that they were tied to (*e.g.*, are all parts of the city equally served with piped water, trucked water, ground wells and pumps?), as well as values of the parameters themselves.

It was the development of an understanding of basic uncertainties associated with the system highlighted during this session, that led participants to begin to discuss the formation of a working group to continue this program of research. On the morning of Sunday, 28 of February, 1999, the workshop participants in the lab insisted on taking the opportunity, while a relatively small group (about 15) were together, to lay out a mandate, organizational structure and set of tasks which would initiate a working group to continue and expand the program of research on the Cooum River and environs. *This is the single most convincing evidence that this kind of a program can, in fact, be successful in an Indian setting.* The fact that the workshop participants took ownership of the program of research, relieving it of its dependence on a foreign researcher, in order to carry it on indigenously and continuously, is evidence that not only did they see the issue as important, but that the way that it has been addressed through this program (*i.e.*, using an adaptive ecosystem management approach, characterized by holistic systems-based inquiry and participatory processes), has the potential for success in the Indian context.

Box 5.4 summarizes the outcome of the initial meeting the Cooum Working Group. This group (which consisted of participants from a variety of agencies, institutions and NGOs) identified as their main role the support of efforts in planning for, and managing, the Cooum system. They also explicitly indicated during the meeting that the group should remain outside of the sphere of influence of any of the government agencies, of academic departments, or even of NGOs. They also perceived that to remain both effective and free to pursue what was deemed to be important aspects of the situation, the group should remain relatively informal. The genesis of this working group may be the beginning of the development of an epistemic community (Haas, 1990:40-43; Lee, 1993, 130), as discussed in Chapter 2. For this to occur, the group would have to be seen as credible and influential. In this respect, it is fortunate that the group included several rather highly respected individuals with strong connections to government agencies. It is yet too early to tell, but the spontaneous generation of such a group gives hope that despite the barriers to adaptive

A Working Group for the Cooum River
Environmental Management Research Program

General organization of the working group:
i) Core working group -undertakes activities such as model development (*e.g.*, application and testing), data collection, *etc.*. (This group consists of researchers focussing on the Cooum system as its primary interest).
ii) Extended core group - organization and direction of research program, workshops, *etc.*.
iii) Public/Interested parties -workshop participation, provision of data where appropriate, *etc.*.

Main purpose:
i) A research working group to undertake an on-going program of research, and act as a depository/ dispensary of information in support of planning and management of the Cooum River & Environs.

Initial focus:
i) Improve the database and system model by proper parametization and clarification of those relationships which are at this point taken as estimates, or defaults.

Some Initial Tasks:
i) Collection of further data for better parametization of the system model.
ii) Application testing and model improvement.
iii) Identification of topics associated with the Cooum system that could be taken up by the working group and others (*e.g.,* PhD candidates).
iv) Development of a bibliography of sources of information on Chennai waterways.
v) Identification of contact persons and development of a list of phone numbers, *etc.*.

Box 5.4: Summary of the organization of the Cooum working group as developed at the initial meeting on February 28, 1999.

management due to the institutional and bureaucratic culture of many of the government agencies and other institutions, such programs may indeed be possible.

Working Session 6: Future Directions for the Program of Research

Immediate objectives and intended products

Session 6 was the "wrap-up" at the end of the workshop. It was intended to present a summary of the workshop results to participants, to generate of a set of recommendations regarding action to rehabilitate and manage the Cooum system, and to provide a forum for a discussion of future directions for the program of research.

Results

Three primary presentations were made to the 35 to 40 participants at the final working and valedictory sessions. These were a presentation by participants at the morning session regarding the establishment of a working group, a presentation of simulation results from the Cooum DSS, and a presentation and discussion of the evolution of participants' conceptual understanding of the system represented by the 'Rich Picture' of the problem situation.

The presentation of simulation results was simply a review of simulation output from a Baseline scenario as developed by groups in working session 5. (This had been produced by the researcher shortly before the final session. Simulation results had not yet been produced by workshop participants due to the working session being usurped by the initial meeting of the Cooum working group earlier in the day). This presentation generated some discussion on the nature of the Baseline scenario by participants not present in working session 5. The only significant observation at this time was that the figure produced in the scenario simulation which represented outfall of treated effluent from the Koyembedu sewage treatment plant was much less than the indicated overflow of untreated sewage from the same facility. This was attributed to insufficient capacity of the STP to treat all of the sewage routed to it in the simulation. Participants recalled a discussion several days earlier in working session 3. At this time, uncertainty about Metrowater facilities' capacity to treat all sewage generated by the population had been raised as an issue. (The Baseline and other scenarios are presented in depth in the following section, and so will not be reviewed further here).

Figure 5.4 presents a reduction of the 'Rich Picture' employed in the second workshop. This diagram was used in this final session to review the evolution of the conceptual understanding of the Cooum system from the first workshop to the end of the second. It was obvious that workshop participants' understanding of the system had evolved from the initial conception at the end of the first workshop. The revisiting of the 'Rich Picture' in the second workshop can be seen, in fact, as an iteration of a learning cycle, in which new information generated by a further year's reflection and experience of the problem situation, insight gained in the development and use of the Cooum DSS, and the incorporation of additional understandings of the problem situation brought by new participants in the program, had led to modification and refinement of the conceptual model of the system.

Particular changes represented in the second version of the 'Rich Picture' (and

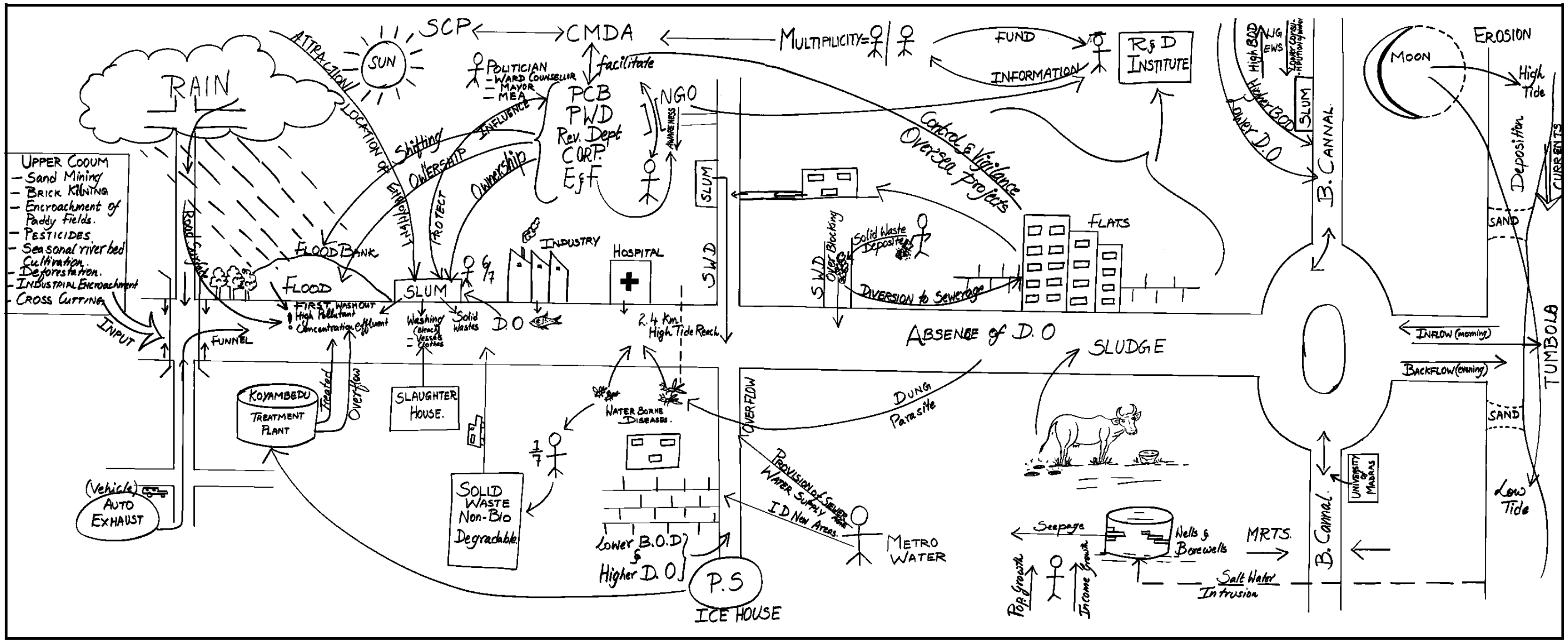

Figure 5.4: A second version of the 'Rich Picture' of the Cooum system. This version incorporates several modifications, clarifications and additions made by participants in the second workshop of the Cooum River Environmental Management Research Program.

discussed in previous sections of this chapter) include:

- a representation of the attraction of the city as a destination to rural migrants,
- the importance of employment in the locational decisions of slum dwellers and new migrants,
- the phenomena of the system shock to the river by the first flush of polluted water during the initial monsoon rains,
- the suppression of tourism by a highly polluted environment,
- an understanding that characteristics of sewage may vary spatially throughout the city depending on factors such as income and water consumption, and
- the common activity of unauthorized diversion of stormwater to the sewerage collection system by city dwellers, which occurs when storm water drains become blocked with solid waste and debris, and threaten to flood the streets.

It was recognized that some of these changes in the conceptual model should be reflected in the future development of the Cooum DSS. For example, the last point above indicates a new understanding of the structure of the system. Figure 4.1 describes the structure on which the Cooum DSS was based. It became apparent during this workshop that the figure should not only include an arrow representing diversion of sewage to the SWD system, but also one indicating diversion from the storm water drainage system to the sewerage system.

Finally, the activity of participants earlier in the day, in outlining the formation of a working group, was presented by participants from the morning session. The formation of such a working group was endorsed by the participants in the final session, and it was resolved that support for the formation and operation of the working group be the main recommendation of this workshop. This recommendation may be paraphrased as follows;

1. A working group should be formed to support efforts to manage the Cooum system. It should consist of stakeholders in the situation, and this group should continue to undertake and guide research into the issue and periodically bring together the larger stakeholder group to participate in the process.

At this point, discussion of the working group revolved around the relationship of researchers and NGOs with government agencies, and of these agencies with each other. In particular, issues of openness, access to information, and data sharing were revisited. Out of this discussion, a second main recommendation emerged;

2. There should be an "overseeing" agency of the government which has the role of integrating and coordinating the various agencies which, individually, do not have the jurisdiction to address problems such as the Cooum and its environs in a holistic manner.

Participant Evaluation of the Second Workshop

Participants at the second workshop were asked to evaluate both the workshop and the program of research through a questionnaire provided in their workshop materials package. An addressed and stamped envelope was provided so that the questionnaire could be returned *via* post. Of more than 50 questionnaires distributed, only 6 were completed and returned.[9] Of the respondents, one was self-described as a government official and scientist, two were government agency planners, two were academic researchers, and one was a concerned citizen. While the number of respondents was small, their comments reflected those made to the researcher throughout and following the workshop by many of the other participants in the program.[10]

The questionnaire consisted of three parts. Part A collected basic data on the respondent (*e.g.*, institutional affiliation, occupation, workshop attendance). The second part presented questions evaluating aspects of the second workshop in the program on a scale of 1 to 5. (The are summarized in Table 5.10). It also prompted the respondent for more qualitative (written) feedback associated with each of those questions. Part C asked the respondent to evaluate the program of research as a whole, and was organized in a similar

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[9]It was thought that providing addressed and stamped envelopes for the workshop evaluation would improve the response rate from that of the first workshop. However, this evaluation covered not only the workshop, but the program of research as a whole, and thus, was longer. This may have contributed to the low response rate.

[10]In a couple of instances, some questions were left unanswered by one or another respondent, when they felt they could not evaluate the question, or had no further comments to make. In the case of average ratings in these situations, these are taken as averaged out of those respondents who *did* answer the question.

way to the previous section. Responses to Part C are presented in Chapter 7.

Table 5.10 demonstrates that the second workshop in February 1999 was evaluated positively. The averages of scores of evaluative questions ranged from 3.8 to 5.0 on a scale of 1 to 5. The first question of Part B, having to do with the overall effectiveness of the workshop in stimulating thinking about the problem situation scored an average of 3.8 out of 5. Participants' comments associated with this question generally indicated a desire for more information, more hands-on exercises, further and additional workshops targeted to particular stakeholders (*e.g.*, government agencies) and field trips.

The usefulness of working sessions (question 2a) was also given an average score of 3.8 out of 5 by participants. Comments indicated that participants believed that the working sessions were particularly useful in providing for group discussion, in presenting opportunities to analyse the problem situation, and to exchange knowledge with other participants. One participant noted that time management and group dynamics could be improved.

Comments associated with the evaluation of the 'systems concepts' employed in the workshop were varied, but most had to do with the conceptualization of the system. This aspect of the workshop was given a score of 3.8 out of 5 by workshop participants. In general workshop outputs such as the system conceptualization and the 'Rich Picture' were touted as "interesting" and "useful." Responses from participants on this question indicate that they had been thinking of the problem situation systemically. For example, one participant expressed the desire to further pursue the understanding of subsystems (particularly further investigation of the hydraulic subsystem and its integration with the Cooum system as represented in the 'Rich Picture'). Another indicated the need to examine wider systems such as the Chennai Urban Agglomeration.

The appropriateness of the paper presentations in the workshop were scored at 4.2 out of a total possible score of 5 (papers presented are listed in Table 5.3). Participants' comments had primarily to do with other information that would have been useful to receive. This included financial and legal aspects of the system, further analysis of various subsystems of the Cooum system, and limitations to development and the potential use of space along the

Table 5.10: Average of scores from responses to the evaluation questionnaire for second workshop of the Cooum River Environmental Management Research Program.

	Workshop Evaluation Question	Score (max 5)
1	Workshop effectiveness in stimulating thinking about the problem situation	3.8
2	Usefulness of the workshop working sessions in relation to this problem situation	3.8
3	Usefulness of systems concepts as employed in this workshop in relation to this problem situation	3.8
4	Appropriateness of papers presented in the workshop	4.2
5	Potential usefulness of a Geographical Information System database to support decision making about the Cooum River and environs	5
6	Potential usefulness of simulation modeling to support decision making about the Cooum River and environs	4
7	Potential usefulness of scenario analysis (using the decision support module of the system used in the workshop) to support decision making about the Cooum River and environs	3.6

Cooum banks.

The GIS component of the workshop was appraised by participants to be extremely useful, and was given the highest possible score (5 out of 5). Responses to this section of the questionnaire reflected those of participants at the workshop in general. There was enthusiasm about the potential of GIS to store, analyse and visualize data, and also recognition that available data need to be improved and expanded. In particular, respondents noted that visualization of simulated results and of various water quality and hydraulic variables, and the inclusion of additional socio-economic information, as well as meteorological and other physical data, are desirable. Comments of respondents regarding the simulation and scenario analysis components of the workshop parallelled those for the GIS component – general enthusiasm tempered with the desire for more and better data. Several comments pointed to the role of simulation and scenario analysis in "widening the understanding" of the issue in relation to urban planning, and in providing a "direction to [the] work."

Conclusions

This chapter has discussed the organization, methods and results of the second workshop of the Cooum River Environmental Management Research Program. This concluding section will attempt to review only the most important of the observations and issues discussed above. The concluding chapter will draw all of these observations together and place them in the context of the goals of the research.

One of the highlights of the second workshop was the evidence of the operation of a learning cycle in the continued evolution of the understanding of the problem situation, and conceptualization of the system of interest. In management programs which make actual interventions in the system, such learning comes from new knowledge gained from observing changes in the system generated by interventions. Adaptive management attempts to maximize the knowledge gained in this way. For this research, physical intervention in the situation is not possible. However, evidence of learning from new information, and adapting to that information, did occur. New information was generated in the research through revisiting the conceptualization of the system in the second workshop, in an environment in which new experiences and reflection from the previous year, and the knowledge and understanding of new participants, could contribute to further development of the conceptual model.

New information and further insight into the system came about in part due to the operationalization of the conceptual model in the Cooum DSS. This process laid bare some assumptions and over-simplifications represented in the first round. These, and further exploration of the situation in paper presentations, discussions, and working sessions, prompted participants in the second workshop to renovate their conceptual model of the system. In particular, components such as "push" and "pull" factors of migration, the in-migration of slum dwellers, spatial variation in characteristics of sewerage throughout the city, the relationship between solid waste disposal, and efficiency of the storm water drainage system together with the action of citizens to re-route overflow to the sewerage system, the effect of the degraded condition of the Cooum on tourism, and differentiation of characteristics of lower income groups (LIG *versus* EWS) were thought by participants to be of sufficient importance to represent them in the 'Rich Picture' of the problem situation. Such modifications to the understanding demonstrate that the workshop goals of (1) continuing a process of dialogue, and (2) furthering development of the conceptual model, were achieved.

A third goal of the workshop, that of further developing an understanding of desirable future states of the system, was also accomplished. This was achieved through continued discussion regarding ‘visions’ of the system which included recreational uses, navigable waterways, slum communities improved *in situ*, water suitable for washing and bathing, an aware and actively environment-friendly populous, a healthy tourism industry, and a system of management in which agencies, NGOs, academics and other interested parties cooperatively manage the system. Several of these, in particular the emphasis on *in situ* improvement of slums (as opposed to clearance of slums) and the tourism industry, were views of a future system developed during the second workshop.

It was expected that new information and clarified relationships would be reflected in further development of the prototype Cooum DSS. In the meantime, however, the use of this exploratory tool (in pursuit of the workshop’s fourth goal) raised even more issues. In particular, its use emphasized specific areas of uncertainty which need investigation. The poor quality, inaccessibility and complete absence of spatial data sets, and the lack of detailed understanding of some of the relationships among actors and elements of the system were extensively discussed by workshop participants. In this context, the Cooum DSS acted as a tool to provoke debate, while at the same time providing an accessible and relatively high quality database. The maps produced from this database were "hot items" as they were some of the best quality, unclassified, maps available to workshop participants (including those in government agencies). In part due to this, the further development and dissemination of a spatial database became a primary orientation (stipulated by participants) for future research.

The most significant outcome of this workshop was the spontaneous organization of a working group to take up this program of research. The formation of this group illustrates that workshop participants had taken ownership of the process, were impressed with the process by which the program had so far been conducted, and saw potential in the program to make a meaningful and significant contribution to efforts at rehabilitation and management of the Cooum system. It is also evidence that the intangible products intended for the workshop and its working sessions had come to fruition. It may be that this program of research and the Cooum working group are the genesis of a community of researchers, NGOs, interested members of the public, and government employees, who share a common understanding of the problem situation and can contribute solutions and information which are not bound by jurisdictional barriers, and the mechanistic management culture of institutional environments. On this score, time will tell.

6

Exploratory Scenario Analysis with the Cooum DSS

Introduction

This chapter presents a discussion of the development and simulation results of exploratory scenarios for the Cooum system. These are based on scenarios developed by participants in the second workshop of the Cooum River Environmental Management Research Program in February 1999. Simulations were to be run on the participant-developed scenarios during the second workshop. However, time allocated to undertake the actual simulations was usurped by workshop participants for an impromptu organizational meeting of a working group to continue this program of research. Hence, the simulations were run after the workshop.

In total, nine scenarios are presented below. Three 'Baseline' scenarios (dry season, monsoon season employing mean runoff calculations, and monsoon season using peak runoff calculations) were constructed to provide a basis for comparison to the exploratory management scenarios. Six scenarios were also developed to explore the effects on the system of slum improvement, population increase, increased capacity of the Koyembedu sewage treatment plant (STP), improvement of treatment technology at the STP, artificial increase in flow from the Upper Cooum system, and the effect of the storm flush from the first heavy rains of the northeast monsoon.

Exploratory Scenarios

Nature of the Scenarios

Exploratory scenarios were developed by participants in the second workshop as described above. The scenarios were intended to explore the behaviour of the Cooum system as defined by participants in the first workshop, and modelled in the prototype Cooum River Environmental Management Decision Support System (see Chapter 4). As indicated above, the scenarios were designed by workshop participants, but the actual simulation and interpretation of results was not undertaken in the workshop. This part of scenario analysis was completed afterward by the researcher. The scenarios presented here are based on those designed by workshop participants using the Cooum DSS. They are based on a combination of scenarios designed by four groups of workshop participants, as well as on parameters derived from basic data presented in published works, consultancy reports, theses and other sources which describe characteristics of the Cooum system, (*e.g.,* see Appendix III), and a general knowledge of the system as expressed in the two workshops of the Cooum River Environmental Management Research Program.

Description and simulation results of three Baseline scenarios (1 dry season, 2 monsoon season) and 6 exploratory scenarios are presented here. These are simple scenarios, each of which explores the effect of a single large-scale change in the system. In this sense they undertake 'sensitivity analysis' as each explores the sensitivity of the system to change in a single parameter. Each scenario is subjected to two simulations: one representing a dry season, and the other, a monsoon season variant. The exception to this is the scenario representing the storm flush, or "wash-off" from the first heavy monsoon rains, as only a monsoon season variant is relevant.

Simulation Setup

Each of the scenarios and their variants were subjected to water quality and hydraulic simulation in DESERT. To facilitate comparison, each simulation was set up in an identical manner. That is, means of simulating hydraulic and water quality characteristics of various reaches of the river system, the ‘mesh’ or spatial step employed, the period of simulation and the time step were identical for each simulation.[1]

Once the parameters for each scenario were loaded in DESERT, the most precise steady state meshed method was set for each reach of the system.[2] Thus, the Cooum simulations employed the steady state (diffusion wave) method for hydraulic simulation, and a mass transport (mesh, steady state) method for water quality modelling. The default mesh (the spatial step over which hydraulic and water quality variables are calculated) was set at 25 metres for most of the river network, and at 15 metres for the Central Buckingham Canal reach as well as for the lowest reach on the Cooum River. Higher mesh numbers resulted in iteration convergence warnings when DESERT attempted to calculate water depth and velocity by way of Newton-Raphson iterations.

There is one reach at the extreme downstream end of the Cooum where an iteration convergence warning cannot be avoided without changing the slope of the river bed. This reflects a portion of the Cooum for which the river pools. It is caused by bottom elevations declining along the river course, and then in the lower reaches, rising somewhat toward the mouth. This is not a minor feature of the river and, thus, has not been corrected for in the simulation. For example, in the dry season Baseline scenario, an iteration convergence warning is reported for the reach "CONFL0001" at "POINT 25". Here the water depth (reported as 4.26105 metres) in the most recent iteration had not changed from the previous iteration. As a result, water depth had to be obtained by DESERT using the uniform flow formulation for this reach instead of the steady state hydraulic equations used to calculate depth for the other reaches in the network. According to the DESERT manual, this problem is not of great significance in steady state simulations such as those undertaken here (Ivanov, 1996, 58). However, if dynamic simulation were to be pursued, then a solution should be

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[1]Again, the one exception to this is the storm flush scenario, for which the period of simulation is shorter. However, since all data were indicated as valid for the same date in all scenarios, the model results would have been identical for any period. That is, no data are excluded due to being outside the range of validity for the simulation period, regardless of the duration of the simulation.

[2]In DESERT this is automatically done by choosing "Set Default Model (Mesh)" under DESERT’s Edit menu (Ivanov, 1996, 53).

found.

The simulations, when run in DESERT, employed a time step of 1440 minutes (one day) for a period of one month. However, in the current setup, the results using a weekly or monthly time step are identical, as are the results when simulating using a daily or weekly simulation period. This is because all of the data in each variant (dry or monsoon) of the scenarios are specified as valid on the same date.[3] None fall outside of the time interval of validity for the data. In the future, use of data specified with a variety of dates (pertaining to the period in which the data are valid for use in the simulation) may lead to results which differ from simulations using different simulation periods and time steps.

Scenario Descriptions and Simulation Results

Baseline Scenarios

Three Baseline scenarios ('Baseline-Dry,' 'Baseline-Wet,' and 'Baseline-Peak') were constructed, the simulation results of which provide a basis for comparison for the various exploratory scenarios. The Baseline scenarios represent conditions during the dry season (*e.g.*, April-May) and the monsoon season (*e.g.,* October-November). Two monsoon season Baseline scenarios were constructed which represent different hydraulic characteristics of the Cooum system when the mean runoff calculations are employed (Equation 4.10b) *versus* peak runoff calculations (Equation 4.10a). (Higher rates of storm water runoff are produced with the peak calculation method). The difference between the Dry and the Monsoon season scenarios relates to the initial boundary conditions describing hydraulic and water quality characteristics of the Cooum system (see Tables 6.1 and 6.2), and the dates, particularly the month, specified for the scenarios (15 April for the Dry Season Baseline scenario, and 15 November for the monsoon season Baselines). This results in the calculation of different rates of runoff by the calculators in the Cooum DSS.

In contrast to the hydraulic and water quality boundary conditions, a wide variety of

[3]Data in the dry season scenarios are specified with a date of 15 April, 2001. For the Monsoon season scenarios the date is set for 15 November, 2001.

Table 6.1: Boundary conditions for the dry season Baseline scenario, and dry season variants of all scenarios, as represented in their Infotable1 database files.

IDCODE (river object)	DATE mm/dd/yy	TIME hh:mm	PERIOD	VARIANT	Q m^3/s	BOD mg/l	DO mg/l	N (NH_3) mg/l	T °C
CONF0001	04/15/01	12:00	M	TEST	3.5500	200.0	0.1	60.0	27.0
CONF0002	04/15/01	12:00	M	TEST	3.3000	200.0	0.1	60.0	27.0
CONF0003	04/15/01	12:00	M	TEST	1.3000	200.0	0.1	60.0	27.0
CONF0004	04/15/01	12:00	M	TEST	2.2500	75.0	0.6	55.0	27.0
CONF0005	04/15/01	12:00	M	TEST	1.0500	200.0	0.1	75.0	27.0
CONF0006	04/15/01	12:00	M	TEST	0.7000	200.0	0.1	75.0	27.0
HEAD0001	04/15/01	12:00	M	TEST	2.0000	40.0	3.6	130.0	27.0
HEAD0002	04/15/01	12:00	M	TEST	0.2500	370.0	0.0	60.0	27.0
HEAD0003	04/15/01	12:00	M	TEST	0.2500	200.0	0.0	60.0	27.0
HEAD0004	04/15/01	12:00	M	TEST	0.4500	35.0	0.2	200.0	27.0
HEAD0005	04/15/01	12:00	M	TEST	0.2500	350.0	0.0	50.0	27.0
HEAD0006	04/15/01	12:00	M	TEST	0.3500	350.0	0.0	50.0	27.0
HEAD0007	04/15/01	12:00	M	TEST	0.2500	350.0	0.0	50.0	27.0
ABST0001	04/15/01	12:00	M	TEST	0.2500	0.0	0.0	0.0	27.0
END0001	04/15/01	12:00	M	TEST	3.5500	150.0	0.4	35.0	27.0

Table 6.2: Boundary conditions for the monsoon season Baseline scenarios, and monsoon season variants of all scenarios, as represented in their Infotable1 database files.

IDCODE (river object)	DATE dd/mm/yy	TIME hh:mm	PERIOD	VARIANT	Q m^3/s	BOD mg/l	DO mg/l	N (NH_3) mg/l	T °C
CONF0001	11/15/01	12:00	M	TEST	8.0000	125.0	0.1	35.0	27.0
CONF0002	11/15/01	12:00	M	TEST	6.7500	125.0	0.1	35.0	27.0
CONF0003	11/15/01	12:00	M	TEST	3.6000	125.0	0.1	35.0	27.0
CONF0004	11/15/01	12:00	M	TEST	3.4000	45.0	0.2	10.0	27.0
CONF0005	11/15/01	12:00	M	TEST	3.3500	50.0	0.1	25.0	27.0
CONF0006	11/15/01	12:00	M	TEST	1.7500	50.0	0.1	25.0	27.0
HEAD0001	11/15/01	12:00	M	TEST	3.0000	10.0	6.0	20.0	27.0
HEAD0002	11/15/01	12:00	M	TEST	1.2500	40.0	3.0	10.0	27.0
HEAD0003	11/15/01	12:00	M	TEST	0.2500	150.0	0.1	40.0	27.0
HEAD0004	11/15/01	12:00	M	TEST	1.2500	16.0	4.8	10.0	27.0
HEAD0005	11/15/01	12:00	M	TEST	0.4000	50.0	0.1	25.0	27.0
HEAD0006	11/15/01	12:00	M	TEST	1.6000	50.0	0.1	25.0	27.0
HEAD0007	11/15/01	12:00	M	TEST	0.5000	50.0	0.1	25.0	27.0
ABST0001	11/15/01	12:00	M	TEST	0.2500	0.0	0.0	0.0	27.0
END0001	11/15/01	12:00	M	TEST	8.0000	70.0	0.5	40.0	27.0

parameters was set at identical values for the dry and wet season Baseline scenarios. For example, water consumption (HIG: 150, MIG: 90, LIG: 78 lpcd) and sewage generation coefficients (HIG: 0.6, MIG: 0.6, LIG: 0.6) for the various income groups were left at the same values for both dry and monsoon season scenarios (even though these parameters might be expected to vary with water availability). Doing so allowed differences in the scenarios to be attributed to differences in boundary conditions and runoff alone, for the Baseline scenarios, or these plus a single other parameter in the case of the exploratory scenarios. Parameters such as rainfall (see Table 6.3) were sensitive to the date specified in the 'General Model Parameters' window in the Cooum DSS.

Table 6.4 demonstrates that, in terms of the amount and type effluent involved in the three Baseline scenarios, the scenarios only differ in the amount of stormwater runoff calculated. (This is the total simulated flow of stormwater from all catchments in the city). Table 6.4 also presents the effluent flow characteristics for the exploratory scenarios. A comparison of the figures for Baseline and exploratory scenarios in Table 6.4 demonstrates that the flow quantities for exploratory scenarios are based on the Baseline scenarios.

Given the range of observed values of rates of flow in the Cooum system as reported in Appendix III, it seems possible that the wet season runoff figures are too high. (Perhaps due to the rainfall runoff (*versus* seepage) coefficient being estimated at a rather high value of 0.95, because of the high proportion of hard surface in urban areas). Still, in the simulation of hydraulics, no overflow warnings were given by DESERT even though the Cooum has been known to occasionally overflow its banks. Since Cooum River cross-sections are employed by DESERT in the calculation of water elevations, this is an indication that the

Table 6.3: Precipitation parameters for Baseline and exploratory scenarios.

Month	Mean Hours of Rainfall/Month†	Mean Rainfall per Month (mm)‡
January	10	21.0
February	5	13.0
March	1	3.6
April	1	11.1
May	1	23.1
June	1	53.4
July	5	102.0
August	30	134.7
September	200	103.3
October	250	219.5
November	300	309.1
December	200	145.4

†Specified by workshop participants in the second workshop of the Cooum River Environmental Management Research Program.
‡Data is for Chepauk station, Chennai. (Mott McDonald, 1994b)

Table 6.4: Effluent flows in the various scenarios. (Note: the 'Total' columns apply to the total uncollected sewage and stormwater routed via the storm water drainage system in the entire city, a portion of which is allocated to the Cooum system).

Scenario	STP Treated Effluent m^3/s	STP Overflow Effluent m^3/s	Total Effluent not routed to Koyembedu STP m^3/s	Total Storm Water m^3/s
BASELINE-DRY	0.3935	1.2059	1.0663	0.7143
BASELINE-WET	0.3935	1.2059	1.0663	19.8921
BASELINE-WET_PEAK	0.3935	1.2059	1.0663	47.7411
POP_INCREASE_DRY	0.3935	1.4566	1.2334	0.7143
POP_INCREASE_WET	0.3935	1.4566	1.2334	19.8921
SLUM_IMPR_DRY	0.3935	1.4463	0.8259	0.7143
SLUM_IMPR_WET	0.3935	1.4463	0.8259	19.8921
STORM_FLUSH_WET	0.3935	1.2059	1.0663	47.7411
STP_CAPACITY_DRY	0.8681	0.7313	1.0663	0.7143
STP_CAPACITY_WET	0.8681	0.7313	1.0663	19.8921
STP_TREATMENT_DRY	0.3935	1.2059	1.0663	0.7143
STP_TREATMENT_WET	0.3935	1.2059	1.0663	19.8921
UPSTREAM_INCREASE_DRY	0.3935	1.2059	1.0663	0.7143
UPSTREAM_INCREASE_WET	0.3935	1.2059	1.0663	19.8921

storm water calculations are reasonable. Also, only a portion of the total runoff is actually allocated in the Cooum DSS to the Cooum River itself. The remainder is allocated primarily to the Adyar River system which has a much greater rate of flow, especially during the Monsoon.

The simulation of the Baseline scenarios produces a set of hydraulic and water quality variables which are presented in Figure 6.1 (Dry season *versus* Monsoon season - mean runoff) and Figure 6.2 (Monsoon season - mean runoff *versus* Monsoon season - peak runoff). A comparison of dry season simulated depth (Figure 6.1e) with a table of existing width and depth observed in the Cooum River from a recent hydrographic survey (Inland Waterways Authority of India, 1998, Annex A-1) indicates that the simulation provides a reasonable model of water depth along the Cooum, although it is somewhat shallow (by about 0.25 m) in the lower reaches below about 7 kilometres. The simulation seems to underestimate the depth of water more severely at the extreme lower reach, where depth of the water drops to 0.7 - 1 metre, when all indications are that it is usually observed to be about 2.5 metres. Similarly, Figures 6.1d and 6.2d indicate that, while across most of the

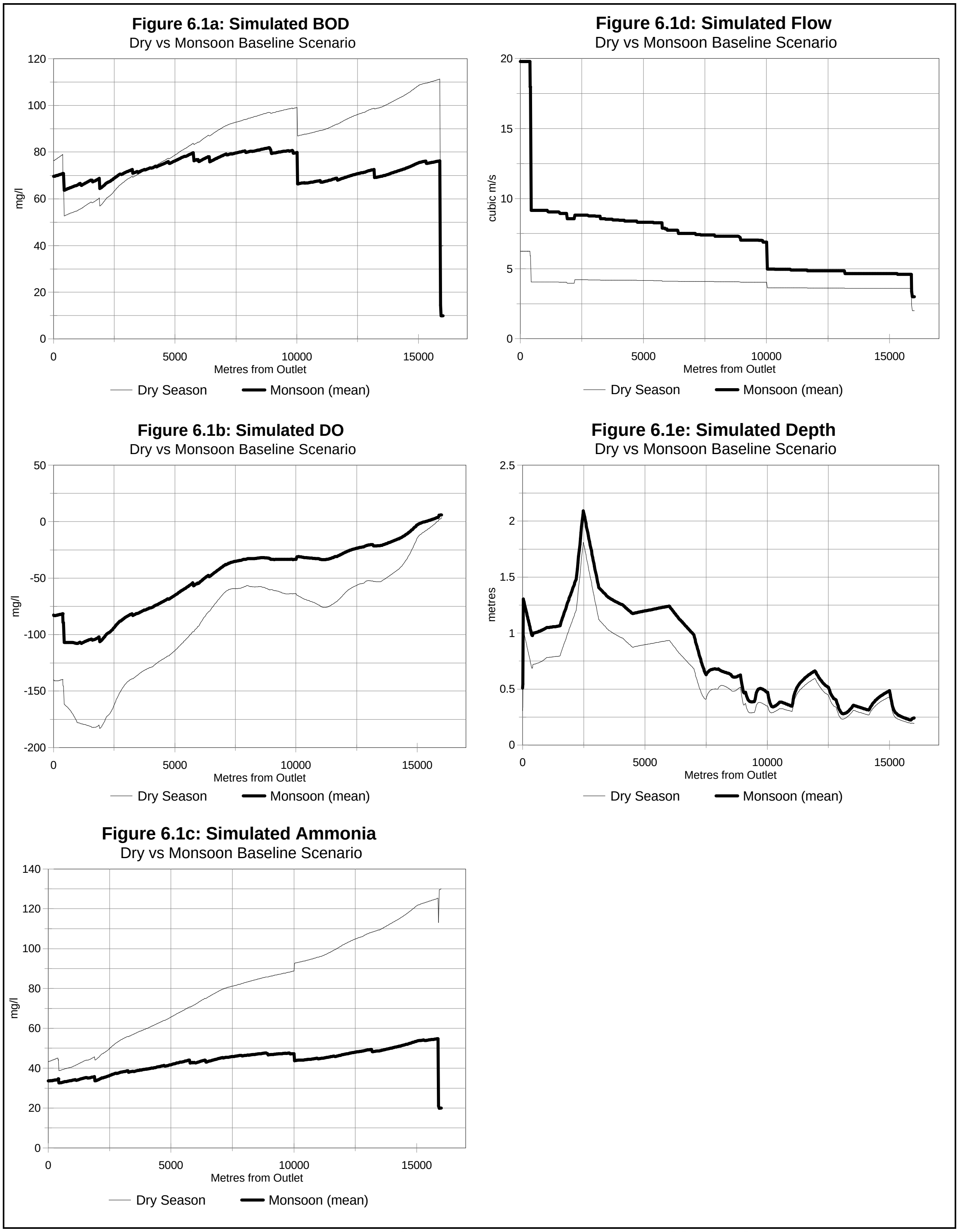

Figure 6.1: Dry and Monsoon Season Baseline Scenario water quality and hydraulic simulation results.

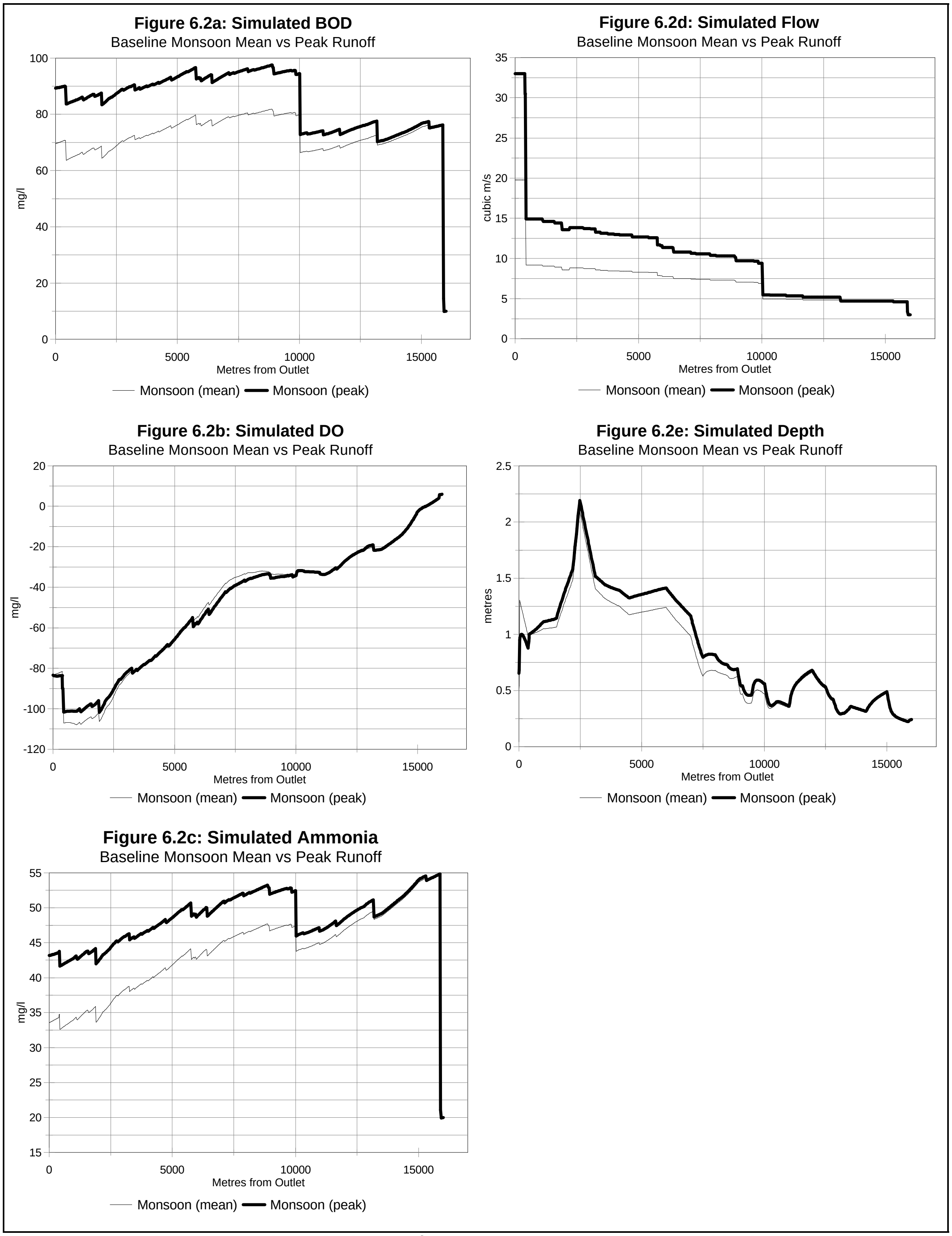

Figure 6.2: Peak vs mean value calculations for wet season scenario water and hydraulic simulations.

course of the river, flow seems to be modelled well, at the extreme lower reach of the system flow uncharacteristically increases dramatically.

The departure in the simulation, from observed behaviour of depth and flow in the Cooum, may be attributed to the inability to model the system with the obstruction typically present in the lower reaches. Removal of the sand bar from the mouth of the river may be expected to result in the alleviation of conditions of pooling and stagnation in the lower reaches, with corresponding increase in the rate of flow and lowering of water depth in the lower reaches of the river. It is interesting, yet also frustrating, to note that this result seems to indicate that, in removing the sand bar at the mouth of the Cooum, progress may be made toward achieving one of the objectives identified in the first workshop – that hydraulic obstacles should be removed and water flow freely through the mouth, while at the same time frustrating another, *i.e.*, that the river be navigable, by reducing water depth!

Figures 6.1a to 6.1c demonstrate the simulated behaviour of the 5-day biochemical oxygen demand, dissolved oxygen and Ammonia variables in the dry and monsoon season Baseline scenarios. Simulated BOD_5 levels in the Dry Season Baseline scenario are very high (~111 mg/l) at the point of discharge from the Koyembedu STP, and thereafter decline steady as organic matter is consumed by aerobic or anaerobic processes, with intermittent increases in BOD_5 at reach conjunctions. The Monsoon Season Baseline scenario displays levels of BOD_5 which are also very high.[4] However, these are also much lower than the initial values in the dry season scenario due to dilution of both stormwater (washed off of the city streets) and sewage quality STP overflow, in the greater volume of relatively clean water from upstream. BOD_5 values, instead of declining as steadily as in the dry season scenario, are more or less maintained in the simulation by frequent stormwater effluent outlets from SWD catchments throughout the course of the river.

Simulated values for Ammonia are similar to the pattern display by BOD_5 values. The dry season figures start out very high (130 mg/l) and steadily decline to about 41 mg/l with slight perturbation in this trend at confluences. The wet season model demonstrates a

[4]Workshop participants specified the BOD_5 characteristics of storm water at a very high 150 mg/l!

much more diluted concentration of Ammonia initially, and a more shallow slope in the decline of values from 55 mg/l upstream, to approximately 32 mg/l in the lower reach. The trend is disturbed by the influx of storm water and greater flow from tributaries along the course of the Cooum. Both the simulated BOD_5 and Ammonia levels are similar to some of the observed values presented from various sources in Appendix III (although observations are mostly of unreported method, mixed dates and wide ranging values!).

However, the simulation results for dissolved oxygen in the Baseline scenarios are another matter. The values reported for DO in the simulations, which start at 6 mg/l for the monsoon scenario and 3.6 mg/l for the dry season scenario, and decline quickly to 'reported' levels as low as -182 mg/l (dry) and -161 mg/l (monsoon), are not possible in reality. There cannot be less than zero mg of oxygen in the water. Also, the magnitude of the range of DO values demonstrated in the simulations is unrealistic. The saturation value of DO in water at 20 degrees Celsius is 9.2 mg/l (Flanagan, 1990, 84) and will be less at higher temeratures, so one can expect the range to vary from zero to somewhat less than 9.2 mg/l. The simulated DO values are still useful, however. They provide an indication of locations at which anaerobic decomposition replaces aerobic processes in the consumption of organic matter in the water, and are also a complementary indicator of biochemical oxygen demand. The author has observed confirming evidence of this indicated lack of DO and presence of anaerobic processes in the Cooum. These can be seen by slow swells of sludge brought to the surface of the Cooum by gaseous releases from anaerobic decomposition at the bottom of the river in locations as far upstream as about 12-13 km.[5]

Figure 6.2 compares the two monsoon season Baseline scenarios. The peak runoff calculations (which would be typical of fairly intense rainfall) result in progressively greater values of flow in the river compared to the simulation using the mean runoff calculation, (which would occur at times of lighter rainfall). Water depth is also greater in most of the lower reaches of the river. In terms of water quality, the DO indicator is roughly the same for both scenarios, with the peak rainfall scenario displaying slightly worse conditions between 5

[5]This was observed by the researcher, for example, at points downstream of the 3rd Avenue crossing of the Cooum River on 19 February, 1999.

and 10 km upstream and slightly better conditions in the lower reach between 400 m and 3 km. The trends for BOD_5 and Ammonia on the other hand, begin at the same level, but as relatively more (highly polluted) storm water is supplied to the system in the peak calculation scenario, the levels of pollutant become more elevated (than in the mean rainfall calculation scenario). If storm water were specified as much less, or not at all polluted, one might expect the opposite trend to occur due to dilution of sewage effluent by clean water. In fact, anecdotal evidence leads one to believe that, aside from the first storm flush, less polluted runoff is typical in the monsoon season.

Periphery Population Increase Scenario

This scenario describes an exaggerated population boom due to in-migration and/or natural increase on the western periphery of the city (Wards 50, 54-55, 62-66, 75, 128-131). The population in these wards is doubled for the purposes of this scenario, which results in a population increase on the periphery of 657 732 persons. New population is assumed to be non-slum dwellers, which means that, for the purposes of the simulation, the Cooum DSS routes the sewage produced by the new population to the appropriate sewage treatment plant. The parameters for the population increase scenario are otherwise identical to the Baseline scenarios. The population increase for west peripheral wards is detailed in Table 6.5.

Table 6.4 indicates that the increase in peripheral population results in an increase in effluent overflow at the Koyembedu sewage treatment plant from 1.21 m^3/s to 1.46 m^3/s, and an increase in uncollected effluent (which in Table 6.4 also includes effluent routed to STPs other than Koyembedu) from 1.07 m^3/s to 1.23 m^3/s. Because of this situation, the simulated BOD_5 and Ammonia levels are higher in the Population Increase scenario than in the Baseline scenarios, and the DO indicator is lower. For example, at 15 875 metres upstream from the mouth (just below the Koymebedu STP outlet), the BOD_5 values for this scenario were 120.32 mg/l (dry season) and 85.26 mg/l (monsoon). (Refer to Figures 6.3a - 6.3f for simulation results). These figures are, respectively, 9.02 mg/l and 8.98 mg/l worse than those simulated for the Baseline scenarios. This gap between the Population Increase scenario and Baselines narrows with distance downstream from the STP until the values become quite

Table 6.5: Population figures used in the Population Increase Scenario. Original population estimates for 2001 are doubled.

Ward	Population Estimate, 2001	Population Doubled
50	43,936	87,872
54	41,098	82,196
55	36,269	72,538
62	50,823	101,646
63	72,706	145,412
64	74,780	149,560
65	61,123	122,246
66	53,263	106,526
75	49,693	99,386
128	37,353	74,706
129	43,536	87,072
130	50,326	100,652
131	40,827	81,654
Total	657,734	1,311,466

similar in the lower reaches (simulated BOD_5 values are only 1.73 mg/l and 1.39 mg/l higher than the Baseline at the mouth of the river).

Similarly, the values derived from the modelling of the Ammonia variable indicate a deterioration from the Baseline simulations, although the magnitudes of deviations from Baseline are mostly small. The largest change occurs in the monsoon season variant in the upper reaches between the Koyembedu STP and the confluence with Arumbakkam/ Virugambakkam Drain. Here the Ammonia values are simulated at 126.97 mg/l for the dry season (only 1.60 mg/l above the Baseline) and 59.77 mg/l for the monsoon season variant (8.98 mg/l higher than the Baseline) at this point. Downstream, the Ammonia levels are still quite high (44.43 mg/l (dry) and 34.43 mg/l (monsoon)), but only deviate from the Baseline by 1.04 mg/l and 0.83 mg/l, respectively.

The dissolved oxygen variable simulated for the Population Increase scenario showed a deterioration with distance downstream from Koyembedu STP, especially for the dry season. Because along most of the course of the Cooum the reported DO values are below zero, however, they do not add much to our understanding of the response of the Cooum system to increased population that the BOD_5 indicator has not already provided. The most meaningful information that this variable provides in the simulation is the point at which it is indicated that no more dissolved oxygen remains in the water. Downstream from this point,

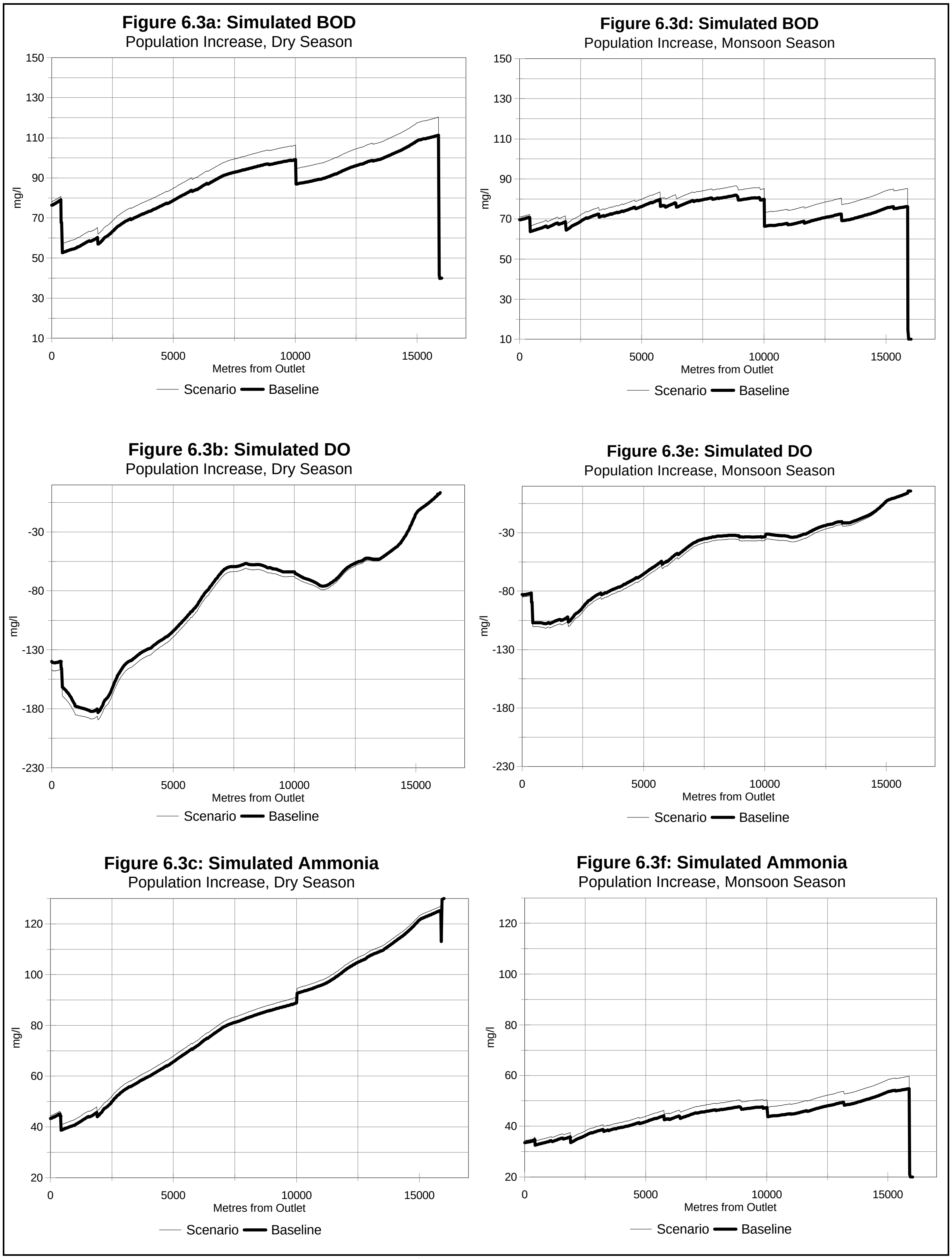

Figure 6.3: Water quality simulation results for the peripheral population increase scenario.

organic material can no longer be broken down by aerobic bacteria (at least at rates beyond the re-aeration rate of the water). In this simulation, this point is found at 15 824.8 metres upstream for the dry season, and 15 398.7 metres upstream for the monsoon season. This is 25.1 metres and 75.2 metres, respectively, further upstream than in the Baseline scenarios, indicating that more of the river exists in anaerobic conditions under the Population Increase scenario than in the Baseline scenarios.

The doubled population in the western peripheral wards translates, for the simulation, to an increase in untreated effluent. It is this increase in untreated effluent which accounts for the deterioration in water quality in the simulation. The magnitude of the deterioration in water quality, however, is not as large as one might expect from the input of so much more untreated sewage from such a large increase in population. This is because not all the population at the periphery is within the Cooum urban storm water drainage catchment, or the Koymebedu (Zone III) sewerage collection zone. The sewerage production of this population is calculated by the Cooum DSS, but is only routed by the system if it falls within the spatial domain of the Cooum drainage and sewage collection systems.

Slum Improvement Scenario

The slum improvement scenario explores the sensitivity of the system to improvement of all slums in Chennai. By "improvement" it is meant that slums in the city are addressed by programs which provide residents with latrines and sewage service, such that sewage produced by the slum population, which in total is about 1/3 of city residents, is routed to sewage treatment plants for treatment. By default, slums in the database are (realistically) treated as un-serviced. That is, normally their wastes are disposed of into the city drains, canals and rivers (directly or via the stormwater drainage system), or into empty lots. In specifying that slums be improved, the Cooum DSS calculates an estimate of the population in the indicated slums, calculates the proportion of ward populations which those slum dwellers represent, and uses this information to recalculate the sewerage efficiency coefficient for wards. The efficiency coefficient determines the proportion of sewage generated by population in a ward routed to the STP for treatment. Aside from the

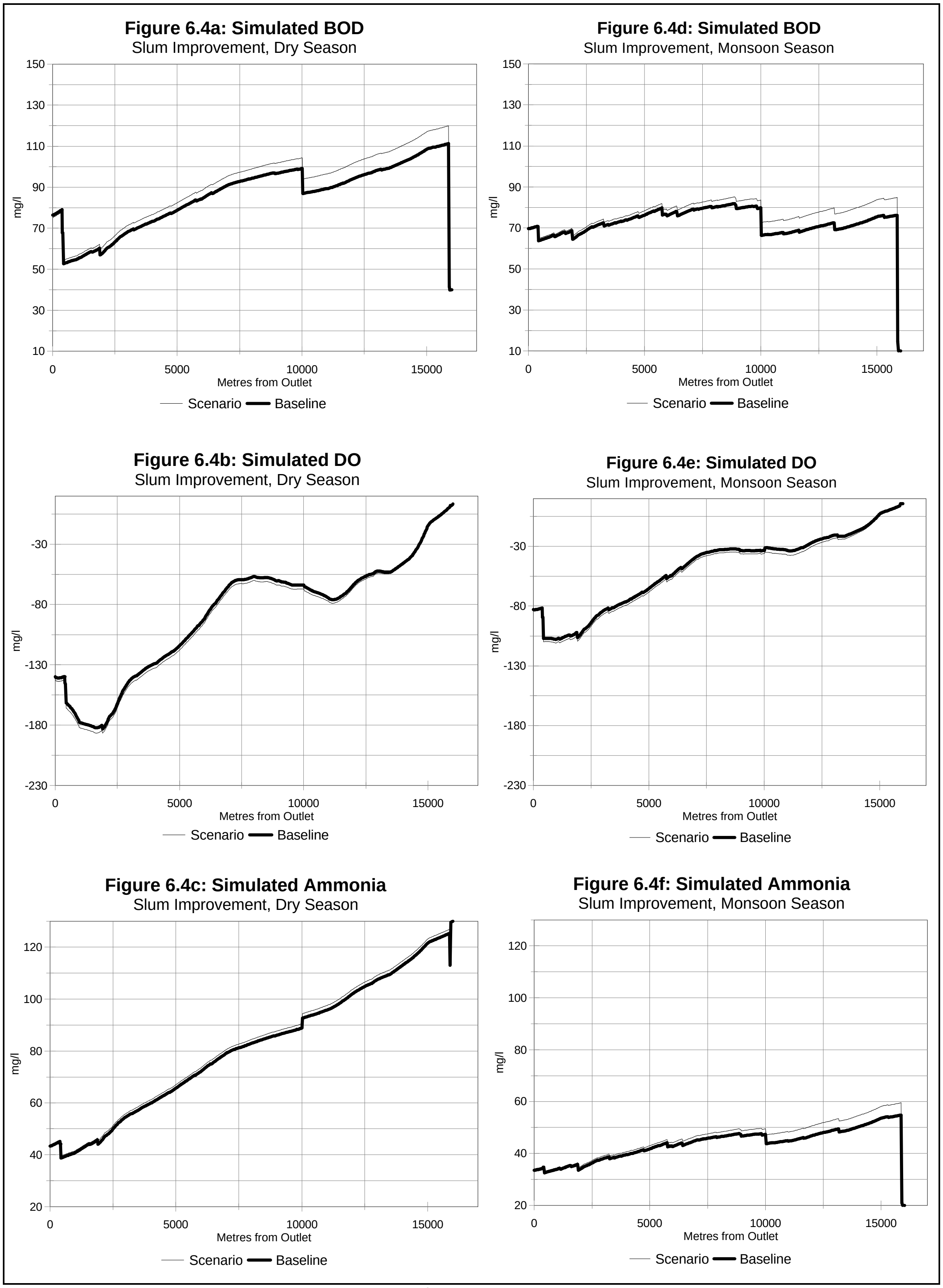

Figure 6.4: Water quality simulation results for the slum improvement scenario.

specification of slums to be improved, the initial parameters of dry and monsoon season variants of this scenario are identical to the Baseline scenarios.

Figures 6.4a-6.4f present the simulation results for the slum improvement scenario, compared to the Baseline scenarios. These figures demonstrate that in both dry season and monsoon season simulations, slum improvement results in a worsened situation for BOD_5 and Ammonia levels, as well for the DO indicator. In the case of BOD_5, upstream at the STP outlet, the values presented are 8.6 mg/l greater than the Baseline in both variants. The values gradually decline, eventually closing the gap between the slum improvement scenario and the Baselines. The same trend exists for the values of Ammonia: near the city limits, there is a surplus over the Baseline of 1.5 mg/l in the dry season and 4.7 mg/l in the monsoon season. This gap is gradually closed and similar values to those in the Baseline scenarios are reported in the lower reaches.

This result at first seems surprising – one would expect that the servicing of previously unsewered areas would result in an overall improvement in the condition of the Cooum waters. However, examination of the summary effluent parameter values for the slum improvement scenarios (Table 6.4) indicates that the treated effluent values are unchanged and the untreated effluent (overflow from the STP) has increased from 1.21 m^3/s to 1.45 m^3/s. The treatment plant is over-capacity and the additional sewage collected from slum areas is being deposited as untreated overflow at the STP location upstream, instead of a little at a time along the entire course of the river! The corresponding amount of uncollected effluent, part of which would normally be deposited along the course of the Cooum, has decreased from a total of 1.07 m^3/s throughout the city to 0.83 m^3/s. This redistribution of the untreated sewage effluent accounts for the worsened conditions upstream.

STP Capacity Increase Scenario

The STP Capacity scenario depicts the upgrading of the Koyembedu STP such that the capacity is increased to 75 million litres per day (from 34 mld). Otherwise, the initial parameters for this scenario are the same as those for the Baseline scenarios. The amount of effluent produced and modelled in this scenario is identical to the Baselines. However, the distribution of this effluent is different. Table 6.4 demonstrates that the treated effluent from Koyembedu STP is increased from 0.39 m^3/s to 0.87 m^3/s and there is a corresponding decrease in untreated overflow from the STP from 1.21 m^3/s to 0.73 m^3/s.

Figures 6.5a to 6.5f portray the simulation results of the dry and monsoon season variants of the STP capacity scenario. These figures indicate that, although levels of BOD_5 and Ammonia still remain high in the simulations, the redistribution of effluent, as described above, dramatically reduces the pollution load in the river. In the upper reaches just below the Koyembedu treatment plant, the BOD_5 indicator for the dry season scenario is 84.95 mg/l, or 26.35 mg/l lower than indicated for the Baseline. The corresponding figure for the monsoon season is 55.66 mg/l which is 20.62 mg/l better than the Baseline. The improvement becomes less pronounced with distance downstream from the STP: BOD_5 at 445 metres (just above the confluence with the North Buckingham Canal and the north arm of the Cooum) is 44.90 mg/l (dry season) and 59.24 mg/l (monsoon) which is 7.83 mg/l and 4.48 mg/l (respectively) lower than the Baseline scenarios. The improvement over the Baseline is 4.91 mg/l and 2.04 mg/l, respectively, at the outlet to the ocean.

As with the other scenarios, the trend with the Ammonia indicator mimics BOD_5. Ammonia levels just below the STP are 109.57 mg/l (dry) and 42.48 mg/l (monsoon) which are, respectively, 15.81 mg/l and 20.62 mg/l lower than the Baseline scenarios. At 445 metres, simulated Ammonia levels have fallen to 34.89 mg/l (dry) and 30.21 mg/l (monsoon). The improvement over the Baseline scenarios is 3.90 mg/l (dry) and 2.33 mg/l (monsoon).

The dissolved oxygen variable simulated for the STP Capacity Increase scenario showed a steady improvement with distance downstream from Koyembedu STP, but remained at values below zero for most of the course of the river through the city. In this simulation, the reach distance at which there is no longer any measurable (simulated) dissolved oxygen in the water is 15 749.6 metres for the dry season and 15 022.8 metres for the monsoon season. This is 50.1 metres and 300.7 metres, respectively, further downstream than is indicated for the Baseline scenarios, and so, indicates an improvement in the condition of the Cooum relative to the Baseline scenarios.

The direction of change in the indicators for this scenario were expected, and the

Figure 6.5: Water quality simulation results for the STP capacity improvement scenario.

magnitude of the change gives some indication that increasing the capacity of STP would have a significant impact on improving the quality of water in the Cooum. It is logical to assume that if more of the sewage is treated before release into the waterway, the quality of water in the river will improve. However, even though the capacity of the STP was more than doubled from 34 mld to 75 mld in the scenario, it still did not have enough capacity to treat all of the sewage routed to it! Going by the figures in Table 6.4 above, the Koyembedu STP would require a capacity of slightly more than 138 mld to treat the sewage routed to it in this simulation.

STP Treatment Upgrade Scenario

This scenario depicts the upgrading of the Koyembedu STP treatment technology, such that effluent water is aerated and unpolluted (for this scenario STP effluent, BOD_5 and Ammonia are set to 0 mg/l, and DO set to 9.00 mg/l). As with the other exploratory scenarios, this one change in parameters is the only deviation from the Baseline scenarios. Also, this scenario does not involve any change in the amount, or reallocation of, stormwater, treated or untreated sewage effluent.

The release of unpolluted effluent has the effect, in the simulations, of slightly improving the levels of BOD_5 and Ammonia in the upper reaches of the Cooum. Simulation results are presented in Figures 6.6a - 6.6f. Just below the STP outlet, the simulated BOD_5 values are 105.84 mg/l (dry) and 72.01 mg/l (monsoon), while the Ammonia indicator is reported at 122.10 and 52.29 mg/l. These represent reductions of 5.46 and 4.28 mg/l for BOD_5 and 3.28 and 4.28 mg/l, respectively, for Ammonia. For both of these variables, however, this improvement declines to almost nothing in the lower reaches of the Cooum.

Improvements indicated by simulated DO are also quite small. The greatest departure from the Baseline scenario occurs for the dry season simulation at the widening of the Cooum by the Island where the reported value of DO (-178.32 mg/l !) is only 4.86 mg/l greater than that simulated for the Baseline scenario. No movement in the point at which the river experiences mainly anaerobic decomposition is observed in the dry season simulation, but this point is pushed 75.2 metres downstream in the monsoon season variant.

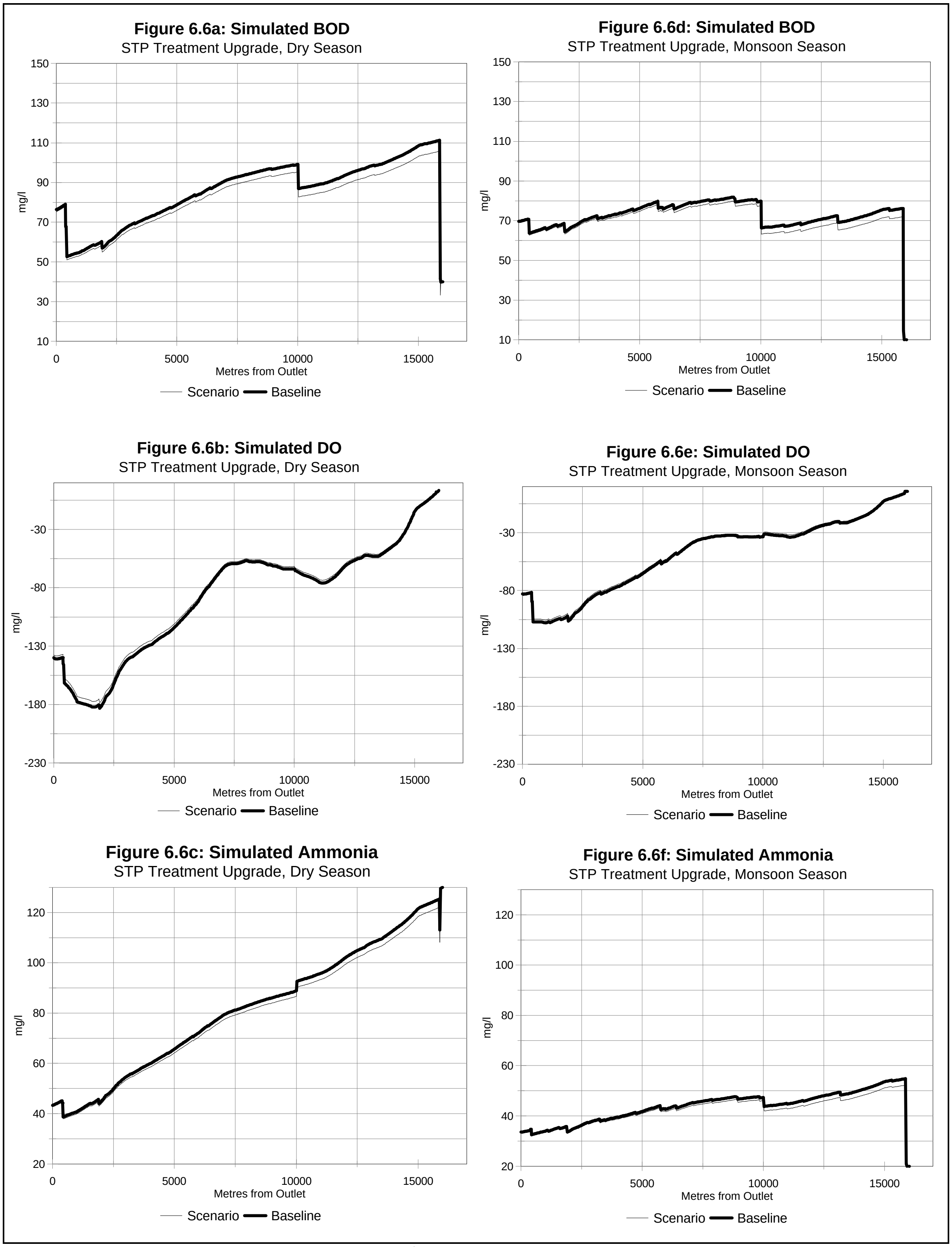

Figure 6.6: Water quality simulation results for the STP treatment upgrade scenario.

For this scenario, indications of improvement are quite small. This may be attributed to parameters of the scenario which describe extremely poor quality untreated effluent in the simulation. The very clean effluent from the STP specified for this scenario, is simply overwhelmed by the untreated effluent so that, although improvements from the Baseline are noticeable, they are minimal.

Increased Base Flow Scenario

The 'Increased Base Flow' or 'Increased Upstream Flow' scenario explores the effect of dramatically increased flow to the Lower Cooum system. For this scenario, the values for the quantity of flow at the city limits are increased from 3 to 9 m^3/s for the monsoon season, and from 2 to 6 m^3/s for the dry season (this tripling of the base flow is derived from a user scenario constructed during the second workshop). The scenario is otherwise identical to the Baseline.

This increased rate of flow into the main river at the system boundary does not effect the flows of effluent which originate from population within the system, so no change in the magnitudes or distributions of these (as depicted in Table 6.4) occurs. The increased base flow of relatively clean water does, on the other hand, have a great impact on the simulated values of water quality indicators, (Figures 6.7a - 6.7f). Very simply, the larger amount of less polluted water dilutes the more polluted water added to the system along the course of the Cooum within the city limits. In the dry season variant of this scenario, for example, BOD_5 values were simulated from 37.57 mg/l lower (having a value of 73.73 mg/l) just downstream of the STP, to 22.22 mg/l lower (with a value of 54.21 mg/l) at the mouth, than in the dry season Baseline simulation. The corresponding values for the monsoon season were 37.53 mg/l lower upstream where the simulated BOD_5 was indicated at 38.76 mg/l, and 10.35 mg/l lower than the Baseline at the mouth of the Cooum, with a value of 59.28 mg/l. Figures 6.7a and 6.7d indicate that this is a substantial improvement over both the dry and monsoon season Baseline simulations.

The point at which there is no longer any dissolved oxygen in the Cooum River is pushed downstream in this scenario more than in any other. The dry season variant illustrates

Figure 6.7: Water quality simulation results for the upstream flow increase scenario.

a 50.1 metre improvement, while the corresponding shift for the monsoon season simulation is 476.2 metres. However, despite this indicated improvement in the upper reaches, Figures 6.7b and 6.7e demonstrate a mixed response of the DO component in the dry and monsoon variants of the simulation. Figures 6.7c and 6.7f indicate a similar difference for simulated Ammonia, which explains the pattern observed for DO. The difference in the response of Ammonia in the dry and monsoon simulations originates in the specification of water quality characteristics of the upstream base flow (see the HEAD0001 records in Tables 6.1 and 6.2, above). The dry season input from the Upper Cooum system is associated with a very high value of Ammonia (120 mg/l), while the monsoon season value is much lower (20 mg/l).

This results in the input of water into the system which has a relatively low BOD_5 value in both the dry and monsoon seasons, a low Ammonia value in the monsoon season variant, but a high Ammonia value for the dry season. Because of this, and because of the increase flow specified in this scenario for the dry season, simulated values of Ammonia in the dry season are higher than the Baseline, while for the monsoon season they are lower than the Baseline. (For the dry season, values of Ammonia are 2.28 mg/l greater than the Baseline at the STP outlet, while they are 37.53 mg/l lower at this location for the monsoon variant. Downstream, at 445 metres, the dry season simulation produces a value for Ammonia which is 10.15 mg/l greater than the Baseline, while the monsoon season simulation reports a value 4.58 mg/l below its corresponding Baseline scenario).

The 'Increase Upstream Flow' scenario provides more insight into the response to increase flow of the Cooum system water quality than was expected. In other scenarios the dry season upstream flow was low enough that the effect on the system of their high Ammonia values was not immediately evident. The increased flow in this scenario demonstrates not only a large impact on Ammonia values , but also illustrates the impact of elevated levels of Ammonia on simulated values of dissolved oxygen. Despite the fact that BOD_5 levels are much reduced in the simulation of the dry season variant of this scenario, the DO indicator worsens relative to the dry season Baseline scenario. This may be attributed to the consumption of Oxygen by Ammonia as it decays as specified in the reaction scheme for dissolved oxygen in the water quality model (see Chapter 4). Despite this worsening of

Ammonia and DO indicators for the dry season variant, however, this scenario still depicts the greatest positive impact on water quality for all the scenarios explored.

First Storm Water Flush Scenario

For the 'First Storm Water Flush' scenario, an attempt is made to mimic the effect of the first flush of stormwater off the city streets by the first heavy monsoon rains. For this scenario, the water quality of runoff is set to values similar to raw sewage (BOD_5=250 mg/l, Ammonia=150 mg/l, DO=0 mg/l). The period of simulation is set to 1 day, and the peak runoff calculation is used.

Figures 6.8a to 6.8c portray the expected 'system shock' of the first storm flush. It can be seen that as more and more very highly polluted water is washed off the streets and routed to outlets along the course of the Cooum, BOD_5 and Ammonia indicators increase while the simulated DO values decrease. Simulated BOD_5 values in this scenario reach a maximum of 50.83 mg/l over the Baseline scenario, and average 31.72 mg/l greater than the Baseline. Ammonia values are similar, with a maximum deviation from the Baseline of 36.16 mg/l and a mean deviation of 22.93 mg/l. The simulation of dissolved oxygen indicates that, if such a thing were possible, DO values would be as great as 72.48 mg/l lower in the regime set up in this scenario, than in the peak runoff monsoon Baseline. Figure 6.9 presents the deviations from the Baseline of indicators in this scenario. No change is indicated in the point at which DO values drop to zero, because, in the DESERT representation of the river network, storm water only enters the system downstream from this point in the Baseline scenarios.

Exploratory Scenarios Compared

Figures 6.10, 6.11 and 6.12 compare the deviations of the Population Increase, Slum Improvement, STP Capacity, STP Treatment, and Upstream Flow Increase scenarios in terms of their deviation from values produced in the dry season and monsoon Baseline scenarios. (The First Storm Flush Scenario is presented separately from the others because it is not directly comparable – it uses peak runoff calculations, whereas the other monsoon variants

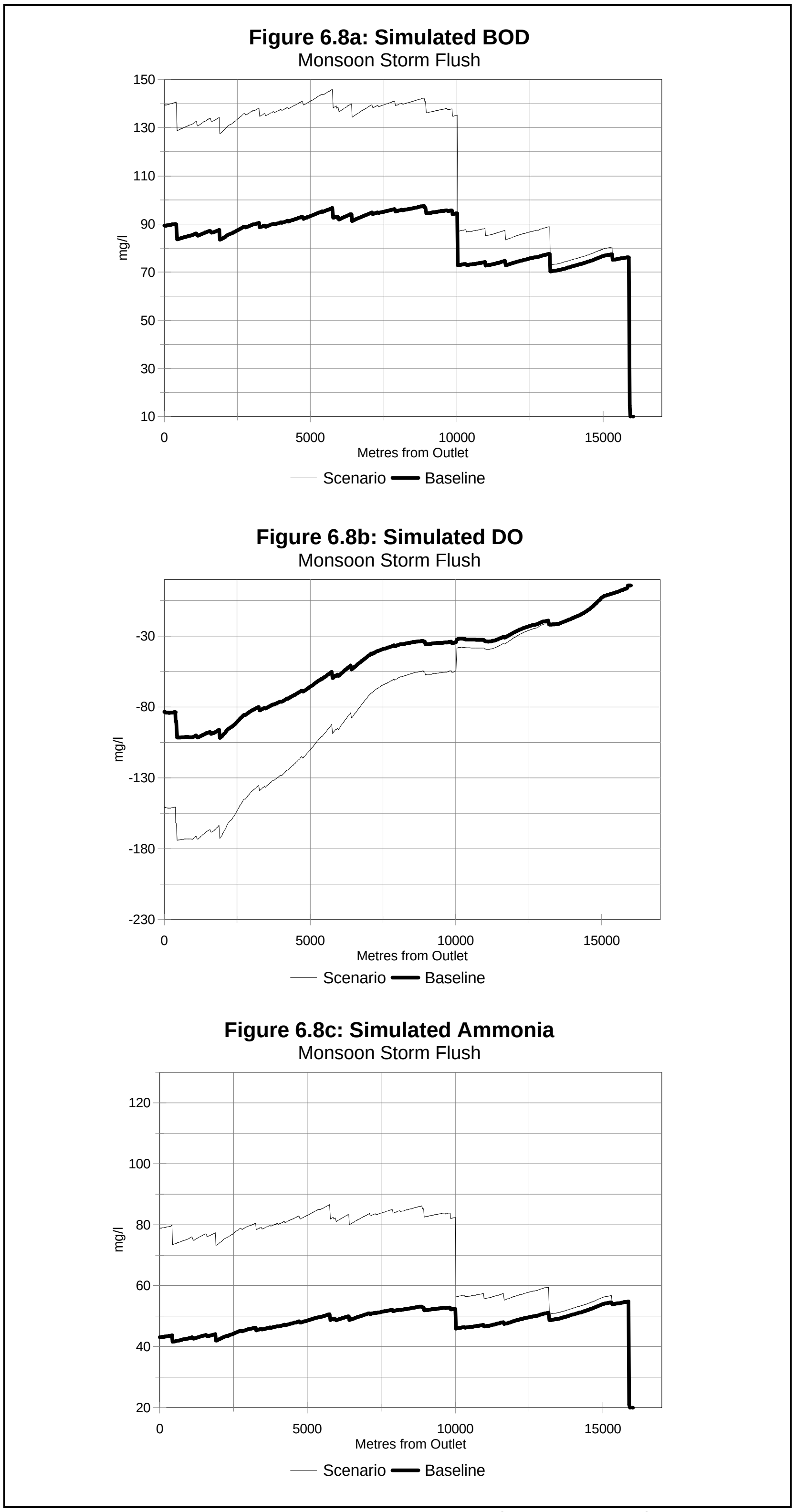

Figure 6.8: Water quality simulation results for the storm flush scenario.

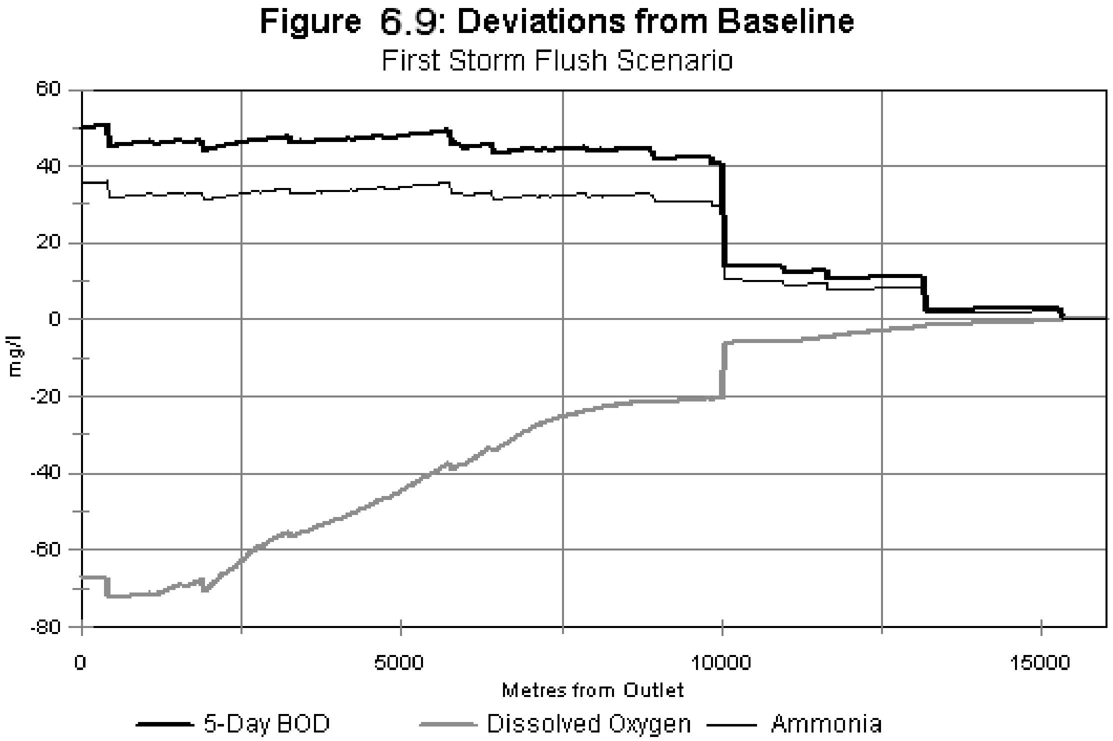

Figure 6.9: Deviations of BOD_5, DO and Ammonia in the 'Storm Flush' exploratory scenario from the Baseline scenario for the monsoon season, using the peak runoff calculation. Values above zero indicate more DO or Ammonia and greater BOD than the Baseline, and *vice versa*.

employ the mean runoff calculation). Table 6.6 presents deviations for the same scenarios at selected reach distances on the Cooum River. In this case, the First Storm Flush Scenario is also presented (note that it uses the peak runoff instead of mean runoff calculations). The direction and magnitude of these deviations have been discussed in the presentations of the individual scenarios, above, but these figures and table present a summary comparison of the relative sensitivity of the Cooum system to the various changes introduced in the exploratory scenarios.

Thus, it can be observed in Figure 6.10 that for the BOD_5 component in both dry and monsoon season variants the greatest deviations (which may be interpreted as improvements in the simulated condition of Cooum waters) are produced from increasing the base flow of the river at the city limits. This observation provides a supporting argument for a plan for

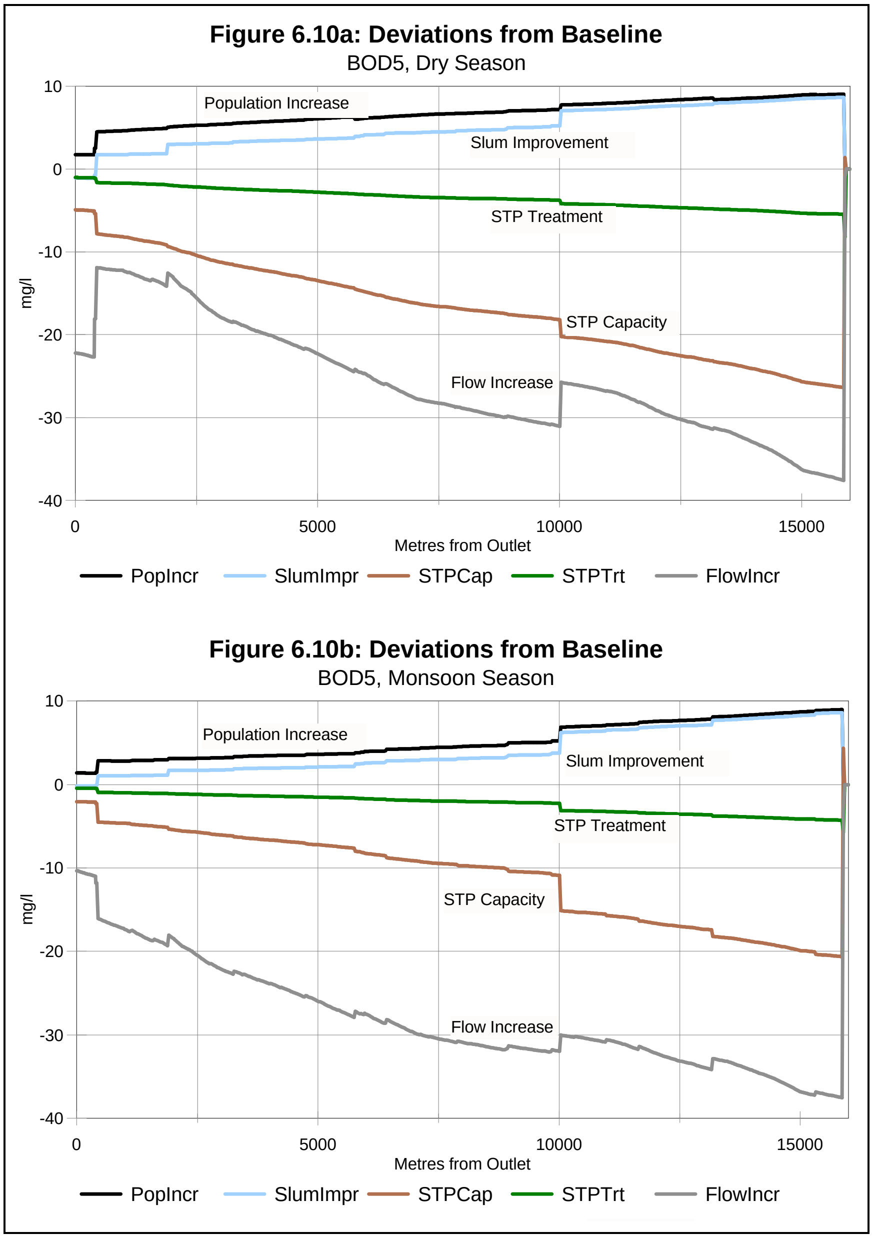

Figure 6.10: Deviations of values of the 5-day biochemical oxygen demand in the various exploratory scenarios from the baseline scenarios. Values below zero indicate less biochemical oxygen demand than the Baseline scenario, values above zero indicate relatively greater BOD than the Baseline.

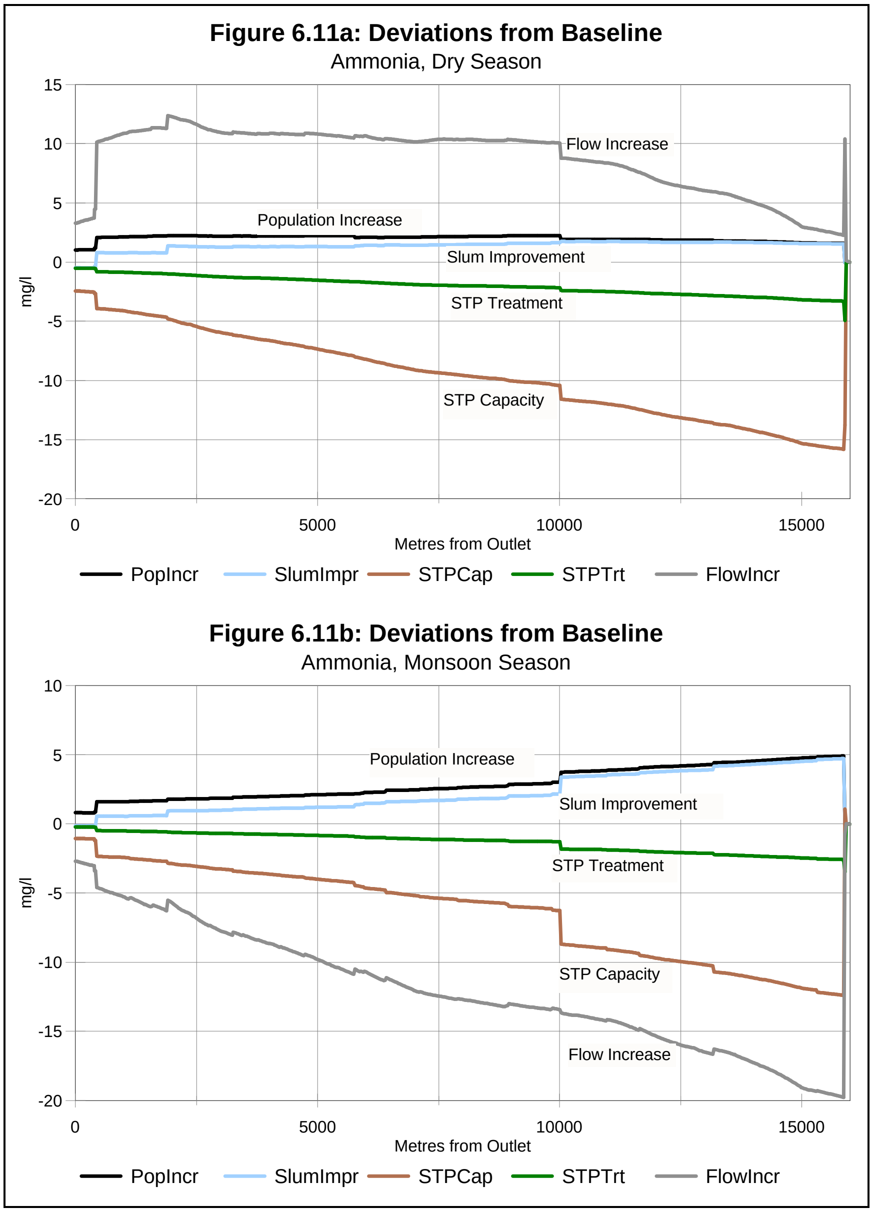

Figure 6.11: Deviations of values for ammonia in the various exploratory scenarios from the baseline scenarios. Values above zero indicate more ammonia present than in the Baseline, while values below zero indicate less ammonia present.

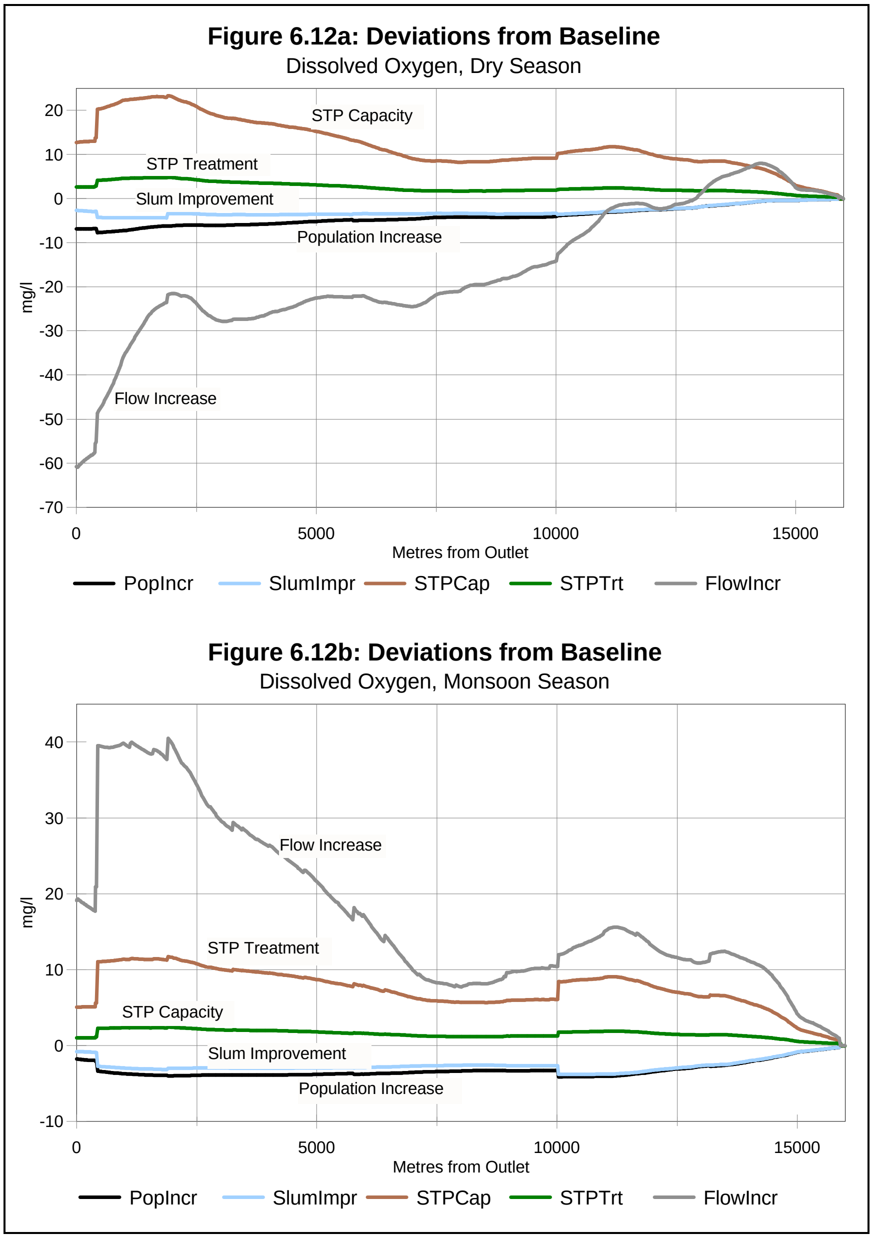

Figure 6.12: Deviations of values of dissolved oxygen in the various exploratory scenarios from the Baseline scenarios. Values below zero indicate less DO present, and values greater than zero indicate higher levels than in the Baseline scenario. Note that these deviations should only be used as an indicator of oxygen demand, as almost all these deviations occur at DO levels below zero, which is not possible in the real world.

artificial flushing of the Cooum championed by some at the Tamil Nadu Public Works Department (*e.g.,* Sahadavan, 1994, 1995, 1996, 1998:7). The next strongest deviations of BOD_5 from the Baseline in an 'improving' direction were produced by the STP Capacity scenario, with a smaller improvement described for the STP Treatment scenario. The final two scenarios, dealing with Slum Improvement and Population Increase, have BOD_5 values for both dry and monsoon variants higher than zero, indicating that in simulations for this indicator, they worsened the condition of the Cooum. The Population Increase scenario is slightly worse in this sense than the Slum Improvement Scenario.

Table 6.6: Deviations of BOD_5, Ammonia and DO in simulations at selected locations.

Variable	Distance	Variant	Population Increase	Slum Improve-ment	STP Capacity Increase	STP Treatment Upgrade	Upstream Increase	Storm Flush-Peak
BOD	**15874.9**	**DRY**	9.02	8.67	-26.35	-5.46	-37.57	
		WET	8.97	8.62	-20.62	-4.27	-37.53	0.00
	445.286	**DRY**	4.51	1.75	-7.83	-1.62	-11.89	
		WET	2.85	1.07	-4.48	-0.93	-16.04	45.16
	0	**DRY**	1.73	-1.07	-4.91	-1.02	-22.22	
		WET	1.39	-0.17	-2.04	-0.42	-10.35	50.05
DO	**15874.9**	**DRY**	-0.11	-0.11	0.85	0.34	0.61	
		WET	-0.24	-0.23	0.66	0.27	0.99	0.00
	445.286	**DRY**	-7.67	-4.25	20.33	4.22	-48.60	
		WET	-3.34	-2.71	11.08	2.30	39.58	-72.48
	0	**DRY**	-6.84	-2.64	12.76	2.65	-60.75	
		WET	-1.75	-0.78	5.06	1.05	19.14	-67.03
N	**15874.9**	**DRY**	1.60	1.53	-15.81	-3.28	2.28	
		WET	8.97	8.62	-20.62	-4.27	-37.53	0.00
	445.286	**DRY**	2.09	0.80	-3.90	-0.81	10.15	
		WET	1.63	0.57	-2.32	-0.48	-4.58	31.84
	0	**DRY**	1.04	-0.47	-2.43	-0.50	3.29	
		WET	0.83	-0.12	-1.05	-0.22	-2.69	35.67

The pattern described in Figures 6.11a and 6.11b for Ammonia is similar to the deviations of BOD_5. With the notable exception of the Flow Increase scenario, which has higher levels of Ammonia than the Baseline in the dry season (for reasons discussed above), the directions and relative magnitudes of simulated responses of Ammonia resemble the responses for the BOD_5 component.

The graphs for dissolved oxygen, (Figure 6.12a and Figure 6.12b), may be interpreted in a similar manner as those for Ammonia (except that the directions representing 'improved' or 'worsened' conditions are reversed). As discussed earlier, however, the simulated values of DO are of uncertain utility in contributing to an understanding of the sensitivity of the Cooum system to changes and interventions explored in the various scenarios. This is because dissolved oxygen is modelled without a lower limit, such that it can have a negative value. In reality, the dissolved oxygen variable cannot have a value below zero. The significance of this is that, below a value of zero in the simulation, organic matter would be broken down by anaerobic processes, instead of aerobic processes. Noxious gasses, such as sulfur dioxide (SO_2), are produced in such conditions. This is more in keeping with observed conditions in the lower reaches of the Cooum.

Thus, the simulated DO values provide an indication of where the Cooum is undergoing anaerobic *versus* aerobic decomposition of organic matter. Table 6.7 presents the point at which DO falls below zero for each of the scenarios. It may be observed that, as with the BOD_5 and Ammonia indicators, the Upstream Flow Increase scenario has the greatest beneficial effect on the quality of Cooum waters, pushing the point of anaerobic decomposition almost one half of a kilometre downstream in the monsoon season, but only 50 metres downstream in the dry season. The next greatest effect is observed in the simulation for STP Capacity Increase (300.7 m (dry), 50.1 m (monsoon)), followed by the STP Treatment Upgrade scenario which improves the situation by only 75 metres in the monsoon season. The Population Increase and Slum Improvement scenarios both indicate a worsening of the situation.

Simulation Accuracy, Assumptions and Potential Improvements

These simulations were constructed with the assumption of unobstructed flow in the river. Primarily, this means that there has been an intervention to keep the sand bar clear at the mouth of the Cooum. This assumption was necessary because of modelling restrictions in

Table 6.7: Upstream Distance at which DO drops to zero (or negative values) in scenario simulations.

Scenario	Reach Distance			Deviation from Baseline Simulation		
	Dry Season	Monsoon (Mean)	Monsoon (Peak)	Dry Season	Monsoon (Mean)	Monsoon (Peak)
Baseline	15799.7	15323.5	15323.5	n/a	n/a	n/a
Population Increase	15824.8	15398.7	n/a	25.10	75.20	n/a
Slum Improvement	15824.8	15398.7	n/a	25.10	75.20	n/a
STP Capacity Increase	15749.6	15022.8	n/a	-50.10	-300.70	n/a
STP Treatment Upgrade	15799.7	15248.3	n/a	0.00	-75.20	n/a
Upstream Increase	15749.6	14847.3	n/a	-50.10	-476.20	n/a
Storm Flush-Peak	n/a	n/a	15323.5	n/a	n/a	0

DESERT, but it is also reasonable, as participants in both workshops agreed that this was a prime and essential intervention. The objective behind such an intervention is to improve water quality by removing the hydraulic obstacle at the mouth, and thus avoid pooling and stagnation and allowing the polluted water to flow out to the sea. It does, in fact, seem that in the Baseline and other scenarios, the levels of BOD_5 and Ammonia are lower in the lower stretches of the Cooum than in some of actual observations (see Appendix III), although these observations vary widely. On the other hand, this may be due in part to the way that dissolved oxygen has been modelled in DESERT.

Regardless of the effect of the way that DO is modelled, and the hydraulic effect of sand bar clearance, the pollution levels of the Cooum are indicated to be extremely high. Even recalling that large inaccuracies may be present due to data of uncertain accuracy and the crudeness of the current water quality simulation model, all Baseline and intervention scenarios demonstrate that none of the interventions explored in the scenarios come anywhere near representing acceptable levels of pollution. The default scenarios, for example, present BOD_5 values above 50 mg/l at all locations within the city, and Ammonia levels greater than 30 mg/l. Generally, 4 mg/l BOD_5 is considered acceptable (Flanagan, 1990, 79), as is a limit of 1 to 3 mg/l of Kjeldahl Nitrogen (Nitrogen including Ammonia, excluding NO_2 and NO_3) for surface waters (*e.g.,* E.C. regulations as reported by Flanagan, 1990, 72).

To improve the model three aspects need to be pursued: continued development of the conceptual model; improvement of the quality of data use to derive parameters for input into the simulation model; and improvement of the water quality model. First, the development of the conceptual understanding of the Cooum system must continue, and this understanding (having to do with structure and processes of the system) should be incorporated into the Cooum DSS. Examples of this kind of continued development are evident in refinements of the conceptual model of the Cooum system which occurred in the second workshop (described above). The refinement of income groupings to distinguish between the economically weaker section and the lower income group, the provision for spatial variation in the characteristics of sewage throughout the city, and the modelling of solid waste and blockages of the SWD system, are potential refinements to the Cooum DSS regarding the structure and processes of the system.

Second, the accuracy and realism of various parameters that the Cooum DSS requires as input from the user, and which are stored in the GIS database, must be improved. Parameters such as the runoff coefficients for storm water drainage catchments, the sewage generation factors for the various income groups, updated slum population and location figures are examples of parameters which could be improved.

Finally, the water quality simulation component of the Cooum DSS must be refined to be more appropriate for the situation of the Cooum in Southern India. For example, one concern regarding the modelling of BOD_5, DO, and Ammonia is that the rates of consumption of organic matter may occur at different rates when aerobic versus anaerobic bacteria are involved. Thus, in the next stage of development, the water quality model should be refined to detect when dissolved oxygen falls below zero, and model organic pollutant indicators using anaerobic processes. Similarly, Sediment Oxygen Demand was set to 0 g/day in the simulations, although it is known that there are large quantities of organic sludge on the bottom and banks of the Cooum. These items, and a host of other refinements, will be addressed as the Cooum River Environmental Management Decision Support System progresses from a prototype to a scientific and management tool.

Conclusions

Despite some difficulties and uncertainties involved in parametizing the system model, the use of the Cooum DSS for the construction of exploratory management scenarios and simulation did lead to insight into basic characteristics and behavior of the system. This occurred because, assuming the primary system relationships are sound,[6] changes could be introduced to the model to explore the direction and general magnitude of response of the system. That is, sensitivity analysis could be undertaken. One example which demonstrates the nature of knowledge generated through such sensitivity analysis comes from the 'Slum Improvement' scenario. In first perusing the simulation results of this scenario it came as a surprise to find that, according to the simulation, improving slums (*i.e.*, providing them with latrines and sewerage service) actually resulted in a deterioration of the condition of the system as indicated by water quality in the Cooum River. In investigating the reason for this, and considering the whole system, it became clear that there is a disparity between estimates of the sewage produced by the population and the stated capacity of treatment plants to deal with it. This has implications for which interventions in the system should be attempted, and also for sequencing of interventions. This is not to say that slum areas should not be improved – there are many benefits to Slum Improvement Programs which water quality indicators do not address!

In general it was found that scenarios which investigated (1) a population increase at the city periphery, (2) improvement of slums, and (3) the first flush of water from city streets at the start of the monsoon, worsened the condition of the Cooum River as indicated by values of the 5-day biochemical oxygen demand, dissolved oxygen and ammonia. Scenarios which explored (1) an increase in the base flow of the river, (2) increase in the capacity of the sewage treatment plant and (3) improvement of the sewage treatment technology improved the condition of the Cooum waters. Although some of the changes indicated were quite large in absolute terms, none of the scenarios indicated a quality of water in the Cooum that approached acceptable standards.

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[6]This was the general consensus of workshop participants.

Finally, it is worth noting that the prototype Cooum DSS in its current form had difficulty modelling the dissolved oxygen indicator. The water quality model was not designed to monitor the value of DO and use alternate equations to model anaerobic processes when the value of DO fell below zero. However, the DO variable provides a useful indicator of the domain of organization in which the system resides. Anaerobic and aerobic conditions are two known attractor states of the system, and the value of dissolved oxygen indicates the threshold between the two. At reaches where DO is zero, the system is characterized by anaerobic processes and their accompanying structures. When dissolved oxygen is present in the system, aerobic processes take over.

7

Conclusions

Introduction

Overall, this program of research was successful, especially in terms of its ability to stimulate new thinking about the problem situation and in initiating a participatory process which has potential to contribute to efforts at rehabilitation and management of the Cooum system in the near future. The ecosystem approach framework employed for the Cooum River Environmental Management Research Program, and many of the techniques and tools used to implement the approach, were appropriate for addressing the problem situation in the Chennai context, and useful in terms of their products. This holistic, qualitative/quantitative approach, grounded in systems thinking, led to new insight into the problem situation of the Cooum River and environs, and ensured a shared understanding by participants in the program of research. The use of GIS and environmental simulation modelling within this program of research was also beneficial. However, this had more to do with support of conceptualization and visualization of the system in both present and future states, than in their more common role of supporting traditional analytic, reductionist, and anticipatory science, (*e.g.*, as in forecasting). Their use also resulted in the production of an accessible spatially referenced database that may be freely used and disseminated by researchers, NGOs and agencies in Chennai. This in itself is a non-trivial achievement.

This chapter presents observations and general conclusions from the Cooum River

Environmental Management Research Program. The discussion is organized around the issue of the ecosystem approach framework which the research has applied, and the two primary methodological and theoretical influences drawn upon to operate the ecosystem approach in this work — Adaptive Management and Soft Systems Methodology. The chapter also revisits the three primary research objectives of this work as stated in Chapter 1. These were (1) an evaluation of an ecosystem approach, influenced by Adaptive Management and Soft Systems Methodology, as applied in this work to the problem of rehabilitation and management of the Cooum River and environs, (2) the evaluation of the use of a GIS in support of environmental modelling in this context, and (3) the development of a spatial database which may be used by researchers, planners and others in Chennai. Finally, an evaluation by participants in the Cooum River Environmental Management Research Program is presented.

Recommendations for action in the Cooum problem situation are also presented in this chapter. These are presented in text boxes at the end of each section, and arise out of the discussion immediately preceding them. Although some of these recommendations are closely related to each other, a basic prioritization is offered by indicating (with symbols following the recommendation) the five most important recommendations in three categories:

⚖ Recommendations which are most likely to contribute to alleviation of the problem situation in the long term, and to promote a more sustainable healthy system.

⌛ Recommendations which will most easily produce ‘deliverables’ and/or are most likely to result in a demonstrable change in the system in the short- or medium-term.

⚔ Recommendations which are likely to be difficult to implement in the current institutional and cultural context (*e.g.*, a culture dominated by programmed, mechanistic approaches to dealing with environmental problems).

Applying the Ecosystem Approach Heuristic to the Cooum Situation

Defining the System

An ecosystem approach to managing environmental problem situations is one which utilizes 'systems' theory and concepts to organize our observations of, and stimulate insight into, real world problems. A principal task in such an approach is to develop an understanding of the 'system of interest' in the context of a problematic situation. In this case, the system of interest pertains to the problem of management and rehabilitation of the Cooum River and environs. The ecosystem approach employed in this work, as presented in Chapter 2, describes two streams of activity that occur in the development of a description of an ecosystem (or, as it has here been called, a 'socio-ecological' system). The two streams involve generating a conceptual understanding of the situation as a 'system' (ecosystem understanding), and comprehension of aspects of the situation regarding the social, institutional, cultural, and political context with which it is associated. This includes an understanding of desirable future states of the system (issues framework).[1] This research has pursued both of these streams simultaneously.[2]

Much of the development of a socio-ecological system description in this work has focussed on the system "as it is," (that is, the current and historical situation), beginning with the development of a common view of the problem that brought participants in the program of research together. In Workshop I, portions of the first session (*An Exercise in Problem Definition*), the second and third sessions (*Toward a System Identification of the Cooum River and Environs – System Components Linkages and Relationships* and *Scoping the Problem Situation – Spatial and Temporal Scales*), as well as the development of a framework to provide the basic structure for a computer simulation model, were oriented

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[1]These two streams of activity correspond also to the two streams of activity described in second generation models (*circa* 1988-1990) of Soft Systems Methodology. Checkland (1999:A14) describes these as a "logic-based stream of analysis" (that is, systems analysis), and a "cultural and political stream which [enables] judgements to be made about the accommodations between conflicting interests."

[2]In reality it would be very difficult to separate these streams of activity. (In this work, the distinction is made for conceptual clarity). For example, keeping in mind that a description of a system is a conceptual construct, its definition (*i.e.*, description of purpose, spatial and temporal scope, primary elements, actors and interrelationships) will be shaped by the perspective of those pursuing the 'ecosystem understanding.' Such an understanding represents a particular view of the world. As such it is influenced by participants' interest in the situation, experience, world view, and beliefs about what is the problem, preferences about what states of the system would be acceptable, *etc*.. Thus, these "issues" helped to determine which elements and relationships were brought into the foreground to define the socio-ecological system in this work. Similarly, as Kay *et al.* (1999:736) point out, one's understandings and preferences will be altered by the experience of developing an understanding of the situation as a 'system.' The two streams are interdependent and recursive.

toward developing and understanding the current state and dynamics of the system. Similarly, the first session in Workshop II (*Re-examining the Cooum System – Sub-systems within the Cooum System*), as well as many of the papers presented and much of the discussion in both workshops, had to do with developing an understanding of the system "as it is."

The ecosystem approach employed in this research has been successful in furthering the understanding of the problem situation. Several aspects of the approach made particularly significant contributions. These include a systemic or holistic approach to the problem situation, and explicit the use of systems thinking to analyse and investigate the situation. Also, involvement of appropriate stakeholders played an important role, particularly in widening the perspective and in deepening an understanding of the system. (The participatory aspect is discussed below in the section on the role of Adaptive Management, but it is important to keep in mind that the holistic and systems-based work was undertaken in a participatory manner).

One of the insights as a result of looking at the problem situation as a whole was the development of what, from all indications, was a new understanding of the situation. This can be summarized in the description of emergent properties of the system that arose from attempting to identify the important interrelationships, elements and actors in the system, and in attempting to identify relevant spatial and temporal scales. As several workshop participants stated, these efforts resulted in a shared understanding of the situation as a system which was variously characterized as a "river system *cum* sewer system," an "urban system" and a "waste disposal system" (see Box 3.4). This system was identified as operating in the built up areas of the city, and was described as distinct from the upper Cooum for which a different set of actors and processes were seen to exist. That is, the lower and upper Cooum systems were identified as subsystems within a wider system. This wider Cooum system was set within a still wider system encompassing the interconnected waterways, tanks and canals in the Chennai region. Both the identification of the system as one which is primarily urban (characterized by sewage production, its disposal and transport), and the location by participants of the lower Cooum system within a hierarchy of systems, are examples of insight into the problem situation initiated by the systemic analysis employed in this work.

These results are typical of systems-based studies, but were novel in the Chennai context. Most significantly, the system itself was seen as having an urban character. Rather than being merely a 'natural' biological and physical system, it was seen also as a social system. It was characterized by human activity, rather than affected by human activity. Instead of seeing sewage merely as an input into the system, the population of Chennai and its role in producing sewage are understood to be *part of* the system. Similarly, rather than merely attempting to manage the biophysical system from the 'outside', the various government agencies were understood to be *inside* the system.

This contribution to the understanding of the situation represented a shift in the way participants thought of the problematic situation of the Cooum River and environs. Because of this, it has implications for how they perceived that such a situation might be alleviated. In this research, for example, a holistic understanding of the nature of the problem situation led to the discussion of potential interventions which were, in essence, aimed at changing the waste production and disposal nature of the system, rather than merely suggesting ways to clean up the river once it was polluted. In addition to the traditional engineering interventions to deal *post hoc* with the presence of pollution in the Cooum River (such as the dredging of sludge and flushing the Cooum), participants more and more began to propose systemic interventions targeted at altering the characteristics of the system which underlie its current organizational state. These included educational awareness campaigns to change attitudes toward the environment and modify the behaviour of citizens with regard to polluting activity, public participation in management programs, rainwater harvesting by individual house owners, and the promotion of tourism and recreation. This shift is also reflected in the recommendations of the workshops. For example, the first workshop indicated that the stakeholder process should continue, while the second recommended the formation and support of a working group with representation from NGOs, government agencies, academia, and interested citizens to support management of the Cooum system, as well as the formation of an agency which could transcend the jurisdictional and communicative barriers of agencies that currently attempt to deal with a only their jurisdictional piece of the Cooum puzzle.

In developing a description of the Cooum system, workshop participants represented the primary elements, actors and relationships in the situation as a 'Rich Picture' (a diagrammatic technique borrowed from Soft Systems Methodology), and used this diagram also to represent their shared conceptual understanding of the situation as a system. Most previous work regarding the Cooum targeted only parts of what participants conceived as the Cooum system. This is particularly true for consultancy studies, which have been the primary source of information for those dealing with the problem situation. Although participants already understood that the problem was multi-dimensional, there was a great deal of enthusiasm at an approach that could make connections between the most important elements and actors in a coherent way.

Further systems-based analysis in the first workshop (primarily influenced by SSM) provided a framework on which to base a simulation model. Facilitated discussion and working sessions led to the identification of subsystems in the Cooum system described in terms of primary actors and elements, transformations occurring in each subsystem, inputs and outputs, the system environments and control. For example, in an attempt to understand the current state and dynamics of the Cooum system, participants discussed and conceptualized subsystems focussing on slums, the physical hydrology of the river, the population-at-large, the sewerage system, the storm water drainage system, the provision of sewerage and water supply, tidal action, animal husbandry, politics, and government agency intervention and control.[3] From such analysis, and through discussion in which these conceptions were contrasted and compared to the real-world problem situation, a deeper understanding of the problem situation arose.

Out of the understanding of the Cooum system represented by the 'Rich Picture' and

[3]An explicit "economic" subsystem was not identified by workshop participants. This is in part due to participants' understanding that about 90% of pollution in the river is due to domestic sewage production. On the other hand, economic activity was expressly incorporated into the system conceptualization in discussion of non-residential (commercial and industrial) encroachments into the river, construction activity in response to economic growth and the associated disposal of debris in the river, the attraction of rural migrants to employment opportunities in the city and the formation of slums, *etc.*.

further investigation of subsystems, a general consensus arose as to the core structure of the system. Primary elements and processes such as the population of Chennai, their activities in transforming water, food, and other goods into waste, the routing of sewage *via* the sewerage system, the monsoon and the routing of storm water *via* the storm water drainage system (and interconnections between these), the treatment of sewage at the Koyembedu STP, and the disposal of waste and stormwater into, and its transport by, the Cooum River (see Figure 4.1), were brought into the foreground to provide a structure around which to build the Cooum DSS. A multitude of interrelated elements and processes was identified as impacting on, and being interrelated with, this basic structure. Importantly, the system structure demonstrated that the overall condition of the system was seen by participants to be indicated by the quality of water in the Cooum River.

①	A *holistic* understanding of the Cooum situation should be pursued further through the application of an ecosystem approach (such as employed in this work). Such an approach will continue to stimulate insight into the nature of the problem situation and provide direction and context for more systematic investigation such as that typically undertaken in the past by government agencies and consultancies. ⚖ ⚔
②	Management programs must target more than physical aspects of the situation. The nature of the Cooum system has been characterized, for example, as an urban system, and not merely as a natural or physical system.
③	The lower Cooum system is distinct from the upper Cooum system. The two subsystems are characterized by different sets of actors, elements and processes. Management efforts should recognize the different character of these subsystems.
④	Management should target systemic characteristics of the Cooum system which underlie its current organizational state (*e.g.*, public awareness, participation) and not over-depend on remedial interventions (such as dredging of sludge).
⑤	Water quality may be used as general indicator for the condition of the Cooum system. Water quality indicators should be collected on a consistent and ongoing basis, and the information made generally available to researchers and the public. ⌛

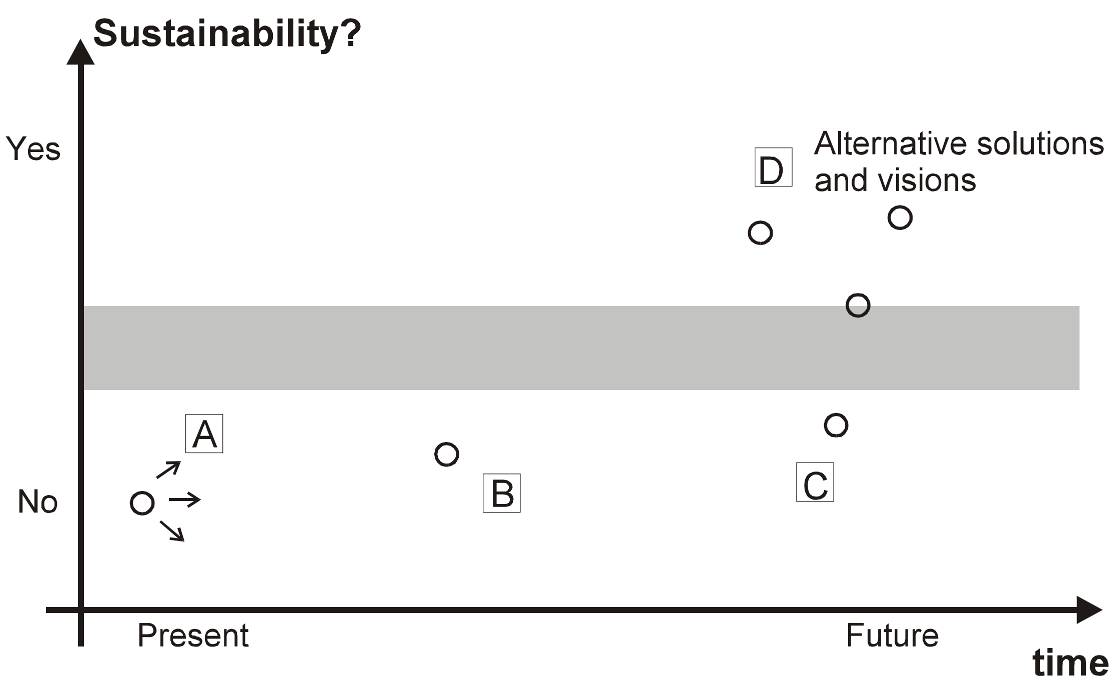
Box 7.1: Defining the system – Recommendations.

The System "As It Is" *versus* the System "As It Could Be"

Efforts to describe the system "as it is" focussed on the present state and dynamics of the system. Such a focus on the present situation, however, may restrict the results of studies to solutions or interventions based on projections of current trends in the system into the future. For example, a common criticism of forecasting techniques, which are grounded in an understanding of a system "as it is," is that perceptions of future states of the system which are possible and reasonable are constrained by the known current state and dynamics of the system (Dreborg, 1996:816). This can lead to the identification of the most probable evolutions of the system, when what we really need to identify are desirable and feasible future states (Robinson 1990: 823). Thus, such an approach may preclude planning for significant change in the structure and processes of the system itself, and has led to the use of techniques such as Backcasting (Robinson, 1990; Dreborg, 1996) and Future Search Visioning (FSV) (Weisbord, 1992; Weisbord and Janoff, 2000) to develop creative solutions not constrained by the preconditions of causal models. Such methods make desired future states of the system a primary focus. The work undertaken in this research has had more in common with approaches such as Backcasting and FSV than with anticipatory techniques such as forecasting (although there are important differences). This is demonstrated by aspects of the research which promote the development of visions of future states of the system which are discontinuous evolutions from the current state, and in the rejection of pure causality and a recognition of the role of teleology in determining the organization of current and future states of the system.

On a theoretical level, the ecosystem approach which guided this work is heavily dependent on systems theory and approaches, as well as on collaborative processes. From the systems perspective, there is an explicit recognition that the evolution of systems is often discontinuous. Non-linear and catastrophic change are common properties of complex systems. (Holling's four box cycle represented in Figure 2.2 is an example, as are 'flips' between multiple attractor states around which a system may self-organize (Kay, *et al*, 1999)). In workshops undertaken for this work, care was taken not only to understand and analyse the current state of the system, but also to allow participants to envision future states of the system that were not necessarily causally linked to the current organizational domain of the system.

Thus, this work has striven to encourage the development of visions of desirable future states of the system which are not necessarily causally linked to the current system via projections of present-day trends and system configurations. To do this, from the very first working session of the first workshop, elements of 'future visioning' were incorporated into the exercises. To demonstrate: when asked to envision the 'problem solved', workshop participants responded with statements describing the river and surrounding area as "A place for fun, frolic and recreation. [It will] make Chennai one of the graceful, beautiful cities in India" and "The Cooum will become a fresh water, healthy river pleasant for boating, swimming, bathing, *etc.*." Such statements represent images of the future which describe a system operating in a different organizational domain than at present. They certainly have no direct causal root in the current (stagnant, odorous, repugnant) state of the Cooum. Further sessions in the first workshop explored objectives representing aspects of visions of desirable future states (*e.g.*, beautification and ecological enhancement, maintenance of a navigable waterway), loosely tying these to indicators (*e.g.*, number of trees planted, flow and depth of



A - Directional Studies; B - Short-term studies; C - Forecasting studies; D - Backcasting studies

Figure 7.1: A comparison of various approaches to solutions on long-term complex issues in terms of the sustainability of the solutions generated. The grey area represents difference of opinion on sustainability criteria. (Steen and Åckerman, 1994, as presented in translation in Dreborg, 1996:815).

water in the waterway), and to management interventions which might encourage the system to evolve in a desired direction (such as greening and landscaping, regulation of flow, *etc.*). This process was taken up also in the second workshop which employed, in a limited way, simulation tools to explore aspects of the system dynamics of such desired future states. Thus, images of desirable future states, and future dynamics, were expressed initially as 'problem solved' statements. They were later manifest in the expression of objectives for rehabilitation and management of the system, in interventions in the system which might encourage the realization of such desirable system states, in informal narratives which arose out of group discussion and debate throughout the workshops, and in aspects of potential future states represented as simulation scenarios in the Cooum DSS.

Steen and Åckerman (1994, as related by Dreborg, 1996: 814-6) illustrate that the use of images or scenarios of desirable future states promotes solutions to long-term complex issues which are more likely to be sustainable than other methods. For example, directional studies which pursue measures to promote behaviour more in tune with nature ('A' in Figure 7.1), and short-term studies ('B' in Figure 7.1) aimed at finding the means to achieve short-term official goals, only target short- and medium-term objectives. They may move society in the "right" direction, but do not satisfy long-term sustainability criteria. Forecasting studies ('C' in Figure 7.1) typically generate solutions which do not result in a sustainable society because they are based on unsustainable presuppositions. Long-term studies which employ images of future states, on the other hand, can result in solutions which represent a sustainable society because they permit such envisioned states to incorporate "more than marginal changes at many levels" (Dreborg, 1996:815). The current study belongs in this last category ('D' in Figure 7.1). According to this argument, this research should have produced visions which, were they to be pursued, would likely result in a system characterized as sustainable. The author believes that, in general, this has occurred.

For example, in Chapter 2, it was noted that a substantive principle of sustainability is meeting the needs of society in the long run (Gardener, 1989:390). By this standard, the current state of the Cooum system is unsustainable. This is demonstrated by the fact that the river's capacity as a sink for waste was long ago surpassed and its condition is understood to negatively affect the health of the population and economic activity in Chennai. Engineering interventions in the system such as dredging, lining, flushing the river, constructing weirs, and constructing intercepting sewers may alleviate these effects. Some of these have been discussed as possible interventions by participants in this workshop and, indeed, some of them have been tried in the past. However, they have resulted in only incremental and temporary improvements.

This work has presented stakeholders, on the other hand, with an opportunity to express images of desired futures in which the character of the system is fundamentally different from its current state. Contrast, for example, the character of a “waste disposal system” to one expressed by workshop participants that is characterised by the role of the river and surrounding area in promoting and supporting tourism, recreation, health and happiness of the population and in presenting a positive image of the city. This vision has stimulated discussion of ‘solutions’ which are also fundamentally different. As mentioned above, traditional engineered solutions to address sludge accumulation, waste treatment, sewage collection, *etc*. were discussed by participants, but these interventions, aimed at dealing with pollution of the river, were seen as insufficient on their own to ‘solve the problem.’ Additional, complementary but qualitatively different, kinds of alternatives were thought to be necessary. Such alternatives as educational campaigns aimed at modifying attitudes and behaviour toward the environment, and the participation of the population in management programs, would be targeted at changing the nature of the system rather than at remedial pollution control.

Similar to the investigation of subsystems of the Cooum system, images of desirable future states arose as ‘types’ (in the sense described by Allen, Bandurski and King, 1994:6). That is, in workshop debate and discussion, desirable future states of the system tended to be defined by a single theme or perspective. These included visions of the future physical hydrology of the system which described free flow and navigable depth of water within the city limits, radically different attitudes of the population toward the environment stimulating environment-friendly behaviour, tourism and recreation generating economic activity based on the river and riverside parks as a sustainable tourism resource, slum habitation which

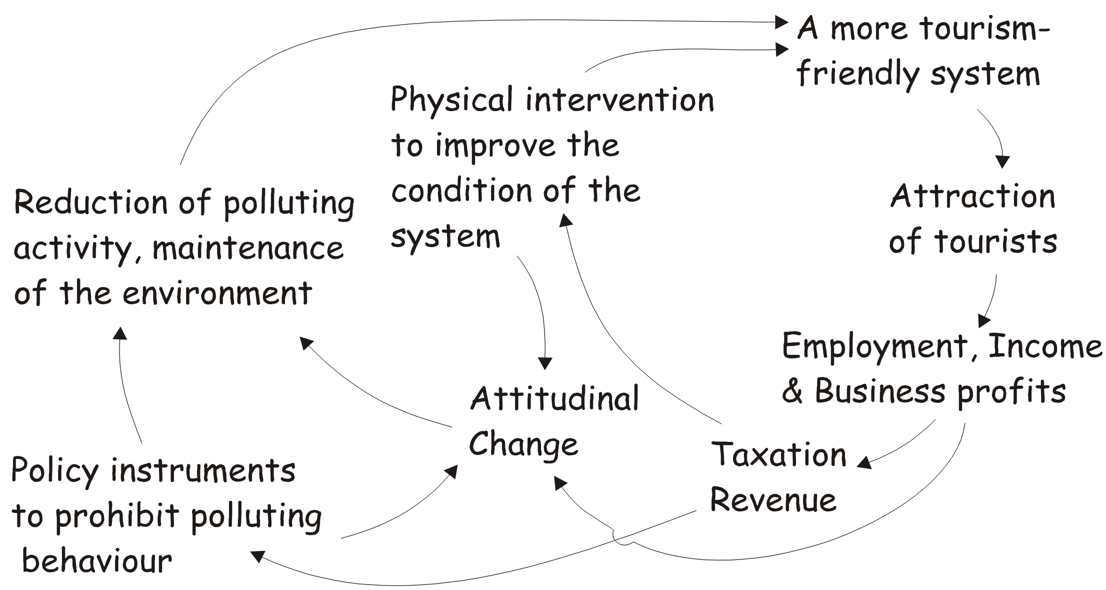


Figure 7.2: A diagrammatic representation of dynamics (activities/ processes) of a potential attractor state of the Cooum System. This diagram was developed by the author on the basis of workshop participant discussion in the second workshop.

provided serviced and hygienic communities for low income groups, and sewerage collection and treatment for all citizens. Description of such aspects of possible future states arose in discussion from exercises and paper presentations that stimulated future visioning. Such discussions produced informal narratives, or descriptions, of the state and dynamics of such futures. Because of the focus on investigating the present situation explicitly as a system, such narratives tended to model systems as well.

An example of such a narrative is one that might be labelled a 'tourism system.' Discussion by participants, primarily in the second workshop, produced a narrative which described an attractor state or domain of organization for the Cooum system in which tourism is a primary activity. In this context, participants discussed the possibility of intervening to make the system more amenable to the tourism industry (by way of interventions such as increase of treatment plant capacity, slum improvement, landscaping, *etc*.). If this could be done, they believed that more tourists would visit Chennai, and the tourism industry would begin to flourish. This would lead to more improvement in the system, which would stimulate increased tourist activity, which would promote maintenance and improvement of a system amenable to tourism in a type of positive feedback referred to as a morphogenic causal loop (Kay *et al.,* 1999:736). In this example, increased revenue to the government from the tourism industry would be reinvested into the system to continue to promote tourism. As well, it was thought that employment and income to entrepreneurs and individuals from the tourism trade would stimulate behaviours which would maintain and improve a tourism-friendly system. This potential domain of attraction for the system is summarized in Figure 7.2.

① Solutions should be avoided which depend on current system dynamics and trends. The system will likely change over time, and may reorganize in a different domain of behaviour. Furthermore, the current domain of organization of the system is not sustainable – solutions which depend on it are also likely to be unsustainable.

② Management should be future-oriented. Aspects of visioning should be employed in exploring desirable future system states for which to develop management goals and objectives. This will likely lead to qualitatively different, more sustainable, interventions than have been attempted in the past for the Cooum situation.

③ Educational campaigns and other interventions aimed at changing the behaviour of Chennai residents, and public participation in management programs should be pursued as specific interventions in the system.

Box 7.2: The System "As It Is" *versus* the System "As It Could Be" – Recommendations.

Engineering *versus* Evolution

In addition to generating a system description of the problem situation, and developing an understanding and expression of values and preferences of stakeholders with regard to the future of the system, this work also addressed aspects of the question, "How do we get there?" Informal narratives of envisioned futures were generated, objectives, indicators and interventions were explored, and scenarios in the Cooum DSS representing aspects of possible future states were developed. However, the reader will have noted there has been no comprehensive construction of state descriptions of preferred futures, nor development of plans for their realization. This represents a major difference from Backcasting studies which produce "alternative images of the future, thoroughly analysed as to their feasibility and consequences" (Dreborg, 1996:826), a course which is charted backward to the present. It is also different from FSV conferences which tend to produce expressions of "the future of the system...designed using ideal characteristics that reflect participant values" and which act as explicit targets for the development of action plans (Baberoglu and Garr, 1992:78-79). While this study has investigated interventions in the system which might promote the achievement of desired futures as expressed by participants, this only has been in the nature of an exploration of the character and feasibility of some of the future images. No roadmap to the future has been put forward.

This is a deliberate aspect of this research which can be traced to the theoretical roots of SSM and complex adaptive systems. From SSM has comes an understanding that complex and ill-structured problematic situations are not amenable to engineered solutions, in part because such 'soft' problems "cannot be defined as a search for an efficient means of achieving a defined end" (Checkland, 1981:316). The ends, goals and purposes may themselves be problematic. The soft systems literature (*e.g.,* Checkland, 1981; Checkland and Scholes, 1990a) concludes that this is typical of problematic situations (such as the Cooum-centred one) that involve human activity.

Because of this, the development of plans to achieve future visions as explicit targets has been avoided in this work. Instead, this research has been oriented toward learning about the system, rather than toward design or optimization. The implication of attempting to comprehensively plan an envisioned future system state and to chart a path to its realization,

> ...is that there are systems to be engineered and the way to do this is by defining system objectives. But the context...is explicitly one of soft ill-structured problem situations in which the planning process is more important than any plan and in which 'problems do not stay solved' (Checkland, 1981:256).

In the context of 'Participatory' or 'Complex planning' processes which generate visions of the future to be used as blueprints, Checkland (1981:256) argued that the needs of such a situation cannot be met by designing "an idealized future for the system being planned for." This view provides further insight into the failure of past attempts to engineer solutions in the Cooum situation. The plan implemented in the late 1960s and early 1970s (Appasamy, 1989:12-14), for example, which involved an engineered system of lined banks, flow regulation, clearance of the mouth of the river, dredging of sludge, and construction of recreational amenities, failed badly. The problem was more complex, and had too much to do with human activity (being grounded in norms, values, and intentions), to allow such a solution to be anything more than short lived. The system was one which could not be adequately defined functionally (*i.e.*, the situation was ill-structured) and the solution seems to have depended on an attempt to understand and control causal linkages, while not allowing room for the role of human activity in determining the nature and operation of the system.

Thus, in these kinds of turbulent situations, there are not systems to be engineered. Rather, there are only real world problematic situations in which to intervene. We use systems thinking to help analyse and understand the situation, build models (conceptualize 'systems'), and compare them with each other and to the real world situation to stimulate insight into the situation and to provoke debate about desirable and feasible change. This informs action in a problematic situation, which then creates new experience of the real world, producing new experience-based knowledge, which further informs action in the situation. (This experience-action learning cycle is depicted in Figure 2.4). The methodology is about the continual process of learning and adaptation. Mitchell (1997:78) drew a similar lesson for management of turbulent environments when he noted that such situations are not amenable to the use of a master plan or 'blueprint' of a future state, and that the *process* is as important as the product in managing such situations.

An approach that is potentially more useful and, in the long term, more effective than attempts to engineer envisioned future states is one that employs images of future states to describe alternative domains of organization of the system. In this context, propensities of the system that maintain its organization in the current domain may be identified and discouraged, while propensities that would encourage its evolution toward an attractor state which characterizes a desired future might be promoted. This approach depends on an understanding of the system as a self-organizing entity (Kay *et al.* 1999:722-3). According to Kay, Regier, Boyle and Francis (1999: 728-729), a central component of such an approach is the development of descriptions ('narratives') of the system that focus on a "qualitative/quantitative understanding" of the system which describes:

- the human context for the narrative;
- the hierarchical nature of the system;
- the attractors which may be accessible to the system;
- how the system behaves in the neighbourhood of each attractor, potentially in terms of a quantitative simulation model;
- the positive and negative feedbacks and autocatalytic loops and associated gradients which organize the system about an attractor;
- what might enable and disable these loops and hence promote or discourage the system from being in the neighbourhood of an attractor; and
- what might be likely to precipitate flips between attractors.

Although this 'systems' language was not employed in the workshops, the similarities of these guidelines with the activities undertaken in this work are obvious.

An example of some of the results of this work, seen from the point of view of self-organization around particular domains or attractor states, is evident in workshop participants' analysis of the current character of the system. For example, some of the current socio-ecological system characteristics which could be considered to be such 'propensities' may be identified as:

- governance and management characterized by disjointed jurisdictional environments,
- mechanistic management cultures in agencies and institutions,
- overriding predominance of reductionist scientific and engineering approaches to problem solving,
- widespread ignorance and disregard of environmental consequences of personal actions, and
- corruption.

Similarly, participants discussed the organization of the system in ways that often highlighted causal loops. An example is provided by a summary of participant discussions on the cumulative effect of individual behaviour and the polluted state of the system. Participants in the workshops noted that, in their experience, the observation by the typical resident of the extreme pollution in the Cooum system resulted in a belief that individual behaviour is insignificant compared to the scale of the problem and that, therefore, there is no point in going to extra effort or cost to avoid contributing to this pollution. Thus, polluting behaviour is accepted. Widespread polluting activity in the system results. The continuation of the problem at such a scale, and the acceptance of such polluting behaviour, reinforces the belief that individual efforts will not make a difference.

This kind of thinking about feedback loops by workshop participants is what led to the identification of interventions such as educational campaigns, and public participation in programs for rehabilitation and management. Such interventions would weaken some of the 'propensities' in the system which lead it to organize in its current domain, and strengthen others so that this 'human activity system' may be encouraged to organize around a different attractor state (such as that characterized by the 'tourism system,' discussed above).[4] The evolution or reorganization of such a behavioural sub-system will alter inputs to the physical subsystem such that it may also "flip" between attractor states. A desired "flip" would see reorganization from the current domain, characterized by high levels of organic pollutants, absence of dissolved oxygen, the presence of anaerobic bacteria and the emission of noxious gases, to one in which inputs to the river are much less polluted, dissolved oxygen is present and so decomposition of organic matter is done *via* aerobic processes, and the system can even support the presence of fish. It is a small step to make the connection of a positive feedback loop between the physical system and an envisioned system state such as that described by the 'tourism system.'

This discussion promotes a conclusion that it is the *propensities* for systems to self organize around particular attractor states that should be targeted by interventions in the system. This is likely to lead to qualitatively different kinds of intervention in the system. This understanding, although not explicitly expressed by participants in 'systems jargon,' is

[4]The environmental NGO 'Citizens' Waterways Monitoring Programme' (WAMP) provides a small-scale example of how such a behavioural propensity for the system to organize as a waste production system can be targeted so as to change the nature of the system. WAMP tells the story of a group of slum youths from Navalar Nagar (a slum clearance board tenement along the waterway) whom they involved in a survey of pollution of Chennai waterways. The youths participated in water quality sampling and surveying of polluting outfalls into the waterways (identifying 720 of them throughout the city) (WAMP, 1999a). After this program was complete, the youths, who had gained knowledge and experience in the issue, took the initiative to organize a campaign of waterfront development in their own slum area. They cleared and relocated huts located on the waterfront, organized a cleaning campaign to clear solid waste from the area, and introduced a door-to-door solid waste collection system. "What was once a typical urban river bank, 'adorned' with solid wastes and filth, was turned into a beautiful recreational park, with trees and flowering plants" (WAMP, 1999b).

reflected in the recommendations of the second workshop. While typical engineering interventions such as "regulation of flow," "maintenance of depth" and "construction and maintenance of intercepting sewers" had been considered, and were seen as potentially useful, they were not put forward by workshop participants. These are typical interventions which have been proposed and tried in the past, and which have been seen to fail to improve the situation. Instead, the two workshop recommendations recognized that (1) management of the system as a whole needs to be addressed by "an overarching agency" to coordinate, monitor and control efforts of agencies to intervene in the evolution of the Cooum system, and (2) such a process is ongoing and should involve stakeholders, and this can be done in part through the involvement of a working group consisting of representatives from pertinent government agencies, academia, NGOs and interested parties, which will undertake to research and monitor the system in support of efforts for its rehabilitation and management. These recommendations are targeted at underlying issues identified by workshop participants, (see the bullet list above), that could be described as propensities in the situation that help to explain the current organization of the system.

①	Stakeholders must be meaningfully involved in the management process. That is, they should be involved at all stages of the process (including problem definition, and determination of goals and objectives for management), and they should have some measure of control of the process. ⚖ ⚔
②	An understanding of the self-organizing character of the Cooum system should be pursued. Interventions should target propensities of the system – undermining those which reinforce the current (undesirable) state, and promoting those which would stimulate the system to reorganize around a different (desirable) attractor. ⚔

Box 7.3: Engineering *versus* evolution – Recommendations.

The Influence of Adaptive Management

Adaptation and Learning

This work has drawn on Adaptive Environmental Assessment and Management (AEAM) to contribute both theory and methods to apply an ecosystem approach. One of the main aspects of AEAM is the idea of adaptation. Adaptation in the context of adaptive management involves active and intentional learning in the (human) management of systems as a mechanism to deal with uncertainty and change. Basically, in adaptive management programs, interventions in natural systems are designed as experiments. Knowledge is generated by managing the system with the explicit understanding that we have incomplete understanding of the systems in which we intervene. Interventions in the system, if properly designed and monitored, may increase our understanding of the system. This improves future management efforts. It is an explicit system of learning which is an analogue to the action-experience cycle promoted in the SSM literature (see Chapter 2).

It was outside the scope of this work to make physical interventions in the Cooum system. However, on a different level, learning was demonstrated in the program of research itself. Consider that initial conceptions of workshop participants regarding the Cooum system were primarily physically-based. This is reflected in past and recent efforts to address the problem of pollution in the river. These have been targeted at physical characteristics of the river, such as dredging, lining of the banks, clearing blockages and constrictions to flow, *etc.*. (This is not to say that an understanding of the multi-dimensional and human aspects of the system was entirely absent, but the history of intervention in the system indicates that it has been approached as a purely physical system).

Explorations of the problem situation during the first workshop, on the other hand, led to the expression of a system in which a wide variety of *human actors* and their *activities* was integral. It also led to the identification of emergent properties, (*e.g.*, the role of the river as a waste sink and carrier for Chennai residents) that reflected the role of human beings in the system. However, while objectives expressing desired future states of the system began to incorporate some human aspects, interventions in the system proposed at the first workshop still reflected a physical bias. For example, interventions such as the increase of STP capacity, slum clearance, removal of the sand bar blockage and landscaping were typical of those proposed. Further exploration of the Cooum system in the second workshop resulted in human activity being more explicitly discussed as an underlying causal factor in the condition of the system. In addition to physical interventions in the system, workshop participants began to propose interventions, such as educational campaigns, which were targeted toward modifying behaviour and values of Chennai residents. This iteration of exploration and analysis of the system demonstrates a learning cycle.

In this case, actual experience of intervening in the system is not present, but cognitive experience, of conceptualizing and analysing the system, makes a contribution to further understanding the situation. Another example is provided by workshop participants' experience in using the prototype Cooum River Environmental Management Decision Support System. Efforts to develop scenarios using the Cooum DSS led participants to a deeper appreciation of the situation with regard to uncertainty in the system, as represented by the scarcity, poor quality and lack of access to information on model parameters. This stimulated participants to form a working group which was largely oriented to reducing this uncertainty. Also, the experience of using the Cooum DSS provided a laboratory in which various changes in the system could be explored. The surprise of the results of the 'Slum Improvement' scenario, for example, may lead to consideration of different ways of implementing and scheduling slum improvement. This demonstrates a learning cycle in which cognitive and simulated experience replace knowledge generated by intervention in the real world.

①	The management process should be explicitly iterative and ongoing, such that it actively operates a learning cycle.⚖

Box 7.4: Adaptation and learning – Recommendations.

Workshops and Participation of Stakeholders

A characteristic method of adaptive management employed here is the use of workshops to bring together managers, scientists and others to make use of existing knowledge, information and expertise, and to design interventions in the system in such a way as to generate knowledge and promote learning (Holling, 1978:8). The workshop process in adaptive management has contributed to this work by providing a general guide for workshop size, participant mix, activities and objectives. This research incorporated two workshops modified from the AEAM model. The first of these, in March of 1998, was constructed to parallel the description of an initial adaptive management workshop given by

ESSA (1982:2).[5] That is, it "considered all elements of the project": problem definition, scoping and focussing, system description, discussion of goals and objectives (both for the program of research and for management of the system), discussion of data and information needs, identification of possible management actions, and the development of a framework for a simulation model. The second workshop, also in the AEAM tradition, continued the analysis of the system and had participants undertake exploratory scenario analysis using the prototype Cooum DSS. Both workshops worked well with respect to accomplishing these activities.

There were, however, modifications to the workshops that set them apart from the standard adaptive management model. The most obvious was the general structure of the workshops. The workshops in this research were a combination of a formal seminar style typical of "workshops" in India, and a more Western style workshop that consists of working sessions, each with an explicit intended product. Initially, the mix of paper presentations and working sessions was intended to allow for the accomplishment of tasks such as problem definition, scoping, *etc*., while at the same time providing a workshop that was not too alien from the expected norm. The paper presentations were also intended to support the working sessions by providing information and ideas as "fuel for the fire" of the working sessions. The experience of the workshops has demonstrated that they served this purpose. The paper presentations also served another related role – reserved time at end of the paper for full group discussion. This was often used by participants to further pursue the paper topic in the context of the Cooum system. For example, Mr. Gonzoga's paper on slums in the second workshop provided the opportunity for workshop participants to discuss (and incorporate into their conceptual model of the system) the role of the urban economy in drawing rural migrants (new slum dwellers) to the city, and also to discuss the benefits of *in situ* improvements of slums along the banks of the Cooum River, as opposed to the conventional interventions (clearance) in that situation. This discussion led to modification of the 'Rich Picture' of the Cooum system, and to the later development of the 'Slum Improvement'

[5]These workshops also strongly resemble the current approach to workshops of ESSA Technologies Ltd., a major AEAM practitioner (Meisner, 1999).

scenario for exploration of the system using the Cooum DSS.

The participant mix of these workshops was also somewhat different from the traditional AEAM workshop. Adaptive Management is often expert driven, due to the focus on scientific experimentation in the management program, and also the emphasis on (simulation) model building. This research program avoided this pitfall. Not only were planners and scientists (representing a variety of agencies and institutions) involved in the workshops, but NGOs such as the Citizens' Waterways Monitoring Program, Exnora International, the Sustainable Chennai Support Programme and INTACH also participated, as did several interested citizens and consultants. The result was the development of an understanding of the problem situation and a conceptual model of the system which represented a communal understanding of stakeholders (not just experts), and ownership of the product and process of the program of research by a more inclusive set of stakeholders than would typically be the case in Chennai. Participation of such a group from the start of the research program should help to foster ownership of the process, and aid in public cooperation and participation in any management efforts which might, in the future, derive from it.

Additionally, the representation of government agencies at the workshops was unique. It was noted at several points in the first workshop, for example, that this program of research was the first time that all of the pertinent government agencies (often seen to be working at cross purposes) were represented at the same table to discuss the problem of the Cooum River and environs. In the best case scenario, this would promote cooperation and coordination in a fragmented institutional environment.

Not all stakeholders were represented, however. For example, one significant group, slum dwellers who make their homes along the banks of the Cooum River, were not present. This group has particularly high exposure to the Cooum, their homes being located next to the river. They are continuously subject to noxious odours, mosquito menace, sewage quality water, and all the ill health effects that these imply. Also, they are often seen as a principal part of the problem. Slum dwellers would be most immediately affected by any management intervention in the system, and indeed, may be the target of such actions. Because of this, slum dwellers were a common topic of discussion during the workshops. While some participants in the workshops often spoke in the place of slum dwellers (*e.g.,* the Slum Clearance Board and NGO representatives), none of this group were actually present to contribute their unique experience and knowledge of the situation. This was not an oversight. Rather, the cultural milieu (particularly caste and class, rank and station issues) in Chennai would not have permitted their participation. Further work in this program of research needs to target this group to incorporate their perspectives and to stimulate their participation in, and ownership of, rehabilitation and management efforts of the Cooum system.

A final comment on participation and this program of research relates to the formation of a working group by participants. This outcome has been the best indication that this research, as far as it has gone, has been successful. Workshop participants felt strongly enough about the problem situation, the usefulness of the workshop forum, what they referred to as the "stakeholder process" and the products of the workshop represented by both the conceptual model of the Cooum system and the Cooum DSS, to take ownership of the process and carry it forward. There have been several meetings, shortly after the second workshop, of researchers in this group who are interested in pursuing development of the GIS database and DESERT water quality model. There has also been some sharing of data and networking among academics, facilitated by members of the working group. Early in 2000 a proposal for the development of a Web site for dissemination of data and information regarding the Cooum has come forward from some of the participants, and an email group for issues associated with Chennai waterways has been created.[6] It is possible that this group will evolve into a legitimate voice and source of information and expertise on the situation in the sense of an epistemic community as described by Haas (1990: 40-43). For this to happen, continued participation and sponsorship of individuals from various government agencies (in addition to NGOs, academic institutions and other stakeholders), is critical.

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[6]Continuation of initial activities of this group seem to have been hampered by difficulty securing resources such as space for meetings and computer facilities. Later activities (starting in early 2000) have been organized by one of the participating NGOs (WAMP) which has reemerged after two years of inactivity to run several public meetings related to the Cooum problem situation (*e.g.*, a public consultation entitled "Status Report on the Waterways and Possible Solutions," 5 March 2000 and the "Clean Cooum" press conference, 31 March 2000).

①	A forum should be provided for government agencies, which is outside of the current institutional context, to facilitate communication and sharing of data. (The AEAM-derived workshop model used in this research is an appropriate and effective way of providing such a forum). ⌛

②	The 'Stakeholder Process' initiated in this research program should be continued, and the development of an epistemic community around the issues of the Cooum River and waterways in Chennai should be pursued. ⌛

③	Further work (research and management efforts) should include stakeholders which have so far not been involved in the process (*e.g.*, slum dwellers).

Box 7.5: Workshops and participation of stakeholders – Recommendations.

Simulation Modelling and the Cooum System

Another technique borrowed from AEAM to help operate the ecosystem approach is simulation modelling. This technique uses computer tools to represent mathematically main components and processes of the system, and provides a 'simplified laboratory world' in which the system's behaviour may be explored and management actions tested, without the problem of irreproducibility that characterizes real-world environmental problem situations. Such a model may be put to many uses; it may, for example, provide a predictive tool, or be employed to generate results which represent testable hypotheses about management interventions. However, in this research, the development of a simulation tool and decision support system has served most usefully through the *process* of its development. In this sense, it served to operationalize the conceptual model of the Cooum system – along the way stripping bare for examination a wide variety of assumptions and demonstrating gaps in our knowledge. Boyce (1997:229), in discussing adaptive management and the use of simulation (population viability analysis), captures the essence of this thought when he stated that,

> ...to my mind, the greatest value in [simulation] is not the numbers generated by the models but in the identification of a model that formalizes our current understanding of the ecology of a particular population or species.

This statement holds true whether that system is oriented toward grizzly bear populations or water quality in an urban setting. Thus, the model of Cooum system represents the current understanding of the system as expressed by participants in the research (or at least those aspects of it amenable to symbolic, logical or mathematical representation).

Assumptions exposed in formalizing participants' conceptualization of the Cooum system are such things as the expectation that slum improvement means (immediate) provision of latrines and sewerage services to all slum dwellers, all slum dwellers currently live in un-serviced areas, the generation of sewerage within income groups does not vary spatially across the city, and population is distributed more or less evenly within wards of the city. These and other assumptions built into the formal understanding of the system represented by the Cooum River Environmental Management Decision Support System were outlined in Chapter 4.

A particularly important assumption, however, appears in the framework of the model itself (Figure 4.1). It has been argued in this chapter that a complex and adaptive system might organize itself at several different attractor states. The formal expression of the structure of the system, however, does not allow for significant change or reorganization in certain basic components and processes. Thus, there is an assumption about the structure of the Cooum system that, regardless to which state of organization the system evolves, there will be the underlying components of population (that consume water and food and produce sewage), a sewerage system (which transports sewage, treats some or all of it and releases that into the Cooum River), the monsoon (which seasonally changes the character of the system through the input of large quantities of fresh water *via* precipitation), the stormwater drainage system (which routes rainfall to the Cooum River), the Upper Cooum system (which provides input of river water at the city limits), and the Cooum River itself which transports sewage, treated wastewater and storm water from its urban sewage collection area and watershed to the Bay of Bengal.

If this assumption of the basic structure of the system were violated, the Cooum DSS could not represent the Cooum system. The DSS and the simulation model incorporated within it were constructed with this in mind. It is not likely that these basic components will change, and if this were to be so, the nature and character of the problem situation would change with it, necessitating the development of a new understanding of the situation and a new undertaking to identify relevant systems. Having stated this, the Cooum DSS is "wide open” with regard to its ability to represent the Cooum system in various potential organizational configurations. This is because the core structure described in Chapter 4 is only a framework. A wide variety of components, processes, activities, and environmental influences could radically change, and still be incorporated into scenarios in the Cooum DSS. These are represented by the parameters associated with the components described above. For example, if the human activity system represented by the population component were to radically change its mode of behaviour such that all solid waste and water waste were to be disposed of “properly,” this could be represented in the system by way of the ‘efficiency’ of the sewerage system. This parameter describes portions of the city which are un-sewered, incorporates an estimate of individual households not connected to the collection system in sewered areas, and takes into account blockages to the sewerage system due to solid waste. Changed behaviour of the population might also be reflected in the proportion of water consumed that is produced as sewage, and in the levels of consumption of water in various income groups. These are all parameters that can be specified by a user of the Cooum DSS.

Actually specifying such parameters, however, can be a problem. Participants in the second workshop found that the experience of constructing exploratory scenarios in the Cooum DSS highlighted the basic lack of specific information on the Cooum system. This was despite the fact that participants were confident that the model captured the essence of the relationships (activities and processes) among components and actors. For example, in specifying the value of the sewage generation coefficient (the parameter describing the proportion of water consumed that is transformed into sewage), the basic relationship was known. But it was not known precisely what the parameter figures were that expressed the amount of sewage that would be generated by households of a stated income class and having a particular level of water consumption. “Best guess” estimates had to be used.

Such data issues lead to a serious concern regarding the accuracy of DSS and simulation model results. They are also representative of a very common problem in developing areas. Gar-On Yeh (1999:61) and Hall (1999:383-384) both asserted that the poor quality and lack of data, such as base maps and socio-economic information beyond that collected in censuses, are the greatest hindrance to the effective use of GIS and DSS tools in support of sustainable development in developing countries. Where locally collected data do exist in India, it has been found that it can be up to 30% in error (Bhatnagar, *et al.*, 1994, as reported in Hall, 1999:384)! In this research, issues of basic uncertainty and lack of data were highlighted by the need of users to specify a variety of model parameters. This provoked discussion and debate among participants about the need for sharing of information and data among agencies and institutions, and the need for basic research into many aspects of the system not heretofore undertaken. This represented an important outcome of this research, and is highlighted by the fact that the Cooum working group was formed at an impromptu meeting which, significantly, arose out of discussions focussing on the lack of access to, and poor quality of data. An important associated issue identified by participants is the fragmented institutional framework for dealing with environmental problems such as the Cooum situation, and an institutional culture that dissuades, or complicates, the sharing of even non-sensitive data.

In addition to difficulties in specifying parameters for system states that could be represented in the prototype Cooum DSS, some potential states of the system, expressed by workshop participants could not be accommodated by the Cooum DSS. For example, the tourism narrative (above) could be represented in terms of its effect on water quality (*via* changes in population behaviour or reinvested revenue), but the nature of the tourism system is not captured. An economic subsystem model incorporating tourism might be appropriate here, and is a possible improvement that could be developed in the future. Other improvements to the prototype Cooum DSS were suggested by participants who used the tool. These included the ability to represent spatial variation in the characteristics of sewage throughout the city, and the incorporation of the additional indicators in the water quality model in the DESERT component of the prototype system. As identified in Chapter 6, these correspond to 3 general areas for which improvement can be made in future development of the Cooum DSS: (1) continued and ongoing improvement of the conceptual understanding of the system, so that all (and only) principal processes and components are modelled , (2) more detailed research into key relationships of the Cooum system, which can then improve parametization of the model, and (3) continued development of the water quality model.

Actual products from the use of the prototype Cooum River Environmental Management Decision Support System during the second workshop arose from the construction of exploratory scenarios by workshop participants, and their use in simulation. In all, seven coherent scenarios were developed. These included the construction of Baseline scenarios for the system during monsoon and dry seasons, and exploration of the effects on the system of slum improvement, increased capacity and improved treatment at the Koyembedu STP, population growth at the periphery of the city, increase in upstream flow, and the first flush of storm water in the monsoon. This activity was productive in itself, as demonstrated by the discussion above, and the scenarios themselves represent a product of the workshop. However, these exploratory scenarios were not subjected to simulation during the workshop (except for one Baseline scenario which was quickly run before the final session). To complete the process of sensitivity analysis and exploration of the Cooum system using the Cooum DSS, the scenarios were run by the researcher through the water quality and hydraulic simulator after the second workshop. This activity also was found to be very productive.

Despite uncertainty in the system, represented (in some instances) by patchy or "best guess" data for parametization, this sensitivity analysis was able to generate a description of the general behaviour of the system as indicated by basic water quality and hydraulic variables. It also indicated, in terms of direction and general magnitude of change, the effect introduced by changes to the system in simple exploratory scenarios. These analyses produced some interesting and illuminating results. For example:

- The Koyembedu sewage treatment plant had not nearly enough capacity to treat the amount of sewage supposed to be routed to it each day. This model indicated that more than a fourfold increase in its 34 mld capacity would be required to treat all of the sewage routed to the STP in the Baseline scenarios.

- 'Improvement' of all the slums in the system had a deleterious effect on the water quality of the Cooum River. This is attributed to the lack of capacity of the Koyembedu sewage treatment plant to treat the additional sewage routed to it from the newly serviced slums.
- The most significant improvements of water quality occurred when the polluted water of the Cooum was diluted with an increase of relatively unpolluted water from the Upper Cooum system, and by treating a greater proportion of the sewage released into

the river.

- Despite the fact that several of the exploratory scenarios produced simulation results representing significant improvements from the Baseline scenarios, none of them came close to describing a situation in which water quality could be considered acceptable.

There are three modes in which the Cooum DSS has, and could be, used: as a canvas for the expression of desirable future states of the system, as a tool for exploration and learning about the organization and behaviour of the system, and as a predictive tool. The first two modes were undertaken in this research. The first mode, the expression of a desirable future state, has been somewhat restricted in the limited use that workshop participants were able to make of the prototype system during the second workshop. This is because initial use of the Cooum DSS by the participants began as simple, single change, exploratory scenarios in order to explore the prototype DSS itself as well as to investigate the nature of the Cooum system. This precluded the development of scenarios representing broader visions of system states. Still, some of the simple changes in the system (such as improvement of slums, and the upgrade of STP characteristics) in the exploratory scenarios can be viewed as the expression of aspects of envisioned future states of the system.[7] The development of more comprehensive scenarios is a task for future research.

The second potential use of the Cooum DSS is the one most explicitly pursued in this work. That is, the exploration of the nature of the system by way of scenario analysis. This has generated some further insight into the system, as described above and in Chapter 6. However, this has so far been "single shot" exploration. The exploratory scenarios have taken a single intervention or change in the system, represented it with a single set of parameters, and subjected it to simulation to explore the direction and magnitude of change in the system as represented by water quality and hydraulic indicators. Further work might pursue the development of sets of scenarios for each of the changes explored here. For each scenario set, a progression of values for a parameter could be specified. This would serve to

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[7]Some scenarios developed by workshop participants in their exploration of the Cooum DSS actually pursued this line more seriously. These, however, were too complex for initial exploration and sensitivity analysis, and so were not appropriate to present here.

develop an understanding of the domain of organization and behaviour of the system. The development of scenario sets would also help to overcome the problem of poor quality, dated, or incomplete data (typical of the currently available information) for those who might wish to use the Cooum DSS as a predictive tool.

In a similar manner, the Cooum DSS could be used to explore sets of conditions (parameters) required to "flip" the system to an alternative (desirable) state of organization. For example, the DSS might be used to determine configurations in which the entire stretch of the Cooum within the city contained a minimum level of dissolved oxygen, such that noxious odours from anaerobic decomposition of organic matter would be eliminated, and the river could support hardy varieties of fish. This obviously also corresponds to the expression of desired configurations of the system as discussed above.

① Development of a database and simulation model (such as the Cooum DSS) should be pursued as a means to clarify assumptions, indicate gaps in knowledge and inadequacies of data, and express current understanding about the system.

② Simulation models can and should be developed with the explicit recognition that several different states of organization may be possible for the system. If possible, the potential for reorganization of system behaviour should be incorporated into the model.

③ Where data are absent or inadequate for use in a DSS or simulation model, allowance should be made for user specification of parameters. This will facilitate the use of speculative scenarios and allow incorporation of improved data by future users of the system.

④ Basic research into several aspects of the Cooum situation must be undertaken. For example, the relationships among income, water consumption and sewage production need to be explored.

⑤ Government agencies must be more open with regard to sharing of data and information among themselves and with the public.

⑥ The Cooum DSS should be further improved with the incorporation of sub-models to deal with relationships which emerged as important during the second workshop (*e.g.*, an economic sub-model which can characterize tourism in the system).

⑦ The sewage collection and treatment system in Chennai should be upgraded. Results of several of the exploratory scenarios indicated that capacity to treat sewage generated in the system is a problem. If other interventions such as the provision of sewerage to un-serviced areas and slum improvement are to make a difference to water quality, capacity of the STP will have to be dramatically increased, other means of sewage treatment pursued, or the sewage must be routed elsewhere. ⌛

Box 7.6: Simulation modelling and the Cooum system – Recommendations.

GIS in Support of the Modelling Process

An exploration and evaluation of the use of a geographical information system in support of environmental simulation modelling (from AEAM) was one of the goals of this work. GIS, it seemed, was a natural complement to environmental simulation which had, at the time, been incorporated into very few adaptive management projects. Since then, however, the use of GIS in support of simulation modelling, and adaptive management, has greatly increased. A search on the World Wide Web in early 2000, for example, returned over 10 000 hits on web sites having the phrase "Adaptive Management" and over 1 000 hits, within these sites, on the term "Geographic Information System." Other evidence of the growth of GIS in association with adaptive management can be seen in the creation of a GIS department in ESSA Technologies Ltd., a large consulting firm specializing in AEAM applications (Meisner, 1999), and in the development of an online GIS-based information management system (CIMS) associated with the Chesapeake Bay Program (Chesapeake Bay Program, 1999).

The experience of the use of GIS in this research confirms these indications that GIS is a strong complement to simulation modelling and a useful tool in support of adaptive management. The obvious roles of GIS in this context have to do with the manipulation, query and display of data in support of visualization and exploration of various aspects of the problem situation by users of the Cooum DSS, and for analysis and reporting of spatial data to provide spatially specific parameters for input into the environmental model. These roles of GIS in this research were supported by the use of GIS to construct a base map of the study area (one which was both geometrically accurate and spatially referenced), to develop a set of thematic map layers (city wards, sewage collection areas, storm water drainage catchments, sewage routing units, the city boundary, SWD and sewerage zones, waterways, and slum locations), and to relate to the thematic features in these map layers (*e.g.*, slums or wards) their various attributes (such as ward population or indicators of environmental conditions of the slums).

GRASSLAND GIS (as a key module of the prototype Cooum River Environmental Management Decision Support System) was particularly useful as a visualization tool.

Participants in the second workshop found the capacity to access, view and query digital representations of areal units and slums in the study area to be important to the development of exploratory management scenarios. For example, it allowed users to develop a 'feel' for the data, and the situation which that data portray, as well as providing a resource for the retrieval by query of required information in the DSS (such as identifiers of slums to be improved, or of wards in which population changes will be explored). Participants indicated that additional data not directly required to generate parameters for the environmental model (such as zoning and land use, green space and vegetation) would be useful additions to the database.

Use of the GIS was also effective in illuminating data issues. For example, the exploration of data using the GIS module stimulated discussion about the quality and availability of both spatial and attribute data in the Cooum DSS database. Such discussion centred largely on issues (and concerns) regarding the lack of availability and poor quality of data for use in decision support for management of the Cooum situation. Items such as the ancient character of the topographic sheets available to researchers, the extremely poor quality of ward maps (described as "mere sketch maps"), and the lack of studies to update the 1975 and 1986 slum surveys (TNSCB, 1975; MMDA, 1987) were among the those cited. While highlighting such problematic data issues, use of the GIS simultaneously demonstrated to workshop participants the potential utility of GIS technology combined with an accurate database. The fact that the database was spatially referenced, and that a large amount of pertinent data in the form of map layers and attribute data was easily accessible to participants, was particularly telling.

Such demonstrated potential, especially in the face of data accessibility, scarcity and quality problems, generated much interest and enthusiasm among participants using the Cooum DSS. It is also possible that the fact that the research employed "GIS" technology itself contributed to the enthusiasm for the Cooum DSS and for the program of research. Indeed, the use of GIS, a new and popular technology in India, may provide a vehicle for the introduction of programs of research (such as this one) which feature it. The use of GIS, particularly the demonstrated utility of the tool, and participants' enthusiasm over the potential of this technology to aid researchers, and government agencies and others in dealing with the Cooum problem, was a factor in the spontaneous formation of a working group to carry on the development of the GIS database and other tasks. Workshop participants were particularly interested in improving and expanding the spatial database. This was stated as part of the initial focus of the working group.

Another important contribution that GIS made to this work was the provision of tools for development of the prototype Cooum DSS. GRASSLAND GIS was developed in part using Tcl/Tk (a fourth generation macro language), which is distributed with GRASSLAND GIS, and is also available generally as an 'Open Source' development and scripting tool. Tcl/Tk was used to construct the graphical user interface of the Cooum DSS, and to undertake many of the routines that the Cooum DSS performs. The use of 'Open Source' development tools for much of the system development, and of low cost or free system components, led to the creation of an affordable and accessible system. The modular construction of the Cooum DSS, and the use of a macro language for much of its development, also makes it an easily modifiable system for those who wish to make minor modifications or to pursue more extensive system development.

Use was also made of Tcl/Tk as GRASSLAND's macro language to automate some of the procedures of the GIS which more directly supported parametization of the environmental simulation model. While some procedures, such as overlays of map layers (such as that which produced the 'routing units' layer) were undertaken by manual operation of the GIS, others were automated using Tcl. For example, the generation of area figures from the GIS map layers of 'routing units,' city wards, sewage collection areas and storm water drainage catchments were automated with Tcl code. Aside from illustrating the use (and usefulness) of GIS automation capabilities in this work, these examples also demonstrate the role of GIS spatial analysis and reporting functions in generating parameters for simulation modelling in the Cooum DSS.

Finally, the use of GIS entailed the development of a spatial database. This set of data was made available to participants in the program of research and to other interested individuals. The database represented accessible data in an environment in which access to such data is generally restricted. The database was also unique in that it was geometrically correct, having been rectified using Survey of India topographic sheets, and geographically referenced. These are basic characteristics of maps generally absent in the available information in Chennai. The fact that printouts of the maps of wards, sewage collection areas, stormwater drainage catchments and slums were enthusiastically claimed by government agency participants highlights the usefulness of an accurate database on which there are no restrictions on dissemination.

① GIS components of further work should be highlighted. As a popular technology GIS may 'legitimize' the ecosystem approach in the eyes of those who would otherwise be sceptical of other aspects of the approach, such as stakeholder involvement.

② Additional datasets dealing with themes such as zoning, land use, vegetation and green space should be incorporated into the GIS database.

③ Data in the GIS database should be improved as regards accuracy and completeness of datasets, and should be updated to reflect current conditions.

④ Use of 'Open Source' and 'Public Domain' tools for the construction and maintenance of databases and the DSS is recommended. This will help to make the system accessible to researchers, NGOs and other interested parties which may not have funding for more expensive commercial software.

⑤ The GIS database should be accessible to all agencies, researchers, NGOs and other interested parties at no more than the cost of distributing the data to them.

Box 7.7: GIS in support of the modelling process – Recommendations.

SSM and the Cooum River Environmental Management Research Program

Techniques and Procedures Adapted from SSM

Soft Systems Methodology informed this work from its inception. Its fruitful use has given credence to Allan, Bandurski and King's (1994:45) recommendation of SSM as a particularly appropriate methodology "for making operational the ecosystem approach." SSM has contributed a set of techniques to the description of the Cooum situation as a socio-ecological system, as well as informing the approach itself. In this work, techniques borrowed from SSM have to do with (in SSM terminology) the 'unstructured' (non-systems) exploration of the 'problematic situation,' the 'development of conceptual models' and ‘comparison’ of conceptual models with the real world to generate ‘debate about desirable and feasible change.’ Particularly obvious influences can be seen in the use of adaptations of the ‘Rich Picture’ and ‘CATWOE’ techniques.

Working sessions which were based on SSM generally received better response from workshop participants and achieved their objectives more consistently than did working sessions employing more standard techniques. For example, the sessions dedicated to developing a ‘Rich Picture’ of the problem situation, and to conceptualizing the system and subsystems through facilitated discussion based on ‘CATWOE’ analysis, were extremely successful, not only meeting the objectives of the particular tangible outputs of the session, but also generating enthusiasm and fostering collaboration among the workshop participants. Working sessions based more on standard techniques, such as those oriented toward the generation (*via* brainstorming) and ordering (using pair-wise comparison) of objectives for management of the system, on the other hand, were somewhat more difficult, and did not receive the same affirmation from participants.

The development of a ‘Rich Picture’ is a standard SSM technique used to represent the problem situation, without necessarily exploring it as a ‘system.’ In this research, the technique was very effective in representing the constellation of actors, elements, and interrelationships in the situation, without employing systems concepts or analysis for this representation.[8] In the development and use of the ‘Rich Picture’ is was found that;

- it aided the understanding of the cultural climate of the situation because many value judgements about aspects of the problem were drawn out and expressed,[9]
- the diagram was able to convey the ‘feel’ of the situation for workshop participants,
- the ‘Rich Picture’ acted as a focal point or reference for discussion throughout the two workshops,

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[8]The initial development of this diagram followed a problem definition exercise, which may have aided in the construction by supplying a large set of elements and actors already identified. The ‘Rich Picture’ served to organize these and portray relationships among them.

[9]This is portrayed, for example, in depictions of a lack of communication among agencies. This was seen to hinder management and development efforts and promote multiplicity. Another example is the indication in the diagram of animal husbandry which was seen as a nuisance and a polluting factor in the situation.

- the diagram came to represent a common understanding of 'the system' once the working sessions moved into systems analysis of the situation,
- it provided a link between the first and second workshop, and continual modification of the diagram to represent new understanding of the situation, allowed new participants to join in ownership of the earlier work,
- the 'Rich Picture' was a tangible product of the workshops and represented a communal understanding about which participants were universally enthusiastic, and as such, its development helped to promote communication and cooperation among the various stakeholders.

In SSM, after the exploration of a real-world problem situation is undertaken in an 'unstructured' manner using techniques such as Rich Pictures, the methodology then shifts to explicit systems thinking and systems analysis of the situation. A typical way to do this in SSM is to develop root definitions of alternative systems in the situation, and use these to build conceptual models. In this work 'CATWOE' analysis ,a technique for building root definitions in SSM, was modified to provide structure to a facilitated session to explore important 'themes' in the 'Rich Picture.' This provided an effective means of drawing out the primary activities and processes in the situation and modelling them as the core of important subsystems. Drawing out such themes as population, slums, and agency intervention and control helped to reduce the complex situation to a few key components. Analysing them in terms of the 'CATWOE' components (Customer, Actor, Transformation, Weltanschauung, Owner, Environment) also provoked further discussion as to the nature of the system (leading to further modification of the 'Rich Picture'). This triggered discussion about the relationship of such subsystems within the larger system (that is, regarding what makes the subsystem important in the context of the larger system), and in regard to their place in the hierarchy of systems. The 'CATWOE' nemonic was not as useful in addressing physical subsystems of the Cooum system as it was in dealing with the human activity systems for which it was designed. As a result, subsystems such as the physical hydrology of the river and tidal action were described more generically in terms of physical processes.

It became obvious as the description of the socio-ecological system progressed that not only were each of these subsystems situated within the hierarchy of the Cooum system, but each was also part of other hierarchies. For example, in addition to constituting a subsystem of the Cooum system, government agencies each have roles within larger governmental systems. Similarly, the lower Cooum (urban) watershed is part of a larger Cooum system, which is also part of a larger regional system, *etc.*). This is a further demonstration of complexity in the situation.

①	Use of tools and techniques of Soft Systems Methodology are recommended as vehicles to express the perception and understanding of stakeholders regarding the problem situation, and to address uncertainty and complexity in the situation associated with human actors and intentions.
②	Use of the 'Rich Picture' technique is recommended as an effective way to represent a common understanding of the problem situation, to provide a focal point or reference for discussion and debate, and in an ongoing program, to serve as a bridge between workshops.
③	CATWOE analysis is recommended as an effective technique to express key themes (relevant systems) having to do with human activity in the problem situation.
④	Subsystems must be understood in the context of their hierarchical position and relationships within the system of interest, but they should also be explored in relation to their positions in other relevant hierarchies. This will help to organize an understanding of complexity in the situation, and also aid in maintaining flexibility with regard to understanding of the scope of the system and the choice of scale at which to observe it.

Box 7.8: Techniques and procedures adapted from SSM – Recommendations.

The Cultural Stream of Analysis

It was noted above that the two streams of analysis (Ecosystem Understanding and Issues Framework) in the ecosystem approach employed in this work correspond to the two streams of analysis indicated by Checkland and Scholes (1990a:28-30) in SSM – the *logic-based stream of analysis* and the *stream of cultural analysis*. It was also noted that these streams are undertaken simultaneously. It is not coincidence that the ecosystem approach framework employed, and the way it has here been operated, parallels SSM in this matter.

Checkland (1999:A15) noted that the "mature practice" of SSM follows a four stage model[10] which is essentially the logic-based stream of analysis in which the cultural stream has been subsumed. Accordingly, the 'logical' activities undertaken in this work, regarding the identification and analysis of the system, were also placed simultaneously in the social, cultural, political and institutional context of the situation.

For example, in facilitated discussion of processes and activities occurring in the system, processes were discussed by workshop participants partly in terms of how they affect humans (as beneficiaries or victims) in the situation, and with regard to what makes the activity/process meaningful in the problem context (which helps to illuminate the perspective involved). This discussion led to the construction of conceptual models ('types' of subsystems within the Cooum system) using the 'CATWOE' technique. An example is the activity system drawn out of the 'Rich Picture' and labelled "provision of sewerage" by the participants. In this human activity system, the actor (who undertakes the activity) was seen to be the CMWSSB, and the beneficiaries were the citizens of Chennai served by sewerage collection. The system was meaningful in the context of the problem situation because participants believed that it is desirable that sewage be collected and properly treated before release into the environment.

Similarly, the roles of actors in the system and the expected behaviours of such actors (including normative judgements about those behaviours) were continually a topic of discussion in the workshops. Once again, the role of the individual citizen as a polluter provides an example. The expected behaviour of the citizen is to dispose of waste (solid waste and wastewater) in whatever way is most convenient. The current values associated

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[10]The four general activities in this model are (Checkland, 1999:A15):

1. Finding out about a problem situation, including culturally/politically;
2. Formulating some relevant purposeful activity models;
3. Debating the situation, using the models, seeking from that debate both
   (a) changes which would improve the situation and are regarded as both desirable and (culturally) feasible, *and*
   (b) the accommodations between conflicting interests which will enable action-to-improve to be taken;
4. Taking action in the situation to bring about improvement.

((a) and (b) of course are intimately connected and will gradually create each other).

with this were seen as nonchalant or uncaring with regard to the effect on the environment, or on the health of fellow citizens. By the end of the second workshop, this aspect of the population subsystem was given much weight by participants, who saw such an important interrelationship among roles, norms and values that, in their eyes, it helped to explain the overall nature and organization of the Cooum system.

Political aspects of the situation also were discussed throughout. These primarily had to do with issues of power. The 'Owner' in the CATWOE model makes this explicit (*e.g.*, legislators and the CMWSSB institution in the sewerage system above), as does the identification of 'Owners of the Problem Situation' or stakeholders, which in this work began with questions posed in the first working session of Workshop I, and in exploration of the situation *via* the 'Rich Picture.' An example of political aspects of the system identified by workshop participants is the control of access to data. Control of access to data by government agencies, by private firms, and sometimes by academics or their institutions, is an exercise and demonstration of power in the situation.[11] Workshop participants identified lack of access to high quality and complete data as a primary hindrance to development efforts, as a barrier to the effective participation of stakeholders in management efforts, and as an impediment to overall efforts to intervene to improve the problem situation. These three examples which could be considered to fit within the 'Issues Framework' domain of Figure 2.1 correspond, respectively, to the 'Analysis of the Intervention,' 'Social System' Analysis and 'Political System' Analysis, (that is, analyses 'one,' 'two' and 'three') of the cultural stream of inquiry described by Checkland and Scholes (1990a:44-53).

①	Efforts must be made to ensure that the context or 'cultural climate' of the problem situation is explored. Attention to the context of the situation is as important as logical analysis of its more easily reduced aspects.
②	Understanding of human factors in the Cooum situation (such as attitudes toward waste and the environment and the control of access to data) should inform management efforts. This research, for example, identified public awareness campaigns and mechanisms to bridge jurisdictional boundaries as potential interventions for management of the system.

Box 7.9: The cultural stream of analysis – Recommendations.

[11]These have been described as 'Commodities' of power in the SSM literature (*e.g.*, Checkland, 1999:A20),

Soft *versus* Hard Systems Thinking

Also noted above is the influence of SSM in avoiding the explicit design of new desirable systems, and the preference for approaching this research as the operation of a system of learning, which informs action to improve the situation. Figure 7.3 demonstrates the mode in which "soft" systems thinking is appropriate (*i.e.*, in "fuzzy, ill-defined situations involving human beings and cultural considerations") as compared to those for which "hard" systems thinking is sufficient, (that is, in well-defined technical problems) (Checkland, 1999: A10).

Thus, rather than developing visions of the future as blueprints (fixing goals and targets to be attained) which would require a system to be engineered out of the "mess" of the problematic situation, this work uses images of the future as narratives to explore potential domains of self organization of the system. Propensities within such domains or attractor states need to be identified, so that managers might know which ones to encourage. Also of

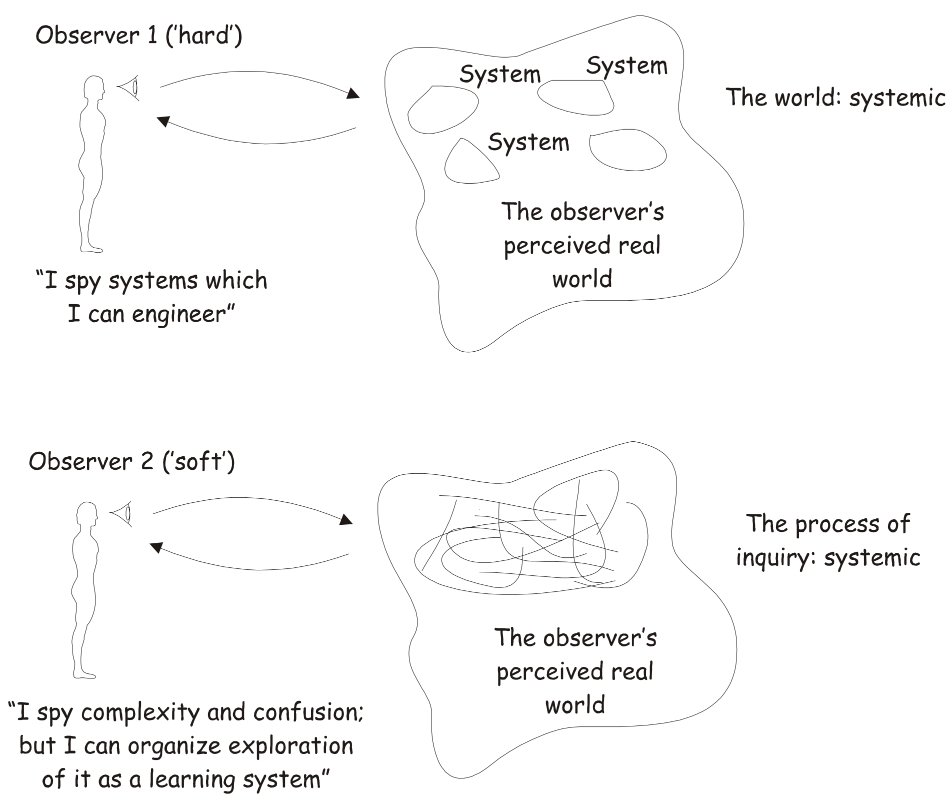

Figure 7.3: The hard and soft systems stances (Checkland, 1999:Figure A2). Observer 1 corresponds to a comprehensive approach.

critical importance was the identification of the propensities for the current attractor so that it would be known which of these to discourage. While development and expression of desirable futures are necessary to disconnect from the present in order to allow non-linear evolutions of the system to be attained, much emphasis has also been placed, in this work, on understanding dynamics of the present state of the system so that managers will be able to create the context for the evolutionary changes required for the system to 'flip' to a more desirable domain of organization.

In this context, a focus on the present is necessary in order to understand which propensities of the system that cause it to organize in its current domain should be undermined. On the other hand, a focus on the future should not produce an overly detailed blueprint. If propensities of the current organizational state are weakened, then it is enough to know which propensities of a potentially desirable alternative state to foster. Once the system re-organizes itself, a new system dynamic will emerge of which, plan or no plan, we are unlikely to have a comprehensive understanding. Such an understanding of the new state and dynamics of the system will be pursued, and the system managed within a new domain of organization. Thus, the influence of SSM, knowledge of the tendency of both natural and human complex systems to self-organize, and the experience of exploring the Cooum situation as a complex socio-ecological system, lead to the conclusion that management of the system should be strategically incremental, rather than comprehensive. This reinforces Trist's (1980) observations that planning in turbulent environments requires an approach which is continuous and adaptive (Mitchell 1997:77-78).

① Management of complex self-organizing systems such as the Cooum system should be incremental. Such a management approach is characterized by a series of successive interventions which allow management of the system to be adaptive, *i.e.*, to respond to changing values, evolving goals, new understanding of the system, and evolution of the system itself.⚖

② Management of the system should be strategic. That is, it should be future-oriented and based on an understanding of the self-organizing behaviour of the system. Propensities of the system to self-organize in a particular domain of behaviour should be reinforced, while propensities which encourage the system organize around undesirable attractors should be undermined.⚖

Box 7.10: Soft *versus* hard systems thinking – Recommendations.

Objectives of this Program of Research

The first chapter presented several research objectives that have given direction to this research. These were the application of an ecosystem approach to the Cooum problem in Chennai, the use of GIS in support of simulation modelling, and the development of a spatial database. This final section will review these in light of the experience of undertaking this work, and will provide some concluding statements regarding the Cooum River Environmental Management Research Program and achievement of these objectives.

The primary research objective of this work was *to apply the ecosystem approach to the problem of rehabilitation and management of the Cooum River in Chennai*. This goal requires a three-part response. First, it begs the question; Was the approach undertaken in this work an 'Ecosystem Approach'? Second, were Adaptive Management and SSM appropriate methodological influences in attempting to operate the approach? Third, was the approach useful or effective with regard to the problem to which it was applied?

The first of these questions is simply answered. It is evident from the discussion above, and in previous chapters, that this work is deeply rooted in systems thinking. Systems theory underlies the approach and systems concepts such as hierarchy, emergence, self-organization and interaction among system elements and actors are used to make sense of the complexity of the real world problem which this research has addressed. Additionally, jurisdictional and administrative boundaries and artificial planning horizons are forgone in favour of the identification of pertinent systems in determining the spatial and temporal scope of the investigation. This work is distinguished from hard systems or systems engineering approaches by its identification and analysis of human aspects of the problem situation (human activity, cultural and political contexts), its emphasis on the use of the approach to generate insight and inform intervention in the situation rather than to design systems, and by the participatory nature of the program. It is also distinguished from systems approaches oriented explicitly to human organizations by its focus on an environmental problem situation and the identification of biological and physical components and processes in addition to human activity. Therefore, it can be stated that this work has employed an ecosystem approach.

Second, the two primary methodologies (Adaptive Management and SSM), and their associated sets of tools and techniques, used to operate the approach in this work, were appropriate and effective. The workshop structure and simulation techniques borrowed from Adaptive Management were employed with success, as were modifications of 'Rich Picture' and conceptual modelling techniques of Soft Systems Methodology. Only a few tools employed in the workshops did not work out as well as expected, but these were more mainstream planning tools (such as pair-wise comparison). More important than tools and techniques, however, were the influence from Adaptive Management, SSM and complex system theories of basic concepts such as adaptation, self organization, and 'soft' or human activity systems. While not discussed with participants explicitly in such terms, these ideas emerged through the workshop process, and were reflected in participants' narratives of desirable alternative system states, and in some of the potential actions for management of the system suggested by participants.

Finally, the experience of operating the ecosystem approach in the Cooum River Environmental Management Research Program indicates that this application has furthered the understanding of the situation and has the potential to beneficially influence efforts at rehabilitation and management of the system. The use of this holistic, systems-based approach, as far as it can be taken in a research application, has led to what seems to be a qualitatively different understanding of the situation than previously existed. The identification of the Lower Cooum (urban) system as the system of interest in the problem situation, the characterization of that system as an urban waste carrier, and the expression of the underlying nature of the system as based on human activity, exemplify this understanding. Appreciation of the human character of the Cooum system also led to the identification of different ways of dealing with the situation than have been tried in the past, that is, management directed at human activity rather than merely at physical intervention in 'natural' or physical components of the system. Additionally, the participatory nature of the research program has ensured that this conception of the system is a shared understanding, creating common ground among stakeholders in the situation.

The spontaneous organization of a working group to carry on the program of research in the same manner is the final indication that the ecosystem approach, including the Adaptive Management and SSM influences in this application, is seen by stakeholders in the situation to be both appropriate and useful.

The second main goal of this research was to *evaluate the usefulness of geographic information systems (GIS) in support of environmental modelling*. The application of GIS in this program of research has also been successful. This is not surprising as this set of tools seems to be a natural complement to simulation modelling described in the AEAM literature. Indeed, GIS is now a common tool associated with Adaptive Management. In this work, GIS proved to be a successful complement to the modelling component of Adaptive Environmental Management particularly with regard to the construction and maintenance of the spatial database, query and visualization of the database, and pre-processing of data for input to the hydraulic and water quality model. The modular coupling of a GIS and Environmental Model within a DSS is also appropriate in this context. The modular structure of the Cooum DSS, and its inclusion of 'Open Source' tools for system development, facilitate independent development of components, and replacement of modules, so that costs of the system are minimized, and system development and modifications may be more easily undertaken locally in Chennai.

The use of a GIS in this work also led to the achievement of the third main goal of this work. That is, to *provide a useful tool in the form of a GIS database and system model to planners, researchers and interested parties in Chennai.* This database in digital form has been left with several of the participants in the Cooum River Environmental Management Research Program. Also, as noted above, hardcopy products based on the GIS database were requested by, and provided to, several of the government agency representatives at the workshops. The database itself represents accessible, accurate, geometrically correct and spatially referenced information relevant to the Cooum problem situation. This is an uncommon resource in Chennai, and represents a simple but significant achievement of this program of research.

An Evaluation of the Program of Research

The discussion above indicates that this research was successful and productive from the perspective of the researcher who undertook this work. The primary research objectives were met, a contribution has been made to the fields of geography and ecosystem management, tangible products of the research were produced for the use of anyone whom they might benefit, and new knowledge of the problem situation has been generated. However, it is appropriate also to evaluate the program of research from the perspective of stakeholders in the situation who were participants in Cooum River Environmental Management Research Program.

Participant evaluations of the first and second workshops were presented in Chapters 3 and 5, respectively. Both of these evaluations were very favourable and indicated that respondents believed the workshops to have been effective in stimulating thinking about the Cooum problem, to have consisted of appropriate and useful working sessions and paper presentations, and that the simulation and GIS components of the research were effective in aiding exploration of the problem situation.

Respondents to the second workshop assessment also evaluated the program of research as a whole. This evaluation is summarized in Table 7.2. The summary scores for questions (for which workshop participants were asked to rate the program on a scale of 1 to 5) were quite high, ranging from 4.0 to 4.4. All the respondents indicated that they believed that the program of research had real potential to contribute to management of the problem situation, and to support efforts of their particular agency or organization in addressing the problem.[12] In response to comments about how the program might be improved, almost all respondents referred either obliquely or directly to the continuation of a participatory process involving all pertinent stakeholders, and further coordination with implementing agencies. In general, both the participatory nature of the program of research, and the systemic and holistic approach to the problem, were rated as appropriate by the respondents. Again, this

[12]One participant who did not represent any agency or organization did not respond to the later question.

was reflected both by respondent comments, and by comments from other participants throughout the workshop.

Table 7.1: Average of scores from responses to survey questions evaluating the Cooum River Environmental Management Research Program.

	Program of Research Evaluation Question	Score
1a	In general, as an ongoing Program of Research, do you feel this program has potential to make a contribution to management of the Cooum River and its environs?	4
1b	With regard to your agency/organization in particular, do feel this program of research has potential to support decision making and management of the Cooum River and its environs?	4.4
2	Is the Stakeholder or Participatory aspect of this program of research an appropriate approach in the context of environmental management of the Cooum River and its surrounding area?	4
3	Is the Holistic or Systems approach employed in this program of research an appropriate approach in the context of environmental management of the Cooum River and its surrounding area?	4.3
4	Do you think that this program of research should continue?	100%
5a	Do wish to participate in this program of research in the future?	80%
5b	If yes, how would you like to participate (check as many boxes as are appropriate)?	
	Participate in future workshops	80%
	Present a paper at future workshops	40%
	Provide data and other information to improve understanding and modeling of the system	20%
	Help to further develop the system model and decision support system	80%
	Stay informed about the program of research in general	60%

All respondents indicated that the program of research should continue and all but one[13] intended to participate in the program in the future. Overall, the evaluations by respondents to the questionnaire, as well as opinions of participants (both offered and solicited), were very favourable toward the overall program of research. Where criticisms and suggestions for improvements were made, they mainly referred to the need for access to data and for further studies on various aspects of the system. Several critical comments were also directed at the facilities provided for the second workshop which were not as good as those in the first workshop. The most common favourable comments had to do with the

[13]This respondent indicated that he would be unable to participate in the near future “due to other official commitments.”

participatory nature of the workshops, the GIS-based decision support system, the conceptualization of the system (represented by the ‘Rich Picture’) and the nature of the working sessions.

Such participant responses indicate that the program of research was perceived as useful, productive and successful by those who participated in it. There was, however, a rather poor response rate for the evaluation. This might lead one to question the representativeness of these results, were it not for the large amount of positive feedback received from participants informally. Furthermore, there were other important indications of the perceived utility of this research. First, participants in the first workshop in March of 1998 demonstrated their enthusiasm for the research by emphasising that a main recommendation from the workshop be that the “stakeholder process” of the program of research should continue. A second meaningful indication was the spontaneous formation of a working group at the second workshop in February of 1999, which had the explicit purpose of continuing this research. I join the participants at the final session of the second workshop in the Cooum River Environmental Management Research Program in endorsing the formation of this working group, and I offer this work in support of their efforts.

Appendix I

Schedules and Participant Lists for Workshops in the Cooum River Environmental Management Research Program

Madras - Waterloo University Linkage Programme
Department of Geography, University of Madras

Workshop 1 of the Cooum River Environmental Management Research Programme

A System Study for Environmental Management of the Cooum River and Environs

Workshop Schedule

GENERAL INFORMATION

Date: 18- 20 March, 1998

Venue: Conference Hall, Department of Politics and Public Administration
Centenary Building, University of Madras, Chennai 600 005, India

Registration: No fee

Hospitality: Lunch and tea will be provided, courtesy of the Department of Geography, University of Madras

Context: This is the first in a series of 2 workshops, (the second workshop to be held in November 1998), which will work through systems-based methodologies (*e.g.*, components of Adaptive Environmental Assessment and Management (AEAM)) to develop, compare and evaluate management scenarios for rehabilitation and maintenance of the Cooum river, Chennai.

The first workshop will see discussion focused on issues such as management goals for the Cooum river and environs, spatial and temporal scope of the problem situation, key actors, indicator variables, desirable and feasible management interventions in the system and the development of a framework for a dynamic simulation model and geographic information system database. In the second workshop, the participants will employ the simulation model to perform scenario analyses and develop, compare and evaluate possible management scenarios for future management of the Cooum river and environs over various time horizons.

Inaugural Speaker:
Dr. S. Ramachandran
Director
Institute for Ocean Management
Anna University
10:00 am, 18 March, 1998

Valedictory Speaker:
Dr. T. Sekar, I.F.S.
Director of Environment
Department of Environment and Forests
Government of Tamil Nadu
3:30 pm, 20 March, 1998

DAY 1			***18 March, 1998***
10:00	Opening Session		
	Welcome	Dr. S. Subbiah Professor, Department of Geography, University of Madras Coordinator, Madras-Waterloo Linkage Programme	
	Inauguration	Dr. S. Ramachandran Director, Institute for Ocean Management, Anna University	
	Vote of Thanks	Dr. T. Vasantha Kumaran Professor, Department of Geography, University of Madras	
10:45	Tea		
11:00	Introductory Session	Martin J. Bunch Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada	
	Workshop overview and methodologies		
11:30	Working Session 1 *An exercise in problem identification*		
12:00	Paper 1	Er. P.V. Sahadevan Deputy Chief Engineer, (Plan Formulation) Water Resources Organization, Public Works Department	
	Rehabilitation and Sustainable Maintenance of Chennai Waterways – How Should We Go About It?		
1:00	Lunch		
2:00	Working Session 2 *Defining the system of the Cooum river and environs: System components, linkages and relationships*		
3:30	Tea		
3:45	Paper 2	S. Ananthapadmanabhan Superintending Engineer Chennai Metropolitan Water Supply and Sewerage Board	
	Intercepting Sewers for Sustainable Maintenance of Waterways in the City		

DAY 2		*19 March, 1998*
10:00	Paper 3	Mr. C. Rajendran Chief Entomologist Directorate of Public Health and Preventative Medicine
	The Vectors and Parasites of Public Health Importance in the Cooum River and Environs	
10:45	Working Session 3 *Scoping the problem situation: Spatial and temporal scales*	
11:30	Tea	
11:45	Working Session 4 *Setting Goals for Rehabilitation and Management of the Cooum river*	
1:00	Lunch	
2:00	Paper 4	Martin J. Bunch Research Associate Madras-Waterloo University Linkage Programme Department of Geography, Faculty of Environmental Studies, University of Waterloo, Canada
	Modelling and Scenario Analysis for the Construction and Comparison of Management Scenarios: The Development of a Prototype Cooum River Environmental Management Decision Support System	
2:30	Working Session 4 (*Results presentation and discussion*)	
3:00	Paper 5	K.R. Thyagarajan Superintending Engineer Tamil Nadu Slum Clearance Board
	Slums on the Banks of the Cooum and Programmes to Address Them	
3:45	Tea	
4:00	Working Session 5 *Group sessions: Generating management alternatives for use in scenario analysis*	

(Possible working group foci:)

Group 1:	Hydrology	Group 3:	Regulatory environment
Group 2:	Urban Infrastructure	Group 4:	Population

DAY 3		**20 March, 1998**
10:00	Paper 6	Mr. G. Dattatri Project Advisor, UNCHS Sustainable Chennai Support Project
	Basic Information for Cleaning of the Waterways	
10:30	Working Session 6 *Data requirements, sources, availability and quality: Matching available knowledge and data to possible management interventions*	
11:30	Tea	
11:45	Working Session 7 *Linking data, knowledge and models: What we can and can not do*	
1:00	Lunch	
2:00	Working Session 8 *Discussion of further steps and the Second Workshop* *Review and evaluation of the workshop*	
3:15	Tea	
3:30	Valedictory Address	Dr. T. Sekar, I.F.S. Director of Environment Department of Environment and Forests Goverment of Tamil Nadu
	Closing Comment	Martin J. Bunch Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
	Vote of Thanks	Dr. S. Subbiah Professor, Department of Geography, University of Madras Coordinator, Madras-Waterloo Linkage Programme

Changes to the posted schedule: 2 short paper presentations added on the morning of the 3rd day:

Paper 7
Biological Treatment of Waste Water - A low cost alternative

Ms. Sangeetha Sriram
Project Officer
Citizens' Waterways Monitoring Programme,
Exnora International, Exnora Naturalists' Club

Paper 8
Selected Population Issues

Dr. S. Sivarajasingham
Consultant
Environment and Rural Development Planning

Workshop 1

A System Study for Environmental Management of the Cooum River and Environs

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Madras - Waterloo University Linkage Programme
Department of Geography, University of Madras

Workshop 2 of the Cooum River Environmental Management Research Programme

Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs

Workshop Schedule

GENERAL INFORMATION

Date: 24 - 28 February, 1999

Venue: Department of Geography
University of Madras
Chennai 600 005

Phone: 568778 ext: 303
Fax: 566693
E-mail: geog@giasmd01.vsnl.net.in

Registration: No fee

Hospitality: Lunch and tea will be provided

Context: This workshop is the second in a series of 2 workshops (the first was held in March 1998). These workshops, and the programme of research to which they belong, employ innovative "systems-based" methodologies to explore the problem situation of the Cooum river and environs, and to develop a Decision Support and Simulation System for the Cooum river system which will be used to develop, compare and evaluate future possible management scenarios for rehabilitation and maintenance of the Cooum river, Chennai.

Inaugural Speaker:
Mr. S.A. Subramani, I.A.S.
Vice-Chairman
Chennai Metropolitan Development Authority

10:00 am, 24 February, 1999

Valedictory Speaker:
Mr. V. Rajagopal
Chief Engineer
Chennai Metropolitan Water Supply and Sewerage Board

3:30 pm, , 28 February, 1999

Notes:

1. Not all workshop participants are expected to present a formal paper during the course of this workshop. It is asked, however, that participants will come prepared to express their particular viewpoints and provide information within their areas of expertise. Papers may be submitted for inclusion as appendices in the workshop report.

2. Workshop participants will be asked to evaluate various aspects of the workshop as well as its overall effectiveness. Comments, criticisms and suggestions are solicited at all times, and a questionnaire and stamped mailing envelope will be provided for workshop participants to submit a confidential written evaluation following the workshop. As the evaluation and comments of participants are very important in determining usefulness and future direction of this programme of research, please be certain to complete the written evaluation.

DAY 1		***24 February, 1999***
10:00	Welcome	Dr. S. Subbiah Professor Department of Geography, University of Madras
	Inaugural Address	Mr. S.A. Subramani, I.A.S. Vice-Chairman Chennai Metropolitan Development Authority
	Vote of Thanks	Dr. T. Vasantha Kumaran Professor Department of Geography, University of Madras
10:45	Tea	
11:00	Introductory Session	Martin J. Bunch Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
	Workshop Overview and Methodologies, Review & Presentation of Workshop 1 Report	
11:45	Paper 1	Er. P.V. Sahadevan Deputy Chief Engineer, (Plan Formulation) Water Resources Organization, Public Works Department
	An Overview of Programmes to Address Waterways in Chennai	
12:30	Paper 2	Dr. R. Ramanibai Reader Department of Zoology, University of Madras (Guindy)
	Are Long-Term Management Programmes Beneficial?	
1:00	Lunch	
2:00	Paper 3	Mr. K. Thangavelu IRSE President, PROBUS & Chief Eng., Ministry of Railways (Rtd)
	Environmental Management of the Cooum River and Environs – Holistic Solutions	
2:30	Paper 4	Ms. Sangeetha Sriram Project Officer, Citizens' Waterways Monitoring Programme, Exnora International, Exnora Naturalists' Club
	Waterways Restoration – Ecological and Social Dimensions	
3:00	Working Session 1 *Re-examining the Cooum System -- Sub-systems within the Cooum system*	

DAY 2 ***25 February, 1999***

10:00	Paper 5	Mr. Benjamin Gonzaga Senior Planner, Tamil Nadu Slum Clearance Board
	Rehabilitation of Slums Along Waterways for Better Environment – Myth or Realty?	
10:30	Paper 6	Mr. S. Ananthapadmanabhan Superintending Engineer Chennai Metropolitan Water Supply and Sewerage Board
	Water Supply and Sewage Production in Chennai: Implications for Pollution of the Cooum River	
11:00	Paper 7	Dr. V.S. Gowri, Technical Assistant and Dr. S. Ramachandran, Director Institute for Ocean Management, Anna University
	Chemical and Biological Characteristics of the Cooum River	
11:30	Tea	
11:45	Working Session 2 *Action oriented objectives: Management Scenarios Part I*	
1:00	Lunch	
2:00	Paper 8	Mr. B. Dhanraj Senior Entomologist, Corporation of Chennai
	Control of Mosquito Vectors in the Cooum River (Note: this paper rescheduled to Day 3)	
2:30	Paper 9	Mr. Martin J. Bunch Research Associate Madras-Waterloo University Linkage Programme Deptartment of Geography, University of Waterloo, Canada
	Modelling Hydrology and Water Quality in the Cooum using DESERT	
3:00	Paper 10	Mr. S. Muthiah Indian National Trust and Cultural Heritage (INTACH) President Emeritus, T.T. Maps & Publications Ltd. Publisher, Madras Editorial Services
	Extempo: Critical Comments on the Programme of Research	
3:30	Tea	
3:45	Working Session 3 *Operationalizing Objectives: Management Scenarios Part II*	

DAY 3 — ***26 February, 1999***

(NOTE: WORKING SESSION 3 WAS CONTINUED FROM 10:00 - 10:30 AM ON DAY 3, AND PAPER 8 WAS RE-SCHEDULED TO 10:30 AM DAY 3. OTHER ACTIVITIES WERE DELAYED 1.5 HOURS)

10:00	System Model Demonstration *The Prototype Cooum River Environmental Management Decision Support System*	
10:30	Working Session 4 *Introduction to the Cooum River Environmental Management Decision Support System*	
11:30	(Tea)	
1:00	Lunch	
2:00	Working Session 5 *Sensitivity and Scenario Analysis using the Cooum River Environmental Management Decision Support System*	
3:30	(Tea)	

DAY 4 — ***27 February, 1999***

ALL DAY	Open Lab Participants drop in to continue work on sensitivity and scenario analysis using the *Cooum River Environmental Management Decision Support System* in preparation for presentation of results on 28 February.	

DAY 5 — ***28 February, 1999***

MORNING	Open Lab Participants drop in to continue work on sensitivity and scenario analysis using the *Cooum River Environmental Management Decision Support System* in preparation for presentation of results on the afternoon of 28 February.	
1:00	Lunch	
2:00	Working Session 6 *Presentation and discussion of model results* *Future directions for the programme of research*	
	Closing Comment	Martin J. Bunch, Research Associate Madras-Waterloo University Linkage Programme Department of Geography, University of Waterloo, Canada
	Valedictory Address	Mr. V. Rajagopal Chief Engineer Chennai Metropolitan Water Supply and Sewerage Board
	Vote of Thanks	Dr. S. Subbiah Professor, Department of Geography, University of Madras Coordinator, Madras-Waterloo Linkage Programme

Workshop 2

Decision Support & Scenario Analysis for Environmental Management of the Cooum River and Environs

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Appendix II

Cooum River Environmental Management Decision Support System: GIS Database and System Development

GIS Database Development

Development of the basemap employed in construction of the GIS database

The GIS database of the Cooum River Environmental Management Decision Support System was initially developed using Arc/Info version 7.1.1. Key coverages were later imported into GRASSLAND GIS. In order to construct a GIS database that was as accurate as possible and provided a proper coordinate and projection environment, it was necessary to develop a basemap of the study area. The following steps outline the construction of this base map.

1. The topographic sheets for the Chennai area were scanned on to disk (600 dpi, 8-bit greyscale). Scans of individual map sheets are stored in "tiff" format. Topographic sheets which were scanned were the Survey of India map sheets:

   66 c 4 - 1:50000 scale
   66 c 4/6 - 1:25000 scale
   66 c 8/2 - 1:25000 scale
   66 c 8/3 - 1:25000 scale

2. For each of the maps used in constructing the basemap, control points were collected at the intersections of marked lines of longitude and latitude on the maps. These were converted to decimal degrees for use in Arc/Info GIS.

3. Using Arc/Info, a line coverage was created in geographic (decimal degree) coordinates for the entire study area. Arcs were created for each line of latitude and longitude on all the maps covering the study area: *i.e.*, at 2'30" intervals. Vertices were added to these lines every second, or 0.000278dd using the DENSIFYARC command at the arc level. (This was intended to facilitate projection of the coverage, as each vertice will be projected to new coordinates).

4. This coverage was projected to a simple conic projection with the following parameters:

Projection	simple conic
Units	meters
Spheroid	everest
X coordinate shift	500000
Number of standard parallels	1
Longitude of the central meridian (DMS)	80 15 0.000
Latitude of the origin (DMS)	0 0 0.000
Latitude of the standard parallel (DMS)	13 5 0.000

This process resulted in a line coverage which provided a visual reference to evaluate the accuracy of the geometric transformation and projections of the newly incorporated grids (scanned map sheets).

5. Using REGISTER at the ARC level, the scanned (.tif) images were registered to the coordinates of the corners of the map sheets as indicated by the lines of latitude and longitude on the map scans themselves. Using REGISTER in ARC, control points were set in the scanned images. REGISTER evaluates the fit that will be performed by a 1st order affine transformation. (The reported scaling, rotation and RMS errors are recorded below in Table AII.1). Transformation information for the map scans is stored in a world file (.tfw) associated with the "tiff" file. Ground control points (GCPs) on the scanned images were entered as (x, y) coordinate pairs. Coordinates are entered in decimal degrees, which have been calculated from the geographic map coordinates using the following formula:

$$decimalDegree = DD + \frac{MM}{60} + \frac{SS}{3600}$$

where;

DD = degrees
MM = minutes (1/60th of a degree)
SS = seconds (1/60th of a minute, 1/3600th of a degree)

6. The registered tif files (scanned maps) were rectified and "clipped" using RECTIFY at the ARC level. RECTIFY applies an affine transformation (scaling and rotation) to

the specified tiff file and clips the file according to a specified bounding box (in this case the bounding corners of the map area on the scanned map sheets).

7. The clipped and rectified tiff files were imported to grids in Arc/Info using IMAGEGRID at the ARC level. This created four new grids (sub-images of the basemap under construction) from the tiff files, incorporating the geometric coordinate information applied to the tiffs in the previous procedures.

8. The grids were projected into the same coordinate space as arc line coverage using the PROJECT command at the ARC level.

9. The goodness of fit of the registration, rectification and the projection transformation applied to the grids created in the previous steps was evaluated by visually inspecting the match between the independently created and projected line coverage (above) when this was displayed with an image (*i.e.*, a new projected grid) drawn in the background. All of the grid sub-images were determined, at the worst, to be within ½ of a pixel of what was to become the resolution (25m) of the final raster database in GRASSLAND. *E.g.*, for the sub-image 66c45a:

   a) Pixel size is 2.149 metres.
   b) Thickness of the lines of latitude and longitude from the scan is typically 5 or 6 pixels (greater than 10 to 12 metres).
   c) In the e-w direction, the arcs of the reference line coverage were compared to the 2 visible lines of longitude scanned from the original maps. The lines and arcs were about 10 metres apart along their entire length as measured from the arc to the centre of the scanned line.
   d) In the n-s direction, the arcs of "scgrid" were compared to the 2 visible lines of latitude scanned from the original maps. The lines and arcs seemed to be about 5 metres apart along their entire length as measured from the arc to the centre of the scanned line. However, the arc was typically situated within the pixels representing the line of latitude.

10. The sub-image grids were adjusted so that their edges matched up. First, a link coverage was created, adding links using the commands EDITFEATURE LINK and

ADD at the ARC/EDIT level. These were then used to adjust the grids. Links were defined for the two diagonal grids (66c45a and 66c83a) so that only 2 grids would have to be adjusted. These link coverages contained a series of links along the edges of the 2 grids (of map sheets 66c45a and 66c83a), and a few links scattered throughout the grids where lines of latitude and longitude were evident. The whole of these grids was subject to a rubber sheeting operation initiated with the ADJUST command.

11. Each grid at this point had a cell size (an artifact of the tiff scans) which did not match with all the other grids. These had to be resampled to the same size before a master grid (basemap) could be made. A resolution of 5 metres was chosen for the master grid, because this would allow sampling up (to reduce database size) while still retaining the detail needed to use the master grid to assist in the geometric correction of other coverages. At the GRID level, RESAMPLE() was used to resample the grids to 5 metres resolution and MERGE() was employed to combine them into a single grid.

Transformation and Projection of Basic Coverages in Arc/Info

Four main datasets (wards, slums locations, sewerage catchments, and stormwater drainage catchments) were constructed, on which all of the rest of the GIS data layers built for use in the Cooum DSS were based. The original analogue maps and the resulting Arc/Info coverages, however, were lacking a proper projection and coordinate system. The following steps describe the transformation and projection of these initial coverages to a more useful form.

1. Tics (control points) were collected on the coverages to be corrected/projected. Control points were collected at locations that were easily identified, such as road intersections, on both the coverage to be projected and the basemap.

2. Transformation coverages were created. Tics (control points) corresponding to those

collected in step 1 were created in a coverage having a proper projection and coordinate system (that of the basemap created for the study area). Tic coordinates were collected from the basemap and stored in the transformation coverage.

3. Coverages were transformed using the TRANSFORM command in Arc/Info. This performed a first order, or affine, transformation. Root Mean Square (RMS) errors reported for the transformations are provided below in Table AII.1. (Ward and Slum coverages are based on the same base map, so identical transformation coverages were used). The transformation was acceptable for all coverages except for the SWD catchments. (Step 4 describes further adjustment to improve the geometry of the coverages).

Table AII.1: RMS errors for transformation of basic GIS coverages.

Coverage Theme	RMS (input units)	RMS (output units)
Wards	0.036	18.118
Slums	0.036	18.118
Stormwater Drainage Catchments	0.155	78.933
Sewerage Catchments	0.019	28.703

4. A link coverage was created for each of the data coverages, so as to ‘tweak’ the coverages to match more closely with features (*e.g.*, roads, water features) on both the basemap, and with other coverages. Links define the distance and direction for a point in a coverage to be shifted in a ‘rubber sheeting’ operation. The ADJUST command was used to adjust the coverages once the link coverages were constructed.

5. A standard hull from the HULL coverage was used to replace the coastline and city boundaries in all coverages. Parts of the HULL come from the ward coverage and part from the stormwater drainage catchments coverage. This was done to match up all boundaries in order to eliminate the generation of spurious polygons along the boundary edges during overlay operations which might use these coverages as input.

6. Proper projection information for the coverages was given using the PROJECTCOPY

command to copy the projection information from the simple conic master grid coverage.

Incorporation of Data into the GRASSLAND GIS Database

Databases that were generated using Arc/Info were imported and incorporated into GRASSLAND in the manned described below.

1. A projection was defined in GRASSLAND which corresponded to the projection information of the Arc/Info coverages. A description of this projection is:

Projection (proj):	Equidistant Conic
Spherical/Ellipsiod (ellps):	Everest 1969
Central Meridian (lon_0):	80.250000 dd
Origin (lat_0):	0.000000 dd
1st Standard Parallel (lat_1):	13.083333 dd
2nd Standard Parallel (lat_2):	13.083333 dd

2. Using the Open Geospatial Datastore Interface (OGDI) capability of GRASSLAND, Arc/Info coverages were opened (in native Arc/Info format) in the GRASSLAND "Librarian." In the Librarian (by selecting "File | Open Connection"), an OGDI connection may be made. To do this, a URL for the dataset must be specified in the following manner (the hostname and domain are required only if the coverage is stored remotely):

   gltp://*hostname_domain*/*ODBC_driver*/*database_path*/*coverage_name*

   e.g., gltp:/ae/d:/arcfiles/cooum6/slums91

   where,

ae	is the arc_export ODBC driver
d:/arcfiles/cooum6/	is the path to the database
slums91	is the name of an Arc/Info vector (point) coverage

3. Once Arc/Info coverages were open, they were selected in the Librarian window and imported as raster layers into GRASSLAND by selecting "Import" under the File menu. In this process, a dialogue box requests a name, description, and resolution for

the imported datalayer. The GRASSLAND database is constructed with a 25 metre resolution.

(Arc/Info coverages were imported as raster, rather than vector, coverages in GRASSLAND because the 'v.support' module of GRASSLAND does not allow proper import of all polygons. Area vector coverages were instead rebuilt from the raster layers using GRASS routines in GRASSLAND).

Spatial Data Attributes and ODBC

Several of the ASCII format data files in the Cooum DSS are attributes of spatial entities represented in the GRASSLAND GIS database (*e.g.*, slums.dat relates to the *slums_1986* data layer, population.dat relates to the *wards* data layer). Although these data files do not have to be directly associated to the GRASSLAND part of the database in order for the Cooum DSS to function, they may be linked using the Object Database Connectivity (ODBC) functionality of Windows 95/98/NT. This allows query of these attributes via the GRASSLAND Mapviewer interface, and also provides for these attributes to be imported and incorporated into the GRASSLAND database. For this reason, many of the ASCII data files in the Cooum DSS have been structured to facilitate ODBC connections.

In order to make an ODBC connection to GRASSLAND, the following steps must be taken:

1. A text ODBC driver must be installed in the system (these are usually already installed with a Windows 95/98/NT setup). It has been found that the Microsoft Text driver works well for ODBC connections with GRASSLAND. This driver may be set up as a "User DSN," using the 'ODBC Administrator' in the Windows 'Control Panel'. The driver setup must specify the path to the data files (*i.e.*, a Cooum DSS scenario's data directory). The driver must also be configured to recognize *.dat extensions, and to expect comma delimited text files as data sources.

2. The data files must be comma delimited. Row and column headings must be enclosed in quotation marks. Non-numeric data must be enclosed in quotation marks.

Most of the Cooum DSS ASCII format data files are "ODBC-ready" in this way.

WARNING: Do not change the structure of Cooum DSS files. The system may not function properly if an unexpected format is encountered.

3. In the GRASSLAND Librarian, select the vector layer that is to be linked to a data file (raster layers cannot be linked using ODBC). Select "ODBC Link" from the librarian. Choose the ODBC text driver that was configured in step 1, above, from the list of available data sources. Select the data file to be linked from the list of available "Tables" in the data source directory. A list of attributes (columns) in the data file will appear, and a default SQL (structured query language) selection query will be loaded. It is recommended that the default query be used, unless users are familiar with SQL. The default query will allow access to all the information in the data file, rather that extracting only a portion of it.

Database Descriptions

This section consists of tables which furnish details about data employed in the Cooum DSS. Table AII.2 provides a list and general description of data in the Cooum DSS GIS database. Table AII.3 describes category values of raster data in the GRASS format database. Table AII.4 describes the structure and content of ASCII format data files. Table AII.5 provides details of other important files in the Cooum River Environmental Management Decision Support System. *These tables do not describe scripts, or code for executable programs, which comprise the programming of the Cooum DSS itself.*

Table AII.2: Data in the GRASSLAND GIS database.

GIS Data Layers	Description	Source
Raster data layers (25 metre resolution)		
SWD_10000.mask	Areas in the '10000' series of the SWD catchment index. These are areas that were serviced with storm water drains in 1994.	Derived from 'swd_catchments' raster data layer with reference to Mott MacDonald Ltd. (1994a) *Madras City – Urban Drainage Catchments.* [1:20000].
SWD_20000.mask	Areas in the '20000' series of the SWD catchment index. These areas were NOT serviced with storm water drains in 1994, and have been estimated to route runoff via overland flow	Derived from 'swd_catchments' raster data layer with and estimated with reference to: Mott MacDonald Ltd. (1994a) *Madras City – Urban Drainage Catchments.* [1:20000].
slums_1986	Locations of 'raw' slums (which had not been addressed by any sort of improvement program) in 1986.	Derived from the vector (point) data layer of the same name.
hull	Area within the city limits. This data layer is used as a mask to prepare other data for use in the GIS, and to produce vector layers of the city boundary.	Derived from the raster data layer 'swd_catchments'.
runits_sew.id	Routing units that are the smallest common unit among ward, sewerage catchment, and stormwater drainage catchment areas. Units in this data layer have identifiers corresponding to their sewage catchment parent units.	Produced from an overlay of ward, sewerage catchment, and stormwater drainage catchment data layers.
runits_swd.id	Routing units that are the smallest common unit among ward, sewerage catchment, and stormwater drainage catchment areas. Units in this data layer have identifiers corresponding to their SWD catchment parent units.	Produced from an overlay of ward, sewerage catchment, and stormwater drainage catchment data layers.
runits_ward.id	Routing units that are the smallest common unit among ward, sewerage catchment, and stormwater drainage catchment areas. Units in this data layer have identifiers corresponding to their corporation division (ward) parent units.	Produced from an overlay of ward, sewerage catchment, and stormwater drainage catchment data layers.
sewage_catchments	Sewage catchment areas in Chennai as of 1997. Catchments are organized into 5 zones, each serviced by a sewage treatment plant.	Shaw Technical Consultants (P) Ltd. and Hyder Consulting Ltd. (1997) *Plan Showing Proposed Improvements to the Existing Collection System within the City Limits*. [1:60000 copy of 1:30000 original]. Chennai: CMWSSB

Table AII.2 continued...

sewage_catchments.zones	Zones of collection areas for sewage treatment plants in Chennai as of 1997.	Derived from the 'sewage_catchments' raster data layer
swd_catchments	Storm water drainage catchments in Chennai as of 1994. Storm water drainage catchments drain into one of several major drains, canals or rivers in Chennai.	Mott MacDonald Ltd. (1994a) *Madras City – Urban Drainage Catchments.* [1:20000].
swd_catchments.sheds	Urban watersheds organized around major drains, canals or rivers in Chennai. These are comprised of several smaller urban drainage catchments.	Derived from the 'swd_catchments' raster data layer.
wards	Corporation Divisions in Chennai, as of the 1991 Census of India.	Corporation of Madras (1991) *City Map*. [1: 19200]. Chennai: Corporation of Madras.
waterways	Major rivers, canals and drains in Chennai. This data layer is intended for use as a visual reference.	Mott MacDonald Ltd. (1994a) *Madras City – Urban Drainage Catchments.* [1:20000].
Vector (Area) data layers		
hull	City boundary	Derived from the raster data layer of the same name.
sewage_catchments	Sewage catchment areas in Chennai as of 1997. Catchments are organized into 5 zones, each serviced by a sewage treatment plant.	Derived from the raster data layer of the same name.
sewage_catchments.zones	Zones of collection areas for sewage treatment plants in Chennai as of 1997.	Derived from the raster 'sewage_catchments' data layer
swd_catchments	Storm water drainage catchments in Chennai as of 1994. Storm water drainage catchments drain into one of several major drains, canals or rivers in Chennai.	Derived from the raster data layer of the same name.
swd_catchments.sheds	Urban watersheds organized around major drains, canals or rivers in Chennai. These are comprised of several smaller urban drainage catchments.	Derived from the 'swd_catchments' raster data layer.
wards	Corporation Divisions in Chennai, as of the 1991 Census of India.	Derived from the raster data layer of the same name.

Table AII.2 continued...

Vector (Line) data layers		
hull	Same as the vector (area) data layer of the same name.	
sewage_catchments	Same as the vector (area) data layer of the same name.	
sewage_catchments.zones	Same as the vector (area) data layer of the same name.	
swd_catchments	Same as the vector (area) data layer of the same name.	
swd_catchments.sheds	Same as the vector (area) data layer of the same name.	
wards	Same as the vector (area) data layer of the same name.	
Vector (Point) data layers		
slums_1986	Locations of 'raw' slums (which had not been addressed by any sort of improvement program) in 1986.	Tamil Nadu Slum Clearance Board (1986) *Slums in Madras City, 1986* . [1:20000].
ward_labelpoints	Point locations for ward labels.	Digitized from a display of the 'wards' raster data layer.
Vector (Text annotation) data layers		
sewerage_zone.labels	Text annotation for sewerage zones.	Digitized from a display of the 'sewage_catchments.zones' raster data layer.
swd_shed.lables	Text annotation for urban stormwater drainage watersheds.	Digitized from a display of the 'swd_catchments.shed' raster data layer.
ward.labels	Text annotation for corporation divisions (wards).	Digitized from a display of the 'wards' raster data layer.

Table AII.3: Categories for raster data in the GRASSLAND GIS database.

GIS Data Layers	Cat Value	Category Description
SWD_10000.mask	0 1	No data Area delineated and specified on original basemap (Mott McMacdonald, 1994a) as serviced with storm water drains.
SWD_20000.mask	0 1	No data Area NOT delineated and specified on original basemap (Mott McMacdonald, 1994a) as serviced with storm water drains. Area is part of an estimated overland flow urban drainage catchement.
slums_1986	1 ... to ... 996	Index number of slums in Chennai
hull	0 1	No data (outside of city) Area within the city limits.
runits_sew.id	Index routing units, sewerage collection area labels (see "sewage_catchments" for index desrciptions).	

Table AII.3 continued...

runits_swd.id	Index routing units, SWD catchment labels (see “swd_catchments” for index desrciptions).	
runits_ward.id	Index routing units, ward labels (see “wards” for index desrciptions).	
sewage_catchments	100 - 199	Index of sewerage collection areas in Zone I (routed to Ocean outfall or Kodungaiyur STP)
	200 - 299	Index of sewerage collection areas in Zone II (routed to Kodungaiyur STP or Aerated Lagoon)
	300 - 399	Index of sewerage collection areas in Zone III (routed to Koyembedu STP)
	400 - 499	Index of sewerage collection areas in Zone IV (routed to Nesapakkam STP)
	500 - 599	Index of sewerage collection areas in Zone V (routed to Perungudi STP)
sewage_catchments.zones	1	Sewerage collection Zone I (Ocean outfall or Kodungaiyur STP)
	2	Sewerage collection Zone II (Kodungaiyur STP / Aerated Lagoon)
	3	Sewerage collection Zone III (Koyembedu STP)
	4	Sewerage collection Zone IV (Nesapakkam STP)
	5	Sewerage collection Zone V (Perungudi STP)
swd_catchments	12101 to 27099 (composite index: seviced | waterway | unique identifier)	
	1xxxx	Area serviced with storm water drains
	2xxxx	Area NOT serviced with storm water drains. Catchement is estimated for overland flow.
	x10xx - x10xx	Urban drainage catchment draining to coast (or outside of city)
	x21xx - x20xx	Urban drainage catchment draining to North Buckingham Canal (then draining to the Cooum)
	x22xx - x22xx	Urban drainage catchment draining to Central Buckingham Canal (then draining to the Cooum)
	x23xx - x23xx	Urban drainage catchment draining to Central Buckingham Canal (then draining to the Adyar)
	x24xx - x24xx	Urban drainage catchment draining to South Buckingham Canal (then draining to the southern city periphery)
	x30xx - x30xx	Urban drainage catchment draining to Cooum River
	x40xx - x40xx	Urban drainage catchment draining to Adyar River
	x50xx - x50xx	Urban drainage catchment draining to Captain Cotton Canal (then draining to N. Buckingham Canal, and the Cooum)
	x60xx - x60xx	Urban drainage catchment draining to Otteri Nullah (then draining to N. Buckingham Canal, and the Cooum)
	x70xx - x70xx	Urban drainage catchment draining to Arumbakkam / Virugembakkam Drain (then draining to the Cooum)
	x80xx - x80xx	Urban drainage catchment draining to Mambalam Drain (then draining to the Adyar)
	xxx01 - xxx99	Unique SWD catchment identifier in an urban watershed

Table AII.3 continued...

swd_catchments.sheds	1 2 3 4 5 6 7 8	Coastal (or outside of city) Urban Drainage Shed Buckingham Canal Urban Drainage Shed Cooum River Urban Drainage Shed Adyar River Urban Drainage Shed Captain Cotton Canal Urban Drainage Shed Otteri Nullah Urban Drainage Shed Arumbakkam / Virugembakkam Drain Urban Drainage Shed Mambalam Drain Urban Drainage Shed
wards	1 ... to ... 155	Ward or Corporation Division numbers
waterways	0 1	No data Waterway

For the following file descriptions, most of the ASCII format files are located in one of two locations in the Cooum DSS: in the scenario data directory (1), or in the base scenario directory itself (2), *i.e.*:

(1) *<cdss_path>*
└ scenarios
└ *<scenario_name>*
└ **data**

(2) *<cdss_path>*
└ scenarios
└ ***<scenario_name>***

Table AII.4: Structure and content of ASCII format data files in the Cooum DSS.

Fields/Column Header	Field Description	Function/File Description
runits.index		comma delimited, field descriptor column headers
RUNITS14-ID	routing unit index (unique identifier)	This file is used as input in the calculations of the amount of sewerage generated in routing units (which are small areal units that may be described as the lowest common denominator among wards, SWD catchments and sewerage catchments). The file is generated from the GIS coverages using a Tcl script Possible ODBC link: *none* Location: scenario data directory
AREA(m^2)	routing unit area (in metres squared)	
SWDCATCH5-ID	stormwater drainage catchment index (unique identifier)	
SWDCATCH_AREA(m^2)	stormwater drainage catchment area (in metres squared)	
SEWCATCH6-ID	sewerage catchment index (unique identifier)	
SEWCATCH_AREA(m^2)	sewerage catchment area (in metres squared)	
WARD91-ID	municipal ward index (unique identifier)	
WARD91_AREA(m^2)	municipal ward area (in metres squared)	
swdcatch.index		comma delimited, no column headers
SWD catchment index	index of stormwater drainage catchments (see description of category values for swd_catchements in Table AII.2)	Used for constructing data files detailing sewage and rainfall effluent of SWD catchments. (Built from a GIS coverage via Tcl script Possible ODBC link: *none* Location: scenario data directory
SWD catchment index (precipitation header)	as above, but with "PREC" prefix (used in defining SWD catchment outlets with rainwater effluent).	
Area	Area of the SWD catchment (m^2)	
popGrowthRates.dat		comma delimited, field descriptor column headers
Ward	Ward numbers (1 to 155)	This file provides data which may be used to project population numbers for wards. Possible ODBC link: *wards* Location: scenario data directory
2001-2 ... to ... 2031-2	annual growth rates for wards (percent of population) for years 2001-2 to 2031-2	

Table AII.4 continued...

population.dat		comma delimited, field descriptor column headers
Ward	Ward numbers (1 to 155)	This file provides population data which is used as input in sewage generation calculations. Possible ODBC link: *wards* Location: scenario data directory
2001 ... to ... 2031	population of wards for years 2001 to 2031	
efficiency.dat		comma delimited, field descriptor column headers
Ward	Ward numbers (1 to 155)	This file provides data which is used to determine what proportion of sewage generated by a ward's population is routed via the sewerage system to an STP. Possible ODBC link: *wards* Location: scenario data directory
2001-2 ... to ... 2031-2	efficiency rating for ward (proportion of sewage routed via sewerage system vs SWD system) for years 2001 to 2031	
proportion_lig.dat		comma delimited, field descriptor column headers
Ward	Ward numbers (1 to 155)	This file provides income distribution data which is used as input in sewage generation calculations. Possible ODBC link: *wards* Location: scenario data directory
2001 ... to ... 2031	proportion of population of wards which is classified as "low income group" for years 2001 to 2031	
proportion_hig.dat		comma delimited, field descriptor column headers
Ward	Ward numbers (1 to 155)	This file provides income distribution data which is used as input in sewage generation calculations. Possible ODBC link: *wards* Location: scenario data directory
2001 ... to ... 2031	proportion of population of wards which is classified as "high income group" for years 2001 to 2031	
rainfall.dat		comma delimited, field descriptor column headers
Catchment	SWD catchment index	This file provides rainfall data in SWD catchments, for each month of the year. This is used as input in runoff calculations. Possible ODBC link: *swd_catchments* Location: scenario data directory
1 ... to ... 12	average rainfall (mm) in SWD catchments for each month	

Table AII.4 continued...

runoffcoef.dat		comma delimited, field descriptor column headers
Catchment	SWD catchment index	This file provides runoff coefficient data in SWD catchments, for each month of the year. This is used as input in rainfall runoff calculations. Possible ODBC link: *swd_catchments* Location: scenario data directory
1 ... to ... 12	proportion of rainfall (0 to 1) which runs-off SWD catchments to their outlets, for each month	
slums.dat		comma delimited, field descriptor column headers
Master_Slum_Index	slum index number	This file supplies data on slums in Chennai. The slum ward location, 1986 survey zone, and number of huts in slums, provide input used to modify ward population figures in the case of slum improvement or clearance. Possible ODBC link: *slums_1986* Location: scenario data directory
1991_Ward_No	1991 ward where slum is located	
1981_Ward_No	1981 ward where slum is located	
1986_Survey_Serial_No	Serial number for the slum in the 1986 *Survey of Slums in Madras Metropolitan Area* (MMDA, 1986)	
1986_Survey_Zone_Code	1 Extended areas of the city 2 Peripheral areas in the MMA 3 Madras City (South) 4 Madras City (North)	
Name_of_Slum	Name of the slum	
Boundary-East	Feature on slum's E. Boundary	
Boundary-West	Feature on slum's W. Boundary	
Boundary-North	Feature on slum's N. Boundary	
Boundary-South	Feature on slum's S. Boundary	
Land_Ownership_Category	1 Government 2 Town Panchayat 3 Township 4 Private 5 TNHB 6 Municipality 7 Corporation 8 Temple 9 TNSCB 10 Others 11 Mosque 12 Church	
Age_of_Slum	Age of slum in years	
Type_Category	1 Linear slum 2 Scattered hut development 3 Planned hut development	
Shelter_Units	Number of huts in slums	
Drain_Status	0 Underground	

Table AII.4 continued...

Road_Status	0 Covered 1 Uncovered	
%Thatched	% huts w/ thatched superstructure	
%Pucca	% huts w/ 'pucca' superstructure	
%Tiled	% huts w/ tiled superstructure	
%Asbestos	% huts w/ asbestos superstructure	
%Tinned	% huts w/ tinned superstructure	
Addressed_by_Other_ Scheme	0 addressed 1 not addressed	
Existence_of_Organisation	0 organization exists in the slum 1 no organization exists in slum	
Working_Water_Points/Hut	no. of working water points per hut in the slum	
Non-working_Water_Points /Hut	no. of water points per hut in the slum that are not working	
Working_Latrines/Hut	no. of working latrines per hut in the slum	
Non-working_Latrines/Hut	no. of latrines per hut in the slum that are not working	
Working_Street_Lights/Hut	no. of working street lights per hut in the slum	
Non-working_Street_Lights /Hut	no. of street lights per hut in the slum that are not working	
Community_Facilities/Hut	no. of community facilities per hut in the slum	
Shops/Hut	no. of commercial enterprises per hut in the slum	
Ownership_Category	1 Government land 2 Private land 3 Religious institution land	
runitsewerage.dat		comma delimited, no column headers
runit	Routing unit index number	This file is an intermediate data file produced by the r_sew.exe calculator. It is used as input for the sewerage.exe calculator. Possible ODBC link: *none* Location: scenario data directory
swd_catchement	Storm water drainage catchment index number	
sewage_catchment	Sewage collection area index number	
ward	Ward number	
sewage	Sewage produced by population in the routing unit (m^3/day)	

Table AII.4 continued...

sewerage.dat		comma delimited, no column headers
ward	Ward number	This file is an intermediate data file produced by the population.exe calculator. It is used as input for the sewerage.exe calculator. Possible ODBC link: *none* Location: scenario data directory
sewage	Sewage produced by population in the ward (m^3/day)	
parameters.txt		space delimited, no column headers, field descriptors in angle brackets
<DATE>	Start date of simulation (dd/mm/yyyy)	This file is a model parameter file. Information stored in this file is considered evenly distributed throughout the study area, or space is not important in determining its value. Each of the parameters may be modified by users of the Cooum DSS via the DSS module graphical user interface. The parameters are used as input for the various calculators. Possible ODBC link: *none* Location: scenario data directory
<END_DATE>	End date of the simulation (dd/mm/yyyy)	
<TIME>	Start time of simulation (hh:mm)	
<PERIOD>	Period for which simulation is performed (H|D|W|M|Y)	
<VARIANT>	Name of the simulation setup	
<STP_CAPACITY>	Capacity of sewage treatment plant (mld)	
<STP_BOD5>	Biochemical oxygen demand characteristics of STP effluent (mg/l)	
<STP_COD>	Chemical oxygen demand characteristics of STP effluent (mg/l)	
<STP_SS>	Suspended solids characteristics of STP effluent (mg/l)	
<STP_TDS>	Total dissolved solids characteristics of STP effluent (mg/l)	
<STP_N>	Nitrogen characteristics of STP effluent (mg/l)	
<STP_P>	Phosphorous characteristics of STP effluent (mg/l)	
<STP_T>	Temperature characteristics of STP effluent (mg/l)	
<STP_DO>	Dissolved oxygen characteristics of STP effluent (mg/l)	
<SEW_BOD5>	Biochemical oxygen demand characteristics of raw sewage (mg/l)	

Table AII.4 continued...		
<SEW_COD>	Chemical oxygen demand characteristics of raw sewage (mg/l)	
<SEW_SS>	Suspended solids characteristics of raw sewage (mg/l)	
<SEW_TDS>	Total dissolved solids characteristics of raw sewage (mg/l)	
<SEW_N>	Nitrogen characteristics of raw sewage (mg/l)	
<SEW_P>	Phosphorous characteristics of raw sewage (mg/l)	
<SEW_T>	Temperature characteristics of raw sewage (mg/l)	
<SEW_DO>	Dissolved oxygen characteristics of raw sewage (mg/l)	
<SWD_BOD5>	Biochemical oxygen demand characteristics of storm water (mg/l)	
<SWD_COD>	Chemical oxygen demand characteristics of storm water (mg/l)	
<SWD_SS>	Suspended solids characteristics of storm water (mg/l)	
<SWD_TDS>	Total dissolved solids characteristics of storm water (mg/l)	
<SWD_N>	Nitrogen characteristics of storm water (mg/l)	
<SWD_P>	Phosphorous characteristics of storm water (mg/l)	
<SWD_T>	Temperature characteristics of storm water (mg/l)	
<SWD_DO>	Dissolved oxygen characteristics of storm water (mg/l)	
<SG_HIG>	Sewage generation factor for the high income group (proportion of water consumed)	
<SG_MIG>	Sewage generation factor for the middle income group (proportion of water consumed)	
<SG_LIG>	Sewage generation factor for the low income group (proportion of water consumed)	

Table AII.4 continued...

<WC_HIG>	Water consumption of the high income group (lcd)	
<WC_MIG>	Water consumption of the middle income group (lcd)	
<WC_LIG>	Water consumption of the low income group (lcd)	
<1_RAINHOURS>	Average hours of rainfall in January (mm)	
<2_RAINHOURS>	Average hours of rainfall in February (mm)	
<3_RAINHOURS>	Average hours of rainfall in March (mm)	
<4_RAINHOURS>	Average hours of rainfall in April (mm)	
<5_RAINHOURS>	Average hours of rainfall in May (mm)	
<6_RAINHOURS>	Average hours of rainfall in June (mm)	
<7_RAINHOURS>	Average hours of rainfall in July (mm)	
<8_RAINHOURS>	Average hours of rainfall in August (mm)	
<9_RAINHOURS>	Average hours of rainfall in September (mm)	
<10_RAINHOURS>	Average hours of rainfall in October (mm)	
<11_RAINHOURS>	Average hours of rainfall in November (mm)	
<12_RAINHOURS>	Average hours of rainfall in December (mm)	
<slumHH_size_1>	average household size of slums in zone 1 of the 1986 slum survey	
<slumHH_size_2>	average household size of slums in zone 2 of the 1986 slum survey	
<slumHH_size_3>	average household size of slums in zone 3 of the 1986 slum survey	
<slumHH_size_4>	average household size of slums in zone 4 of the 1986 slum survey	

Table AII.4 continued...

infotab1.dat		comma delimited, field descriptor column headers
IDCODE	Identifier of river objects related to *river reach confluences, headwaters, system termination and abstractions*. These correspond to river objects defined in the water quality and hydrology simulation model	This file is an intermediate data file. It is the final form of the data used to parameterize the environmental simulation model and represents the initial conditions of the simulation. This ASCII format data is placed into the infotab1.dbf database file with the Param1.exe data transport program. Note: This file is identical in data content to the .dbf (dbase III) file with the same prefix. Possible ODBC link: *File is ODBC ready, but requires a vector GIS layer with "IDCODE" attributes.* Location: scenario data directory
DATE	Start date of simulation (dd/mm/yyyy)	
TIME	Start time of simulation (hh:mm)	
PERIOD	Period for which simulation is performed (H|D|W|M|Y)	
VARIANT	Name of this simulation setup	
Q	Quantity of water flowing past the point at the river object (m^3/s)	
DO	Dissolved oxygen characteristic of the water at the river object	
BOD	Biochemical oxygen demand characteristic of the water at the river object	
N	Nitrogen characteristic of the water at the river object	
T	Temperature characteristic of the water at the river object	
infotab2.dat		comma delimited, field descriptor column headers
IDCODE	Identifier of river objects representing *STP outlet, STP overflow, and sewage effluent from SWD catchment outlets*. These correspond to river objects defined in the water quality and hydrology simulation model	This file is an intermediate data file produced by the sewerage.exe calculator. It is the final form of the data used to parameterize the environmental simulation model. This ASCII format data is placed into the infotab1.dbf database file with the Param1.exe data transport program.
DATE	Start date of simulation (dd/mm/yyyy)	
TIME	Start time of simulation (hh:mm)	Note: This file is identical in data content to the .dbf (dbase III) file with the same prefix.
PERIOD	Period for which simulation is performed (H|D|W|M|Y)	Possible ODBC link: *File is ODBC ready, but requires a vector GIS layer with "IDCODE" attributes.*
VARIANT	Name of this simulation setup	Location: scenario data directory

Table AII.4 continued...

Q	Quantity of water flowing past the point at the river object (m^3/s)	
DO	Dissolved oxygen characteristic of the water at the river object	
BOD	Biochemical oxygen demand characteristic of the water at the river object	
N	Nitrogen characteristic of the water at the river object	
T	Temperature characteristic of the water at the river object	
infotab3.dat		comma delimited, field descriptor column headers
IDCODE	Identifier of river objects representing *storm water effluent from SWD catchment outlets*. These correspond to river objects defined in the water quality and hydrology simulation model	This file is an intermediate data file produced by the rain.exe calculator. It is the final form of the data used to parameterize the environmental simulation model. This ASCII format data is placed into the infotab1.dbf database file with the Param1.exe data transport program. Note: This file is identical in data content to the .dbf (dbase III) file with the same prefix. Possible ODBC link: *File is ODBC ready, but requires a vector GIS layer with "IDCODE" attributes.* Location: scenario data directory
DATE	Start date of simulation (dd/mm/yyyy)	
TIME	Start time of simulation (hh:mm)	
PERIOD	Period for which simulation is performed (H|D|W|M|Y)	
VARIANT	Name of this simulation setup	
Q	Quantity of water flowing past the point at the river object (m^3/s)	
DO	Dissolved oxygen characteristic of the water at the river object	
BOD	Biochemical oxygen demand characteristic of the water at the river object	
N	Nitrogen characteristic of the water at the river object	
T	Temperature characteristic of the water at the river object	

Table AII.5: Other important files in the Cooum DSS.

<table>
<tr><th colspan="2">*<data_file_prefix>*.doc</th><th>ASCII, space delimited, no column headers, field descriptors in angle brackets</th></tr>
<tr><td><maxY></td><td>Maximum value for the y-axis when graphing the associated data</td><td rowspan="7">This file is a documentation file associated with a data file (.dat) with the same file prefix. The Cooum DSS requires this file in order to load the associated data into the "Point Plotter" in the decision support module of the system.

Possible ODBC link: *none*

Location: scenario data directory</td></tr>
<tr><td><minY></td><td>Minimum value for the y-axis when graphing the associated data</td></tr>
<tr><td><yIncrement></td><td>Increment value for labels and lines on the y-axis</td></tr>
<tr><td><yIncrNum></td><td>Number of increments ("yIncrement") to build on the y-axis</td></tr>
<tr><td><yLabel></td><td>Label for the y-axis</td></tr>
<tr><td><impact></td><td>Data files that will need to be updated if the data file associated with this .doc file is changed</td></tr>
<tr><td><meta></td><td>Descriptive comments regarding the associated data</td></tr>
<tr><th colspan="2">**infotab1.dbf**</th><th>binary dBase III (.dbf) file</th></tr>
<tr><td colspan="3">This file is identical in content to the infotab1.dat file described in Table AII.3, above. It is input for the DESERT environmental simulation model. For further information on infotables, see the DESERT 1.1 documentation (Ivanov *et al*, 1996).
Location: scenario data directory</td></tr>
<tr><th colspan="2">**infotab2.dbf**</th><th>binary dBase III (.dbf) file</th></tr>
<tr><td colspan="3">This file is identical in content to the infotab2.dat file described in Table AII.3, above. It is input for the DESERT environmental simulation model. For further information on infotables, see the DESERT 1.1 documentation (Ivanov *et al*, 1996).
Location: scenario data directory</td></tr>
<tr><th colspan="2">**infotab3.dbf**</th><th>binary dBase III (.dbf) file</th></tr>
<tr><td colspan="3">This file is identical in content to the infotab3.dat file described in Table AII.3, above. It is input for the DESERT environmental simulation model. For further information on infotables, see the DESERT 1.1 documentation (Ivanov *et al*, 1996).
Location: scenario data directory</td></tr>
<tr><th colspan="2">**masttab.dbf**</th><th>binary dbase III (.dbf) file</th></tr>
<tr><td colspan="3">The MasterTable file contains the list of "objects" present in the river system. It is input for the DESERT environmental simulation model. For further information on Master Table files, see the DESERT 1.1 documentation (Ivanov *et al*, 1996).
Location: scenario data directory</td></tr>
<tr><th colspan="2">**proftab.dbf**</th><th>binary dbase III (.dbf) file</th></tr>
<tr><td colspan="3">The ProfileTable file contains the reach bathymetry and weir characteristics of the river system. It is input for the DESERT environmental simulation model. For further information on Profile Table files, see the DESERT 1.1 documentation (Ivanov *et al*, 1996).
Location: scenario data directory</td></tr>
</table>

Table AII.5 continued...

maptab.bna	ASCII (.bna) file
The MapTable file describes the geographical position of structural objects in the river system. It is a MapViewer™ format (.BNA) file and its presence is optional. It is input for the DESERT environmental simulation model. For further information on MapTable files, see the DESERT 1.1 documentation (Ivanov *et al*, 1996). *Location*: scenario data directory	
<*name*>.unv	ASCII (.unv) file
<*name*>.unv file is a "Universe file" which provides for the representation of the river system. It specifies the name of the system's Master Table, Profile Tables, Info Tables, Map Tables, as well as providing details of their structure. For further information on universe files see the DESERT 1.1 documentation (Ivanov *et al*, 1996). *Location*: scenario data directory	
Plottab.xls	binary excel (.xls) file
The Plottab.xls is a spreasheet file (Microsoft Excel format) which may be used to receive and store the results of a simulation model run in DESERT. Cells of the file must have some information (e.g., "1's") to provide DESERT with information on the size of the sheet to be written. For further information on connecting to export files, see the DESERT 1.1 documentation (Ivanov *et al*, 1996). *Location*: scenario data directory	
<*name*>.mod	ASCII (.mod) file
This file employs the MODUS simulation language to describe a system's water quality model solutions. For further information on MODUS or water quality modelling with DESERT, see the DESERT 1.1 documentation (Ivanov *et al*, 1996). *Location*: scenario data directory	
groups.txt	ASCII (.txt) file
This file defines groups of areas associated with various data files in a scenario. A "group" is a set of polygons in the study area which a user wishes to treat as a single entity for purposes of assigning values, *etc*.. Groups for all data files are recorded in this definitions file. Group definitions begin with the name of the database (starting a new line -- no path information allowed), followed by group names (enclosed in <angled brackets>, no spaces) and a list of area index numbers (separated with a comma and/or space). *E.g.*, dbFile.dat <group1> 1,2,3,4,5 dbFile.dat <group2> 34 36 22 120 *Location*: scenario directory	
history.txt	ASCII (.txt) file
This file is a record of modifications to a scenario's parameter file, and changes to its data files via calculator and data transport programs in the Cooum DSS. This file may also contain user comments and meta information about a scenario, at the user's discretion. It is accessible through the main window in the Cooum DSS graphical user interface, which functions as a basic text editor. *Location*: scenario directory	
defaults.txt	ASCII (.txt) file
This file sets some installation specific defaults for the Cooum River Decision Support and Environmental Management System. The default values are entered one (1) per line, with the default label first, followed by a single space, and then by a string: NAME string *Location*: base cdss directory	

<*drive*>\Grassland └ <*subdirectories*>	Location of GRASSLAND 1.1 application (See GRASSLAND documentation (L.A.S., 1996) for more information.)
<*drive*>\<*desert_path*>\Desert └ <*subdirectories*>	Location of DESERT 1.1 application (See DESERT documentation (Ivanov *et al*, 1996) for more information.)
<*drive*>\<*cdss_path*>\cdss	Startup files for the Cooum DSS[a]
├Associated Files └ <*optional_subdirectories*>	Various tools and information to aid continued development of the Cooum DSS
├Bin └ <*optional_subdirectories*>	Executable programs - 'calculators' & 'data transport'[b] (C/C++ code and project files for executable programs)
├Chennai	GRASS format GIS database of the Chennai area
├PERMANENT	Primary GRASS mapset for Chennai
└ <*optional_mapsets*>	(User-generated mapsets for Chennai)
├Doc	Documentation files for the Cooum DSS
├Lib	Tcl/Tk script library[c]
├Mapping	User-generated map and GIS support files
└ Scenarios	Cooum DSS scenarios
├default	Default scenario for the Cooum system[d]
└ data	Data files for the default scenario[e]
└ <*CDSS_scenarios*>	User-generated scenarios

a	readme.1st	slums.exe	c	bldLib.tcl	plotter.tcl
	defaults.txt	slum_improvement.exe		groupMan.tcl	precipLib.tcl
	cdss.tcl	slum_clearance.exe		grpLib.tcl	runits.tcl
		sewerage.exe		initLib.tcl	slumLib.tcl
b	dbmod.exe	r_sew.exe		miscLib.tcl	tclIndex
	param1.exe	rain.exe		paramLib.tcl	utilLib.tcl
	population.exe			plotLib.tcl	
d	groups.txt	infotab3.dat		popGrowthRates.doc	runoffcoef.dat
	history.txt	infotab3.dbf		proftab.dbf	sewerage.dat
		maptab.bna		proportion_hig.dat	slums.dat
e	efficiency.dat	Masttab.dbf		proportion_hig.doc	slumArray.dat
	efficiency.doc	parameters.txt		proportion_lig.dat	swdcatch.index
	infotab1.dat	Plottab.xls		proportion_lig.doc	default.unv
	infotab1.dbf	population.dat		rainfall.dat	default.mod
	infotab2.dat	population.doc		runits.index	
	infotab2.dbf	popGrowthRates.dat		runitsewerage.dat	

Figure AII.1: Cooum DSS directory structure and file locations.

Conceptual Functioning of Cooum DSS 'Calculator' and 'Data Transport' Programs

Figures AII.2 to AII.9 are flow charts of 'calculator' and 'data transport' executable programs in the Cooum River Environmental Management Decision Support System. These are presented to demonstrate the logic and functioning of the programs. The programs were developed in C/C++. Both the executables and the source code (C++ Builder project files) are stored in the 'bin' directory of the Cooum DSS.

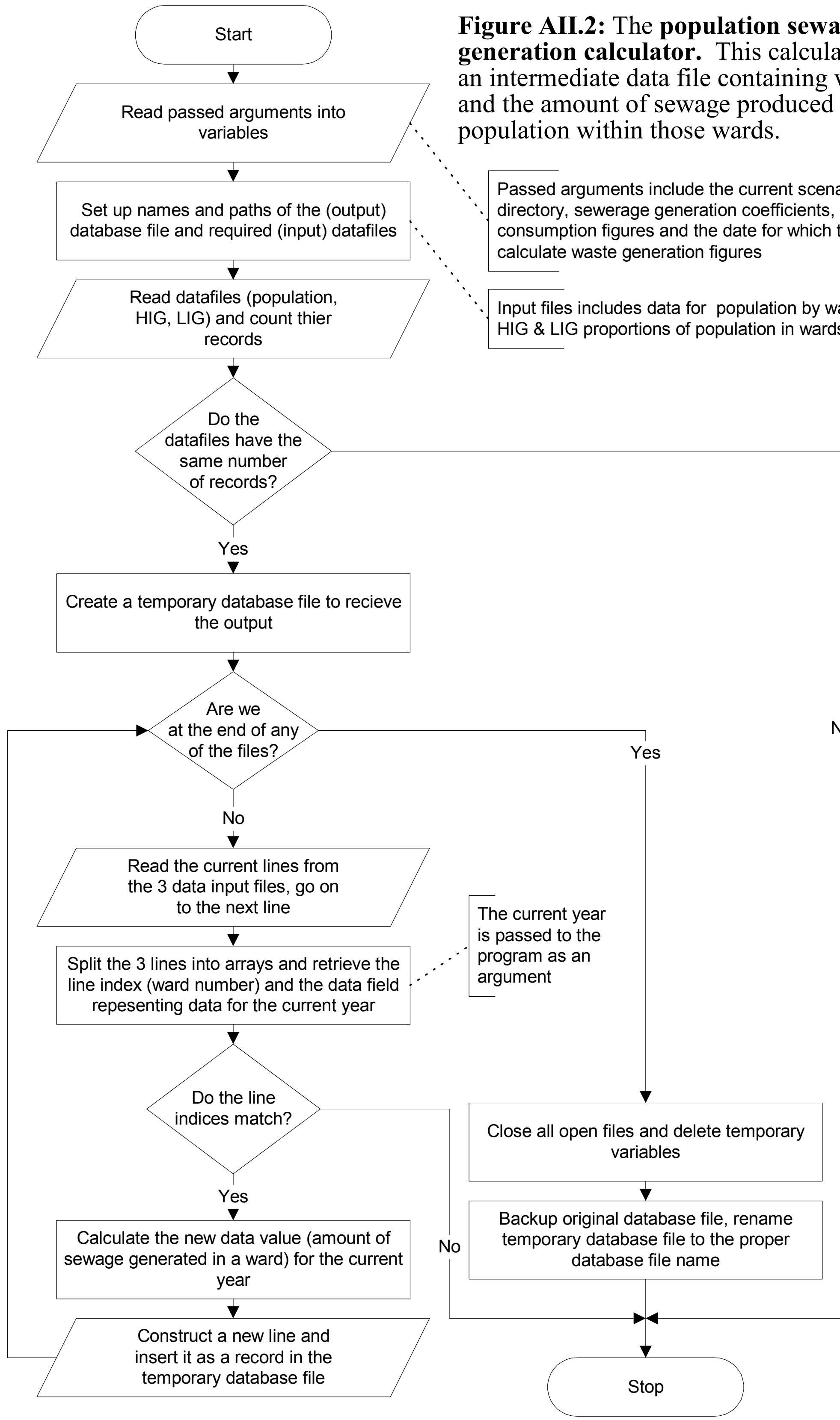
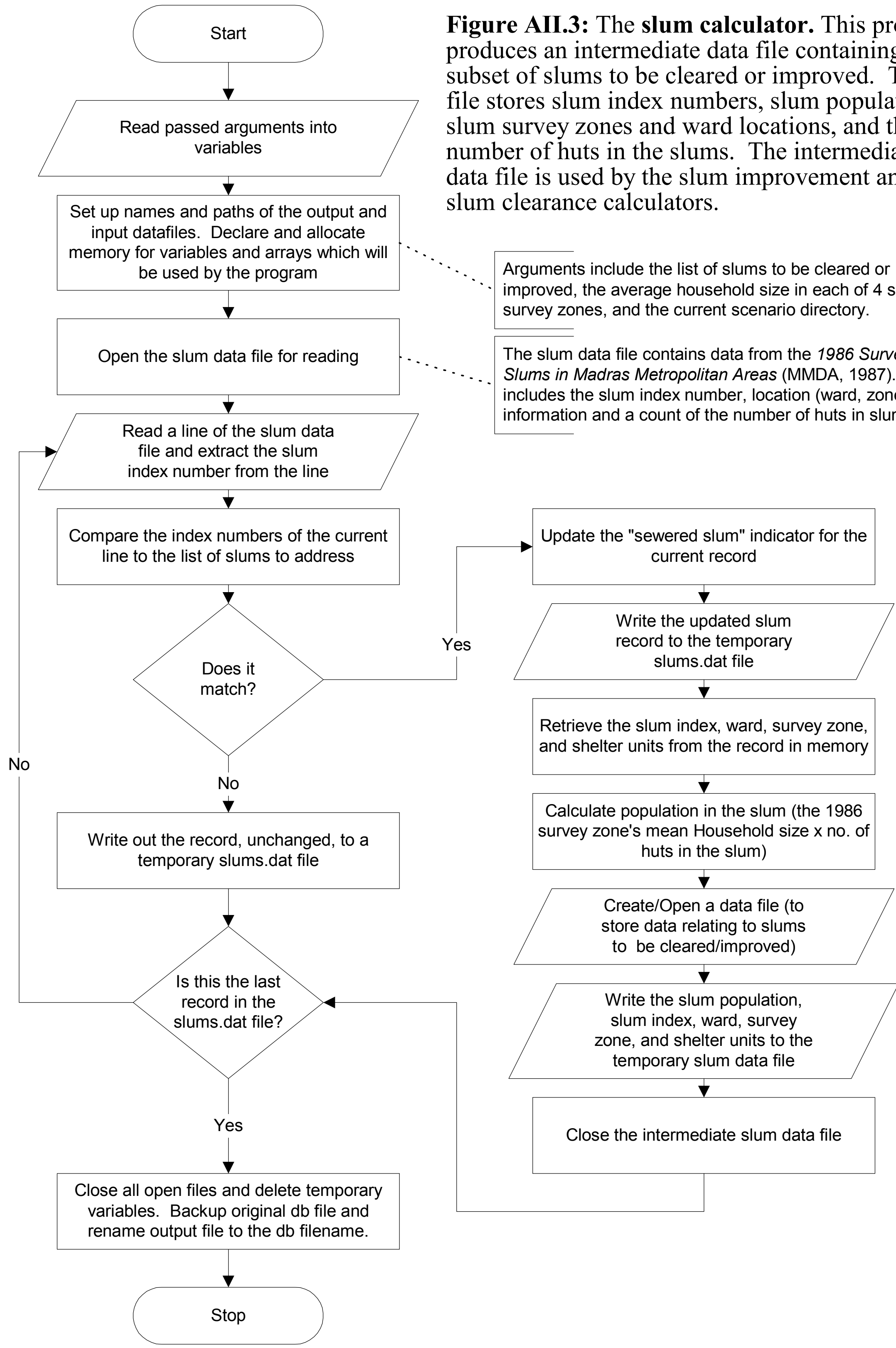


Figure AII.2: The **population sewage generation calculator.** This calculator produces an intermediate data file containing ward indices and the amount of sewage produced (m^3/day) by population within those wards.

Figure AII.3: The **slum calculator.** This program produces an intermediate data file containing a subset of slums to be cleared or improved. This file stores slum index numbers, slum population, slum survey zones and ward locations, and the number of huts in the slums. The intermediate data file is used by the slum improvement and slum clearance calculators.



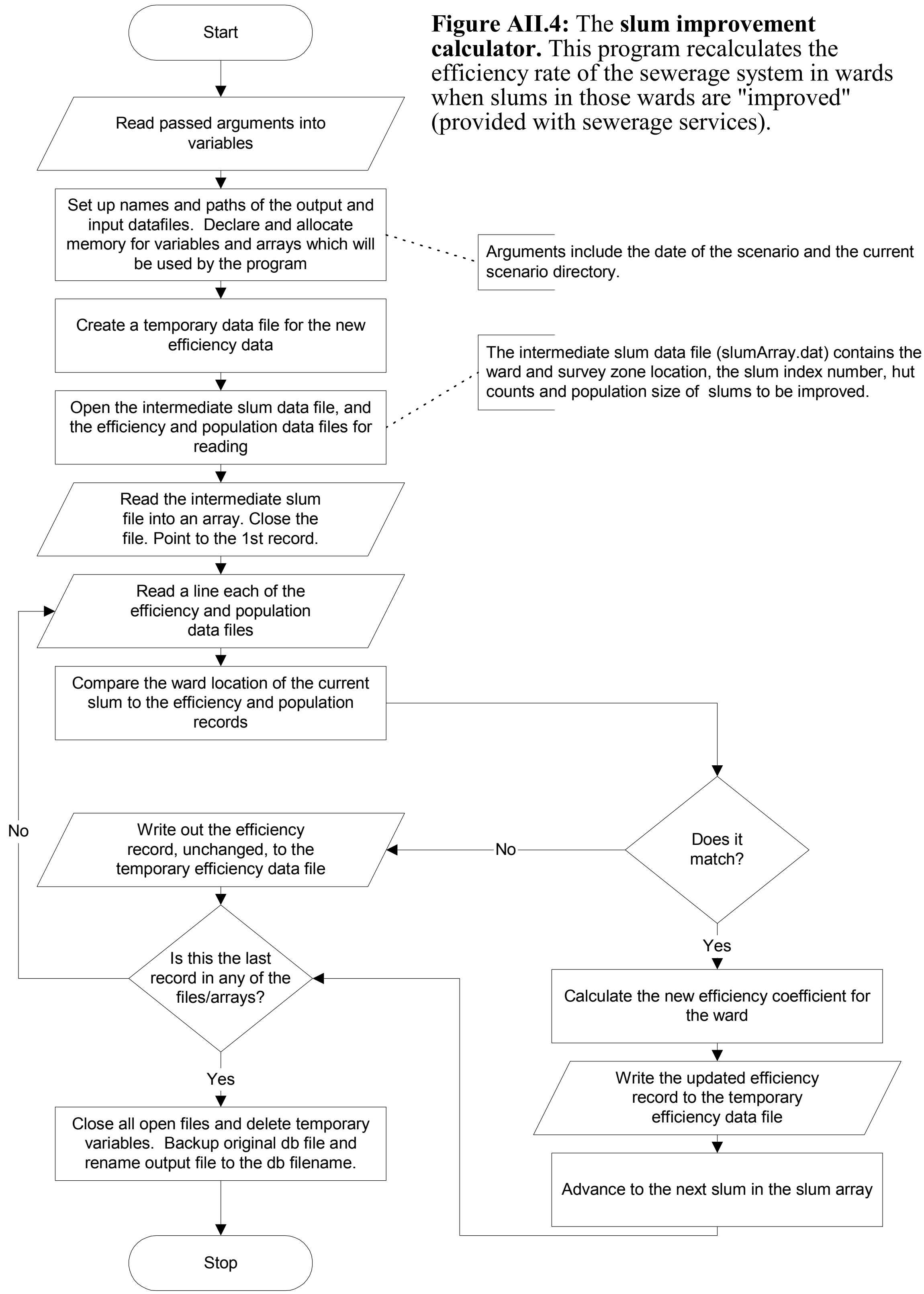
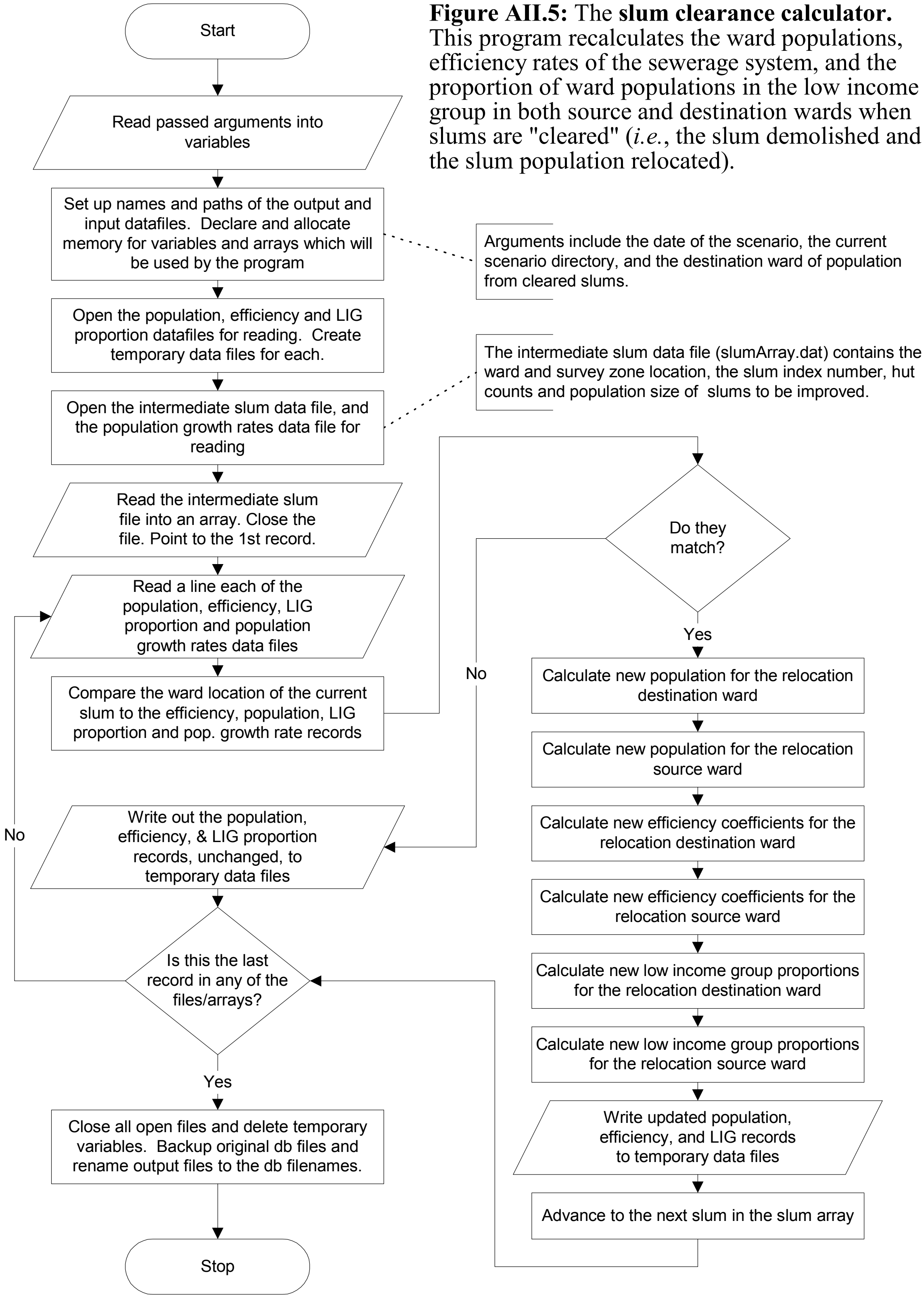


Figure AII.4: The **slum improvement calculator.** This program recalculates the efficiency rate of the sewerage system in wards when slums in those wards are "improved" (provided with sewerage services).

Figure AII.5: The **slum clearance calculator.** This program recalculates the ward populations, efficiency rates of the sewerage system, and the proportion of ward populations in the low income group in both source and destination wards when slums are "cleared" (*i.e.*, the slum demolished and the slum population relocated).



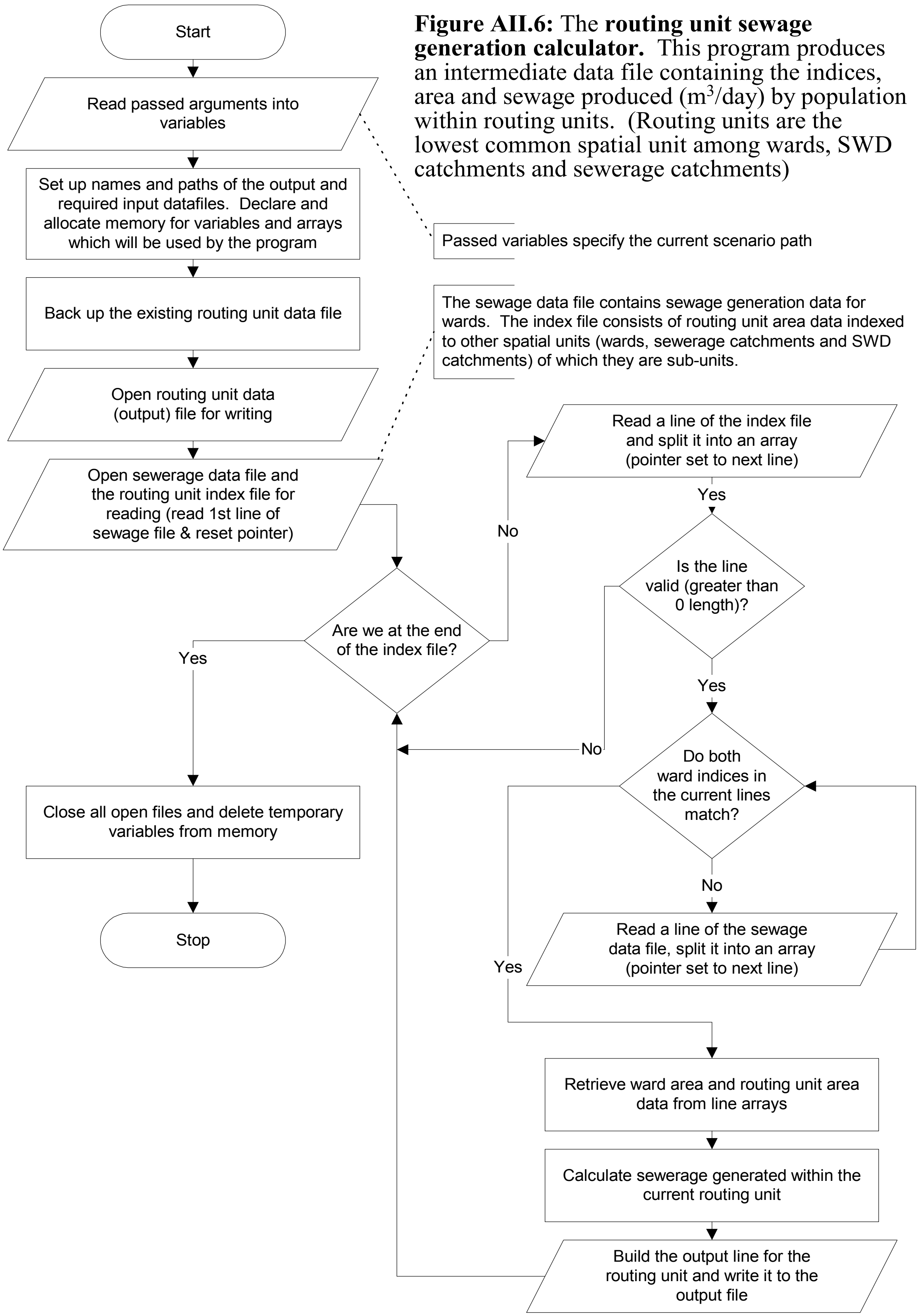


Figure AII.6: The **routing unit sewage generation calculator.** This program produces an intermediate data file containing the indices, area and sewage produced (m^3/day) by population within routing units. (Routing units are the lowest common spatial unit among wards, SWD catchments and sewerage catchments)

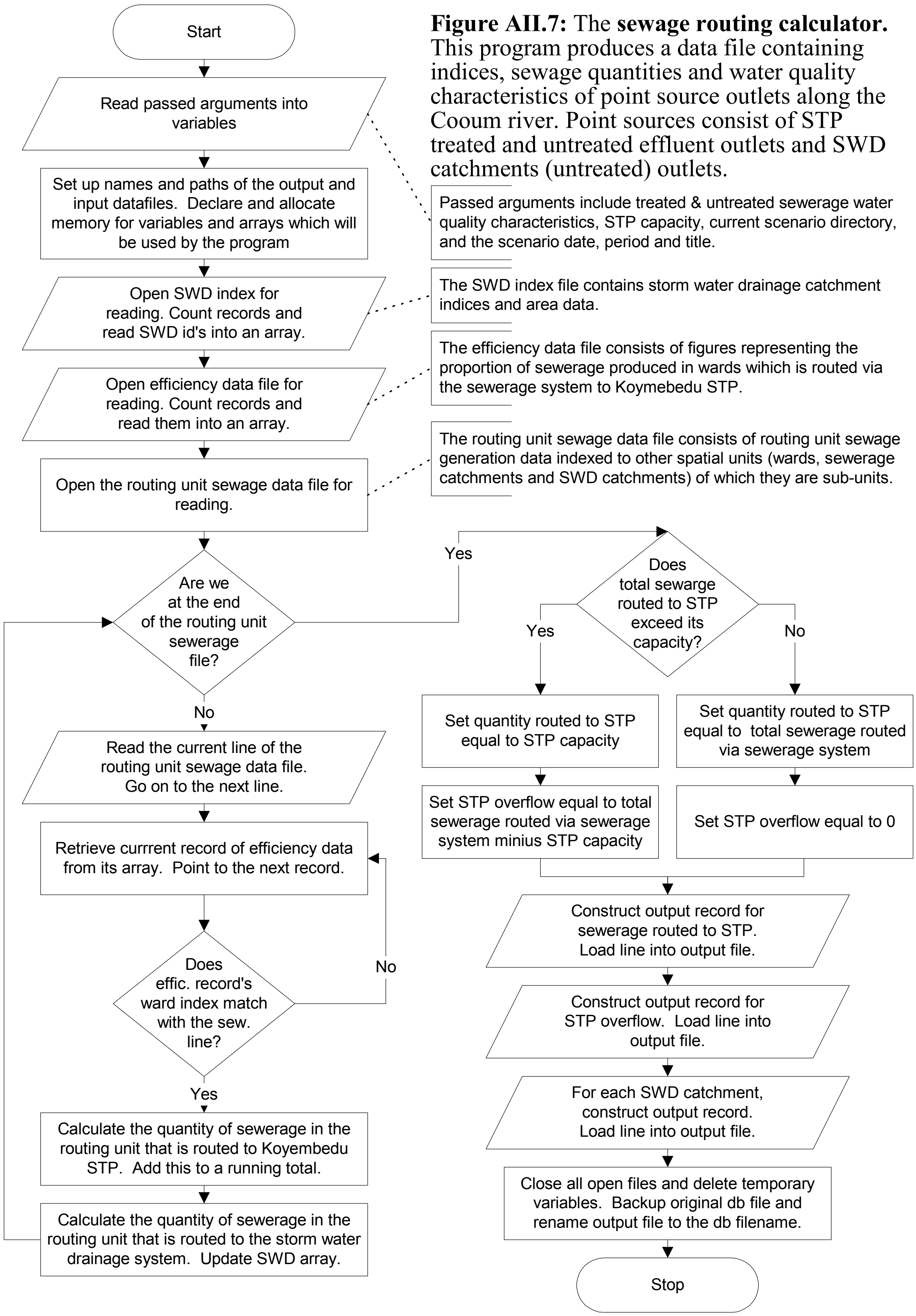


Figure AII.7: The **sewage routing calculator.** This program produces a data file containing indices, sewage quantities and water quality characteristics of point source outlets along the Cooum river. Point sources consist of STP treated and untreated effluent outlets and SWD catchments (untreated) outlets.

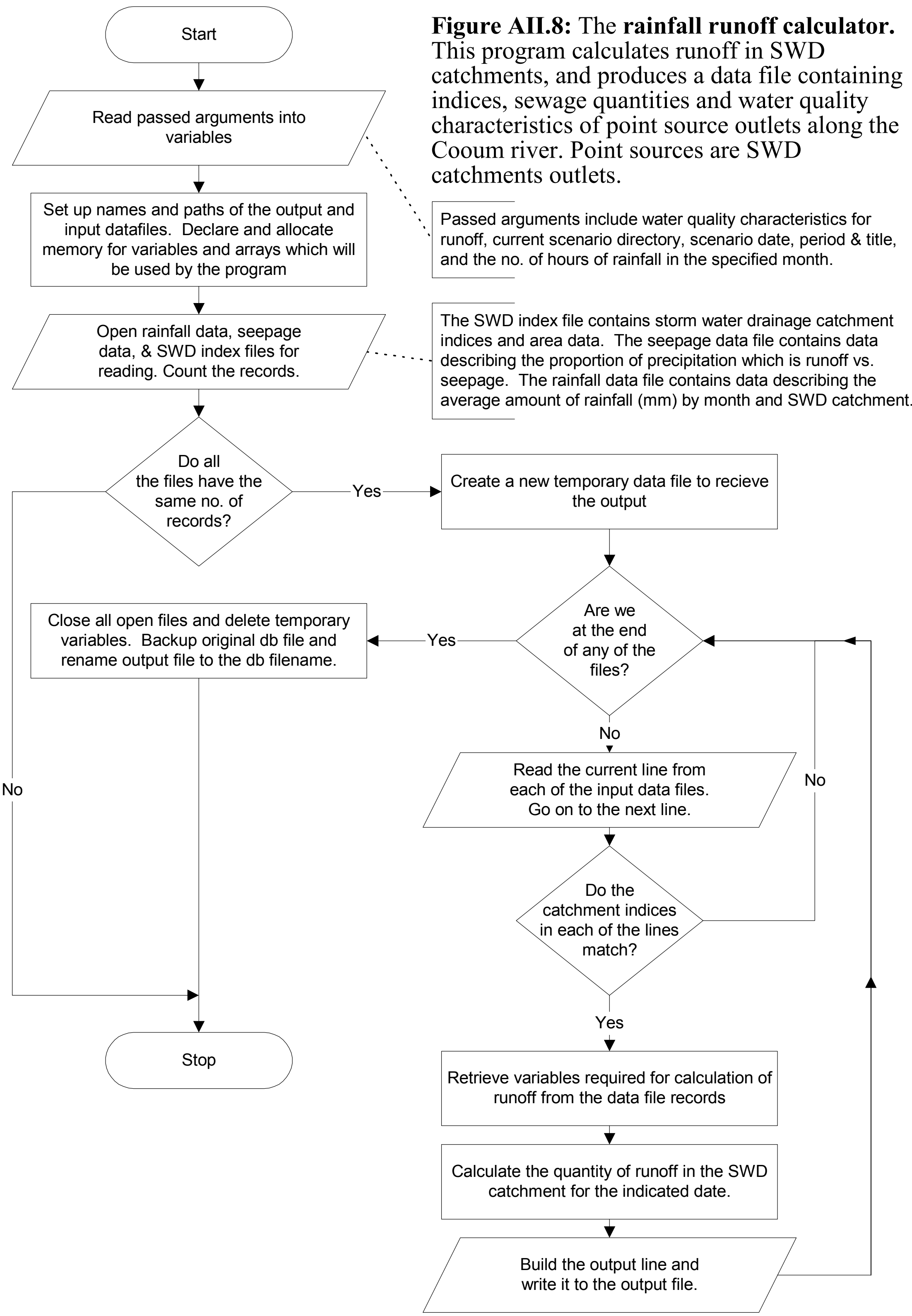


Figure AII.8: The **rainfall runoff calculator.** This program calculates runoff in SWD catchments, and produces a data file containing indices, sewage quantities and water quality characteristics of point source outlets along the Cooum river. Point sources are SWD catchments outlets.

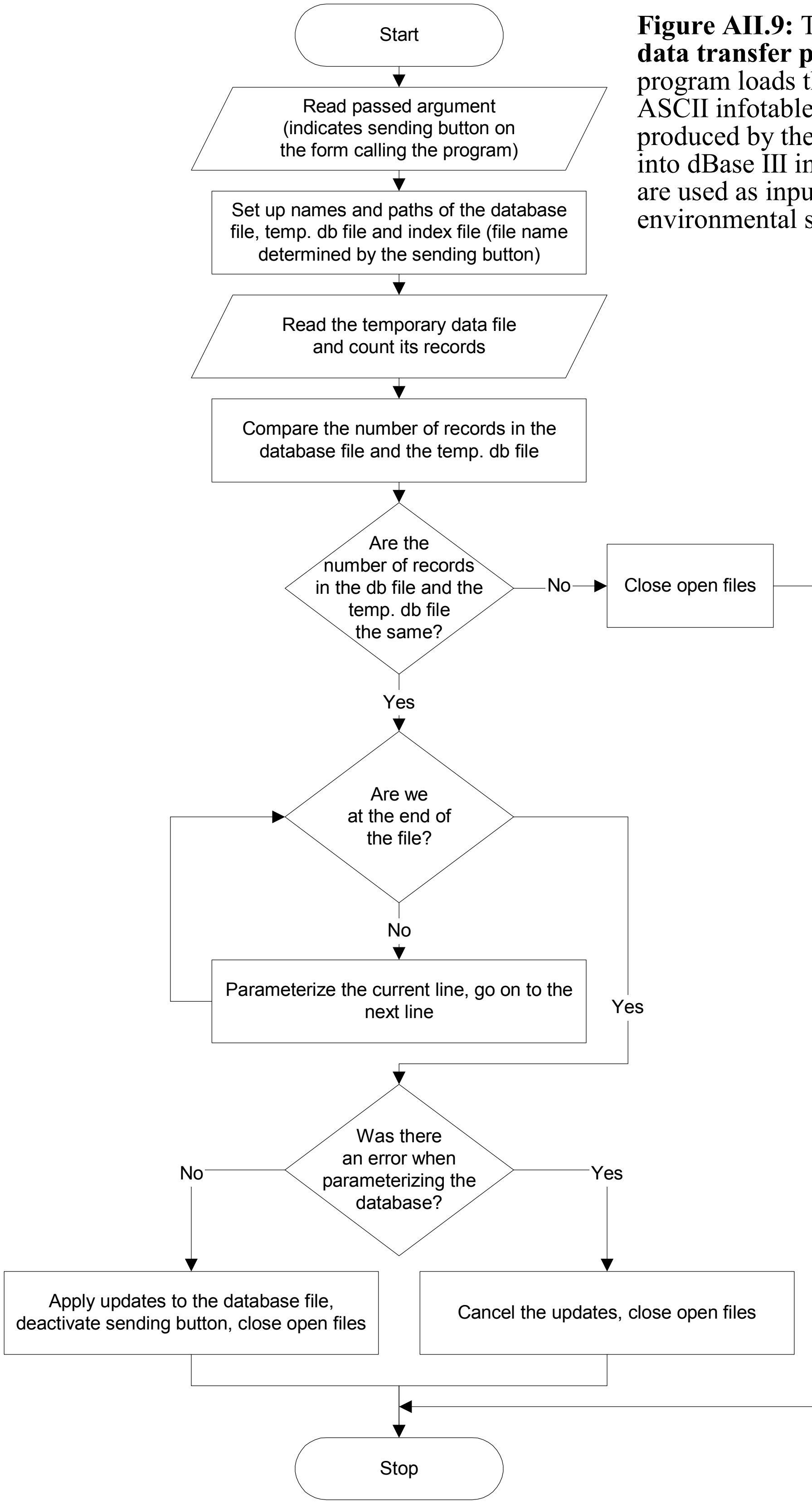


Figure AII.9: The **parametization data transfer program.** This program loads the data stored in ASCII infotable files (that are produced by the DSS/GIS modules) into dBase III infotable files (that are used as input to the environmental simulation model).

Appendix III

Water Quality Indicators for the Cooum System

Water Quality Indicators for the Cooum System

This Appendix presents water quality indicators for the Cooum River, Buckingham Canal, Otteri Nullah and Captain Cotton Canal (Table AIII.2). Table AIII.1 below indicates the sources of this data (the number of the source correspond to superscripts in Table AIII.2).

Table AIII.1: Sources and comments on water quality indicator data.

	Reference	*Notes*
1	Chengalvarayan, D., A.V. Raghypathy, and S. Cheandrasekaran (1999) "Surface Water Quality in Cooum and Adayar – Avoiding Risk". Paper presented at the Seminar on the International Day for Natural Disaster Reduction, 13 October 1999, at the Anna Institute of Management. Chennai: Anna University.	
2	Gunaselvam, M (1999) "Preserving the Identity of Waterfronts in Chennai City" (unpublished). Chennai: Department of Geography, University of Madras.	Data is from the Tamil Nadu Pollution Control Board, 1992, based on the means of several samples (typically 9, but in one instance at least, 8).
3	Ravichandran, S. (1987) "Water Quality Studies on Buckingham Canal (Madras, India) – A Discriminant Analysis" in Hydrobiologia 154:121-126.	Data are means from monthly samples taken from 1981 to 1983.
4	Sridhar, M.K.S. (1982) "A Field Study of Estuarine Pollution in Madras, India" in *Marine Pollution Bulletin* 13(7):233-236.	Data are published in 1982, assumed colleced in 1981. Data seem to be collected in conditions of high tide, with flushing action and cleared sandbar at mouth of cooum. Data for Buckingham canal – location is unspecified but from the discussion the sample seems to be taken from the section in the city north of the Coowm - B. Canal confluence.
5	Government of Tamil Nadu (1997) *Terms of Reference for Consultancy Services for Preparation of Master Plan, Immediate Works Programme and Bid Documents for Chennai Waterways Rehabilitation and Reclamation Project*. Chennai: TNPWD	Data is from Table 2 "Inner Chennai Waterway Characteristics" which originates from a Trent Severn study (1997) "Environmental Improvement of the Watercourses of Greater Chennai". The TDS value for the North B. Canal seemed to be a typo. Table 2 indicates "20553.67". "2553.67" is recorded here.
6	Mott Macdonald Ltd. (1994) *Sludge Disposal Consultancy, Madras: Final Report*. Chennai: Department of Environment and Forests, Government of Tamil Nadu.	
7	Marinos, P.G., G.C. Koukis, G.C. Tsiambaos and G.C. Stournaras (1997) "Effects of Trace Metals on Human Health: A Case Study from River Cooum, Madras, India" in *Engineering Geology and the Environment*. International Symposium on Engineering Geology and the Environment 23-27 June, 1997. Athens: IAEG.	Reach distances are estimated from a very small scale map provided with the article and are approximate only.
8	Gowri, V.S. (1997) *Impacts of Adyar and Cooum River Discharges on the Water and Sediment Qualities of Marina Beach, Chennai*. PhD Dissertation. Chennai: Faculty of Science and Humanities, Anna University.	Samples and measurements were taken at low tide. 'Hardness' figures were reported in the source as 'Salinity'. Figures for DO were originally in ml/l, but this is a typo. In the author's calculation of DO, volume units cancel out, leaving the measurement in mg/l. Flow data is converted from mld.
9	Gowri, V.S. (1997) *Impacts of Adyar and Cooum River Discharges on the Water and Sediment Qualities of Marina Beach, Chennai.* PhD Dissertation. Chennai: Faculty of Science and Humanities, Anna University.	Chlorinity calculated from salinity figures provided in (8) above using the formula: (Cl/1.8705)-0.03

Table AIII.2:
Water Quality Indicators

	Date	E.C.	Total Hardness mg/l	pH Os/cm	As mg/l	Ca mg/l	Mg mg/l	Cd Og/l	Zn Og/l	Ni mg/l	Hg mg/l	Cu mg/l	Fe mg/l	Hexavalent Cr mg/l
COOUM RIVER														
~1.25 Km upstream	1997				0.125 [7]			0.0140 [7]			<0.050 [7]	0.010 [7]		
~2.2 Km upstream	1997				0.528 [7]			<0.010 [7]			0.26 [7]	0.037 [7]		
~3.1 Km upstream	1997				0.968 [7]			0.0180 [7]			0.335 [7]	0.039 [7]		
~4.1 Km upstream	1997				1.672 [7]			0.0120 [7]			0.409 [7]	0.022 [7]		
~6 Km upstream	1997				0.352 [7]			<0.010 [7]			0.297 [7]	<0.010 [7]		
~8 Km upstream	1997				0.528 [7]			0.0110 [7]			0.297 [7]	<0.010 [7]		
~9.8 Km upstream	1997				0.176 [7]			0.0110 [7]			0.335 [7]	<0.010 [7]		
~11.5 Km upstream	1997				0.704 [7]			0.0180 [7]			0.335 [7]	<0.010 [7]		
~13 Km upstream	1997				7.488 [7]			0.2830 [7]			1.637 [7]	0.016 [7]		
~14.2 Km upstream	1997				5.460 [7]			0.0160 [7]			1.227 [7]	0.014 [7]		
~16 Km upstream	1997				5.372 [7]			0.0200 [7]			1.302 [7]	0.026 [7]		
unspecified – dry season	1997													
unspecified – monsoon season	1997													
unspecified	1997			7.76 [5]				BDL [5]	0.34 [5]	BDL [5]	BDL [5]	0.110 [5]		BDL [5]
Anna Nagar Bridge	11/95	600 [1]		8.20 [1]			36 [1]					0.400 [1]	2 [1]	
Anna Nagar Bridge	01/96	2120 [1]		7.90 [1]			77 [1]					0.300 [1]	6 [1]	
Anna Nagar Bridge	03/96	2650 [1]		- [1]			32 [1]					0.100 [1]	10 [1]	
Anna Nagar Bridge	05/96	1480 [1]		- [1]			35 [1]					0.200 [1]	12 [1]	
Anna Nagar Bridge	07/96	2350 [1]		- [1]			48 [1]					0.100 [1]	8 [1]	
Choolaimedu Causeway	11/95	810 [1]		7.90 [1]			18 [1]					0.200 [1]	4 [1]	
Choolaimedu Causeway	01/96	2280 [1]		8.20 [1]			53 [1]					0.100 [1]	8 [1]	
Choolaimedu Causeway	03/96	2220 [1]		- [1]			22 [1]					0.200 [1]	12 [1]	
Choolaimedu Causeway	05/96	1670 [1]		- [1]			44 [1]					0.300 [1]	18 [1]	
Choolaimedu Causeway	07/96	2000 [1]		- [1]			38 [1]					0.200 [1]	10 [1]	
Bridge near Mount Rd Tarapur Tower	11/95	880 [1]		8.60 [1]			26 [1]					0.200 [1]	10 [1]	
Bridge near Mount Rd Tarapur Tower	01/96	5490 [1]		8.20 [1]			115 [1]					0.200 [1]	12 [1]	
Bridge near Mount Rd Tarapur Tower	03/96	2480 [1]		- [1]			22 [1]					0.200 [1]	8 [1]	
Bridge near Mount Rd Tarapur Tower	05/96	1960 [1]		- [1]			41 [1]					0.200 [1]	10 [1]	
Bridge near Mount Rd Tarapur Tower	07/96	5570 [1]		- [1]			154 [1]					0.300 [1]	12 [1]	
Cooum & B. Canal Near Gen Hosp.	11/95	1530 [1]		8.20 [1]			33 [1]					0.200 [1]	8 [1]	
Cooum & B. Canal Near Gen Hosp.	01/96	7370 [1]		8.00 [1]			24 [1]					0.300 [1]	10 [1]	
Cooum & B. Canal Near Gen Hosp.	03/96	2490 [1]		- [1]			24 [1]					0.200 [1]	16 [1]	
Cooum & B. Canal Near Gen Hosp.	05/96	1770 [1]		- [1]			42 [1]					0.300 [1]	17 [1]	
Cooum & B. Canal Near Gen Hosp.	07/96	2080 [1]		- [1]			44 [1]					0.300 [1]	10 [1]	
Periyar Bridge near Palavan House	11/95	4640 [1]		8.30 [1]			116 [1]					0.600 [1]	15 [1]	
Periyar Bridge near Palavan House	01/96	2430 [1]		7.80 [1]			60 [1]					0.400 [1]	18 [1]	
Periyar Bridge near Palavan House	03/96	22200 [1]		- [1]			280 [1]					0.500 [1]	20 [1]	
Periyar Bridge near Palavan House	05/96	10300 [1]		- [1]			154 [1]					0.400 [1]	20 [1]	
Periyar Bridge near Palavan House	07/96	12400 [1]		- [1]			360 [1]					0.300 [1]	16 [1]	
Napeir Bridge	11/95	3050 [1]		8.10 [1]			34 [1]					0.400 [1]	12 [1]	
Napeir Bridge	01/96	3570 [1]		8.10 [1]			110 [1]					0.200 [1]	12 [1]	
Napeir Bridge	03/96	48100 [1]		- [1]			680 [1]					0.100 [1]	10 [1]	
Napeir Bridge	05/96	19400 [1]		- [1]			840 [1]					0.200 [1]	12 [1]	
Napeir Bridge	07/96	15000 [1]		- [1]			468 [1]					0.200 [1]	16 [1]	
Upper Reach dry season)	1994													
Upper Reach (monsoon season)	1993-4													
Middle Reach (dry season)	1994													
Middle Reach (monsoon season)	1993-4													
Lower Reach (dry season)	1994													
Lower Reach (monsoon season)	1993-4													
~ 9.8 km upstream of the mouth	1/94		752 [8]	7.20 [8]				0.0020 [8]	3.21 [8]					
~ 8.9 km upstream of the mouth	1/94		752 [8]	7.30 [8]				0.0030 [8]	3.63 [8]					
~ 7.1 km upstream of the mouth	1/94		933 [8]	7.45 [8]				0.0050 [8]	3.28 [8]					
~ 4.8 km upstream of the mouth	1/94		2377 [8]	7.45 [8]				0.0050 [8]	3.52 [8]					
~ 2.6 km upstream of the mouth	1/94		3099 [8]	7.50 [8]				0.0055 [8]	3.31 [8]					
Cooum South Arm ~2 km from mouth	1/94		4723 [8]	7.30 [8]				0.0070 [8]	3.29 [8]					
Cooum North Arm ~2.2 km from mouth	1/94		8333 [8]	7.40 [8]				0.0060 [8]	3.28 [8]					
~ 9.8 km upstream of the mouth	4/94		1113 [8]	7.35 [8]				0.0030 [8]	3.22 [8]					
~ 8.9 km upstream of the mouth	4/94		1113 [8]	7.30 [8]				0.0033 [8]	3.25 [8]					
~ 7.1 km upstream of the mouth	4/94		1203 [8]	7.30 [8]				0.0057 [8]	3.45 [8]					
~ 4.8 km upstream of the mouth	4/94		1474 [8]	7.35 [8]				0.0050 [8]	3.4 [8]					
~ 2.6 km upstream of the mouth	4/94		2016 [8]	7.40 [8]				0.0054 [8]	3.37 [8]					
Cooum South Arm ~2 km from mouth	4/94		3821 [8]	7.15 [8]				0.0072 [8]	3.55 [8]					
Cooum North Arm ~2.2 km from mouth	4/94		4001 [8]	7.35 [8]				0.0067 [8]	3.22 [8]					
~ 9.8 km upstream of the mouth	7/94		1474 [8]	6.90 [8]				0.0020 [8]	3.28 [8]					
~ 8.9 km upstream of the mouth	7/94		1510 [8]	6.95 [8]				0.0030 [8]	3.32 [8]					
~ 7.1 km upstream of the mouth	7/94		933 [8]	6.90 [8]				0.0050 [8]	3.55 [8]					
~ 4.8 km upstream of the mouth	7/94		4182 [8]	7.00 [8]				0.0048 [8]	3.79 [8]					
~ 2.6 km upstream of the mouth	7/94		12124 [8]	6.90 [8]				0.0056 [8]	3.31 [8]					
Cooum South Arm ~2 km from mouth	7/94		12485 [8]	7.25 [8]				0.0074 [8]	3.44 [8]					
Cooum North Arm ~2.2 km from mouth	7/94		1447 [8]	7.15 [8]				0.0054 [8]	3.18 [8]					
~ 9.8 km upstream of the mouth	9/94		535 [8]	7.05 [8]				0.0010 [8]	2.94 [8]					
~ 8.9 km upstream of the mouth	9/94		499 [8]	7.02 [8]				0.0015 [8]	2.75 [8]					
~ 7.1 km upstream of the mouth	9/94		427 [8]	7.05 [8]				0.0039 [8]	3.49 [8]					
~ 4.8 km upstream of the mouth	9/94		391 [8]	7.00 [8]				0.0041 [8]	3.56 [8]					
~ 2.6 km upstream of the mouth	9/94		752 [8]	7.50 [8]				0.0043 [8]	3.08 [8]					
Cooum South Arm ~2 km from mouth	9/94		3026 [8]	7.35 [8]				0.0051 [8]	3.09 [8]					

Table AIII.2
(continued)

(COOUM RIVER, CONTINUED)	Date	E.C.	Total Hardness mg/l	pH Os/cm	As mg/l	Ca mg/l	Mg mg/l	Cd Og/l	Zn Og/l	Ni mg/l	Hg mg/l	Cu mg/l	Fe mg/l	Hexavalent Cr mg/l
Cooum North Arm ~2.2 km from mouth	9/94		3207 [8]	7.55 [8]				0.0069 [8]	3.25 [8]					
~ 9.8 km upstream of the mouth	1/95		463 [8]	7.60 [8]				0.0021 [8]	3.55 [8]					
~ 8.9 km upstream of the mouth	1/95		680 [8]	7.20 [8]				0.0022 [8]	3.94 [8]					
~ 7.1 km upstream of the mouth	1/95		716 [8]	7.15 [8]				0.0048 [8]	4.1 [8]					
~ 4.8 km upstream of the mouth	1/95		644 [8]	6.95 [8]				0.0045 [8]	4.27 [8]					
~ 2.6 km upstream of the mouth	1/95		680 [8]	7.05 [8]				0.0043 [8]	3.87 [8]					
Cooum South Arm ~2 km from mouth	1/95		788 [8]	7.80 [8]				0.0055 [8]	3.83 [8]					
Cooum North Arm ~2.2 km from mouth	1/95		860 [8]	7.80 [8]				0.0071 [8]	3.75 [8]					
Cooum Mouth	8/93		25300 [8]	7.60 [8]				0.0300 [8]	5.42 [8]					
Cooum Mouth	9/93		26490 [8]	7.65 [8]				0.3400 [8]	5.31 [8]					
Cooum Mouth	10/93		18080 [8]	7.20 [8]				0.0400 [8]	5.84 [8]					
Cooum Mouth	11/93		12300 [8]	7.25 [8]				0.0200 [8]	5.98 [8]					
Cooum Mouth	12/93		7790 [8]	7.15 [8]				0.0100 [8]	5.2 [8]					
Cooum Mouth	1/94		21320 [8]	7.45 [8]				0.0100 [8]	5.02 [8]					
Cooum Mouth	2/94		28000 [8]	7.65 [8]				0.0100 [8]	5.19 [8]					
Cooum Mouth	3/94		18260 [8]	6.90 [8]				0.0200 [8]	5.2 [8]					
Cooum Mouth	4/94		7250 [8]	7.35 [8]				0.0200 [8]	5.5 [8]					
Cooum Mouth	5/94		9230 [8]	7.05 [8]				0.0200 [8]	5.6 [8]					
Cooum Mouth	6/94		11220 [8]	7.20 [8]				0.0100 [8]	5.7 [8]					
Cooum Mouth	7/94		21140 [8]	7.15 [8]				0.0100 [8]	5.2 [8]					
Cooum Mouth	8/94		22140 [8]	7.05 [8]				0.0100 [8]	5.15 [8]					
Cooum Mouth	9/94		24390 [8]	7.70 [8]				0.0100 [8]	5.12 [8]					
Cooum Mouth	10/94		2010 [8]	8.05 [8]				0.0250 [8]	5.2 [8]					
Cooum Mouth	11/94		4900 [8]	7.50 [8]				0.0300 [8]	5.3 [8]					
Cooum Mouth	12/94		12120 [8]	8.15 [8]				0.0100 [8]	5.02 [8]					
Napeir Bridge (mean of 9 samples)	1992			7.09 [2]										
Napeir Bridge (max. of 9 samples)	1992			7.63 [2]										
Napeir Bridge (min. of 9 samples)	1992			6.17 [2]										
Outlet to sea (during high tide)	1981		6996 [4]			531 [4]	1379 [4]							
Cooum estuary	1981													
1.0 Km upstream (during high tide)	1981		6254 [4]			529 [4]	1200 [4]							
2.0 Km upstream (during high tide)	1981		4452 [4]			311 [4]	894 [4]							
3.0 Km upstream (during high tide)	1981		3392 [4]			181 [4]	715 [4]							
4.0 Km upstream (during high tide)	1981		3021 [4]			243 [4]	587 [4]							
6.0 Km upstream (during high tide)	1981		1325 [4]			27 [4]	306 [4]							
BUCKINGHAM CANAL														
unspecified – dry season	1997													
unspecified – monsoon season	1997													
North Buckingham Canal	1997			8.12 [5]				BDL [5]	0.35 [5]	BDL [5]	BDL [5]	0.350 [5]		BDL [5]
Central Buckingham Canal	1997			7.44 [5]				BDL [5]	2.41 [5]	BDL [5]	BDL [5]	0.860 [5]		BDL [5]
South Buckingham Canal	1997			7.80 [5]				BDL [5]	0.17 [5]	BDL [5]	BDL [5]	0.180 [5]		BDL [5]
B. Canal basin (dry season)	1994													
B. Canal basin (monsoon season)	1993-4													
Central (dry season)	1994													
Central (monsoon season)	1993-4													
South (dry season)	1994													
South (monsoon season)	1993-4													
Wallajah Road Bridge (mean:9 Samples)	1992			6.96 [2]										
Wallajah Road Bridge (max:9 Samples)	1992			7.45 [2]										
Wallajah Road Bridge (min:9 Samples)	1992			6.35 [2]										
Stn1 (suburb N) (mean:monthly samples)	1981-83			7.78 [3]										
Stn2 (city N) (mean:monthly samples)	1981-83			7.53 [3]										
Stn3 (city Cen.) (mean:monthly samples)	1981-83			7.31 [3]										
Stn4 (city S) (mean:monthly samples)	1981-83			6.92 [3]										
Stn5 (suburb S) (mean:monthly samples)	1981-83			7.05 [3]										
Unspecified, probably N-Cen. Chennai	1981													
OTTERI NULLAH														
unspecified – monsoon season	1997													
unspecified	1997			7.22 [5]				BDL [5]	0.43 [5]	BDL [5]	BDL [5]	0.250 [5]		BDL [5]
unspecified – dry season	1997													
Upper Reach (dry season)	1994													
Upper Reach (monsoon season)	1993-4													
Middle Reach (dry season)	1994													
Middle Reach (monsoon season)	1993-4													
Lower Reach (dry season)	1994													
Lower Reach (monsoon season)	1993-4													
Nr.Thiru Mangalam (mean:9 samp,TDS=8)	1992			7.06 [2]										
Nr.Thiru Mangalam (max:9 samp,TDS=8)	1992			7.92 [2]										
Nr.Thiru Mangalam (min.:9 samp,TDS=8)	1992			6.73 [2]										
CAPTAIN COTTON CANAL														
Upper Reach (dry season)	1994													
Upper Reach (monsoon season)	1993-4													
Middle Reach (dry season)	1994													
Middle Reach (monsoon season)	1993-4													
Lower Reach (dry season)	1994													
Lower Reach (monsoon season)	1993-4													

Table AIII.2

(continued)

	Date	Total Cr mg/l	Pb Og/l	Se mg/l	Sluphides mg/l	SO_4 mg/l	SO_3 mg/l	SO mg/l	(Chorides) Cl mg/l	NH_3-N mg/l	NH_4-N O/l	Nitrites NO_2-N mg/l	Nitrates NO_3-N mg/l
COOUM RIVER													
~1.25 Km upstream	1997		<0.100 [7]	<0.250 [7]									
~2.2 Km upstream	1997		0.101 [7]	0.385 [7]									
~3.1 Km upstream	1997		0.151 [7]	0.289 [7]									
~4.1 Km upstream	1997		0.126 [7]	0.385 [7]									
~6 Km upstream	1997		0.101 [7]	<0.250 [7]									
~8 Km upstream	1997		<0.100 [7]	<0.250 [7]									
~9.8 Km upstream	1997		<0.100 [7]	<0.250 [7]									
~11.5 Km upstream	1997		0.151 [7]	<0.250 [7]									
~13 Km upstream	1997		0.328 [7]	0.289 [7]									
~14.2 Km upstream	1997		0.202 [7]	0.481 [7]									
~16 Km upstream	1997		0.227 [7]	0.674 [7]									
unspecified – dry season	1997												
unspecified – monsoon season	1997												
unspecified	1997	BDL [5]	0.090 [5]		3.3 [5]				501.33 [5]				
Anna Nagar Bridge	11/95					61.00 [1]			103.00 [1]				
Anna Nagar Bridge	01/96					86.00 [1]			540.00 [1]				
Anna Nagar Bridge	03/96					72.00 [1]			561.00 [1]				
Anna Nagar Bridge	05/96					70.00 [1]			440.00 [1]				
Anna Nagar Bridge	07/96					108.00 [1]			691.00 [1]				
Choolaimedu Causeway	11/95					62.00 [1]			152.00 [1]				
Choolaimedu Causeway	01/96					53.00 [1]			612.00 [1]				
Choolaimedu Causeway	03/96					48.00 [1]			460.00 [1]				
Choolaimedu Causeway	05/96					67.00 [1]			421.00 [1]				
Choolaimedu Causeway	07/96					80.00 [1]			504.00 [1]				
Bridge near Mount Rd Tarapur Tower	11/95					67.00 [1]			142.00 [1]				
Bridge near Mount Rd Tarapur Tower	01/96					108.00 [1]			1715.00 [1]				
Bridge near Mount Rd Tarapur Tower	03/96					96.00 [1]			633.00 [1]				
Bridge near Mount Rd Tarapur Tower	05/96					82.00 [1]			590.00 [1]				
Bridge near Mount Rd Tarapur Tower	07/96					240.00 [1]			1360.00 [1]				
Cooum & B. Canal Near Gen Hosp.	11/95					130.00 [1]			248.00 [1]				
Cooum & B. Canal Near Gen Hosp.	01/96					115.00 [1]			2232.00 [1]				
Cooum & B. Canal Near Gen Hosp.	03/96					120.00 [1]			504.00 [1]				
Cooum & B. Canal Near Gen Hosp.	05/96					96.00 [1]			529.00 [1]				
Cooum & B. Canal Near Gen Hosp.	07/96					168.00 [1]			3525.00 [1]				
Periyar Bridge near Palavan House	11/95					331.00 [1]			390.00 [1]				
Periyar Bridge near Palavan House	01/96					77.00 [1]			648.00 [1]				
Periyar Bridge near Palavan House	03/96					220.00 [1]			9000.00 [1]				
Periyar Bridge near Palavan House	05/96					196.00 [1]			3960.00 [1]				
Periyar Bridge near Palavan House	07/96					252.00 [1]			3996.00 [1]				
Napeir Bridge	11/95					168.00 [1]			432.00 [1]				
Napeir Bridge	01/96					106.00 [1]			1008.00 [1]				
Napeir Bridge	03/96					96.00 [1]			18000.00 [1]				
Napeir Bridge	05/96					320.00 [1]			6552.00 [1]				
Napeir Bridge	07/96					420.00 [1]			4500.00 [1]				
Upper Reach dry season)	1994												
Upper Reach (monsoon season)	1993-4												
Middle Reach (dry season)	1994												
Middle Reach (monsoon season)	1993-4												
Lower Reach (dry season)	1994												
Lower Reach (monsoon season)	1993-4												
~ 9.8 km upstream of the mouth	1/94		0.320 [8]						400.00 [8]	10.4 [8]		0.200 [8]	62.00 [8]
~ 8.9 km upstream of the mouth	1/94		0.450 [8]						400.00 [8]	10.59 [8]		0.100 [8]	51.00 [8]
~ 7.1 km upstream of the mouth	1/94		0.480 [8]						500.00 [8]	10.9 [8]		0.200 [8]	42.00 [8]
~ 4.8 km upstream of the mouth	1/94		0.450 [8]						1300.00 [8]	10.41 [8]		0.200 [8]	51.00 [8]
~ 2.6 km upstream of the mouth	1/94		0.350 [8]						1700.00 [8]	9.6 [8]		0.200 [8]	34.00 [8]
Cooum South Arm ~2 km from mouth	1/94		0.390 [8]						2600.00 [8]	11.65 [8]		0.200 [8]	48.00 [8]
Cooum North Arm ~2.2 km from mouth	1/94		0.480 [8]						4600.00 [8]	10.8 [8]		0.100 [8]	40.00 [8]
~ 9.8 km upstream of the mouth	4/94		0.440 [8]						600.00 [8]	155.00 [8]		2.250 [8]	48.00 [8]
~ 8.9 km upstream of the mouth	4/94		0.470 [8]						600.00 [8]	165.0 [8]		0.500 [8]	126.00 [8]
~ 7.1 km upstream of the mouth	4/94		0.520 [8]						650.00 [8]	165.00 [8]		1.250 [8]	131.00 [8]
~ 4.8 km upstream of the mouth	4/94		0.500 [8]						800.00 [8]	163.0 [8]		1.250 [8]	153.00 [8]
~ 2.6 km upstream of the mouth	4/94		0.460 [8]						1100.00 [8]	150.00 [8]		1.750 [8]	118.00 [8]
Cooum South Arm ~2 km from mouth	4/94		0.430 [8]						2100.00 [8]	215.0 [8]		0.500 [8]	108.00 [8]
Cooum North Arm ~2.2 km from mouth	4/94		0.450 [8]						2200.00 [8]	160.00 [8]		3.000 [8]	134.00 [8]
~ 9.8 km upstream of the mouth	7/94		0.141 [8]						800.00 [8]	21.5 [8]		0.200 [8]	26.00 [8]
~ 8.9 km upstream of the mouth	7/94		0.245 [8]						820.00 [8]	21.60 [8]		0.200 [8]	28.00 [8]
~ 7.1 km upstream of the mouth	7/94		0.550 [8]						500.00 [8]	21.2 [8]		0.200 [8]	31.00 [8]
~ 4.8 km upstream of the mouth	7/94		0.520 [8]						2300.00 [8]	20.47 [8]		0.200 [8]	26.00 [8]
~ 2.6 km upstream of the mouth	7/94		0.420 [8]						6700.00 [8]	19.6 [8]		0.200 [8]	28.00 [8]
Cooum South Arm ~2 km from mouth	7/94		0.360 [8]						6900.00 [8]	21.52 [8]		0.100 [8]	26.00 [8]
Cooum North Arm ~2.2 km from mouth	7/94		0.420 [8]						8000.00 [8]	20.7 [8]		0.100 [8]	28.00 [8]
~ 9.8 km upstream of the mouth	9/94		0.124 [8]						280.00 [8]	11.40 [8]		0.050 [8]	23.00 [8]
~ 8.9 km upstream of the mouth	9/94		0.198 [8]						260.00 [8]	12.3 [8]		0.052 [8]	20.00 [8]
~ 7.1 km upstream of the mouth	9/94		0.480 [8]						220.00 [8]	12.30 [8]		0.053 [8]	23.00 [8]
~ 4.8 km upstream of the mouth	9/94		0.440 [8]						200.00 [8]	10.5 [8]		0.052 [8]	48.00 [8]
~ 2.6 km upstream of the mouth	9/94		0.400 [8]						400.00 [8]	12.00 [8]		0.100 [8]	20.00 [8]
Cooum South Arm ~2 km from mouth	9/94		0.390 [8]						1660.00 [8]	14.0 [8]		0.053 [8]	23.00 [8]

Table AIII.2: Water Quality Indicators (continued) *(COOUM RIVER, CONTINUED)*	Date	Total Cr mg/l	Pb Og/l	Se mg/l	Sluphides mg/l	SO_4 mg/l	SO_3 mg/l	SO mg/l	(Chorides) Cl mg/l	NH_3-N mg/l	NH_4-N O/l	Nitrites NO_2-N mg/l	Nitrates NO_3-N mg/l
Cooum North Arm ~2.2 km from mouth	9/94		0.320 [8]						1760.00 [8]	12.40 [8]		0.052 [8]	20.00 [8]
~ 9.8 km upstream of the mouth	1/95		0.350 [8]						240.00 [8]	12.2 [8]		0.050 [8]	31.00 [8]
~ 8.9 km upstream of the mouth	1/95		0.470 [8]						360.00 [8]	14.47 [8]		0.052 [8]	37.00 [8]
~ 7.1 km upstream of the mouth	1/95		0.550 [8]						380.00 [8]	16.6 [8]		0.100 [8]	57.00 [8]
~ 4.8 km upstream of the mouth	1/95		0.490 [8]						340.00 [8]	13.41 [8]		0.550 [8]	51.00 [8]
~ 2.6 km upstream of the mouth	1/95		0.480 [8]						360.00 [8]	16.9 [8]		0.054 [8]	28.00 [8]
Cooum South Arm ~2 km from mouth	1/95		0.520 [8]						420.00 [8]	16.59 [8]		0.052 [8]	28.00 [8]
Cooum North Arm ~2.2 km from mouth	1/95		0.520 [8]						460.00 [8]	16.2 [8]		0.100 [8]	40.00 [8]
Cooum Mouth	8/93		0.390 [8]						14016.59 [9]	5.50 [8]		0.500 [8]	20.00 [8]
Cooum Mouth	9/93		0.380 [8]						14675.87 [9]	7.5 [8]		0.700 [8]	40.00 [8]
Cooum Mouth	10/93		0.450 [8]						10016.59 [9]	6.00 [8]		38.000 [8]	71.00 [8]
Cooum Mouth	11/93		0.780 [8]						6814.37 [9]	39.0 [8]		15.000 [8]	34.00 [8]
Cooum Mouth	12/93		0.520 [8]						4315.76 [9]	232.00 [8]		4.100 [8]	28.00 [8]
Cooum Mouth	1/94		0.050 [8]						11811.60 [9]	7.5 [8]		0.320 [8]	17.00 [8]
Cooum Mouth	2/94		0.050 [8]						15512.44 [9]	6.80 [8]		2.400 [8]	20.00 [8]
Cooum Mouth	3/94		0.100 [8]						10116.31 [9]	21.0 [8]		1.700 [8]	26.00 [8]
Cooum Mouth	4/94		0.540 [8]						4016.59 [9]	145.00 [8]		1.750 [8]	82.00 [8]
Cooum Mouth	5/94		0.550 [8]						5113.54 [9]	110.0 [8]		0.650 [8]	32.00 [8]
Cooum Mouth	6/94		0.630 [8]						6216.04 [9]	19.56 [8]		0.040 [8]	26.00 [8]
Cooum Mouth	7/94		0.450 [8]						11711.88 [9]	14.8 [8]		0.020 [8]	45.00 [8]
Cooum Mouth	8/94		0.200 [8]						12265.90 [9]	12.55 [8]		0.020 [8]	12.00 [8]
Cooum Mouth	9/94		0.300 [8]						13512.44 [9]	0.3 [8]		0.020 [8]	42.00 [8]
Cooum Mouth	10/94		0.400 [8]						1113.54 [9]	3.00 [8]		0.450 [8]	40.00 [8]
Cooum Mouth	11/94		0.900 [8]						2714.65 [9]	12.1 [8]		0.100 [8]	15.00 [8]
Cooum Mouth	12/94		0.500 [8]						6714.65 [9]	6.25 [8]		0.100 [8]	23.00 [8]
Napeir Bridge (mean of 9 samples)	1992									25.0 [2]			
Napeir Bridge (max. of 9 samples)	1992									50.0 [2]			
Napeir Bridge (min. of 9 samples)	1992									9.0 [2]			
Outlet to sea (during high tide)	1981							1379 [4]		7.0 [4]		- [4]	
Cooum estuary	1981								13000.00 [4]	9.5 [4]		0.500 [4]	trace [4]
1.0 Km upstream (during high tide)	1981							1200 [4]		12.0 [4]		- [4]	
2.0 Km upstream (during high tide)	1981							894 [4]		15.0 [4]		- [4]	
3.0 Km upstream (during high tide)	1981							715 [4]		20.0 [4]		- [4]	
4.0 Km upstream (during high tide)	1981							587 [4]		23.0 [4]		- [4]	
6.0 Km upstream (during high tide)	1981							306 [4]		30.0 [4]		- [4]	
BUCKINGHAM CANAL													
unspecified – dry season	1997												
unspecified – monsoon season	1997												
North Buckingham Canal	1997	0.57 [5]	BDL [5]		2.0 [5]				8920.33 [5]				
Central Buckingham Canal	1997	0.90 [5]	BDL [5]		8.7 [5]				989.67 [5]				
South Buckingham Canal	1997	BDL [5]	BDL [5]		10.7 [5]				372.33 [5]				
B. Canal basin (dry season)	1994												
B. Canal basin (monsoon season)	1993-4												
Central (dry season)	1994												
Central (monsoon season)	1993-4												
South (dry season)	1994												
South (monsoon season)	1993-4												
Wallajah Road Bridge (mean:9 Samples)	1992									39.0 [2]			
Wallajah Road Bridge (max:9 Samples)	1992									69.0 [2]			
Wallajah Road Bridge (min:9 Samples)	1992									2.0 [2]			
Stn1 (suburb N) (mean:monthly samples)	1981-83					11.83 [3]	22.8 [3]				8.96 [3]		0.10 [3]
Stn2 (city N) (mean:monthly samples)	1981-83					68.83 [3]	70.1 [3]				554.41 [3]		5.06 [3]
Stn3 (city Cen.) (mean:monthly samples)	1981-83					37.41 [3]	56.4 [3]				157.41 [3]		1.20 [3]
Stn4 (city S) (mean:monthly samples)	1981-83					66.41 [3]	45.8 [3]				61.83 [3]		1.14 [3]
Stn5 (suburb S) (mean:monthly samples)	1981-83					48.08 [3]	42.4 [3]				58.33 [3]		1.73 [3]
Unspecified, probably N-Cen. Chennai	1981								380.00 [4]	8.2 [4]		nil [4]	trace [4]
OTTERI NULLAH													
unspecified – monsoon season	1997												
unspecified	1997	0.44 [5]	BDL [5]		5.3 [5]				349.33 [5]				
unspecified – dry season	1997												
Upper Reach (dry season)	1994												
Upper Reach (monsoon season)	1993-4												
Middle Reach (dry season)	1994												
Middle Reach (monsoon season)	1993-4												
Lower Reach (dry season)	1994												
Lower Reach (monsoon season)	1993-4												
Nr.Thiru Mangalam (mean:9 samp,TDS=8)	1992									38.0 [2]			
Nr.Thiru Mangalam (max:9 samp,TDS=8)	1992									53.0 [2]			
Nr.Thiru Mangalam (min.:9 samp,TDS=8)	1992									26.0 [2]			
CAPTAIN COTTON CANAL													
Upper Reach (dry season)	1994												
Upper Reach (monsoon season)	1993-4												
Middle Reach (dry season)	1994												
Middle Reach (monsoon season)	1993-4												
Lower Reach (dry season)	1994												
Lower Reach (monsoon season)	1993-4												

Table AIII.2 (continued)

	Date	Total Kjeldahl N, mg/l	DO mg/l	BOD mg/l	COD mg/l	TDS mg/l	TSS mg/l	Temp ºC	Trans-parency m	Turbidity (Klett scale)	Free CO_2 mg/l	3 min permanganate value, mg/l
COOUM RIVER												
~1.25 Km upstream	1997											
~2.2 Km upstream	1997											
~3.1 Km upstream	1997											
~4.1 Km upstream	1997											
~6 Km upstream	1997											
~8 Km upstream	1997											
~9.8 Km upstream	1997											
~11.5 Km upstream	1997											
~13 Km upstream	1997											
~14.2 Km upstream	1997											
~16 Km upstream	1997											
unspecified – dry season	1997											
unspecified – monsoon season	1997											
unspecified	1997		BDL [5]	71.00 [5]	194.67 [5]	1434.0 [5]						
Anna Nagar Bridge	11/95		4.60 [1]	28.00 [1]		331.0 [1]						
Anna Nagar Bridge	01/96		5.00 [1]	34.00 [1]		1360.0 [1]						
Anna Nagar Bridge	03/96		4.80 [1]	40.00 [1]		1700.0 [1]						
Anna Nagar Bridge	05/96		6.00 [1]	30.00 [1]		950.0 [1]						
Anna Nagar Bridge	07/96		5.50 [1]	52.00 [1]		1410.0 [1]						
Choolaimedu Causeway	11/95		4.80 [1]	45.00 [1]		458.0 [1]						
Choolaimedu Causeway	01/96		4.70 [1]	42.00 [1]		1440.0 [1]						
Choolaimedu Causeway	03/96		4.90 [1]	32.00 [1]		1420.0 [1]						
Choolaimedu Causeway	05/96		4.90 [1]	44.00 [1]		1070.0 [1]						
Choolaimedu Causeway	07/96		5.20 [1]	40.00 [1]		1340.0 [1]						
Bridge near Mount Rd Tarapur Tower	11/95		4.00 [1]	44.00 [1]		505.0 [1]						
Bridge near Mount Rd Tarapur Tower	01/96		3.90 [1]	48.00 [1]		3570.0 [1]						
Bridge near Mount Rd Tarapur Tower	03/96		4.00 [1]	44.00 [1]		1590.0 [1]						
Bridge near Mount Rd Tarapur Tower	05/96		4.20 [1]	38.00 [1]		1250.0 [1]						
Bridge near Mount Rd Tarapur Tower	07/96		4.60 [1]	56.00 [1]		3560.0 [1]						
Cooum & B. Canal Near Gen Hosp.	11/95		5.20 [1]	92.00 [1]		893.0 [1]						
Cooum & B. Canal Near Gen Hosp.	01/96		3.00 [1]	60.00 [1]		4700.0 [1]						
Cooum & B. Canal Near Gen Hosp.	03/96		2.00 [1]	58.00 [1]		1590.0 [1]						
Cooum & B. Canal Near Gen Hosp.	05/96		2.50 [1]	60.00 [1]		1130.0 [1]						
Cooum & B. Canal Near Gen Hosp.	07/96		2.20 [1]	58.00 [1]		1330.0 [1]						
Periyar Bridge near Palavan House	11/95		0.50 [1]	40.00 [1]		2500.0 [1]						
Periyar Bridge near Palavan House	01/96		0.70 [1]	70.00 [1]		1560.0 [1]						
Periyar Bridge near Palavan House	03/96		1.00 [1]	66.00 [1]		14700.0 [1]						
Periyar Bridge near Palavan House	05/96		1.10 [1]	70.00 [1]		6180.0 [1]						
Periyar Bridge near Palavan House	07/96		1.50 [1]	64.00 [1]		7440.0 [1]						
Napeir Bridge	11/95		0.70 [1]	20.00 [1]		1692.0 [1]						
Napeir Bridge	01/96		2.00 [1]	52.00 [1]		2280.0 [1]						
Napeir Bridge	03/96		1.00 [1]	42.00 [1]		31000.0 [1]						
Napeir Bridge	05/96		1.90 [1]	48.00 [1]		11600.0 [1]						
Napeir Bridge	07/96		2.40 [1]	56.00 [1]		9000.0 [1]						
Upper Reach dry season)	1994											
Upper Reach (monsoon season)	1993-4											
Middle Reach (dry season)	1994											
Middle Reach (monsoon season)	1993-4											
Lower Reach (dry season)	1994											
Lower Reach (monsoon season)	1993-4											
~ 9.8 km upstream of the mouth	1/94		0.00 [8]				58 [8]	25.00 [8]				
~ 8.9 km upstream of the mouth	1/94		0.00 [8]				108 [8]	25.00 [8]				
~ 7.1 km upstream of the mouth	1/94		0.00 [8]				280 [8]	25.00 [8]				
~ 4.8 km upstream of the mouth	1/94		0.00 [8]				98 [8]	25.20 [8]				
~ 2.6 km upstream of the mouth	1/94		0.00 [8]				116 [8]	25.20 [8]				
Cooum South Arm ~2 km from mouth	1/94		0.00 [8]				98 [8]	25.20 [8]				
Cooum North Arm ~2.2 km from mouth	1/94		0.00 [8]				184 [8]	25.20 [8]				
~ 9.8 km upstream of the mouth	4/94		0.60 [8]				121 [8]	26.50 [8]				
~ 8.9 km upstream of the mouth	4/94		0.00 [8]				169 [8]	26.50 [8]				
~ 7.1 km upstream of the mouth	4/94		0.00 [8]				333 [8]	26.50 [8]				
~ 4.8 km upstream of the mouth	4/94		0.00 [8]				129 [8]	26.70 [8]				
~ 2.6 km upstream of the mouth	4/94		0.20 [8]				204 [8]	26.70 [8]				
Cooum South Arm ~2 km from mouth	4/94		0.00 [8]				243 [8]	27.00 [8]				
Cooum North Arm ~2.2 km from mouth	4/94		0.00 [8]				236 [8]	27.00 [8]				
~ 9.8 km upstream of the mouth	7/94		0.00 [8]				86 [8]	27.10 [8]				
~ 8.9 km upstream of the mouth	7/94		0.00 [8]				59 [8]	27.10 [8]				
~ 7.1 km upstream of the mouth	7/94		0.00 [8]				158 [8]	27.20 [8]				
~ 4.8 km upstream of the mouth	7/94		0.00 [8]				125 [8]	27.20 [8]				
~ 2.6 km upstream of the mouth	7/94		0.00 [8]				104 [8]	27.30 [8]				
Cooum South Arm ~2 km from mouth	7/94		0.00 [8]				194 [8]	27.30 [8]				
Cooum North Arm ~2.2 km from mouth	7/94		0.00 [8]				267 [8]	27.30 [8]				
~ 9.8 km upstream of the mouth	9/94		0.20 [8]				65 [8]	24.60 [8]				
~ 8.9 km upstream of the mouth	9/94		0.10 [8]				55 [8]	24.60 [8]				
~ 7.1 km upstream of the mouth	9/94		0.20 [8]				125 [8]	24.70 [8]				
~ 4.8 km upstream of the mouth	9/94		0.20 [8]				62 [8]	24.70 [8]				
~ 2.6 km upstream of the mouth	9/94		0.10 [8]				92 [8]	24.80 [8]				
Cooum South Arm ~2 km from mouth	9/94		0.10 [8]				232 [8]	24.80 [8]				

Table AIII.2 (continued)

(COOUM RIVER, CONTINUED)	Date	Total Kjeldahl N, mg/l	DO mg/l	BOD mg/l	COD mg/l	TDS mg/l	TSS mg/l	Temp °C	Trans-parency m	Turbidity (Klett scale)	Free CO_2 mg/l	3 min permanganate value, mg/l
Cooum North Arm ~2.2 km from mouth	9/94		0.10 [8]				185 [8]	24.80 [8]				
~ 9.8 km upstream of the mouth	1/95		0.00 [8]				82 [8]	25.00 [8]				
~ 8.9 km upstream of the mouth	1/95		0.00 [8]				95 [8]	25.00 [8]				
~ 7.1 km upstream of the mouth	1/95		0.00 [8]				240 [8]	25.10 [8]				
~ 4.8 km upstream of the mouth	1/95		0.00 [8]				75 [8]	25.00 [8]				
~ 2.6 km upstream of the mouth	1/95		0.00 [8]				128 [8]	25.30 [8]				
Cooum South Arm ~2 km from mouth	1/95		0.00 [8]				172 [8]	25.40 [8]				
Cooum North Arm ~2.2 km from mouth	1/95		0.00 [8]				165 [8]	25.30 [8]				
Cooum Mouth	8/93		0.10 [8]				135 [8]	26.00 [8]				
Cooum Mouth	9/93		1.20 [8]				145 [8]	27.00 [8]				
Cooum Mouth	10/93		0.20 [8]				121 [8]	25.80 [8]				
Cooum Mouth	11/93		0.20 [8]				65 [8]	26.00 [8]				
Cooum Mouth	12/93		0.20 [8]				30 [8]	25.80 [8]				
Cooum Mouth	1/94		0.10 [8]				33 [8]	26.00 [8]				
Cooum Mouth	2/94		0.10 [8]				50 [8]	27.00 [8]				
Cooum Mouth	3/94		0.10 [8]				184 [8]	27.10 [8]				
Cooum Mouth	4/94		0.50 [8]				131 [8]	28.20 [8]				
Cooum Mouth	5/94		0.40 [8]				325 [8]	27.90 [8]				
Cooum Mouth	6/94		0.20 [8]				115 [8]	27.80 [8]				
Cooum Mouth	7/94		0.10 [8]				166 [8]	26.10 [8]				
Cooum Mouth	8/94		1.80 [8]				139 [8]	26.20 [8]				
Cooum Mouth	9/94		0.20 [8]				151 [8]	27.00 [8]				
Cooum Mouth	10/94		0.20 [8]				119 [8]	25.20 [8]				
Cooum Mouth	11/94		0.10 [8]				37 [8]	26.20 [8]				
Cooum Mouth	12/94		0.10 [8]				144 [8]	26.10 [8]				
Napeir Bridge (mean of 9 samples)	1992			138.00 [2]	358.00 [2]	7283.0 [2]	115 [2]					
Napeir Bridge (max. of 9 samples)	1992			315.00 [2]	725.00 [2]	14274.0 [2]	332 [2]					
Napeir Bridge (min. of 9 samples)	1992			45.00 [2]	128.00 [2]	1712.0 [2]	32 [2]					
Outlet to sea (during high tide)	1981											
Cooum estuary	1981									20 [4]		5 [4]
1.0 Km upstream (during high tide)	1981											
2.0 Km upstream (during high tide)	1981											
3.0 Km upstream (during high tide)	1981											
4.0 Km upstream (during high tide)	1981											
6.0 Km upstream (during high tide)	1981											
BUCKINGHAM CANAL												
unspecified – dry season	1997											
unspecified – monsoon season	1997											
North Buckingham Canal	1997		4.75 [5]	16.33 [5]	314.67 [5]	2553.7 [5]						
Central Buckingham Canal	1997		BDL [5]	375.33 [5]	1204.00 [5]	2524.7 [5]						
South Buckingham Canal	1997		BDL [5]	124.67 [5]	337.33 [5]	2621.3 [5]						
B. Canal basin (dry season)	1994											
B. Canal basin (monsoon season)	1993-4											
Central (dry season)	1994											
Central (monsoon season)	1993-4											
South (dry season)	1994											
South (monsoon season)	1993-4											
Wallajah Road Bridge (mean:9 Samples)	1992			243.00 [2]	606.00 [2]	1668.0 [2]	723 [2]					
Wallajah Road Bridge (max:9 Samples)	1992			400.00 [2]	1216.00 [2]	2590.0 [2]	1474 [2]					
Wallajah Road Bridge (min:9 Samples)	1992			42.00 [2]	72.00 [2]	362.0 [2]	200 [2]					
Stn1 (suburb N) (mean:monthly samples)	1981-83	0.25 [3]	10.97 [3]	2.33 [3]	7.45 [3]			29.95 [3]	0.27 [3]		8.57 [3]	
Stn2 (city N) (mean:monthly samples)	1981-83	11.21 [3]	0.27 [3]	33.94 [3]	351.39 [3]			30.97 [3]	0.05 [3]		4.96 [3]	
Stn3 (city Cen.) (mean:monthly samples)	1981-83	2.78 [3]	5.37 [3]	14.61 [3]	132.60 [3]			30.85 [3]	0.28 [3]		7.34 [3]	
Stn4 (city S) (mean:monthly samples)	1981-83	2.80 [3]	6.59 [3]	7.79 [3]	61.54 [3]			31.58 [3]	0.53 [3]		6.62 [3]	
Stn5 (suburb S) (mean:monthly samples)	1981-83	3.29 [3]	10.55 [3]	4.25 [3]	29.16 [3]			31.01 [3]	0.46 [3]		3.71 [3]	
Unspecified, probably N-Cen. Chennai	1981									81 [4]		13 [4]
OTTERI NULLAH												
unspecified – monsoon season	1997											
unspecified	1997		BDL [5]	160.67 [5]	549.33 [5]	1119.3 [5]						
unspecified – dry season	1997											
Upper Reach (dry season)	1994											
Upper Reach (monsoon season)	1993-4											
Middle Reach (dry season)	1994											
Middle Reach (monsoon season)	1993-4											
Lower Reach (dry season)	1994											
Lower Reach (monsoon season)	1993-4											
Nr.Thiru Mangalam (mean:9 samp,TDS=8)	1992			173.00 [2]	441.00 [2]	1531.0 [2]	419 [2]					
Nr.Thiru Mangalam (max:9 samp,TDS=8)	1992			370.00 [2]	752.00 [2]	1828.0 [2]	1370 [2]					
Nr.Thiru Mangalam (min.:9 samp,TDS=8)	1992			55.00 [2]	192.00 [2]	1108.0 [2]	108 [2]					
CAPTAIN COTTON CANAL												
Upper Reach (dry season)	1994											
Upper Reach (monsoon season)	1993-4											
Middle Reach (dry season)	1994											
Middle Reach (monsoon season)	1993-4											
Lower Reach (dry season)	1994											
Lower Reach (monsoon season)	1993-4											

Table AIII.2

(continued)

	Date	Alka-linity mg/l	Soluble Reactive P, mg/l	Phosph-ate, PO_4 mg/l	Total P mg/l	H_2S mg/l	CH_4 Blue/ Active Subst. Og/l	Dis. Organic C, mg/l	organic matter (4 h P.V.), mg/l	Flow m^3/s
COOUM RIVER										
~1.25 Km upstream	1997									
~2.2 Km upstream	1997									
~3.1 Km upstream	1997									
~4.1 Km upstream	1997									
~6 Km upstream	1997									
~8 Km upstream	1997									
~9.8 Km upstream	1997									
~11.5 Km upstream	1997									
~13 Km upstream	1997									
~14.2 Km upstream	1997									
~16 Km upstream	1997									
unspecified – dry season	1997									<0.30 [5]
unspecified – monsoon season	1997									1.0-2.5 [5]
unspecified	1997									
Anna Nagar Bridge	11/95									
Anna Nagar Bridge	01/96									
Anna Nagar Bridge	03/96									
Anna Nagar Bridge	05/96									
Anna Nagar Bridge	07/96									
Choolaimedu Causeway	11/95									
Choolaimedu Causeway	01/96									
Choolaimedu Causeway	03/96									
Choolaimedu Causeway	05/96									
Choolaimedu Causeway	07/96									
Bridge near Mount Rd Tarapur Tower	11/95									
Bridge near Mount Rd Tarapur Tower	01/96									
Bridge near Mount Rd Tarapur Tower	03/96									
Bridge near Mount Rd Tarapur Tower	05/96									
Bridge near Mount Rd Tarapur Tower	07/96									
Cooum & B. Canal Near Gen Hosp.	11/95									
Cooum & B. Canal Near Gen Hosp.	01/96									
Cooum & B. Canal Near Gen Hosp.	03/96									
Cooum & B. Canal Near Gen Hosp.	05/96									
Cooum & B. Canal Near Gen Hosp.	07/96									
Periyar Bridge near Palavan House	11/95									
Periyar Bridge near Palavan House	01/96									
Periyar Bridge near Palavan House	03/96									
Periyar Bridge near Palavan House	05/96									
Periyar Bridge near Palavan House	07/96									
Napeir Bridge	11/95									
Napeir Bridge	01/96									
Napeir Bridge	03/96									
Napeir Bridge	05/96									
Napeir Bridge	07/96									
Upper Reach dry season)	1994									0.24 [6]
Upper Reach (monsoon season)	1993-4									2.50 [6]
Middle Reach (dry season)	1994									0.00 [6]
Middle Reach (monsoon season)	1993-4									1.50 [6]
Lower Reach (dry season)	1994									0.10 [6]
Lower Reach (monsoon season)	1993-4									1.80 [6]
~ 9.8 km upstream of the mouth	1/94			18.15 [8]						
~ 8.9 km upstream of the mouth	1/94			19.8 [8]						
~ 7.1 km upstream of the mouth	1/94			13.2 [8]						
~ 4.8 km upstream of the mouth	1/94			19.8 [8]						
~ 2.6 km upstream of the mouth	1/94			11.55 [8]						
Cooum South Arm ~2 km from mouth	1/94			23.1 [8]						
Cooum North Arm ~2.2 km from mouth	1/94			16.5 [8]						
~ 9.8 km upstream of the mouth	4/94			16.5 [8]						
~ 8.9 km upstream of the mouth	4/94			14.85 [8]						
~ 7.1 km upstream of the mouth	4/94			11.55 [8]						
~ 4.8 km upstream of the mouth	4/94			6.6 [8]						
~ 2.6 km upstream of the mouth	4/94			8.25 [8]						
Cooum South Arm ~2 km from mouth	4/94			1.65 [8]						
Cooum North Arm ~2.2 km from mouth	4/94			24.75 [8]						
~ 9.8 km upstream of the mouth	7/94			18.15 [8]						
~ 8.9 km upstream of the mouth	7/94			19.18 [8]						
~ 7.1 km upstream of the mouth	7/94			17.82 [8]						
~ 4.8 km upstream of the mouth	7/94			21.12 [8]						
~ 2.6 km upstream of the mouth	7/94			16.5 [8]						
Cooum South Arm ~2 km from mouth	7/94			11.88 [8]						
Cooum North Arm ~2.2 km from mouth	7/94			13.86 [8]						
~ 9.8 km upstream of the mouth	9/94			9.57 [8]						
~ 8.9 km upstream of the mouth	9/94			8.25 [8]						
~ 7.1 km upstream of the mouth	9/94			8.91 [8]						
~ 4.8 km upstream of the mouth	9/94			6.93 [8]						
~ 2.6 km upstream of the mouth	9/94			7.57 [8]						
Cooum South Arm ~2 km from mouth	9/94			10.89 [8]						

Table AIII.2
(continued)

(COOUM RIVER, CONTINUED)	Date	Alka-linity mg/l	Soluble Reactive P, mg/l	Phosph-ate, PO_4 mg/l	Total P mg/l	H_2S mg/l	CH_4 Blue/ Active Subst. Og/l	Dis. Organic C, mg/l	organic matter (4 h P.V.), mg/l	Flow m^3/s
Cooum North Arm ~2.2 km from mouth	9/94			8.91 [8]						
~ 9.8 km upstream of the mouth	1/95			4.95 [8]						
~ 8.9 km upstream of the mouth	1/95			8.25 [8]						
~ 7.1 km upstream of the mouth	1/95			8.58 [8]						
~ 4.8 km upstream of the mouth	1/95			9.9 [8]						
~ 2.6 km upstream of the mouth	1/95			9.24 [8]						
Cooum South Arm ~2 km from mouth	1/95			9.57 [8]						
Cooum North Arm ~2.2 km from mouth	1/95			7.92 [8]						
Cooum Mouth	8/93			6.6 [8]						
Cooum Mouth	9/93			1.65 [8]						
Cooum Mouth	10/93			6.6 [8]						
Cooum Mouth	11/93			4.95 [8]						
Cooum Mouth	12/93			6.6 [8]						
Cooum Mouth	1/94			4.95 [8]						4.16 [8]
Cooum Mouth	2/94			6.6 [8]						4.84 [8]
Cooum Mouth	3/94			10.56 [8]						6.58 [8]
Cooum Mouth	4/94			26.4 [8]						4.13 [8]
Cooum Mouth	5/94			20.1 [8]						6.18 [8]
Cooum Mouth	6/94			14.52 [8]						6.59 [8]
Cooum Mouth	7/94			10.53 [8]						6.98 [8]
Cooum Mouth	8/94			6.4 [8]						7.61 [8]
Cooum Mouth	9/94			7.26 [8]						3.08 [8]
Cooum Mouth	10/94			0.99 [8]						7.97 [8]
Cooum Mouth	11/94			4.62 [8]						8.21 [8]
Cooum Mouth	12/94			4.95 [8]						5.15 [8]
Napeir Bridge (mean of 9 samples)	1992									
Napeir Bridge (max. of 9 samples)	1992									
Napeir Bridge (min. of 9 samples)	1992									
Outlet to sea (during high tide)	1981		0.50 [4]						4 [4]	
Cooum estuary	1981		0.90 [4]							
1.0 Km upstream (during high tide)	1981		0.20 [4]						10 [4]	
2.0 Km upstream (during high tide)	1981		0.70 [4]						11 [4]	
3.0 Km upstream (during high tide)	1981		1.50 [4]						18 [4]	
4.0 Km upstream (during high tide)	1981		1.00 [4]						20 [4]	
6.0 Km upstream (during high tide)	1981		2.00 [4]						25 [4]	
BUCKINGHAM CANAL										
unspecified – dry season	1997									<0.30 [5]
unspecified – monsoon season	1997									0.50 [5]
North Buckingham Canal	1997									
Central Buckingham Canal	1997									
South Buckingham Canal	1997									
B. Canal basin (dry season)	1994									0.00 [6]
B. Canal basin (monsoon season)	1993-4									0.30 [6]
Central (dry season)	1994									0.00 [6]
Central (monsoon season)	1993-4									0.70 [6]
South (dry season)	1994									0.00 [6]
South (monsoon season)	1993-4									0.50 [6]
Wallajah Road Bridge (mean:9 Samples)	1992									
Wallajah Road Bridge (max:9 Samples)	1992									
Wallajah Road Bridge (min:9 Samples)	1992									
Stn1 (suburb N) (mean:monthly samples)	1981-83	162.16 [3]	0.14 [3]		0.83 [3]	1.81 [3]	22.91 [3]	1.11 [3]		0.09 [3]
Stn2 (city N) (mean:monthly samples)	1981-83	418.00 [3]	1.87 [3]		4.91 [3]	78.50 [3]	305.00 [3]	4.10 [3]		0.24 [3]
Stn3 (city Cen.) (mean:monthly samples)	1981-83	141.50 [3]	1.13 [3]		2.24 [3]	58.86 [3]	132.08 [3]	3.01 [3]		1.49 [3]
Stn4 (city S) (mean:monthly samples)	1981-83	141.33 [3]	0.80 [3]		3.23 [3]	22.95 [3]	136.25 [3]	3.48 [3]		2.90 [3]
Stn5 (suburb S) (mean:monthly samples)	1981-83	184.75 [3]	0.82 [3]		1.74 [3]	10.65 [3]	102.91 [3]	2.56 [3]		3.67 [3]
Unspecified, probably N-Cen. Chennai	1981		1.98 [4]							
OTTERI NULLAH										
unspecified – monsoon season	1997									1.0-2.5 [5]
unspecified	1997									
unspecified – dry season	1997									<0.30 [5]
Upper Reach (dry season)	1994									0.14 [6]
Upper Reach (monsoon season)	1993-4									1.60 [6]
Middle Reach (dry season)	1994									
Middle Reach (monsoon season)	1993-4									0.50 [6]
Lower Reach (dry season)	1994									0.15 [6]
Lower Reach (monsoon season)	1993-4									0.30 [6]
Nr.Thiru Mangalam (mean:9 samp,TDS=8)	1992									
Nr.Thiru Mangalam (max:9 samp,TDS=8)	1992									
Nr.Thiru Mangalam (min.:9 samp,TDS=8)	1992									
CAPTAIN COTTON CANAL										
Upper Reach (dry season)	1994									0.14 [6]
Upper Reach (monsoon season)	1993-4									0.40 [6]
Middle Reach (dry season)	1994									- [6]
Middle Reach (monsoon season)	1993-4									- [6]
Lower Reach (dry season)	1994									- [6]
Lower Reach (monsoon season)	1993-4									- [6]

References

ADB
1994 *Tamil Nadu Environmental Monitoring and Pollution Control, Final Report, Volume II*. Madras: Asian Development Bank.

Allen, Timothy F.H., Bruce L. Bandurski and Anthony W. King
1993 *The Ecosystem Approach: Theory and Ecosystem Integrity*. Initial report of a multi-year project of the Ecological Committee to the International Joint Commission's Great Lakes Science Advisory Board.

Ananthapadmanabhan, S.
1998 "Intercepting Sewers for Sustainable Maintenance of Waterways in the City" in *The Cooum River Environmental Management Research Programme: A System Study for Environmental Management of the Cooum River and Environs: Workshop Report*. Chennai: Madras-Waterloo University Linkage Programme, Department of Geography, University of Madras.

Appasamy, Paul
1989 *Managing Pollution in the Waterways of Madras City: An Initial Assessment*. Madras Institute of Development Studies Working Paper No. 88. Chennai: Madras Institute of Development Studies.

Atkinson, C.J.
1986 "Towards a Plurality of Soft Systems Analysis" in the *Journal of Applied Systems Analysis*, 13:19-31.

Azariah, J. and H. Azariah
1987 "Let the Fishes Live in Cooum" in *Black Buck,* 3(3&4):12-18.

Baburoglu, Oguz N. and M. Andy Garr, III
1992 "Search Conference Methodology for Practitioners: An Introduction" in Marvin B. Weisbord, ed., *Discovering Common Ground: How Future Search Conferences Bring People Together to Achieve Breakthrough Innovation, Empowerment, Shared Vision, and Collaborative Action*. San Francisco: Berrett-Koehler Publishers.

Bardwell, Lisa, V.
1991 "Problem-Framing: A Perspective on Environmental Problem-Solving" in *Environmental Management*, 15(5):603-612.

Bhatnagar, S.C., R. Rajan and K. Das
1994 *A Manual for DLPDSS*. Ahamedabad: Indian Institute of Technology, as reported in Hall, Patrick A.V. (1999) "Experience and Potential" in G.E. Kersten, Z. Mikolajuk and A. Gar-On Yey, eds., *Decision Support Systems for Sustainable Development: A Resource Book of Methods and Applications*. London: Kluwer Academic Publishers.

Bhavani, R.
1998 Interview of Dr. R. Bhavani, Researcher, Department of Geography, University of Madras, by Martin J. Bunch on 27 February, 1998.

Blaszczynski, J.
1992 "Regional Soil Loss Prediction Utilizing the RUSLE/GIS Interface," in A.I. Johnson, C.B. Pettersson and J.L. Fulton (eds), *Geographic Information Systems (GIS) and Mapping-Practices and Standards*. ASTM STP, 1126.

Bowonder, B.
1987 "Environmental Changes in Developing Countries: A Systems Perspective" in the *Journal of Applied Systems Analysis*, 14:81-98.

1984 "Multiple Perspective Analysis in Environmental Management," in *The Environmental Professional*, 6:216-222.

Boyce, Mark S.
1997 "Population Viability Analysis: Adaptive Management for Threatened and Endangered Species" in Mark S. Boyce and Alan Haney, eds., *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources*. New Haven and London: Yale University Press.

Briassoulis, Helen
1989 "Theoretical Orientations in Environmental Planning: An Inquiry into Alternative Approaches" in *Environmental Management*, 13(4):381-392.

Brinkerhoff, Derek W. and Marcus D. Ingle
1989 "Integrating Blueprint and Process: A Structured Flexibility Approach to Development Management," in *Public Administration and Development*, 9:487-503.

Bunch, Martin J.
1999 "Modelling Hydrology and Water Quality in the Cooum using DESERT." A paper presented at the 2nd Workshop in the Cooum River Environmental Management Research Programme entitled *Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs*, 25 February, 1999. Chennai: Department of Geography, University of Madras.

1998 "Modelling and Scenario Analysis for the Construction and Comparison of Management Scenarios: The Development of a Prototype Cooum River Environmental Management Decision Support System." A paper presented at the 1st Workshop in the Cooum River Environmental Management Research Programme entitled *A System Study for Environmental Management of the Cooum River and Environs*, 19 March, 1998. Chennai: Department of Geography, University of Madras.

1996 "The Physical Ecology of Slums in Madras; A GIS Analysis of the 1986 Survey of Slums," in *The Indian Geographical Journal*, 71(1):12-32.

1994 *The Physical Ecology of Slums in Madras, 1986*. Master of Arts Thesis. Waterloo, Ontario: Department of Geography, Faculty of Environmental Studies, University of Waterloo.

Burrough, P. A.
1986 *Principles of Geographic Information Systems for Land Resources Assessment*. Oxford: Clarendon Press.

Byers, B.W. and S.F. Clamons
1997 *GRASS 4.2 Reference Manual*. Waco, Texas: GRASS Research Group, Baylor University.

CERL
1999 *Cooperative Research and Development Between LAS and CERL for the Purpose of Technology TRANSFER*. [Online, 20 April 1999]. Available at http://pandora.cecer.army.mil/grass/LAS/faq/crada.html.

Checkland, Peter B.
1999 "Soft Systems Methodology: A 30-Year Retrospective" in Peter B. Checkland and Jim Scholes (1990) *Soft Systems Methodology in Action*. (1999 printing). Toronto: John Wiley & Sons, Ltd..

1981 *Systems Thinking, Systems Practice*. Toronto: John Wiley & Sons, Ltd..

1979 "Techniques in 'Soft' Systems Practice Part 2: Building Conceptual Models" in the *Journal of Applied Systems Analysis*, 6:33-40.

1976 "Towards a Systems-Based Methodology for Real-World Problem Solving" in R.J. Beishon & G. Peters (eds)., *Systems Behaviour*, 2nd Edition. London: Harper Row in association with the Open University.

Checkland, Peter B. and Jim Scholes
1990a *Soft Systems Methodology in Action*. Toronto: John Wiley & Sons, Ltd.

1990b "Techniques in Soft Systems Practice Part 4: Conceptual Model Building " in the *Journal of Applied Systems Analysis*, 17:39-43.

Chengalvarayan, D., A.V. Raghypathy, and S. Cheandrasekaran
1999 "Surface Water Quality in Cooum and Adyar – Avoiding Risk". Paper presented at the Seminar on the International Day for Natural Disaster Reduction, 13 October 1999, at the Anna Institute of Management. Chennai: Anna University.

Chesapeake Bay Program
1999 *Chesapeake Information Management System* [Online, 19 December, 1999]. Available at http://www.chesapeakebay.net/cims.

Clark, Robert G. and Antony W Diamond
1993 "Restoring Upland Habits in the Canadian Prairies: Lost Opportunity or Management by Design" in *Transactions of the North American Wildlife and Natural Resources Conference*, 58:551-564.

CMWSSB
1998 *Chennai Sewerage Project, 21.2.98, Table 1: Zone wise Population for the year 2001.* Unpublished data. Chennai: Chennai Metropolitan Water Supply and Sewerage Board.

Coleman, Martha B., Tamara L. Bearly, Ingrid C. Burke and William K. Lauenroth
1994 "Linking Ecological Simulation Models to Geographic Information Systems: An Automated Solution," in *Environmental Information Management: Ecosystem to Global Scales*, W.K. Michener, J.W. Brunt and S.G. Stafford, (eds.). London: Taylor and Francis, Ltd.

Corporation of Madras
1991 *City Map*. [1: 19200]. Chennai: Corporation of Madras.

Costanza, Robert and Jack Greer
1995 "The Chesapeake Bay and its Watershed: A Model for Sustainable Ecosystem Management?" in L.H. Gunderson, C.S. Holling and S.S. Light (eds.), *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

CSIRO
2000 *Sustainable Land Management for the Murray Darling Basin - An Integrated Approach* [Online, 10 January 2000]. Available at http://www.csiro.au.

Curry, Leslie
1991 "Guest Essay: The Need for Cumulative Synthetic Theory" in *The Canadian Geographer*, 35(1): 2-9.

Dattatri, G.
1998 "Basic Information for Cleaning of the Waterways." A paper presented at the 1st Workshop in the Cooum River Environmental Management Research Programme entitled *A System Study for Environmental Management of the Cooum River and Environs*, 20 March, 1998. Chennai: Department of Geography, University of Madras.

Dattatri, G. and P.B. Anand
1991 "Development Strategy for Madras 2011: An Agenda for Action" in *Madras 2011: Policy Imperatives - An Agenda for Action, Seminar Theme Paper*, p. 1-15, The Times Research Foundation, eds.. Madras: Madras Metropolitan Development Authority.

Dewhurst, Stephen M., W.W. Covington, and D.B. Wood
1995 "Developing a Model for Adaptive Ecosystem Management" in *The Journal of Forestry*, 93(12):35-41.

Dhanraj, B
1999 "Control of Mosquito Vectors in the Cooum River." A paper presented at the 2nd Workshop in the Cooum River Environmental Management Research Programme entitled *Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs*, 26 February, 1999. Chennai: Department of Geography, University of Madras.

Dreborg, Karl H.
1996 "Essence of Backcasting" in *Futures*, 28(9):813-828.

Elliot, Susan J.
1999 "And the Question Shall Determine the Method" in *The Professional Geographer*, 51(2): 240-243.

Engel, Bernard A., Srinivasan, Raghavan and Chris Rewerts
1993 "A Spatial Decision Support System for Modelling and Managing Agricultural Non-Point-Source Pollution," in M.F. Goodchild, B.O. Parks and L.T. Steyaert (eds), *Environmental Modelling with GIS*. New York: Oxford University Press.

ESSA
1982 *Review and Evaluation of Adaptive Environmental Assessment and Management*. Vancouver: Environment Canada.

Etzioni, Amitai
1986 "Mixed Scanning Revisited" in *Public Administration Review*, 46(1):8-14.

1967 "Mixed-Scanning: A "Third" Approach to Decision-Making" in *Public Administration Review*, 27(5):385-392.

Exnora International
2000 "Exnora International - An Acquaintance" [Online, 15 March 2000]. Available at http://www.exnora.indiaa.com.

Feijoó, Claudia and Fernando Momo
1991 "Socio-economic Levels and Environmental Perception in a Small Town in Argentina" in *The Environmentalist* 11(3):163-170.

Flanagan, P.J.
1990 *Parameters of Water Quality: Interpretation and Standards, Second Edition*. Dublin: Environmental Research Unit.

Flood, Robert L. and Ewart R. Carson
1993 *Dealing with Complexity: An Introduction to the Theory and Application of Systems Science, Second Edition*. New York: Plenum Press.

1988 *Dealing with Complexity: An Introduction to the Theory and Application of Systems Science*. New York: Plenum Press.

Francis, George R. and Henry A. Regier
1995 "Barriers and Bridges to the Restoration of the Great Lakes Basin Ecosystem" in L.H. Gunderson, C.S. Holling and S.S. Light (eds.), *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

Funtowitz, Silvio
1999 *Post Normal Science* [Online, 24 March,1999]. Available at http://taws03.jrc.it/post_normal.html.

Funtowicz, Silvio and Jerome R. Ravetz
1994 "Emergent Complex Systems" in *Futures*, 26(6): 568-582.

Ganpathy, S.V.
1964 "A Hydrobiological Study of the River Cooum in Madras, South India, with Special Reference to Fisheries" in *Archif für Hydrobiologie*, 60(2):200-224.

Gar-On Yeh, Anthony
1999 "Decision Support with Geographic Information Systems" in *Decision Support Systems for Sustainable Development: A Resource Book of Methods and Applications*. London: Kluwer Academic Publishers.

Gardner, Julie E.
1989 "Decision Making for Sustainable Development: Selected Approaches to Environmental Assessment and Management," in *Environmental Impact Assessment Review*, 9:337-366.

Gibbs, James P., Howard L. Snell and Charlotte E. Causton
1998 "Effective Monitoring for Adaptive Wildlife Management: Lessons from the Galápagos Islands" in the *Journal of Wildlife Management*, 63(2): 1055-1065.

Gonzaga, Benjamin
1999 "Rehabilitation of Slums Along Waterways for Better Environment – Myth or Realty?." A paper presented at the 2nd Workshop in the Cooum River Environmental Management Research Programme entitled *Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs*, 25 February, 1999. Chennai: Department of Geography, University of Madras.

Government of India
1999 *Economic Survey, 1998-99*. Delhi: Ministry of Finance, Government of India. [Available for download in pdf format from: www.nic.in/indiabudget/es98-99/].

1991 *Census of India, 1991: Madras Population Tables*. Electronic data provided by the National Informatics Centre (Chennai), Government of India.

Government of Tamil Nadu

1997 *Terms of Reference for Consultancy Services for Preparation of Master Plan, Immediate Works Programme and Bid Documents for the Chennai Waterways Rehabilitation and Reclamation Project*. Chennai: Tamil Nadu Public Works Department.

1981 *Census of India, 1981: Series 20, Tamil Nadu, Part XIII A and B; District Census Handbook, Town Directory and Divisionwise Primary Census Abstract, Madras*. (A.P. Muthuswami, I.A.S., Director of Census Operations). Madras: Government of Tamil Nadu.

1971 The Tamil Nadu Slum Areas (Improvement and Clearance) Act, 1971. Madras: Government of Tamil Nadu, Law Department.

Gowri, V.S.

1997 *Impacts of Adyar and Cooum River Discharges on the Water and Sediment Qualities of Marina Beach, Chennai*. Doctoral Thesis. Chennai: Faculty of Science and Humanities, Anna University.

GRASS Development Team

1999 *GRASS Homepage*. [Online, 20 April, 1999]. Available at http://www.baylor.edu/~grass.

Gratson, M. W., J. W. Unsworth, P. Zager, and L. Kuck

1993 "Initial Experiences with Adaptive Resource Management for Determining Appropriate Antlerless Elk Harvest Rates in Idaho" in *Transactions of the North American Wildlife and Natural Resources Conference*, 58:610-619.

Grayson, R.B., J.M. Doolan and T. Blake

1994 "Application of AEAM (Adaptive Environmental Assessment and Management) to Water Quality in the Latrobe River Catchment" in the *Journal of Environmental Management*, 41:245-258.

Gunaselvam, M.

1999 *Preserving the Identity of Waterfronts in Chennai City*. Chennai: Department of Geography, University of Madras (unpublished).

Gunderson, Lance H., C.S. Holling and Stephen S. Light

1995a *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. L.H. Gunderson, C.S. Holling and S.S. Light (eds.). New York: Columbia University Press.

1995b "Barriers Broken and Bridges Built: A Synthesis," in L.H. Gunderson, C.S. Holling and S.S. Light (eds.), *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

Haas, Ernst
1990 *When Knowledge is Power: Three Models of Change in International Organizations*. Berkeley: University of California Press.

Hackett, Paul M.W.
1993 "Modelling Environmental Concern: Theory and Application," in *The Environmentalist*, 13(2):117-120.

Hall, Patrick A.V.
1999 "Experience and Potential" in G.E. Kersten, Z. Mikolajuk and A. Gar-On Yey, eds., *Decision Support Systems for Sustainable Development: A Resource Book of Methods and Applications*. London: Kluwer Academic Publishers.

Heggade, Odeyar D.
1998 *Urban Development in India: Problems, Policies and Programmes*. New Delhi: Mohit Publications.

Hennessey, Timothy M.
1994 "Governance and Adaptive Management for Estuarine Ecosystems: The Case of Chesapeake Bay," in *Coastal Management*, 22:119-145.

Hettelingh, Jean-Paul
1990 *Uncertainty in Modelling Regional Environmental Systems: The Generalization of a Watershed Acidification Model for Predicting Broad Scale Effects*. RR-90-3 April 1990. IIASA: Laxenburg, Austria.

Hindu
2000 "Rs. 800-cr scheme to cleanse Chennai waterways proposed" in *The Hindu*, [Online Edition]. 10 January, 2000.

1999 "Schemes to improve city waterways" in *The Hindu*, 1 February, 1999:3.

Holling, C.S.
1995 "What Barriers, What Bridges?" in L.H. Gunderson, C.S. Holling and S.S. Light (eds.) *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

1990 "Integrating Science for Sustainable Development," in the *Journal of Business Administration*, 19(1&2):73-83.

1978 *Adaptive Environmental Assessment and Management.* C.S. Holling (ed.). Toronto: International Institute for Applied Systems Analysis.

Hudson, B.
1979 "Comparison of Current Planning Theories: Counterparts and Contradictions," in the *Journal of the American Planning Association*, 45(4): 387-398.

Imperial, Mark T., Hennessey, Tim and Donald Robadue, Jr.
1993 "The Evolution of Adaptive Management for Estuarine Ecosystems: the National Estuary Program and its Precursors" in Ocean & Coastal Management, 20(2):147-180.

Inland Waterways Authority of India
1998 *Report on Reconnaissance Hydrographic Survey and Pre-Feasibility Study on Cooum River and South Buckingham Canal*. New Delhi: Government of India.

INTACH
1996 *CISDEM – Community Information Services on Development and Environment Matters: A Study Report to Promote Setting up of Community Information Services*. Chennai: The Indian National Trust for Art and Heritage, Tamil Nadu Regional Chapter.

Ivanov, Pavel, Ilya Masleiv, Maddumage Kularathna, Carlo De Marchi and László Somlyódy
1996 *Decision Support System for Evaluating River Basin Strategies (DESERT): User's Manual*. Laxenburg, Austria: International Institute for Applied Systems Analysis and Institute for Water and Environmental Problems (Barnaul, Russia).

Johnson, F.A., B.K. Williams, J.D. Nichols, J.E. Hines, W.L. Kendall, G.W. Smith, and D.F. Caithamer
1993 "Developing an Adaptive Management Strategy for Harvesting Waterfowl in North America" in *Transactions of the North American Wildlife and Natural Resources Conference*. 58:565-583.

Kay, James J.
2000 Notes on uncertainty and complexity. A personal communication to Martin J. Bunch. 16 May, 2000.

1997 "The Ecosystem Approach: Ecosystems as Complex Systems", in Murray, T., Gallopin, G., (eds.) Proceedings of the First International workshop of the CIAT-Guelph Project: *Integrated Conceptual Framework for Tropical Agroecosystem Research Based on Complex Systems Theories*, Centro Internacional de Agricultura Tropical, Cali, Colombia, 26-28 May, 1997. Working Document No. 167. Cali, Columbia: CIAT.

Kay, James J. and Michelle Boyle
1999 *An adaptive Self Organizing Holarchic Open (SOHO) Systems approach to Ecosystem Sustainability and Health*, as presented in Kay *et al*., 1999.

Kay, James J., Boyle, Michelle, Regier, Henry A. and George Francis
1999 "An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity" in *Futures*, 31(7):721-742.

Khator, R. and L. Ross
1991 "Water Pollution Policy in India" in (J. Rose, ed.) *Water and the Environment*. Philadelphia: Gordon and Breach Science Publishers.

Kreher, Harald
1994 "Some Recurring Themes in Using Soft Systems Methodology" in the *Journal of the Operational Research Society*, 45(11): 1293-1303.

Kurzejeski, E. W., R. L. Clawson, R. B. Renken, S. L. Sheriff, L. D. Vangilder, C. Hauser, and J. Faaborg
1993 "Experimental Evaluation of Forest Management: the Missouri Ozark Forest Ecosystem Project" in *Transactions of the North American Wildlife and Natural Resources Conference*, 58:599-609.

LaPatra, Scott E., Susan C. Ireland, Joseph M. Groff, Kathy M. Clemens and John T. Siple
1999 "Adaptive Disease Management Strategies for the Endangered Population of Kootenai River White Sturgeon" in Fisheries, 24(5):6-13.

L.A.S.
1996 *GRASSLAND User's Guide for Windows 95 and Windows NT, Version 1.1*. Montreal: Logiciels et Applications Scientifiques (L.A.S.) Inc. (now Global Geomatics Inc.).

Lee, Kai N.
1993 *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, D.C.: Island Press.

1989 "The Columbia River Basin: Experimenting with Sustainability" in *Environment*, 31(6):6-11, 30-31.

Lee, Kai N. and Jodi Lawrence
1986 "Restoration Under the Northwest Power Act - Adaptive Management: Learning from the Columbia River Basin Fish and Wildlife Program," in *Environmental Law*, 16(3):424-460.

Light, Stehpen S., Lance H. Gunderson and C.S. Holling
1995 "The Everglades: Evolution of Management in a Turbulent Ecosystem," in L.H. Gunderson, C.S. Holling and S.S. Light (eds.), *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

Lindblom, Charles E.
1959 "The Science of "Muddling Through"" in *Public Administration Review*, 19:79-88.

Lonergan, Stephen C.
1993 "Impoverishment, Population, and Environmental Degradation: The Case for Equity" in *Environmental Conservation*, 20(4):328-334.

Maidment, David R.
1993 "GIS and Hydrological Modelling," in M.F. Goodchild, B.O. Parks and L.T. Steyaert (eds), *Environmental Modelling with GIS*. New York: Oxford University Press.

Marinos, P.G., G.C. Koukis, G.C. Tsiambaos and G.C. Stournaras
1997 "Effects of Trace Metals on Human Health: A Case Study from River Cooum, Madras, India" in *Engineering Geology and the Environment*. Proceedings of the International Symposium on Engineering Geology and the Environment 23-27 June, 1997. Athens: IAEG.

Mason, Richard O. and Ian I. Mitroff
1981 *Challenging Strategic Planning Assumptions: Theory, Cases, and Techniques*. Toronto: John Wiley & Sons, Inc..

McLain, Rebecca J. and Robert G. Lee
1996 "Adaptive Management: Promises and Pitfalls" in *Environmental Management*, 20(4):437-448.

Meisner, Don
1999 Telephone interview of Don Meisner, ESSA Technologies, Ltd. by Martin J. Bunch on 16 June, 1999.

Mitchell, Bruce
1997 *Resource and Environmental Management*. Edinburgh Gate, Essex: Addison Wesley Longman Ltd.

1991 "'*BEAT*ING' Conflict and Uncertainty in Resource Management and Development," in B. Mitchell (ed.) *Resource Management and Development*. Toronto: Oxford University Press.

1990 “Integrated Water Management” in B. Mitchell, ed., *Integrated Water Management: International Experiences and Perspectives*. New York: Belhaven Press.

1989 *Geography and Resource Analysis, Second Edition*. Harlow, Essex: Longman Scientific & Technical.

Mitchell, George, Ray H. Griggs, Verel Benson, and Jimmy Williams
1997 “Suggested Values of the Curve Number CN2," Appendix E.2.A in *Erosion-Productivity Impact Calculator (EPIC) Documentation*. [Online, 26 Jan. 1999]. Available at http://www.brc.tamus.edu/epic/appendixes/curvenumber.html. Temple, Texas: U.S. Department of Agriculture, Agricultural Research Service; Grassland, Soil and Water Research Laboratory.

MMDA
1991 *Madras-2011: Policy Imperatives, an Agenda for Action, Seminar Theme Paper.* Madras: Madras Metropolitan Development Authority.

1987 *Survey of Slums in Madras Metropolitan Area*. Madras: Madras Metropolitan Development Authority (and the Economist Group).

1986 Data from the *Survey of Slums in Madras Metropolitan Area* (1987). Unpublished: Madras Metropolitan Development Authority.

MMWSSB
1991 *Madras Water Supply and Sanitation Project: Draft Master Plan for Water Supply, Volumes I & II*. Madras: Madras Metropolitan Water Supply and Sewerage Board.

Morley, David
1986 “Approaches to Planning in Turbulent Environments” in D. Morley and A. Shachar, eds., *Planning in Turbulence*. Jerusalem: The Magnus Press.

Mott MacDonald Ltd.
1994 *Sludge Disposal Consultancy, Madras: Final Report*. (August 1994), A consultancy under consignment from the Overseas Development Administration for the Department of Environment and Forests, Government of Tamil Nadu. Chennai: The Government of Tamil Nadu, Department of Environment and Forests.

1994a *Madras City – Urban Drainage Catchments.* [1:20000]. Chennai: Madras Metropolitan Development Authority.

1994b *Stormwater Drainage Master Plan for Madras City and Pre-Feasibility Study for Madras Metropolitan Area: Final Report*. (October 1994). Chennai: Madras Metropolitan Development Authority.

1994c *Stormwater Drainage Master Plan for Madras City and Pre-Feasibility Study for Madras Metropolitan Area: Final Report – Appendices*. (October 1994). Chennai: Madras Metropolitan Development Authority.

Muthiah, S.
1999 "Extempo: Critical Comments on the Programme of Research." A paper presented at the 2nd Workshop in the Cooum River Environmental Management Research Programme entitled *Decision Support and Scenario Analysis for Environmental Management of the Cooum River and Environs*, 25 February, 1999. Chennai: Department of Geography, University of Madras.

Nagaraj, K. and Rukmani Ramani
1991 "Growth of Madras Metropolitan Area: The Demographic Profile" in MMDA (1991) *Madras 2011: Policy Imperatives, An Agenda for Action. Volume I, Research Papers*. Chennai: The Times Research Foundation and the Madras Metropolitan Development Authority.

Naughton, John
1981 "Theory and Practice in Systems Research" in the *Journal of Applied Systems Analysis*, 8:61-70.

New Indian Express
1999 "Rs 99 crore for cleaning waterways" in *The New Indian Express,* 2 March, 1999:5.

ODA
1995 *The Sludging of Madras Waterways*. Madras: Overseas Development Association (UK).

Patton, Michael Quinn
1990 *Qualitative Evaluation and Research Methods, Second Edition*. Newbury Park, CA: Sage Publications

Raffensperger, Jeff P.
1997 *Elements of Physical Hydrology*. Chapter 4, [Online, 21 Oct. 1999]. Available at http://hydroc.evsc.virginia.edu.eph /CHAP4B.HTM. Virginia: University of Virginia.

Ramkumar, T.K. and S. Sriram
2000 "Welcome to WAMP - Waterways Monitoring Programme." [Online, 6 February 2000]. An open communication posted in the "wamp-chennai" newsgroup. Available at http://www.egroups.com/message/wamp-chennai.

Ranganathan, A.R.
1999 Interview of Mr. A.R. Ranganathan, Chief Planner, Chennai Metropolitan Development Authority by Martin J. Bunch on 28 January, 1999.

1995 Interview of Mr. A.R. Ranganathan, Chief Planner, Madras Metropolitan Development Authority by Martin J. Bunch on 10 March, 1995.

Ravichandran, S.
1987 "Water Quality Studies on Buckingham Canal (Madras, India) – A Discriminant Analysis" in *Hydrobiologia* 154:121-126.

Rittle, Horst
1972 "On the Planning Crisis: Systems Analysis of the First and Second Generations" in *Bedriftsokonimen* NR8:390-396.

Robinson, John B.
1990 "Futures Under Glass: A Recipe for People Who Hate to Predict," in *Futures* 22(8):820-842.

Rondinelli, Dennis A.
1993a *Development Projects as Policy Experiments: An Adaptive Approach to Development Administration*. 2nd Edition. New York: Routledge.

1993b *Strategic and Results-Based Management in CIDA: Reflections on the Process.* Hull, PQ: Canadian International Development Agency.

Rondinelli, Dennis A., John Middleton and Adriaan M. Verspoor.
1990 *Planning Education Reforms in Developing Countries : The Contingency Approach*. Durham, N.C. : Duke University Press.

Sahadavan, P.V.
1998 "Rehabilitation and Sustainable Maintenance of Chennai Waterways – How Should We Go About It?" A paper presented at the 1st Workshop in the Cooum River Environmental Management Research Programme entitled *A System Study for Environmental Management of the Cooum River and Environs*, 18 March, 1998. Chennai: Department of Geography, University of Madras.

1996 *Artificial Floods to Flush Cooum: A Multi-Purpose Reservoir at Korattur-Anicut for Implementation*. (Discussion Document) Chennai: Tamil Nadu Public Works Department.

1995 "A Comprehensive Land and Water Resources Development Plan for Flood Mitigation and for Sustainable Healthy Environs of Madras City" in *Water Energy 2001*, International R&D Conference 1995, New Delhi, India: 709-723.

1994 *Suggestion to Form a Multipurpose Reservoir Across Adayar at Thiruneermalai (A Detailed Technical Report): Proposal- 1 on Water Resources and Environmental Management of Madras Metropolis*. Chennai: Tamil Nadu Public Works Department.

Sanderson, Steven E.
1995 "Ten Theses on the Promise and Problems of Creative Ecosystem Management in Developing Countries," in L.H. Gunderson, C.S. Holling and S.S. Light (eds.), *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press.

Schmiegelow, F. K. A. and S. J. Hannon
1993 "Adaptive Management, Adaptive Science and the Effects of Forest Fragmentation on Boreal Birds in Northern Alberta" in *Transactions of the North American Wildlife and Natural Resources Conference*, 58:584-598.

Schubert, Claudia A., Richard C. Rosatte, Charles D. MacInnes and Thomas D. Nudds
1998 "Rabies Control: An Adaptive Management Approach" in the *Journal of Wildlife Management*, 62(2):622-629.

Semel, B. and P. W. Sherman
1993 "Answering Basic Questions to Address Management Needs: Case Studies of Wood Duck Nest Box Programs" in *Transactions of the North American Wildlife and Natural Resources Conference*, 58:537-550.

Shaw Technical Consultants (P) Ltd. and Hyder Consulting Ltd.
1997 *Plan Showing Proposed Improvements to the Existing Collection System within the City Limits*. [1:60000 copy of 1:30000 original]. Chennai: Chennai Metropolitan Water Supply and Sewerage Board.

Singh, Grumel, C. Venkataramanan, G. Sastry and B.P. Joshi
1990 *Manual of Soil & Water Conservation Practices*. New Delhi: Oxford & IBH Publishing Co. Pvt. Ltd..

Smith, Courtland L., Jennifer Gilden, Brent S. Steel, and Karina Mrakovcich
1998 "Sailing the Shoals of Adaptive Management: The Case of Salmon in the Pacific Northwest" in *Environmental Management*, 22(5):671-681.

Sridhar, M.K.S.
1982 "A Field Study of Estuarine Pollution in Madras, India" in *Marine Pollution Bulletin* 13(7):233-236.

Srinivasan, S.
1991 "Water Supply and Sanitation for Madras: The 2011 Context" in *Madras 2011: Policy Imperatives - An Agenda for Action, Volume III: Research Papers*, p. III.1-III.28, The Times Research Foundation, eds.. Madras: Madras Metropolitan Development Authority.

Steen, P. and J. Åckerman
1994 "Syntes av studier över omställning av energi - och transportsystemen I Sverige" in *SOU 1994*:138. A report from the Swedish Government Committee on Climate, as reported in Dreborg (1996) "Essence of Backcasting" in *Futures*, 28(9):813-828.

Steyaert, Louis T. and Michael F. Goodchild
1994 "Integrating Geographic Information Systems and Environmental Simulation Models: A Status Review," in *Environmental Information Management: Ecosystem to Global Scales*, W.K. Michener, J.W. Brunt and S.G. Stafford, (eds.). London: Taylor an d Francis, Ltd.

Survey of India
1976a *Chengalpattu & Madras Districts, Tamil Nadu* [1:25000] Sheet 66 C/4/6, First Edition. Surveyed: 1970-71. Survey of India, Government of India.

1976b *Chengalpattu & Madras Districts, Tamil Nadu* [1:25000] Sheet 66 C/8/2, First Edition. Surveyed: 1970-71. Survey of India, Government of India.

1971a *Chengalpattu & Madras Districts, Tamil Nadu* [1:50000] Sheet 66 C/4, First Edition. Surveyed: 1970-71. Survey of India, Government of India.

1971b *Chengalpattu & Madras Districts, Tamil Nadu* [1:25000] Sheet 66 C/8/3, First Edition. Surveyed: 1970-71. Survey of India, Government of India.

Tamil Nadu Pollution Control Board (TNPCB)
1989 *STI Progress Report*, Annexure 5. 1 September, 1989. Chennai: Tamil Nadu Pollution Control Board.

Tamil Nadu Public Works Department (TNPWD)
1997 *Terms of Reference for Consultancy Services for Preparation of Master Plan, Immediate Works Programme and Bid Documents for Chennai Waterways Rehabilitation and Reclamation Project*. Chennai: TNPWD

Tamil Nadu Slum Clearance Board (TNSCB)
1986 *Slums in Madras City, 1986* . [1:20000] Madras: Tamil Nadu Slum Clearance Board.

1975 *Slums of Madras City: A Socio-Economic Survey*. Madras: Tamil Nadu Slum Clearance Board.

Times Research Foundation
1991 *Madras – 2011, Policy Imperatives: An Agenda for Action*. Madras: MMDA

Trist, Eric
1980 “The Environment and System-Response Capability” in *Futures*, April 1980:133-127.

UNCHS (Habitat)
1991 *Guide for Managing Change for Urban Managers and Trainers.* Nairobi: The United Nations Centre for Human Settlements (Habitat).

Vasantha Kumaran, T.
1999 Personal conversation, June 14, 1999. University of Waterloo, Ontario, Canada.

Volkman, John M. and Willis E. McConnaha
1993 “Through A Glass, Darkly: Columbia River Salmon, The Endangered Species Act, and Adaptive Management” in *Environmental Law* 23(4):1249-12.

von Bülow, Irmela
1989 "The Bounding of a Problem Situation and the Concept of a System's Boundary in Soft Systems Methodology" in the *Journal of Applied Systems Analysis*, 16:35-41.

Walters, Carl
1986 *Adaptive Management of Renewable Resources*. New York: Macmillan Publishing Company.

Walters, Carl, R.D. Goruk and Donald Radford
1993 “Rivers Inlet Sockeye Salmon: An Experiment in Adaptive Management,” in the *North American Journal of Fisheries Management*, 13:253-262.

WAMP
1999a “Survey of Pollution Outfalls” [Online, 27 Dec. 1999]. Available at http://www.exnora.indiaa.com. Chennai: Exnora International.

1999b “People's Participation in Waterways Restoration and Waterfront Development” [Online 27 Dec. 1999]. Available at http://www.exnora.indiaa.com. Chennai: Exnora International

Wardrop Engineering Inc.
1995 *Industrial Effluents and Hazardous Waste Management Study for the Madras Metropolitan Area – Final Report*. A Consultancy study undertaken by Wardrop Engineering for the MMDA and TNPCB. Madras: MMDA.

Webster-Merriam
1997 *1913 Webster's Revised Unabridged Dictionary*. Noah Porter, ed. [Online, indexed 8 Apr. 1997]. Available at http://humanities.uchicago.edu/forms_unrest/ webster.form.html]. G & C. Merriam Co..

Weisbord, Marvin B.
1992 *Discovering Common Ground: How Future Search Conferences Bring People Together to Achieve Breakthrough Innovation, Empowerment, Shared Vision, and Collaborative Action*. San Francisco: Berrett-Koehler Publishers.

Weisbord, Marvin B. and Sandra Janoff
2000 *Future Search: An Action Guide to Finding Common Ground in Organizations and Communities*. San Francisco: Berrett-Koehler Publishers.

Welsh, Brent B.
1997 *Practical Programming in Tcl and Tk, Second Edition*. Toronto: Prentice Hall.

Williams, Byron K. and Fred A. Johnson
1995 "Adaptive Management and the Regulation of Waterfowl Harvests," in *Wildlife Society Bulletin*, 23(3):430-436.

Woodburn, Ian
1991 "The Teaching of Soft Systems Thinking" in the *Journal of Applied Systems Analysis*, 18:29-37.

Wynne, Brian
1992 "Uncertainty and Environmental Learning: Reconceiving Science and Policy in the Preventive Paradigm," in *Global Environmental Change*, 2(2):111-127.