

*Chapter 7*  
*Conclusions*

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

by

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## Conclusions

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### 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).<sup>1</sup> This research has pursued both of these streams simultaneously.<sup>2</sup>

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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<sup>1</sup>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.”

<sup>2</sup>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.<sup>3</sup> 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

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<sup>3</sup>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.

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| ① | A <i>holistic</i> 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 ( <i>e.g.</i> , 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”

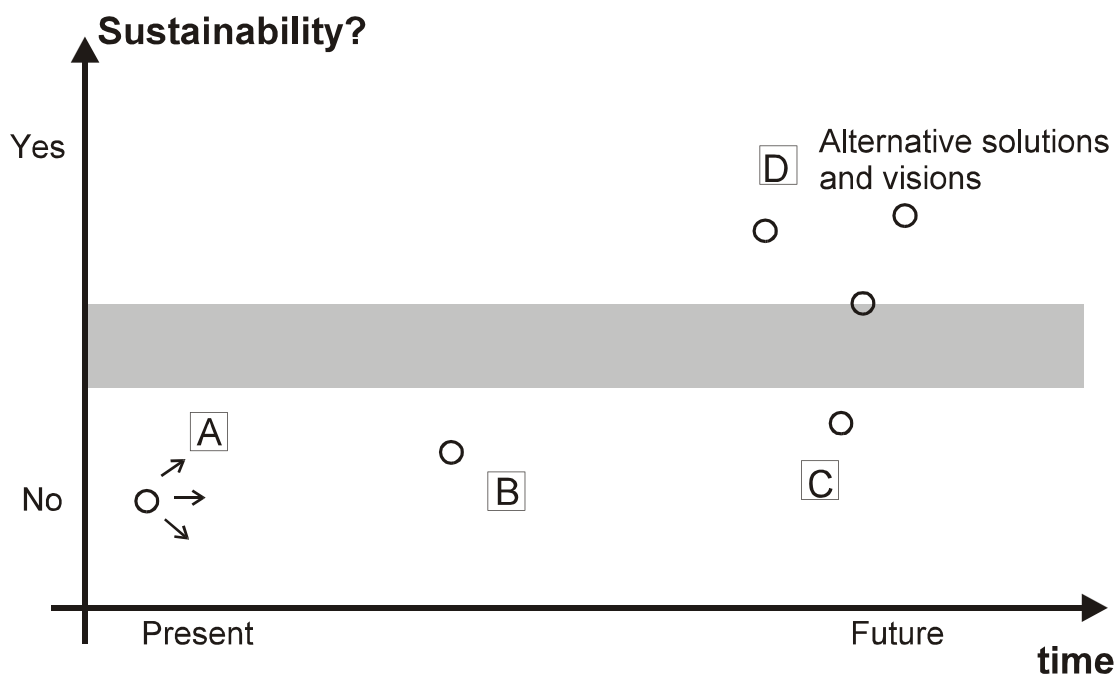
Efforts to describe the system “as it is” focussed on the present state and dynamics of the system. Such a focus on the present situation, however, may restrict the results of studies to solutions or interventions based on projections of current trends in the system into the

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.

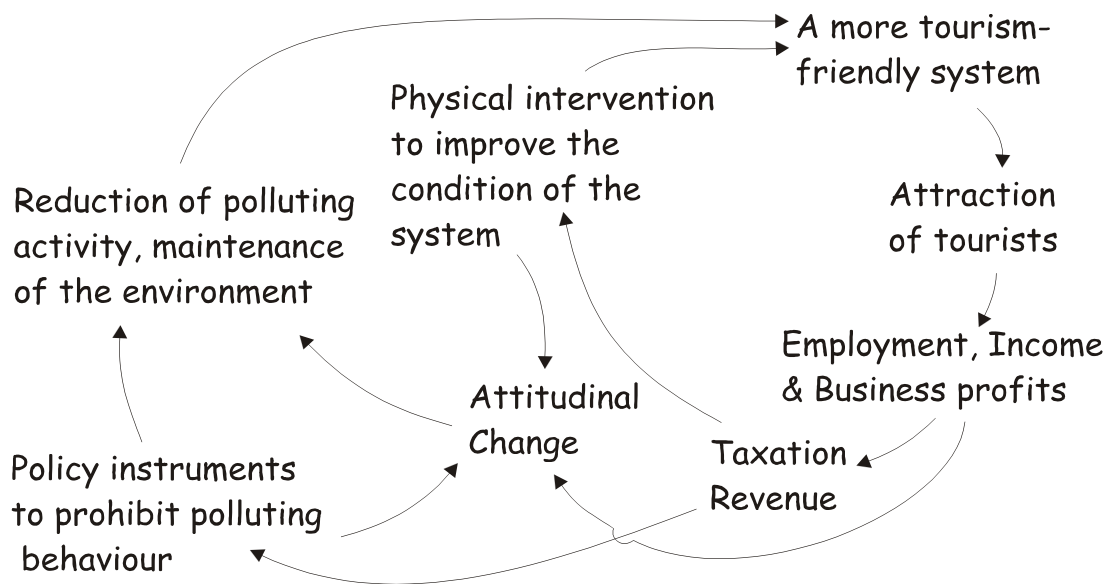
Steen and Åckerman (1994, as related by Dreborg, 1996: 814-6) illustrate that the use of images or scenarios of desirable future states promotes solutions to long-term complex issues which are more likely to be sustainable than other methods. For example, directional studies which pursue measures to 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.

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| 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 come 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).<sup>4</sup> 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

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<sup>4</sup>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 Navalur 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.

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| 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. ∆↑∆
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**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).<sup>5</sup> 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’

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<sup>5</sup>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.<sup>6</sup> 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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<sup>6</sup>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).

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| 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 sewer 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 parametrization 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 parametrization, 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.<sup>7</sup> 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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<sup>7</sup>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 unserved 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 parametrization 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.<sup>8</sup> In the development and use of the ‘Rich Picture’ it 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,<sup>9</sup>
- 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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<sup>8</sup>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.

<sup>9</sup>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’ mnemonic 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<sup>10</sup> 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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<sup>10</sup>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.<sup>11</sup> 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).

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|---|--|
| 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.

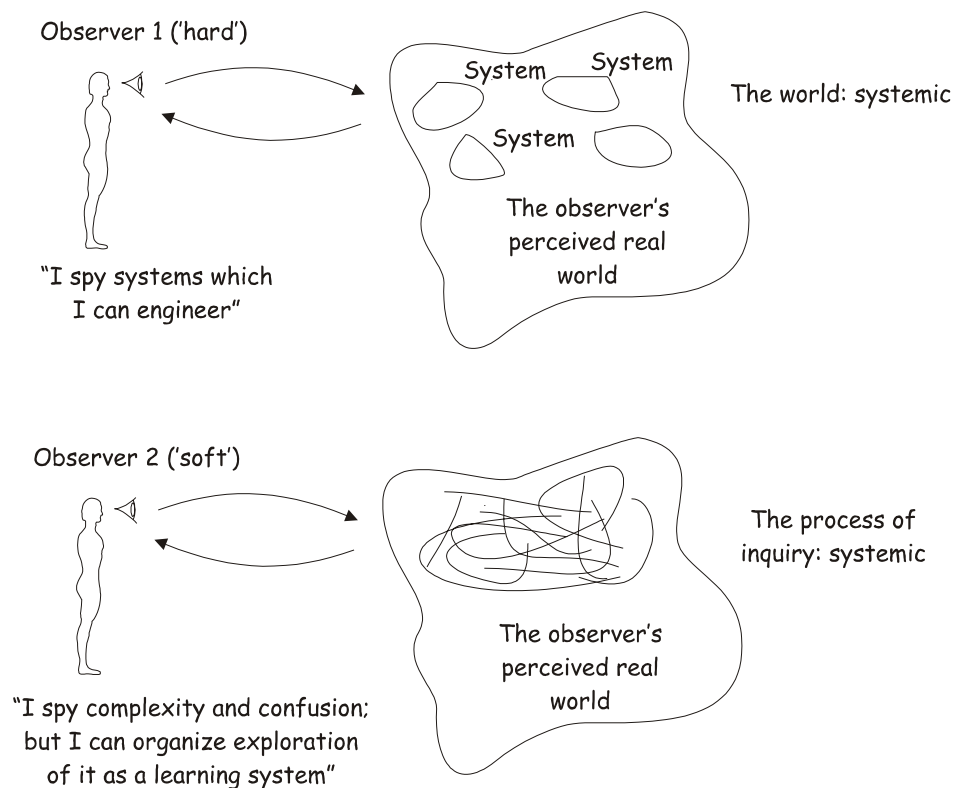
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<sup>11</sup>These have been described as ‘Commodities’ of power in the SSM literature (*e.g.*, Checkland, 1999:A20),

## 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.<sup>12</sup> 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

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<sup>12</sup>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<sup>13</sup> 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

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<sup>13</sup>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.