Urban catchment management in a developing country: the Lotus River project, Cape Town, South Africa

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Abstract This paper describes a 2-year pilot project undertaken in an urban catchment in Cape Town, South Africa. The impermeable area of the Lotus River catchment has doubled over 15 years, from 17% in 1983 to 34% in 1997. Following the abolition of urban influx control in 1990, informal settlements in the catchment grew rapidly and now house about 90,000 out of the catchment's total population of 380,000 people. The informal areas are still largely unserviced, despite a commitment from local government to speed up service delivery to the poorest areas of the city.

Within the Lotus River project, hydrological and ecological assessments of the urban watercourses were undertaken, through physico-chemical and microbiological sampling programmes, macro-invertebrate counts, and vegetation sampling. All available information regarding the catchment was integrated within a GIS platform, including demographic and socio-economic data on the various communities, and hydrogeological information on the underlying aquifer obtained from earlier studies. The integrated nature of the project allows a number of conclusions and recommendations to be drawn, regarding the management of this particular catchment. However, important general lessons have also been learned which can be applied by local authorities responsible for urban catchments in developing countries. The necessity of providing the required institutional structures cannot be overemphasised.
Keywords Urban catchment management; integrated catchment management; hydrology; ecology; community participation; urban environment

Introduction

The population of cities in the developing world is rising rapidly. World-wide, the growth in urban populations is estimated at 2.6% per year, while in Africa cities are growing at an average of 4.4% per year (UNEP, 1999). In many areas urban development takes place on an informal basis, and service provision is inadequate. It is now estimated that 3.3 billion people in the developing world lack sanitary facilities (UNEP,1999). In South Africa alone, 22% of urban households have no access to flush or chemical toilets (SASS, 1996 census data).

In Cape Town, the net growth rate in informal settlements around the formal city was found to average 10% per year between 1993 and 1998, while 6% per year were relocated to formal housing (Abbott and Douglas, 1999). The overall growth rate was therefore approximately 16% per year. The informal areas are still largely unserviced, despite a commitment from local government to speed up service delivery to the poorest areas of the city. This situation is the result of a number of factors, including: past injustice and deprivation under apartheid policies; current difficulties in framing adequate policies to respond to the housing and service delivery crisis; and a lack of financial resources.

The effect on the water environment of this rapid urban growth is severe, and is reflected in deteriorating water quality. This occurs simultaneously with the increased generation of urban run-off, as catchment permeability in the newly settled areas decreases. Evapotranspiration also decreases due to vegetation loss. The new urban residents therefore face problems not only in terms of flood risk, but also in terms of the public health risk associated with faecal contamination of urban watercourses. These problems also manifest them-

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selves further downstream in the catchment area, and in receiving water bodies, and they magnify the negative impact of the city on its environmental surroundings.

The Lotus River project was a multidisciplinary research project carried out during 1997 and 1998, in an urban catchment of Cape Town, typifying the issues associated with rapid urban growth outlined above. It was designed to test the principles of integrated catchment management in an urban context, applied to a developing country situation. Furthermore, it aimed to develop a blueprint for urban catchment management, which could be applied to other urban catchments across South Africa facing similar problems.

Catchment description

The Lotus River catchment is a dynamic, fast-developing area situated on the Cape Flats, which is a flat, sandy tract of land connecting the Cape Peninsula to the mainland of South Africa. Figure 1 shows the geographical situation of the catchment, lying between Table Bay and False Bay, and draining into Zeekoevlei, a polluted urban lake.

The Lotus River catchment makes an excellent case study of a highly impacted urban system, demonstrating the whole spectrum of land uses, socio-economic variations and housing types found in South African cities. It also exhibits acute ecological stress, highly polluted water bodies and significant loss of biodiversity, which has been well documented (Harding, 1996).

Of the two Lotus Rivers, the Great and the Little (both flowing into Zeekoevlei), the catchment area of the Great Lotus was analysed in more detail, as this river is larger and carries a higher pollution load than the Little Lotus. The latter runs primarily through areas of middle-income, formal residential housing. The Great Lotus catchment area, on the other hand, displays the wide variation in land use mentioned above. Of its catchment area of 4816 hectares, 26% of the catchment is cultivated farmland and market gardens. Over the 13 years from 1983 to 1996, the impervious area of the catchment grew from 17% to 34% of the entire catchment area.

The Great Lotus catchment is now home to nearly 380 000 people, only 72% of whom are formally housed. A further 4% live in "site and service" schemes, with self-help housing but with water and sanitation provided to the site, while 24% or some 90 000 people live in unserviced, informal settlements. This proportion is higher than that for South African cities taken as a whole, in which on average some 12% of people live in informal settle-

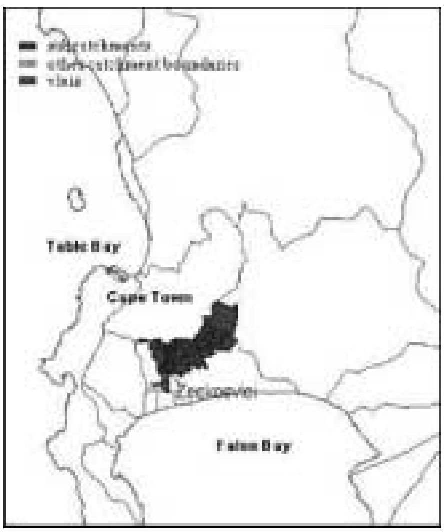

Figure 1 Location of Lotus River catchment area, Cape Town

ments (SASS, 1996 census data). Hence the informal population of the Greater Lotus River catchment is growing especially quickly, due to its desirable location near to job opportunities, and large areas of "municipal open space".

Methodology

The aims and objectives of the Lotus River project were set out in the project proposal as follows:

- to establish a blueprint for urban catchment management in South Africa, focusing upon water quality and ecological stability and improvement, as well as on hydraulics and flood control;
- to carry out a land-use analysis, and to integrate the geo-spatial data available on the catchment from a number of sources onto one GIS platform;
- to identify major sources of pollution in the catchment, both point and non-point sources;
- to carry out a detailed flow gauging study and a water quality sampling programme;
- to study the ecology of the river systems, including riverine and benthic invertebrates, and macrophytes;
- to develop rehabilitation strategies aimed at improving water quality by instream measures, decanalisation, and the re-creation of wetlands;
- to identify all major stakeholders in the catchment and to develop a working model for community management of the catchment.

Hydrology, ecology and water quality

In order to identify pollutant sources, the sampling program entailed frequent flow gauging and water quality sampling at major tributary inflows (weekly to fortnightly in winter, monthly in summer). Macroinvertebrate sampling was also carried out at these points. Less frequent sampling and analyses were carried out for heavy metals, organic compounds, faecal coliform levels and protozoan parasites. The sample points were selected based on a review of the engineering hydrological documentation and site visits. Significant tributary inputs to the Great Lotus River were found to include inflows ranging from stormwater input from urban sub-catchments to agricultural runoff from the drainage system in the marshy Philippi Horticultural Area. A continuous datalogger was placed in a stilling basin at the Springfield Road culvert, 8.5 km from the source. The probe measurements included flow velocity, pH and dissolved oxygen, and results were logged every 10 minutes. During selected storm events in winter, samples were taken automatically and analysed as soon as possible.

Results

The Great Lotus River in particular is characterised by very poor water quality, with a high level of faecal coliforms, as well as high nutrient loading. Table 1 summarises the water quality data obtained over the sampling period for the main parameters analysed. The levels of heavy metals and organic compounds were found to be low.

Since sampling was carried out along the length of the Great Lotus River, it was possible to construct profiles of the pollutant concentration and pollutant flux. The effect of each major tributary inflow was found by sampling 20 metres upstream and downstream of each tributary, and also where possible in the tributary itself, together with a flow measurement. Carrying out a mass balance calculation on the pollutant mass flux then enabled the accuracy of the sampling method to be assessed.

The water quality and ecological results obtained were strongly seasonally influenced, due to the hot dry summers and wet winters which are typical of the Cape climate. It is

Table 1 Water quality data for the years of sampling 1997 and 1998, at the point closest to the outflow of the Great Lotus River

1997	Min	Max	Mean
Total Nitrogen (mg N/l)	4.684	15.9	10.991
Total Phosphorus (mg P/l)	0.405	1.304	0.664
Soluble Reactive Phosphorus (mg P/l)	0.317	1.21	0.54
COD (mg O/l)	29.8	84.15	51.188
TSS (mg/l)	4.5	55.5	13.646
Conductivity (mS/m)	94.6	196	148.4
PH	7.35	7.98	7.815
Faecal coliforms (count/100ml)	1.3e3	3.9e7	5.01e6
1998	**Min**	**Max**	**Mean**
Total Nitrogen (mg N/l)	3.272	17.332	9.323
Total Phosphorus (mg P/l)	0.421	0.741	0.588
Soluble Reactive Phosphorus (mg P/l)	0.094	0.594	0.365
COD (mg O/l)	39	107.9	58.642
TSS (mg/l)	6.2	36.85	17.33
Conductivity (mS/m)	52	170	125.564
PH	7.72	8.67	8.192
Faecal coliforms (count/100ml)	4000	4.7e7	5.28e6

interesting to note therefore that while pollutant concentrations did not vary greatly, the measurement of flow (never previously carried out in these urban rivers) allowed the calculation of mass fluxes of pollutants, with results as shown in Figure 2. It can clearly be seen that the mass flux in spring (March 1998), following prolonged rains, is two orders of magnitude higher than in autumn (September 1997), due to increased stream flow, although the

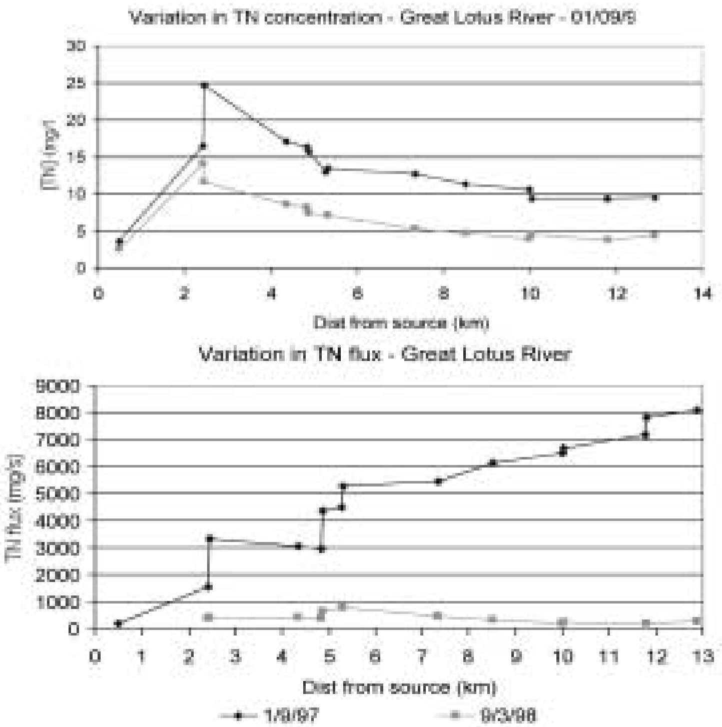

Figure 2 Total nitrogen concentration and mass flux data profiles along the Great Lotus River, for a high flow (September 1997) and a low flow (March 1998) situation

concentration is only twice as high. This suggests that different strategies should be followed for remediating water quality in the high flow and the low flow situations. A similar seasonal pattern was found for phosphorus, although the shape of the longitudinal profile was different, due to the different sources of the pollution.

As the numerical analysis in Table 2 shows, the largest contribution to the nitrogen loading came from the poor residential areas in the north of the catchment, which have a high proportion of informal housing, giving a total of 35.8% of the nitrogen load. On the other hand, these areas contributed only 11.6% to the phosphorus load, while the largest contributions came from subcatchments in the Philippi Horticultural Area. Also, groundwater flow played a more important role in the transport of phosphorus, in the unlined sections. In the lined sections of the canal, through the built-up residential areas, as expected, there was little groundwater contribution to flow.

This brief review of some of the water quality results obtained in the Lotus River study is intended to show that the challenges presented in this situation go far beyond those commonly dealt with in the application of Best Management Practices (BMPs) to urban drainage systems. Service provision to informal areas is the most urgent form of source control of pollution which needs to be applied, together with improved farming practices. The beneficial use of stormwater also has to be approached with caution. In practice, farmers in the Philippi Horticultural Area often abstract water from the Lotus River during the dry summer months to irrigate their crops, while children play in and around the river in the residential areas.

GIS and land-use mapping

The primary objective of this work was to explore the potential for utilising Geographic Information System (GIS)-based techniques to develop a tool for Integrated Catchment Management (ICM), and to integrate existing and acquired geo-spatial data on the catchment onto a single platform. The data collation process was carried out in such a manner as to include data from as many of the key role players in the ICM process as possible. This was for two reasons. Firstly, it helped to determine the practical limitations of "real data

Table 2 Percentage contributions to total nitrogen (TN) and total phosphorus (TP) mass flux in the Great Lotus River, from diffuse and tributary sources with different land uses (01/09/97)

Distance from source	Contribution	TN: % flux contribution	TP: % flux contribution
0.5–2.4 km	Diffuse source contributions from Barcelona, New Rest and upper part of Nyanga/Guguletu	17.15	1.39
~ 2.4 km	Tributary source at NY3 stormwater pipeline draining most of Nyanga and Guguletu	22.5	7.9
	Total contribution of Nyanga, Guguletu, and Barcelona	***35.8***	***11.57***
~ 4.8 km	Tributary source draining Crossroads, Philippi East, Philippi West and Brown's Farm	16.01	2.88
~ 5.3 km	Vygekraal detention pond draining subcatchment of Philippi Horticultural Area	6.1	5.48
~5.3 to 7.3 km	Unlined section along Lansdowne Road permitting groundwater flow	2.32	13.0
~7.3 to 10 km	Unlined section through Philippi Horticultural Area permitting groundwater flow	8.52	21.06
~10 km	Tributary source from Lansdowne-Wetton Corridor	5.74	3.17
~10 to 11.8 km	Diffuse sources from residential area of Ottery and Philippi Horticultural Area	6.66	25.32
~11.8 km	Tributary source from subcatchment of PHA	5.94	10.95
~11.8 to 12.9 km	Diffuse sources from Lotus River residential area	3.64	2.66

sets" on a GIS-based ICM approach. Secondly, by basing the methodology on locally acquired data, it would be possible to ensure that the resultant database design would be compatible with existing local authority databases.

Two methodologies were tested for capturing the land-use data. The first was a cadastral-based approach, while the second was based on mapping the land uses from digital orthophotos. The cadastral-based approach was followed for a selected sub-catchment and a number of land use parameters were estimated. In practice, the method proved far too time consuming to carry out on a catchment-wide basis. As a result, a more rapid method had to be developed. The merits of rapid land use mapping approaches has been very clearly shown in other non-catchment based studies. The Rapid Land Use Assessment (RLA) methodology developed by the Planning and Development Corporation (PADCO) in the Philippines has proved to be an efficient approach to land-use mapping. This methodology relied on the use of satellite imagery for the mapping process. In the case of the Lotus River catchment, 1:20,000 aerial ortho-photo imagery was used in the mapping process. This was available for the years 1983 and 1996.

An inspection of the land use maps utilised in other recent catchment studies (Adinarayana *et al*., 1994; Schmitz & de Villiers, 1997) was conducted. Attention was paid to the degree of detail of the land use mapping carried out. The following factors were considered:

1. the number of classes mapped for each sub-catchment,
2. the total number of classes mapped throughout the catchment, and
3. the size of the smallest land use zone mapped in the catchment.

A comparison of the mapping detail utilised in the production of the maps for these studies with the land-use maps drafted for the Lotus River catchment study, reveals that the latter are far more detailed. Whereas previous modelling exercises tend to homogenise sub-catchment areas, the land-use analysis mapping component of the present study attempted as far as possible to retain the degree of sub-catchment heterogeneity visible on the aerial photography. The use of high resolution digital ortho-photography (0.5 m pixel resolution) enabled land-use classes useful for development of GIS-based vegetation management and rehabilitation strategies to be mapped.

A major constraint on using GIS for a catchment situated in a developing country is the patchy nature of digital data. While South Africa is relatively advanced in having digital cadastral data available for the metropolitan areas, there remain large gaps in this cadastral database, which correspond to the informal settlement areas. This is accompanied by a corresponding absence of physical infrastructure data, while only a limited amount of subsurface infrastructure data is available for the formal areas. Where paper-based maps are available for the storm water drainage network in former township areas, these maps tend to be unreliable and out of date. Secondly, the organisational structure within the local authorities is not geared up to the needs of integrated projects, and hence data acquisition becomes very difficult.

Participatory catchment management

A participatory process of data-gathering and information sharing between the project team and a range of role players in the catchment area eventually resulted in the formation of a Catchment Committee, as an on-going platform for interactions between the local authorities, communities and other stakeholders in the catchment. Preparatory policy-making established the duty of catchment management by the Cape Metropolitan Council in 1997, while the National Water Act of 1998 made provision for the establishment of Catchment Management Agencies. The activities of the Lotus River Catchment Committee therefore acted as a fore-runner of other similar urban catchment management initiatives in

South Africa. Participatory catchment management is essential in rapidly developing areas, in order for stakeholders and residents of the catchment to have a share in decision-making and thereby in implementing recommendations, which may otherwise be quite ineffective in the face of poverty and rapid change.

Conclusions

Urban catchment management in a developing country must deal with a complex variety of issues. It is important to consider current best management practices (BMPs) in stormwater management and urban drainage, as well as evaluating the possible beneficial uses of stormwater, but this needs to be carried out within a context which demands different approaches to those adopted in the developed world. The optimisation of data collection becomes important in selecting techniques that are viable, consistent, and focus on essential data and information. The use of aerial photography is particularly useful in informal areas, in combination with a Geographical Information System (GIS). Finally, a participatory management structure is vital to ensure that the full range of stakeholders in the catchment play a part in the decision-making process.

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