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Shallow urban lakes: a challenge for lake management

Stephen Birch[1] & Janice McCaskie[2]
[1]*SGS Environment, Yorkshire House, Chapel Street, Liverpool, L3 9AG, U.K.*
[2]*Ecology Officer, Wandsworth Borough Council, London, U.K.*

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Abstract

Urban lakes are very different from other lakes: they are shallow, highly artificial and often hypertrophic yet more people come into contact with them than rural, natural lakes. Our knowledge of their ecology and management is poor. This paper describes a project under the EU Life programme to understand and ecologically manage the most important urban lakes in the London Borough of Wandsworth. One main lake has been evaluated: Battersea Park Lake. The magnitude of anthropogenic impacts are quantified and remedies explored. Computer-based decision trees for urban lake management have been developed and are illustrated.

Introduction

The most common perception of lakes, among the population at large, is probably of a large expanse of water in a mountainous or rural setting, such as occur in Scotland or North Wales. However, if the same exercise then attempted to determine the most frequent contact that people have with lakes, it is likely to be urban lakes which would come at, or near, the top. Given the high population density in urban areas and the year–round accessibility of urban lakes, they provide the most important public contact with lakes. Despite this high level of public interface, and hence importance, of urban lakes, especially in a densely populated country such as England, scientists and managers know less about them and the way they function than any of other lakes. There has been a long-standing concentration of research effort on natural or semi-natural lakes, such as the English Lake District lakes or the Norfolk Broads, but very little attention has been paid to urban lakes. Urban lakes are usually shallow, have many different demands made on them, and as a result are vulnerable to changes in water quality through nutrient enrichment.

Those responsible for managing urban lakes are usually local government officers, very few of whom are likely to have any background in either ecology or freshwater science. Most are from the planning, landscape, leisure or land management professions and usually inherit the lake simply as part of an overall responsibility for parks management. Allied to an often chronic lack of funding, this lack of understanding of the functioning of lakes among those responsible for their management, is a major contributory factor in the decline of many of urban lakes.

Urban lake managers are faced with a variety of practical management problems, some of which are associated either with funding or the people who use the lakes, but many of which are also fundamentally ecological. There is a pressing need to make current ecological knowledge about lakes and the way they function, available to lake managers, so that they can make informed decisions about the management of their urban lakes.

London's public parks make an important contribution to the quality of life of residents and their lakes provide a valuable ecological and recreational resource. Over the past fifty years, the amenity value of park lakes in London has been reduced by poor water quality and the deterioration of the bankside vegetation. Wandsworth Borough Council is responsible for managing six small lakes within its parks. The lakes range in size from under 1 ha to about 8 ha. In 1992, all of the lakes were suffering from eutrophication and the aquatic environment, and its surrounds were impoverished. The problems were:

1. The water was usually green with very low visibility.

2. Algal blooms contained toxic cyanobacteria.
3. The banksides were in need of repair and often devoid of vegetation.
4. There were no higher aquatic plants in the water.
5. The lakes had high populations of waterfowl, particularly Canada geese.
6. Where fish were present, they were often overstocked, and the eutrophic conditions would led to fish deaths in hot weather.

In 1993, Wandsworth Borough Council received funding under the European Union Life Programme for a 3 year demonstration project on the rehabilitation of urban lakes. Three lakes of varying size were chosen to demonstrate an approach to rehabilitation and management, the results of which would be made available throughout Europe. Wandsworth gained European partners in Holland, Denmark and France. In the United Kingdom, the project team comprised:

1. Wandsworth Borough Council – Project management, physical rehabilitation works and dissemination of the results.
2. SGS Environment – Directing water quality improvements, fish management, biological monitoring and the development of a management manual for lake managers.
3. Wetlands Advisory Service – Carrying out a research programme into the waterfowl using the lake in relation to the overall populations in London, and to advise on habitat management techniques.
4. Working Knowledge Transfer – Creating electronic presentations to disseminate the aims and results of the project.
5. South Thames College – Involving the local community and schools in the project and inputting to the training potential of the management manual.

Actions needed for lake rehabilitation

Nutrient sources and biological influences

It is clear that there are a number of issues which need to be tackled to improve the water quality in the lakes. Nutrient inputs and the recycling of nutrients from the sediment need to be reduced. Adequate water clarity to establish macrophytes needs to create and maintain a more diverse water environment. None of the lakes have a natural throughput of water. This means there is no flushing of the system and the lakes have to be maintained by the mains water supply as required. The largest lake at Battersea Park received water from the River Thames to counteract losses from leaks and evaporation. The river water is extremely high in phosphates adding a considerable amount of nutrients to the lake. All the lakes are surrounded by trees, so receive a large amount of leaf litter which adds to the accumulation of sediment on the bottom of the lakes and creates a high oxygen demand. Feeding waterfowl is a popular pastime in parks, which attracts larger numbers of birds to the lakes than would naturally occur and leads to uneaten bread rotting in the water. Canada geese numbers were high in all parks, with their droppings adding a significant amount of phosphorus to the water.

A high nutrient content was available in the sediment, which is released into the water column under low oxygen conditions. Fish such as carp and bream were present in some of the lakes and are known to feed in the benthic layer. They stir up the sediment, so encouraging nutrient release and making the water murky. Any aquatic plants will be uprooted.

The management scenario

A variety of actions were tried out on the three project lakes and Battersea Park, the largest lake, is used here as a case study. Battersea Park is a major London park, containing a lake of 8 ha, with a small connected pool of under 1 ha, called the Ladies Pond (Figure 1). The average depth of the lake is just under 1 m and it was constructed around 1860 of puddled clay. It was, and still is, an important landscape feature within the Park. Old postcards of the lake show water lilies and lush colourful emergent vegetation around the lake edges. The lake was originally used for boating in the summer and skating in the winter. Boating still occurs along with pleasure angling and general enjoyment of the water environment. By 1992, the lake was exhibiting all the problems described earlier and the restoration work was started in 1993.

Water supply

In 1992, the only source of water for topping up the lake was from the River Thames. This water had a phosphate content ranging from 2400–5600 μ l^{-1}. As water was required to cater for a loss in water, through leakages and evaporation, a new water supply was seen as a priority. A new supply was found by drilling a 200 mm borehole through to the chalk strata 125 m below the park. This has supplied low nutrient water ($< 10\ \mu\ l^{-1}$ P) since August 1994, although lake levels

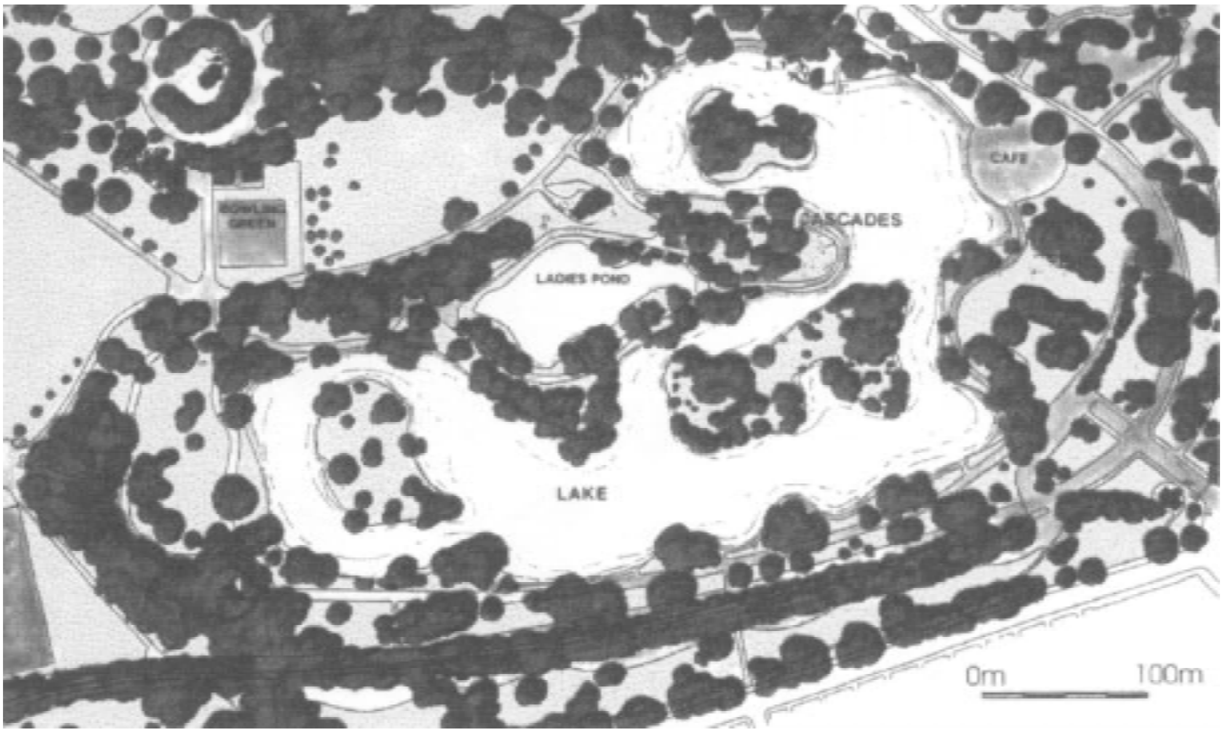

Figure 1. Battersea Park lake, London.

remained higher than this due to sediment phosphorus release (Tables 1 and 2). At present the Council's abstraction licence only allows for enough water to top up the lake, although the borehole could supply more. Options examined include the possibility of increasing the licence to allow the system to be flushed and the water possibly reused for irrigation within the park.

Sediment treatment

The lake had been dredged in the early 1980s at great expense, but with no lasting effect on water clarity. Anoxic mud was present on the lake bed but not at significant depths to warrant dredging again. Instead aerators were installed on the bed of the lake with the dual purpose of keeping dissolved oxygen levels high enough to prevent fish deaths under adverse weather conditions and keeping the sediment layer oxygenated to allow aerobic breakdown of the organic matter.

Low oxygen levels during August 1994 resulted in 200 fish dying before emergency pumps could be installed. The aerators have been operating since December 1994 and no distress to fish was experienced during the very hot summer of 1995. *Ad hoc* reports indicate that the anoxic mud has also disappeared from parts of the lake.

Replanting

At the start of the project, the lake had hard edges and bare banks with compacted soil. There was no vegetation apart from mature shrubs and trees. Certain sections of bank were chosen for replanting and the soil on the banks decompacted and organic matter added. The banks were then replanted with herbaceous plants along the lines of the original planting design.

The establishment of emergent water plants along the edge of the lake was achieved by an organic fibre roll, attached to the edge. The roll acted as a rooting medium and anchor for the plants, which were planted or seeded into it. These have demonstrated a very good rate of establishment and growth. The planting is protected from the public and dogs by new decorative metal railings along the sides of the footpaths. Temporary metal fencing positioned in the water prevents waterfowl from gaining access to the planting.

At the beginning of 1996, the water was considered clear enough to try to establish macrophytes. Circular willow cages, measuring 2.5 m diameter, have been constructed and will be planted up with lilies and submerged species. The willow is covered with mesh to prevent access by fish and the cages have lids to stop waterfowl getting trapped inside or eating the plants.

Table 1. Chemical analysis of Battersea Park Lane

	Battersea Park Lane												
Determainand	Sep–93	Apr–94	Jun–94	Aug–94	Nov–94	Apr–95	Jun–95	Jul–95	Sep–95	Apr–96	Jun–96	Aug–96	Nov–96
pH	–	8.1	7.8	7.7	7.56	8.31	7.81	7.9	8.04	8.3	8.39	8.3	7.77
Ammonia (as NH_4)	0.097	<0.05	0.271	6.27	4.7	0.027	1.69	0.111	<0.026	0.3	2.1	0.59	0.56
Nitrate (as NO_3)	1	1	<0.97	<0.97	1.07	<0.97	39.1?	*	<0.97	<0.89	–	<0.21	<1.15
Total Oxidised Nitrogen (as N)	<1	<1	–	–	–	–	–	–	–	–	<0.35	<0.35	1.17
Nitrate (as NO_2)	0.34	0.24	0.014	0.199	0.049	<0.01	0.129	<0.010	0.031	<0.010	0.4446	<0.066	
Orthophosphate (as P)	0.24	<0.2	0.056	0.76	0.108	0.052	0.2	0.14	0.092	0.036	0.032	0.092	0.047
Total phosphorus (as P)	–	0.322	0.22	0.79	0.148	0.152	0.22	0.32	0.28	0.077	0.068	0.316	0.085
Reactive silicia as (SiO_2)	<1	1.1	2.03	10.8	7.75	0.53	6.18	1.34	0.28	0.8	1.5	7	1.9
Chlorophyll A (meth)	0.058	0.154	0.074	0.319	0.021	0.071	0.039	0.079	0.224	0.036	0.021	0.122	0.016
BOD (5 Day using ATU)	18.6	9.7	4.1	11.9	<2.5	7.6	4.3	*	7.5	4	4.9	4.4	5.4
Iron	0.237	0.552	0.29	0.395	0.163	0.266	0.208	*	0.483	0.119	0.213	0.163	0.106
Chloride (as CL)	33	–	–	–	134	106	105	*	108	87	94	113	100
Aluminium	0.022	0.015	0.07	0.274	0.091	0.142	0.128	0.143	0.138	0.081	0.066	0.195	0.073
Calcium	53	56	52.8	65.8	51.6	61	66.4	*	48.8	67	72	77.5	64
Alkalinity (as HCO_3)	90	159	183	297	232	198	257	278	178	217	243	203	195
Suspended solids	–	–	–	24	18	29	19	*	39	19	48	45	13

All results expressed as mg l^{-1}

Chemical analysis of Ladies' Pond

	Ladies Pool												
Determainand	Sep–93	Apr–94	Jun–94	Aug–94	Nov–94	Apr–95	Jun–95	Jul–95	Sep–95	Apr–96	Jun–96	Aug–96	Nov–96
pH	–	7.6	7.64	7.67	7.55	7.85	7.64	8.03	8.07	8.1	8.09	8	7.91
Ammonia (as NH_4)	0.059	0.56	0.56	2.49	4.49	2	1.35	0.274	0.176	<0.2	<0.2	0.61	0.1
Nitrate (as NO_3)	1	1	<0.97	<0.97	1.4	<0.97	1.34	*	<0.97	<0.89	–	<0.23	<0.28
Total Oxidised Nitrogen (as N)	<1	<1	–	–	–	–	–	–	–	–	<0.35	<0.35	<0.35
Nitrate (as NO_2)	0.018	0.019	0.043	0.047	0.04	0.131	0.037	0.057	<0.010	0.084	0.394	<0.066	
Orthophosphate (as P)	0.68	<0.2	0.068	0.57	0.324	0.056	0.02	0.04	0.028	0.012	0.016	0.132	0.035
Total phosphorus (as P)	–	0.08	0.136	0.6	0.396	0.124	0.1	0.092	0.048	<0.03	<0.03	0.808	0.061
Reactive silicia as (SiO_2)	3.4	1.4	2.29	3.36	4.45	4.26	2.53	1.9	4.12	0.8	1.8	2.9	1
Chlorophyll A (meth)	0.2	0.012	0.063	0.012	0.007	0.033	0.008	0.031	0.072	0.01	0.032	0.04	0.025
BOD (5 Day using ATU)	10.7	1.9	3.1	<2.5	<2.5	4	7.9	*	6.4	2.7	<2.5	2.2	<2.5
Iron	0.094	0.211	0.292	0.459	0.29	0.999	0.116	*	0.253	93.2	0.075	0.255	0.062
Chloride (as CL)	313	–	–	–	156	123	110	*	118	94	105	116	103
Aluminium	<0.015	0.025	0.047	0.267	0.063	0.0874	0.0318	0.135	0.122	0.059	0.0351	0.266	0.0605
Calcium	55	52	56.9	57.6	53.9	125	66.3	*	63.5	68	63	74.7	69.2
Alkalinity (as HCO_3)	162	155	204	249	244	346	239	244	227	193	232	150	184
Suspended solids	–	–	–	5	1	12	4	*	6	14	15	36	11

All results expressed as mg l^{-1}

The lake is surrounded by large numbers of deciduous trees, resulting in considerable amounts of leaf litter entering the lake in the autumn. This can contribute to sediment build up, particularly under anaerobic conditions. New permanent fencing round the lake incorporates discrete leaf traps and, along with the planting itself, should result in less leaves blowing straight into the water. Regular management has also been instituted to remove leaves from the surface of the water during the autumn.

Waterfowl management

Numbers of Canada geese reached a peak of 518 birds in the summer of 1992. This level of geese was perceived as a problem by the Council. How to reduce and maintain lower numbers was not particularly clear and certainly controversial. In London, as a whole, the population of geese had stabilised on the well surveyed sites. However, the overall population was still rising as geese sought out smaller, less favourable sites. The London population of Canada geese is relatively sedentary, with very little movement of geese between London and the surrounding counties. There is considerable seasonal movement between sites as geese try to find the best seasonal conditions – some sites being favoured for breeding, others for moulting and others for winter feeding. Control through management is possible if management is co-ordinated across sites. A range of management techniques has to be used to bring about a decrease in the population of geese and these techniques need to be integrated.

Management of waterfowl before the project began had been *ad hoc*, but based on the need to reduce numbers. Through the project, an Integrated Management Strategy has been developed and successfully implemented. The first clear result obtained from the research was that Battersea Park was favoured as a breeding site for Canada geese. This was due to the presence of large vegetated islands. Birds that had bred at Battersea Park remained for the moult, but it did not provide ideal feeding conditions for them. As soon as they could fly again they would leave the park to find better pre winter feeding. The following management has been undertaken.

- *Physical exclusion*. This was achieved in 1994 by fencing the islands to prevent Canada geese from getting access for nesting. The fence has a gap at the bottom, which allows smaller birds underneath.
- *Habitat modifications*. The habitat is being made less favourable to the geese through the planting schemes and new permanent fencing which prevents easy access to the banks and surrounding grassland.
- *Population management*. Egg pricking has been carried out each year since 1991 resulting in very low recruitment figures. Canada geese are long lived birds so this will only have an effect on the population in the long term. Birds were moved to other sites during the early stages of our work, but this is now seen as inappropriate as it moves a potential problem elsewhere. A small number of birds have been culled, but at a public site, such as a park, this is very difficult. However, it is probably necessary if the current population of birds within an area is too high.

May 1995 saw 35 geese on the lake and there was a very low population all summer. This number of geese is regarded as a sustainable level for good water quality, but how easy it will be to maintain the population at this level is unknown. However, it is clear that ongoing management and monitoring will continue to be necessary.

Fish management

At the start of the project, the fish population was dominated by bream, with all age groups represented. Roach were common, but showing low recruitment. There were low numbers of small perch. Crucian carp were common and large specimens of common carp contributed significantly to the biomass. Battersea Park lake is used by an angling club and the Council's objective was to try to establish and manage a fish population that was satisfactory to anglers, whilst minimising the effect on algal and macrophyte growth. Bream and carp were identified as contributing to water quality problems in the following ways;

1. The fry of bream selectively prey on the large bodied forms of zooplankton. Reduction of these zooplankton reduces grazing pressure on the phytoplankton and so increases algal blooms.
2. Benthic-feeding fish such as carp aid nutrient recycling from the sediment, will uproot macrophytes or prevent their establishment.

The management intention was to reduce the number of bream and carp and restock with tench and crucian carp, managing the fish biomass at an acceptable level. Pike were to be added as a predator when water clarity improved.

The following actions have been undertaken:

1. Eleven different fish netting and removal exercises took place between October 1993 and March 1996. Approximately 2000 kg of carp and 1000 kg of bream were removed from the main lake. No other species of fish were removed. An income was received for the live fish, which will be used to purchase replacement fish.
2. In January 1994, the first restocking of tench occurred, with approximately 200 kg of fish being added to the lake. Subsequent netting exercises revealed evidence of cormorant predation on some of the larger fish and none of the stocked tench were recaptured. Any further stocking of tench would need to be of larger fish, but the cost of buying large tench to stock this 8 ha lake was prohibitive.
3. A fish proof barrier was installed to separate the Ladies pond from the main lake. The pond was drained and as many fish as possible removed. This area will be maintained fish-free at the present time as a comparison with the main lake.

Angling is only permitted within one section of the main lake, so a fish barrier has been erected between this part and the rest of the lake. The barrier allows small fish to pass between the areas but contains large fish within the fishing area. The fishing area is due to be stocked with large tench. The fishing area is 1 ha and the recommended stocking rate is 100 kg of tench, 150 kg of roach and crucian carp relocated from the main part of the lake.

A further netting exercise will take place to remove the few remaining carp from the main lake. Cormorant predation is removing fish of a certain size and age class, so reducing the need for the introduction of pike at this stage.

During 1994, large numbers of *Daphnia* were present in the water at times and water clarity was greatly improved. The phosphate levels in the water had not decreased significantly and the improvements in visibility were most likely to have been as a result of fish removal. As with the waterfowl, it is too early to see how the fish population will stabilise and we do expect to have to continue monitoring and managing the fish stocks as necessary.

Chemical status

In September 1992, the lake was hypereutrophic, measured as total phosphorus of 700 μg l^{-1}, chlorophyll ‘*a*’ 750 μg l^{-1} and Secchi disc extinction of 10 cm. No macrophytes were present and there was a poor invertebrate fauna. The lake is monitored 4 times a year to give annual variability and changes during the project. In 1995 there was better dissolved oxygen levels due to the aeration system. Total phosphate had fallen to 320 μg l^{-1}, chlorophyll *a* to 319 μg l^{-1} and the Secchi disc reading was 50 cm. The establishment of macrophytes is critical and the ability to flush the system with low nutrient water from the borehole is desirable.

A management model

A model of the management process, or system, has been designed to provide a structured approach to facilitate management of these lakes and to be a practical, interactive tool, driven by the needs of the individual lake manager here and elsewhere. It also provides information to lake managers on the important ecological processes in the lake, the way in which management problems arise and the options available for prevention and rehabilitation of such problems. The target user of the model is not the academic community, but those actually responsible for managing lakes on a day to day basis, e.g. local government officers, park managers or management contractors. In addition to this practical application, the model will also have an educational use, particularly in vocational training for park and landscape managers.

The model will be made available in two forms, in document form (as a manual) and as an interactive computer programme, supported by a small manual of operating instructions. The documented version will contain all the information in the model and advice on using the model, but the computer programme will actively direct the user through the model. The user will have to input information and make decisions at key points in order to progress through the model. All input and decisions will be stored in a separate status file which can be printed out as required. A selection of case studies to demonstrate the use of the model and illustrate its main features will also be provided.

Scope of the management model

The first term of reference for the management model was that it should relate to shallow, urban lakes. In order to effectively establish the scope of the model, it was therefore necessary to clearly define what is meant by a ‘shallow, urban lake’. For the purposes of the model, the following definition was developed: "Shallow urban lakes are natural or man-made standing freshwaters with a maximum depth of less than 5 m and a mean depth of usually less than 2 m, located in urban situations, mainly within urban parks. They are primarily used for amenity and recreation and do not include reservoirs used either for potable supply, industrial abstraction or irrigation".

Structure and content of the management model

The initial approach taken in developing the model was to adopt a simple decision-tree structure based on the problems and management actions experienced at Battersea Park lake and the other Wandsworth lakes. However, although this approach would have addressed the main problems associated with eutrophication, it was considered that it would not have a sufficiently wide application to the full range of lake management issues. The basis of the model was therefore developed into a use-related (or functional) approach, in which the management of the lake is orientated specifically to one or more uses or functions of the lake. Factors which interfere with the lake function(s) are identified as problems and remedial options are aimed at restoring and maintaining the lake function(s).

The structure of the model is based on the steps explained below.

Setting objectives

The first activity in the management model is to set objectives and the rest of the model is dependent on this activity. At this first stage in the model, we are trying to clearly identify what the lake is being managed for. This is achieved by selecting one or more uses for the lake and adopting objectives related to providing and maintaining conditions suitable for the selected use(s). Where more than one lake use is selected, they must be prioritised, so that subsequent management decisions can be clearly based on the perceived importance of different uses.

A list of potential uses is provided in the management model as a basis for setting the management objectives. This list is based on the most common and most likely uses of shallow, urban lakes. The options provided are listed in Table 3.

Table 3. List of potential uses in the lake model

1.	Fishing
	(a) Pleasure angling
	(b) Competitive angling
	(c) Specimen angling
2.	Water-based activites
	(a) Non-immersion activities
	(b) Immersion activities
3.	Landscape features
4.	Nature conservation
5.	Wildfowl
6.	Education
7.	General amenity

Fundamental requirements

If the lake is to adequately sustain a chosen use or uses, it is reasonable to assume that it must have certain characteristics. These characteristics have been termed 'fundamental requirements' and the maintenance of these requirements provides a basis for the management of the lake. The 'fundamental requirements' for each of the potential uses have been considered in two categories, minimum requirements and additional desirable features. Minimum requirements are essential characteristics without which the lake can not effectively sustain the chosen use. Additional desirable features are those characteristics which would potentially improve the quality of the lake for the chosen use, thereby increasing its value to users. The next activity in the management model is to assess whether the lake has the required characteristics and is adequately fulfilling its selected function. However, this assessment needs to be based on a baseline description of the lake and the model provides a structure for collecting and retaining information about the lake.

Baseline description

This section of the model provides an opportunity for recording any information available about the lake. Within each of the categories listed in Table 4, an extensive series of questions is provided, prompting the user of the model to enter any information held. It is not anticipated that all the 158 questions can, or need to be, answered for every lake. There may only be a few that are relevant, but the extensive list of questions does permit information about all aspects of the lake to be recorded and stored in the model. The description of the lake can also be amended, updated

Table 4. List of categories provided for the management model for baseline descriptions of the lake.

1.	Location and dimensions (physical characteristics)
2.	Landscape and visual appearance
3.	Wind
4.	Water balance
5.	Lake water chemistry
6.	Source water chemistry
7.	Sediment physical characteristics
8.	Sediment chemistry
9.	Microbiology
10.	Algae
11.	Higher plants
12.	Invertebrates
13.	Fish
14.	Birds
15.	Other animals
16.	Facilities ans access
17.	Existing uses and use–related features
18.	User perceptions/conflicts
19.	Existing management

and added to on an ongoing basis, for example by recording monitoring results.

Current status

An evaluation of the current status (or level of performance) of the lake is undertaken using the information provided in the baseline description. For each fundamental requirement of each potential use of the lake, the relevant items of baseline information have been identified. The user of the model can thus match the answers to the relevant questions in the baseline description with each of the fundamental requirements. The model then requires a decision about whether each fundamental requirement is being satisfactorily achieved or not. The decisions on whether the lake is maintaining the characteristics required to sustain the proposed use(s) determine the next step in the model. If the evaluation concludes that the lake is acceptable (i.e. meeting the fundamental requirements), there is no need for immediate remedial action. The user of the model is therefore directed to the section on monitoring. The results of monitoring feed back into the baseline description, which permits a regular re-evaluation of current status on the basis of monitoring results. If, however, the evaluation of current status concludes that the lake is not satisfactorily achieving its fundamental requirements (i.e. is not 'fit for purpose'), the user of the model is directed into the sections of the model dealing with the diagnosis of problems, analysis of causes and identification of remedial options.

Problems and their causes

The problems and remedies sections of the lake management model are based on a core list of 59 problem types, directly related to the potential uses for the lake. The problem types are number coded as a reference for use through the latter stages of the management model. There is some overlap in the problem types, because many of the same problems relate to more than one use and thus receive a different code number for each use of the lake. A summary of the problem types is given in Table 5. The first activity in assessing the 'problem(s)' with the lake is to diagnose the problem(s) and attribute the observed characteristics to one or more of the 59 problem types. An extensive, but probably not exhaustive, list of possible symptoms is provided within the model. For each symptom, the problem types which could cause that symptom are listed. The range of potential symptoms are listed in the following categories:

- General – Facilities and access
- General – Aesthetic conditions
- General – Health and safety
- Fishing
- Water-based activities
- Landscape/aesthetic feature and general amenity
- Nature conservation
- Wildfowl
- Education

If there is a range of symptoms, it is possible that a variety of problem types will be identified and each one can be considered within the structure provided by the model. Having identified a problem type, the user of the model can check the diagnosis by referring to a complete list of the problem types, recorded in order of their reference numbers. For each problem type, a list of all the likely symptoms is given. Once one or more problems are diagnosed, the management model provides a means of evaluating its significance. The assessment of significance can then be used to determine both the need for remedial action and the order of priority for addressing different problem types. The significance of the problem is assessed in terms of its magnitude and its level of interference with the use(s) of the lake. A simple scoring system is used to give a measure of the magnitude of the problem. Scores are allocated within each of six categories and the scores

Table 5. Summary of use-related problem types identified in the model

Category	Problem descriptor	Problem types (number codes)	Category	Problem descriptor	Problem types (number codes)
Physical characteristics				Control of users is poor	(33), (56)
	Facilities are inadequate	(1),(14),(47),(53)		Lack of suitable subject matter	(49)
	Inadequate space	(2),(15)			
	Lack of clear water	(3)	**Fish**		
	Insufficient depth of water	(4),(16)		Total fish catch numbers are low	(6)
	Access for users is poor	(43)		Preferred species are absent or low in number	
Aesthetic characteristics				Only small fish are present	(8)
				Fish show lack of condition	(9)
	Lake water appears unattractive	(5),(20),(26),(54)		Fish shows lack of condition	(9)
	Lake margins appear unattractive	(5),(21),(27),(55)			
	Feature is not sufficiently visible	(25)	**Nature conservation/wildfowl**		
	Associated features and structures appear unattractive	(28)		Insufficient area of habitat	(29),(37)
				Quality of habitat is poor	(30),(38)
Health and safety				number of species present is low	(31),(39)
	Safety provisions are inadequate	(17),(48)		Population levels of important species are low	(32),(40)
	Sickness and injury among users of water based activities	(18)		Condition of birds is poor	(41)
				Deaths of wildfowl occur	(42)
	Water quality is substandard	(19)			
Users					
	Resource is overused	(11),(22),(34),(44),(50), (57)			
	Resource is under–used	(12),(23),(35),(45), (51),(58)			
	Users have poor perception of the quality of the resource	(13),(24),(36), (46),(52),(59)			

Problem types with multiple refernce codes apply to more than one of the potential uses considered in the model, are summed to give a total magnitude score. Above a given threshold score, it is assumed that remedial action is necessary. The six categories used to evaluate the magnitude of the problem are:

- Level of complaint
- Frequency of the problem
- Seasonality of the problem
- Duration of the problem
- Spatial extent of the problem
- Intensity (or severity) of the problem

As well as attributing magnitude scores within each category, the user of the model is also required to make a judgment on the degree of interference with lake use(s) caused by the problem. This is described in terms of:

- Complete prevention
- Substantial interference
- Noticeable interference
- Little interference
- Very little interference

The incidence of noticeable or greater interference, combined with a magnitude score above the threshold is highly indicative of a significant problem, which requires remedial action.

As well as diagnosing problems and evaluating their significance, the management model is also intended to provide background information about the causes of such problems. This information will hopefully provide the users of the model (i.e. lake managers) with a basic understanding of the processes and interactions occurring within their lakes. Current ecological knowledge and understanding of these shallow lake systems has been presented in a technically correct but relatively simple way in the model. The model is intended for managers of urban lakes, most of which are unlikely to have an ecological background, so it has been important to present the ecology of the lake in a clear and understandable way. This is intended to enable the lake managers to understand why problems occur and why certain remedial actions are appropriate, rather than simply provide a 'recipe book' for lake management. The main factors causing the potential range of problems with shallow urban lakes are discussed under the following headings:

- Physical characteristics
- Aesthetic characteristics
- Health and safety
- Users
- Fish
- Nature conservation/wildfowl

Further discussion of the mechanisms underlying the observed problems is also provided in the management model. This is intended to give some explanation of how and why problems are caused and provide an ecological basis for the management of the lake. The list of causal mechanisms discussed in the model is given in Table 6. Some of the categories (e.g. A,B,C,D & E) are not directly related to the ecological processes within the lake and are therefore outside the original scope of the model. They relate mainly to human activities associated with the lake and are discussed in lesser detail than those issues directly related to lake ecology. However, they may still be very important factors in causing management problems with lakes, particularly the planning, design, policy and funding category.

Remedial options

Once the management problem(s) has been identified and described and a basic understanding of its causes has been achieved, the management model provides a range of options for remedial action. These remedial options cover all the potential uses, problem types and causal mechanisms described in the preceding sections of the management model. The letter codes for the causal mechanisms and the number codes for the

Table 6. Categories of causal mechanisms used in the management model

A.	Planning, design, policy, fundung
B.	Level of users/visitors
C.	*Actions of users/visitors*
D.	*Lake maintenance*
E.	*Grounds maintenance*
F.	***Weather conditions***
G.	***Inputs from water supply***
F.	***Sediment characteristics***
J.	*Oxygen concentrations*
K.	Microbiology(excluding algae)
L.	***Algae***
M.	*Vegetation*
N.	*Zooplankton and other invertebrates*
O.	***Fish***
P.	***Wildfowl***
Q.	***Nutrient and organic enrichment***

Categories in italics are relevant to problem type (54), 'Lake water appears unattractive'(see worked example in text),
Categories in bold italics relate specifically to the symptom of coloured water associated with problem type (54),

problem types are maintained throughout this section of the model to provide a clear reference with preceding sections. A total of 40 remedial options are given in the model, some of which have also contain several sub-headings describing different methods of achieving the same remedial action (Table 7). For each problem type, the user of the model is able to see what range of remedial options are available. A general indication of the start-up cost, ongoing cost and timescale of effect is also provided with each option. The computer version of the model enables the user to access the list of problems and list of remedies at the same time, alongside each other on the screen. The provision of detailed advice on the implementation of the appropriate remedial actions is beyond the scope of the management model. The model provides the user (lake manager) with the advice and information he/she needs to be able to make decisions about which actions to take. The development and implementation of an action plan must then be taken forward by the lake manager.

Monitoring performance

The final component of the lake management model is to monitor the performance of the lake. This stage is reached either once the remedial options have been considered or if the current status is perceived to be acceptable. The monitoring has a threefold function:

1. to measure the effectiveness of any remedial measures taken;
2. to provide an early warning of potential problems;
3. to add to the existing baseline information and thus increase the knowledge and understanding of the lake.

The management model provides information on the variety of monitoring which can be undertaken, what parameters can be measured and how they can be measured. Advice is also provided about developing a monitoring programme appropriate to the lake, its uses, the level of management and the availability of resources. The main options for monitoring are considered within the following categories.

- User satisfaction
- Physical parameters (e.g. water level)
- Visual/aesthetic assessment (e.g. standard of maintenance, appearance)
- Microbiology
- Water quality (e.g. dissolved oxygen, BOD, nutrients)
- Sediment quality (e.g. organic content)
- Biology (e.g. algae, higher plants, invertebrates, fish, wildfowl)

Feedback

Information from the monitoring programme can be used to update or add to the baseline description. As the baseline description is revised, it permits a re-evaluation of the current status of the lake. This could be done , for example, on an annual basis as part of an annually reviewed management programme. A very simple measure of the success of the remedial options taken is if the current status of the lake improves and becomes acceptable. There may also be the need to occasionally reconsider the objectives for the lake. For example, if the evaluation of current status consistently indicates that the use-related requirements are either exceeded or fail to be achieved, it may be appropriate to revise the objectives for the lake, either increasing them if the lake is performing well, or reducing them if a particular use cannot be sustained. This revision of objectives is likely to be undertaken on a longer term basis, e.g. every ten years, or in response to particular events or circumstances.

A simple example will be used to demonstrate the way the management model works. Firstly, an objective will be set and, for the purposes of this example, the 'general amenity' use will be chosen. Once the 'general amenity' use is selected, the model identifies the following:

Minimum requirements:

- Suitable public access and facilities, (according to level of use) e.g.
  - access to site (public and private transport)
  - parking and/or toilet facilities
  - access to lake edge (lakeside paths)
  - disabled access
- Aesthetically acceptable water quality, e.g.
  - colour, clarity, odour, litter, foam, oils, biological growth
- Aesthetically attractive lake margins, e.g.
  - absence of litter, foam
  - marginal plants
  - bank stability
  - bankside landscaping (hard or soft edge)
  - pressure of use,

  additional desirable features
- Safety measures, e.g.
  - prevention of entry to water, safety equipment
  - control of dogs, e.g.exclusion of dogs from specified areas to encourage family use.

Table 7. List of remedial options identified by the management model relating to the worked example

F.	Weather conditions				
	(xix)	Aeration and mixing			
G.	Inputs from water supply		(xxiv)	Shading	
				(xxv)	Salinisation
	(xii)	Catchment management		(xxvi)	Filtration of phytoplankton
	(xiii)	Alternative/new water supply		(xxvii)	Algicides
	(xiv)	Diversion or bypass		(xxix)	Barley straw
	(xv)	Change rate of throughput		(xxx)	Planting of aquatic higer plants
	(xvi)	Treatment of inputs		(xxxi)	Biomanipulation
		(a) Pollutant/treatment removal			
		(b) Nutrient reduction/removal	O	Fish	
		(d) Silt trapping			
		(e) Reedbed treatment		(xxxv)	Selection stocking/ removal of fish
				(xxxvi)	Removal of carp
H.	Inputs from discharges				
			P.	Wildfowl	
	(xxi to xvi as above for G)				
				(xxxviii)	Control of wildfowl
I.	Sediment characteristics				(a) Culling
					(b) Treatment of eggs
	(xvii)	Sediment conditioning			(c) Scaring
	(xviii)	Sediment removal(dredging)			(d) Limitation of access
					(e) Habitat modification
L.	Algae				(f) Relocation
	(xxiii)	Nutrient reduction/removal		(xL)	Control of public feeding of wildfowl
		(a) Control of inputs(see G. above)			(a) Limitation of access
		(b) Treatment of lake water			(b) Public education
		(c) Sediment conditioning of dredging			(c) Provision of alternative food
		(see I above)			(d) Enforcement of byelaws
		(d) Clearance of leaf litter			
		(e) Removal of carp			
		(f) Control of wildfowl			
		(g) Reduction in inputs of bread etc.			

Remedial options are referenced by Roman numerals and relate to the range of causal mechanisms (identified by letter code).

If these characteristics can be maintained, the lake will be able to satisfactorily fulfil its general amenity function. Baseline information is required to assess whether these requirements are being met. For the purposes of this example, it has been assumed that water colouration and lack of clarity occurs persistently in the lake. Consequently, it fails to satisfy the requirement for aesthetically acceptable water quality. As the current status of the example lake is not acceptable, the latter stages of the model, describing problems, causes and remedial options can be applied.

The first step in diagnosing problems using the management model is to identify the observed symptoms of the problem. For example, in the 'General - Aesthetic conditions' category, one of the symptoms listed is:

Water is coloured and/or with surface scums. For this symptom, there are four code numbers (relating to problem types) identified:

- (5) Fishing conditions:- Aesthetic conditions are poor
- (20,26,54) Aesthetic conditions:- Lake water appears unattractive

The problem type, 'Aesthetic conditions - Lake water appears unattractive' is common to three different uses, hence the three code numbers. For the general amenity function, problem type (54) would be identified. A complete list of all the possible symptoms associated with this problem type and identified in the management model is as follows.

(54) Lake water appears unattractive

- complaints from visitors
- water is coloured and/or with surface scums
- litter in water
- foam/oil on water
- unpleasant odour from water/sediments
- unsightly mats of aquatic vegetation, especially filamentous algae
- nuisance swarms of midges occur
- eventual reduction in visitor numbers

The most likely causes of this range of symptoms are discussed in the reference text of the management model. For colouration of the water, high concentrations of suspended solids and dense algal phytoplankton are identified as the most likely causes. A brief discussion of the factors contributing to high suspended solid concentrations and dense phytoplankton is also provided. The likely causal mechanisms are described and discussed under the list of categories given in Table 6. Those which are potentially relevant to problem type (54), 'Lake water appears unattractive', (i.e. most categories) are in italics. The causal mechanisms relating specifically to the symptom of coloured water associated with problem type (54) are also in bold type.

On the basis of these causal mechanisms, the list of remedial options provided by the management model relevant to this problem type and, specifically to the symptom of coloured water, is given in Table 7.

Future development of the management model

The management model is currently at a draft stage and is subject to review, revision and refinement. In particular, the computer version is being revised to make it more user-friendly. As described above, the management model will be made publicly available both as a written manual and as a computer programme. The programme will be on CD-ROM and will be available for use in both Macintosh and Windows environments. It is intended to have a European wide application and translated versions of both the text and computer programme will therefore be provided in two other European languages. The nature and style of the accompanying instruction documents has yet to be finalised, but it is anticipated that there will be a simple summary leaflet of the management model and an instruction manual to accompany the computer programme.

In order to aid the user and provide examples of how the model works, a series of case studies, including Battersea Park, will also be incorporated in the model presentation. In addition, a training application, compatible with the U.K.'s National Vocational Qualification programme is being developed. Thus, a complete package will be prepared and this will be available for purchase from Wandsworth Borough Council. Dissemination has been happening at the local level since the beginning of the project. Residents are kept informed of the work of the project through regular coverage in local papers, features in magazines and special exhibitions and events. A computer presentation was produced for the public and schools to explain the problems the lakes have been suffering and the actions needed to improve the situation. Schools have taken part in the project, testing water quality themselves and observing the different works taking place. Their work has formed exhibitions and one local primary school, Swaffield School is producing its own computer presentation about the project.