Pergamon

Wat. Sci. Tech. Vol. 39, No. 4, pp. 213–220, 1999.

Published by Elsevier Science Ltd
Printed in Great Britain.
0273–1223/99 $19·00 + 0·00

PII: S0273-1223(99)00062-1

INTEGRATED WATER QUALITY AND ENVIRONMENTAL COST-BENEFIT MODELLING FOR THE MANAGEMENT OF THE RIVER TAME

Bob Crabtree*, Matt Hickman** and Dave Martin***

* *WRc plc, Frankland Road, Swindon, SN5 8YR, UK*
** *RPA Ltd, Beccles Road, Loddon, NR14 6LT, UK*
*** *The Environment Agency, Midlands Region, Olton Court, Solihull, B92 7HX, UK*

ABSTRACT

In the UK, the River Tame catchment covers an area of about 1,400 km^2 and forms the northern portion of the Birmingham Conurbation. In the 1960s, wet weather conditions in Birmingham could result in the total depletion of oxygen in the River Trent below the Tame confluence. Construction of a system of purification lakes at Lea Marston, below the major polluting discharges, was completed in the early 1980s. Today, the operation of the Lea Marston Lakes significantly improves the quality of the Tame. However, wet weather pollution episodes in the Tame continues to have a severe impact on water quality in the Trent and put major fisheries at risk. This paper reports on the outcome of an integrated environmental impact and cost-benefit assessment modelling study into the future strategic management of the Lea Marston Lakes. The study demonstrated that the Lea Marston Lakes provide an economically justifiable method for reducing the water quality impact of the Birmingham conurbation and as a result will continue to be operated.

KEYWORDS

Environmental cost-benefit assessment; Lea Marston Lakes; River Tame; SIMCAT; water quality modelling; wet weather pollution.

INTRODUCTION

The River Tame catchment, illustrated in Figure 1, covers an area of about 1,400 km^2 and forms the northern portion of the Birmingham Conurbation. The catchment contains a high proportion of impervious area and has a population of around 1.4 million inhabitants. Two major sewage treatment works discharge to the Tame. There are over 600 combined sewer overflows in the catchment and pollution from storm water runoff is also a significant problem Historically, water quality has been very poor but recent improvements to wastewater infrastructure have improved conditions, particularly under dry weather flows as described by Martin (1994). The Tame is the most significant tributary of the River Trent, which drains central England to the North Sea via the Humber Estuary. The use of artificial purification lakes on the Tame was first investigated in 1966 as part of a strategic study into the quality of the River Trent (Lester, Woodward and Raven, 1972). At that time, wet weather pollution could result in total oxygen depletion in the River Trent below the Tame confluence. In-river purification lakes were considered to be the most effective way of controlling the pollutant load generated in the upper Tame catchment. Construction of a system of purification lakes at Lea Marston, below the major polluting discharges, was completed in the early 1980s. The arrangement of the Lakes is shown in Figure 2. The operation and performance of the Lakes is described by Harkness (1982). All of the River Tame flow passes through Lake 1 and 80% of flow is diverted through Lake 2A. Over 8,000 tonnes of coarse sediments and 9,000 m^3 of litter and other debris are removed form the inlet each year. Dredging of Lake 1 removes 9,000 tonnes of fine sediment each year. Typical retention times in the Lakes are 24 hours during dry weather flow and 3-5 hours during storm conditions.

The Lakes, which are owned and operated by the Environment Agency, form one component of the River Tame improvement strategy. Other components include extensive sewerage improvements and the rationalisation of sewage treatment facilities. This strategy has resulted in dramatic improvements in the quality of both the Tame and the Trent. The Trent now contains a high quality fish population and is currently being actively promoted as a potable water supply. However, wet weather pollution episodes in the Tame continue to have a severe impact on water quality in the Trent and put major fisheries at risk, despite the beneficial effects of the Lea Marston Lakes. The Tame catchment is a major source of toxic contaminants despite the removal of contaminated sediments from Lea Marston Lakes. A review of the significance of the Lakes as a future component of the Tame management strategy was required by the Environment Agency to justify continued operation of the Lakes or the adoption of an alternative approach to reduce the costs of operating the Lakes and asset renewal.

This paper reports on the outcome of a major integrated environmental impact and cost-benefit assessment modelling study to evaluate strategic management options for the Lea Marston Lakes which was carried out in 1997. The paper focuses on the use of modelling tools to provide information to enable the Environment Agency to decide on the future of the Lakes. The two main study objectives were:

i) to assess the current performance of the Lakes and quantify the resulting downstream environmental and economic benefits/disbenefits; and
ii) to identify and quantify the sources of upstream pollution and assess the effectiveness and benefits of potential load reduction strategies within the Upper Tame catchment, above Lea Marston.

ANALYSIS OF CURRENT LAKES PERFORMANCE

Flow and quality data from Environment Agency routine monitoring programmes were used to provide information to assess the significance of the Lakes in removing pollutants and to enable sources of pollutants in the catchment to be quantified. Data analysis was carried out on 33 river quality data sets collected between 1989 and 1996 for 24 determinands, including BOD, total ammonia, Dissolved Oxygen (DO) and a range of toxic metals; 11 river flow gauges; and, 5 major treated sewage effluent discharges.

The partitioning of matched pairs of sample data and mean daily flow into wet and dry weather sequences allowed the performance of the Lakes to be evaluated in terms of removal efficiency, as shown in Table 1. The Lakes have little effect on removing dissolved metals. In general, the Lakes act as sedimentation basins for particulate metals and BOD. The Lakes act as a source of ammonia which is released from anoxic bed sediments. Results indicated a reduced wet weather BOD removal rate due to decreased settling and an increased gain of total ammonia due to disturbance of bed sediments in the Lakes. There appeared to be no difference in loss of metals between wet and dry weather conditions.

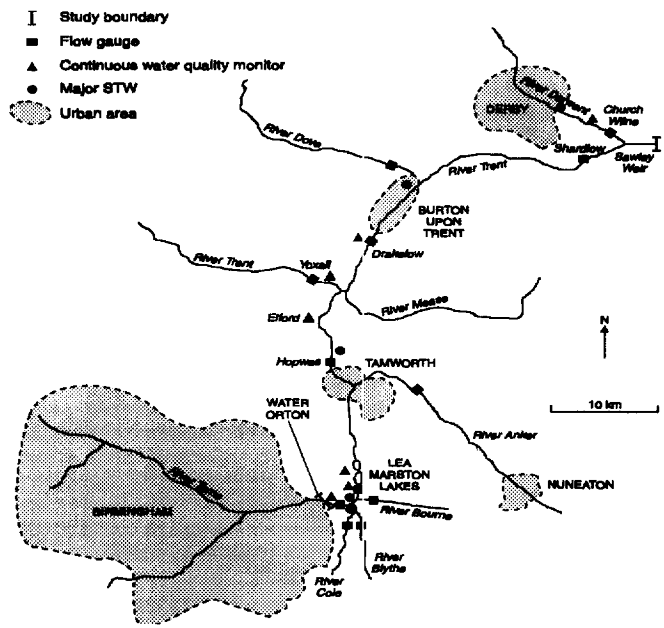

Figure 1. The Tame and Trent Catchment

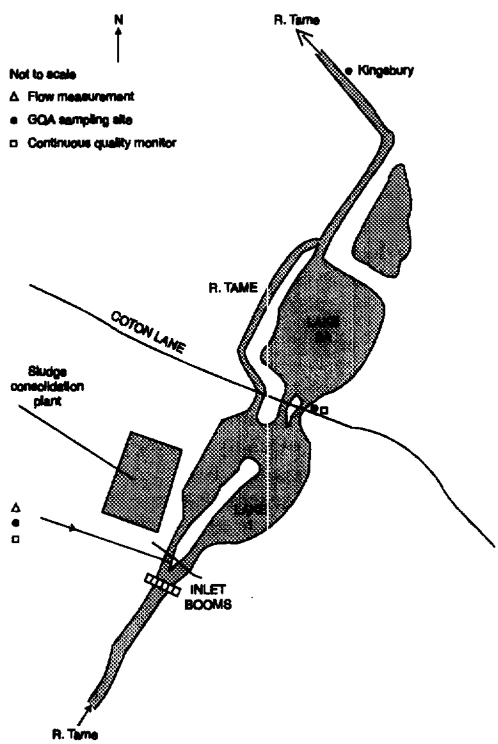

Figure 2. Lea Marston Purification Lakes

Table 1. Annual pollutant removal in Lakes

Parameter		Annual		Wet weather only	
		Load removal	% Input	Load removal	% Input
BOD (tonnes/year)		785	23	90	15
total ammonia (tonnes/year)		+185	+23	+13	+44
total Zinc (kg/year)		12341	16	1731	14
Cadminum (kg/yr)	total	28	9	+1.3	+1
	dissolved	27	16	6	21
Copper (kg/yr)	total	4280	25	603	21
	dissolved	819	11	60	6
Chromium (kg/yr)	total	1730	21	236	21
	dissolved	516	12	23	5
Lead (kg/yr)	total	1535	25	404	26
	dissolved	10	1	11	6

+ = annual gain

RIVER IMPACT MODELLING

A SIMCAT model (Environment Agency, 1997) was produced for the Tame catchment from Water Orton and the River Trent, from the Tame confluence to Sawley Weir above Nottingham (Figure 1). SIMCAT is a deterministic river quality modelling tool which uses a Monte Carlo simulation approach to estimate river quality statistics. SIMCAT is routinely used by the Environment Agency to predict the impact of effluent discharges on river quality. SIMCAT input data are generated from the statistical analysis of river and effluent flow and quality data.

A simple, multiple reach, dynamic model (developed by WRc to support Urban Pollution Management studies (FWR, 1994)) was used to relate episodic flow and water quality inputs above the Lakes to water quality at key downstream locations. The dynamic model was used to produce results for selected historic wet weather events for comparison with water quality standards for episodic pollution (FWR, 1994). The two modelling approaches were used to predict the downstream quality resulting from the following water quality management scenarios:

Scenario 1 Current Upstream Water Quality with-Lakes
Scenario 2 Current Upstream Water Quality without-Lakes
Scenario 3 Current Planned Quality with-Lakes
Scenario 4 Current Planned Quality without-Lakes
Scenario 5 Future Planned Quality with-Lakes
Scenario 6 Future Planned Quality without-Lakes
Scenario 7 Future Predicted Quality with-Lakes
Scenario 8 Future Predicted Quality without-Lakes

Scenarios 3/4 and 5/6 represent the impact of effluent discharges operating up to the limit of the current and future (2001 AD) consent conditions associated with ongoing and planned sewerage and sewage treatment investments in the catchment. Scenarios 7/8 represent the impact of the estimated effluent quality of discharges associated with these improvements. The estimated discharge quality is better than the planned, consent level, quality. Key paired modelling scenarios were 1 and 2, and 7 and 8. These are the current and predicted future situations to compare the effects of improved future effluent discharges with and without the Lakes.

The SIMCAT model was used to predict current and future river quality statistics, pollution loads and to identify the major pollution sources in the catchment. The SIMCAT estimates of the major polluting load sources and losses for the current situation (Scenario 1) above Nottingham on the River Trent are shown in Table 2 for selected parameters related to the Environment Agencys river quality classification system (DoE, 1994).

Table 2. Catchment pollution sources

	BOD tonnes/day	total ammonia tonnes/day	Zn tot kg/day	Cu diss kg/day
All river inputs	13.5	1.3	191.4	30.3
Modelled discharge inputs	6.1	2.1	122.4	11.3
In-river purification	-6.3	-3.0	-62.6	-2.4
Loss in lakes	-2.0	+0.5	-32.9	-1.7
Total	11.3	0.9	218.3	37.5

The summarised results can be compared in terms of polluting loads at Sawley Weir as follows:

- the Tame catchment is the largest contributor of pollution to the Trent;
- currently, Minworth STW is the biggest single pollution source;
- significant losses of BOD and total ammonia occur in the rivers due to self purification;
- the Lakes reduce BOD loads by about 2.0 tonnes per day but increase ammonia by about 0.5 tonnes/day; and,
- the Upper Trent is a minor pollution source compared to the Tame.

SIMCAT scenario results were produced at each of the 14 modelled river sampling locations on the Tame and Trent. Evaluation of these results for similar paired with/without-Lakes scenarios shows the following general trends:

- with-Lakes scenarios have lower downstream DO and BOD values due to loss of BOD and oxygen uptake in the Lakes; and
- with-Lakes scenarios have higher downstream total and un-ionised ammonia values due to anoxic breakdown of organic material in the Lake sediments .

All scenarios, except 7 and 8, had several stretches (particularly below the Lakes), failing to meet long term river quality objectives (RQOs). Table 3 presents a summary of these results.

Table 3. Predicted water quality compliance with long-term River Quality Objectives (RQO)

River	RQO Class	Scenario 1	2	3	4	5	6	7	8
Tame above Lakes	5								
Tame below Lakes	4	F	F	F	F	F	F		
Tame above Trent	4				F				
Trent below Tame	3			F	F				
Trent above Nottingham	3	P+	P+			P+	P+	P+	P+

NOTES: F = predicted class poorer than RQO (one class below)
P+ = predicted class better than RQO (one class above)
Other stretches comply with their RQO

Evaluation of class failures between paired scenarios showed total ammonia failures with the Lakes and total ammonia and BOD failures without the Lakes in the stretches immediately below Lea Marston. Failures were also predicted to occur under future consented discharge conditions (scenarios 5 and 6) in the Trent below the Tame.

The simple dynamic model was used to predict flow, velocity, depth and water quality in 35 two kilometre reaches to represent the study area. The model ran at a 1 hour time step and modelled the decay of BOD and Ammonia, reaeration of DO and loss of DO due to BOD and Ammonia decay. The model was calibrated using flow and continuous water quality data from an observed storm event (9.2 mm rainfall on 8/6/96 - Event 1). Figure 3 shows the flow and quality arriving at the Lakes from Event 1. The model was used to compare the predicted impact of each scenario using Event 1 and for two recent storm events which caused significant pollution episodes. These were an event of 15.0 mm rainfall on 10/7/95 which had a return period of 1 in 2 years and caused major fish kills in the Tame: and, an event of 13.6 mm rainfall on 6/8/96 which had a 1 in 1 year return period. Without-Lakes scenarios were represented by a new channel to bypass Lake 1 and connect with the old river channel around Lake 2A. The new channel was assumed to have the hydraulic characteristics of the river channel above the Lakes. Figure 4 illustrates a typical paired scenario result, for DO on the Trent above Nottingham.

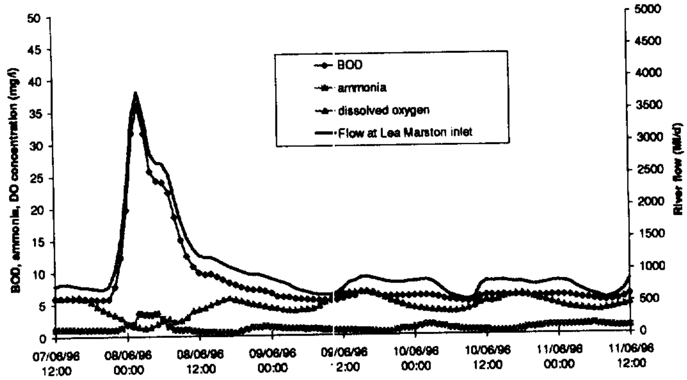

Figure 3. Input of flow, pollutants and dissolved oxygen at Lea Marston for Event 1.

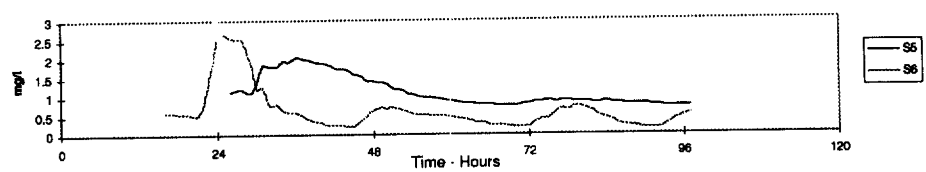

Figure 4. River Trent u/s Nottingham - Dissolved oxygen predicted for Scenarios 1 and 2 for Event 1.

The simple dynamic modelling results demonstrated that a key benefit of the Lakes was to protect the downstream fisheries. The Lakes significantly reduced the impact of DO sags moving down the Tame from Birmingham, and the results can be summarised as follows:

- all with-Lakes scenarios gave protection to the Trent fisheries against fish kills for events with a return period of up to 1 in 1 year;
- all without-Lakes scenarios will not give protection to the Trent fisheries against fish kills for events with a return period of up to 1 in 1 year; and
- all River Tame reaches do not have protection against fish kills for events with a return period greater than 1 in 1 year with or without the Lakes.

COST BENEFIT ASSESSMENT

The Environment Agency is required to support investment proposals by cost-benefit analysis, including environmental benefits, and, as a result, has supported the development of a procedure for applying the techniques of environmental economics in a consistent and practical manner. This technique, the FWR Manual Assessing the Benefits of Surface Water Quality Improvements, was used as the methodology for the calculation of environmental costs associated with the Lakes management options, (FWR, 1996). The Manual sets out a step-by-step guide for calculating the benefits that accrue as the result of a change in water quality by adopting a contingent valuation approach. Although the Manual only examines water quality improvements, the study assumed that a worsening in water quality would result in similar economic dis-benefits. The social cost categories were identified for the catchment and cost estimates were produced using the Manual procedures for: informal recreation, angling, industrial abstractions, drinking water abstractions, amenity, and non-use (or conservation value). The combined calculated per annum benefits for each scenario are shown in Table 4. Scenario 1 was assigned a benefit of £0 to act as a baseline for a comparison of benefits/disbenefits arising from water quality changes from the present.

Table 4. Combined per annum benefits for all use categories compared to Scenario 1

Scenario	1	2	3	4	5	6	7	8
Total Benefit £k	0	-777	-87	-1153	-44	-795	333	-352

- ve = disbenefit

The predicted changes in river quality were used to calculate the cost benefit ratios to identify the most economically viable scenario. As the scenarios referred to different time periods (the current being 1997 to 2000 and the future from 2001 to 2047), their associated costs and benefits were combined to provide four options to estimate costs and benefits over a 50 year period with a discount rate of 6% per annum, based on 1997 prices:

Option A: with-lakes predicted quality (Scenarios 1 and 7);
Option B: without-lakes predicted quality (Scenarios 2 and 8);
Option C: with-lakes consented quality (Scenarios 3 and 5); and
Option D: without-lakes consented quality (Scenarios 4 and 6).

The baseline for the analysis was that represented by the do minimum option. In this case, do minimum was best represented by Option D as it related to consent quality without operation of the lakes. The estimated costs varied between the with and without-lakes scenarios as follows:

- with-lakes: operating costs which were roughly £1m per annum together with capital replacement costs of £2.7m in present values; and
- without-lakes: one-off capital costs associated with the construction of a new river channel/control gate and associated structures, together with the costs of demolishing the treatment works (approximately £1m over two years) and £20,000 per annum for operational needs.

The calculated present value costs are £19.5m for the with-lakes scenarios and £2.8m for the without-lakes scenarios. Therefore, the additional cost of continuing to operate the Lakes is £16.7m. A summary of the results is presented in Table 5.

Table 5. Present value costs and benefits as compared to Option D (do-minimum)

Option	With-Lakes?	Benefits (£ millions)	Costs (£ millions)
Option A	Yes	39.1	16.7
Option B	No	7.8	0
Option C	Yes	21.7	16.7
Option D	No	0	0

The key results of the cost-benefit assessment were:

- a key factor influencing the level of predicted benefits is the impact of wet weather events on the quality of fisheries in the Trent;
- Option A and Option B both relate to future predicted quality, but Option A (with-lakes) provides significant benefits over Option B;
- Options C and D both relate to future consented quality, and again the with-lakes option (Option C) provides benefits over Option D; and
- the option which provides the greatest level of benefits is Option A, which is the current and future predicted quality with the Lakes.

CONCLUSIONS

The results showed the significant improvements in water quality that can be anticipated to arise from the current wastewater capital expenditure, as indicated by comparison of Scenarios 1 and 7 and 2 and 8. However, the full environmental benefit of these improvements will only be obtained if the Lakes continue to operate (Scenario 7) to protect downstream quality from wet weather pollution loads generated above Lea Marston. Continued operation of the Lakes produces the largest value of total net economic benefits. By integrating environmental and economic modelling, the study demonstrated that the Lea Marston Lakes provide an economically justifiable method for reducing the water quality impact of the Birmingham conurbation. The Environment Agency is planning to continue to operate the Lakes for at least the next 10 years as a result of the study and is considering means of reducing wet weather pollution above Lea Marston.

REFERENCES

DoE (1994). The Surface Waters (Rivers Ecosystem Classification) Regulation. Statutory Instrument 1057. Department of the Environment. UK.

Environment Agency (1997). SIMCAT 4.15 - A Guide for Users. Environment Agency.

FWR (1994). Urban Pollution Management Manual. FWR/CL 0002. Foundation for Water Research.

FWR (1996). *Assessing the benefits of surface water quality improvements Manual.* FWR/CL 0005, Foundation for Water Research.

Harkness, N. (1982). The River Tame - a short history of water pollution and control within an industrial river basin. *Wat. Sci. Tech.*, **14**(1-2), 153-165.

Lester, W. F., Woodward, G. M. and Raven, T. W. (1972). River Purification Lakes. Trent Research Programme Vol. 6. Water Resources Board/HMSO.

Martin, J. R. (1994). Water Quality Improvements in the Trent Catchment (UK): A view of their relationship to management and legislative changes. *Wat. Sci. Tech.*, **30**(5), 167-176.