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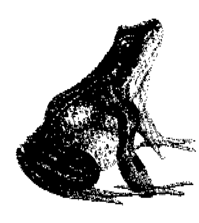
Bankside Storage and Infiltration Systems (ENV 9037)

Final Report to the Department of the Environment

DoE 3266 (P)
JULY 1993



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Report No: DoE 3266 (P)

July 1993

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PREFACE

Water that is abstracted directly from the river and enters the drinking water supply following treatment, rather than first passing through a bankside storage or infiltration system, presents a potential risk to the consumer.

The Department of the Environment placed a contract (PECD 7/7/230) with WRc in January 1992 to conduct a feasibility study on bankside storage and the use of bankside infiltration for the protection of supplies from river abstractions, identifying the costs, advantages and disadvantages of such installations.

This final report presents the work undertaken. The cooperation and assistance of Water Industry staff in this study is gratefully acknowledged.

BANKSIDE STORAGE AND INFILTRATION SYSTEMS (ENV 9037)

S C Nixon and R E Ashby-Crane

SUMMARY

About one third of Britain's drinking water comes from lowland river sources. Much of it is abstracted directly from the river and enters supply following treatment, rather than passing first through a bankside reservoir or bankside infiltration system. In these cases the consumer is potentially at risk from pollution incidents that may affect the rivers.

A feasibility study on the use of bankside storage and bankside infiltration for the protection of supplies from river abstractions, identifying the costs, advantages and disadvantages of such installations has been undertaken. The first stage of the study comprised a literature review and the collation of views from water utilities in the UK on their operational experience with bankside storage and infiltration systems.

Relatively little information was available from the literature relating to the water quality of bankside reservoirs and the use of infiltration systems. The responses to the questionnaire revealed a range of views ranging from the opinion that bankside storage is an essential component of water supply from rivers to the view that intake protection in the form of monitoring is adequate. A cost-benefit analysis was undertaken, as part of a wider procedure to assess the need for bankside storage and infiltration systems. Cost estimates show that in general the capital cost of bankside storage exceeds the potential savings it provides.

The need for bankside storage or infiltration systems can only be sensibly assessed on a site-by-site basis. There are many factors influencing the choice of system including intake protection facilities, enhanced treatment, costs and the extent of pollution control procedures within the catchment. A procedure for assessing the need for such systems has been described and should be considered for practical application.

This study was funded by the Department of the Environment whose persmission to publish is gratefully acknowledged. The views expressed in this report are those of the authors and not necessarily those of the Department of the Environment or any other government department or organisation.

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1. INTRODUCTION

About one third of Britain's drinking water comes from lowland river sources. Much of it is abstracted directly from the river and enters supply following treatment, rather than passing first through a bankside reservoir or bankside infiltration system. In these cases the consumer is potentially at risk from pollution incidents that may affect the rivers. The provision of bankside storage or the use of bankside infiltration offers additional protection against contamination of water supplies. The benefits of bankside storage were recognised in 1971 by the Department of the Environment's (DoE) Steering Committee on Water Quality. Their first annual report recommended that all new bankside storage schemes for the abstraction of water from rivers should incorporate provision for the storage of raw water for at least seven days before treatment, to guard against accidental pollution. Three reasons were given:

1. To permit closure of the intake in the event of accidental pollution of the source of water.
2. To dilute any polluted waters entering the reservoir with the water in storage and to reduce the effects of the variations in water quality occurring in the river.
3. To allow further self-purification to take place.

In their second undated report, the Committee confirmed these recommendations. The former Directorate General of Water of the DoE recognised that short circuiting of water between the inlet and outlet of bankside reservoirs could well be a limiting factor in the operation of such systems. As a result, WRc was commissioned in 1974 to establish by field measurement the extent of short-circuiting in reservoirs of different size and form. These studies concluded that depending on wind speed and direction, all the reservoirs investigated exhibited short-circuiting to a greater or lesser degree and remedial measures were recommended.

This present investigation commenced in January 1992, and was to assess the role of bankside storage and bankside infiltration for the protection of supplies from river abstractions, identifying the costs, advantages and disadvantages of such installations. This report is structured such that the main findings, points of discussion, analysis and conclusions of the research are contained in Sections 3 to 6, and the detailed source documentation on the different aspects of the research are included as Appendices.

2. OBJECTIVES AND WORK PROGRAMME

2.1 Objectives

The objectives of the contract as described in the Programme of Research are as follows:

1. To evaluate the benefits on quality and for operational strategy of bankside storage of abstracted river water.

2. To determine the optimum characteristics for bankside reservoirs to achieve maximum benefits from storage of water for up to seven days supply.

3. To evaluate potential benefits for quality generally, and for achieving minimum adverse effects of pollution, of bankside infiltration alone or with conjoint bankside storage.

The Programme of Research to meet these objectives was as follows:

1. Review published literature from the UK and abroad, and available non-published work, to extract references to obtain information on quality improvements and use of storage to maintain supplies during pollution incidents affecting the source.

2. Supplement with information by questionnaire and visits to selected water undertakings in the UK who have operational experience of bankside storage or bankside infiltration systems, and compile the findings in a database.

3. Include:

    - The strategies of use of the source during emergency periods;

    - A catalogue of intake pollution incidents, with causes, actions, consequences and assessment of recurrence;

    - Methodologies, and assessment of methodologies, for pollution risk assessment, with consideration of future developments;

    - Water Companies' intentions on bankside storage and bankside infiltration schemes, together with assessment of the provision of either, principally for major conurbations and perceived high risk situations;

    - The potential savings of the cost of treatment after storage compared to without storage, and compared to the costs of establishing bankside storage;

- Determination of the optimum means of operation of bankside storage, and the optimum design parameters, from which estimates can be made of the capacity needed in relation to the potential risk of deterioration of source. Similarly, the expected improvement in quality during storage, and the economic area of surface to volume ratios;

- Reference to mixing characteristics of reservoirs including forced mixing.

4. Consider bankside infiltration schemes as an alternative to reservoirs, at suitable sites.

5. Evaluate the potential benefits for quality generally, and for achieving minimum adverse effects of pollution, of bankside infiltration alone or with conjoint bankside storage.

6. Assess the future variation of pollution risk, with particular regard to the policies of HMIP and NRA; include assessment of EC and UK prospective policies and the consequences on the viability of bankside storage/infiltration.

2.2 Work Programme

A review of the literature on bankside storage and infiltration was completed in the early phases of the project and is presented in Appendix B. It was the intention that published information was supplemented with information and operational experience from the water industry. To this end a questionnaire seeking the views of the water industry was sent out to twenty six water companies and utilities, eighteen of which returned replies. Before circulating the questionnaires the relevant person in each water company and utility was contacted by telephone to obtain their agreement to take part in the survey. At that time it was suggested that it might be helpful if a meeting was arranged when the questionnaire could be completed. Only five companies requested a visit, the others were unwilling or unable to commit themselves to the time necessary. Therefore, only selected views have been obtained.

The information gleaned from the review and the questionnaires has been used to assess the need and role of bankside storage and infiltration in the water industry, taking into account the need of the suppliers to operate cost-effectively within the constraints of meeting customer requirements and meeting water quality standards.

3. THE USE AND ROLE OF BANKSIDE STORAGE

The information received during this investigation from the Water Service Industry on the use of bankside storage reservoirs confirms the main uses identified by the original Department of the Environment Steering Committee on Water Quality.

- That bankside storage allows the closure of river intakes during periods of poor raw water quality whilst maintaining supply;
- That water quality variations are smoothed out during storage;
- That bankside storage offers a source of relatively poor water quality for blending with higher quality water;
- That bankside storage allows further self-purification to take place.

A summary of the detailed information obtained on individual bankside storage reservoirs is given in Table 3.1. The responses to the more general questions are summarised in Tables 3.2a and 3.2b.

The operational experience with regard to each of the above uses of bankside storage is further discussed in the following Sections.

3.1 Changes in water quality

Though there are reported improvements in quality through storage, none of the companies that responded seemed to have undertaken a detailed assessment of any improvements. There were, however, recorded examples where storage created a problem, decreasing the quality of water through excessive algal production. Excessive algal growth, particularly in nutrient-rich water is a potential problem with bankside storage. In some cases growth has been so great that the water has been rendered untreatable for certain periods of the year because of filter blockage and associated problems. In one case, the problem was overcome by phosphorus stripping of the raw water before entry into the reservoir. Alternatively, algal problems have been overcome by the use of microstrainers in the treatment process or by the operation of the reservoir in a manner that prevents the growth of undesirable algae (such as blue-green algae). It has been suggested (NRA 1990) that by keeping reservoirs continuously mixed, algal diatom populations should be maintained, rather than the bloom forming blue-green algae.

Table 3.1 Summary of specific information obtained on bankside storage reservoirs

	Reservoir 1	2	3	4	5	6	7	8	9	10
Construction date	1981	1932	c 1930s	1966	c 1960s	1904	early 1900s	1972	1971	1922
River class	1a	-	-	1b	2a	-	2a	-	1	1
Catchment type	A/I	A/I	A/I	A	A	-	A	-	A+F	A+F
Population served	100 000	-	182 000	623 000	70 000	-	80 000	350 000	70 000	28 000
Abstraction rate (Ml d^{-1})	32	50	50	182	24-25	120	5-6	112	29	54
Storage capacity (days)	5	<3	6	16	4	5	3	1	6	2
Mean retention time (days)	-	-	-	3	-	50	2	<1	6	2
Volume (Ml)	138	145	273	3060	100	1054	90	56.6x2	173	109
Surface area (ha)	2.02	-	4.1	39	-	-	3.24	1.15	2.98	2.39
Depth - mean (m)	7.7	5.2	6.6	7.85	-	16.4	2.78	4.92	5.89	4.56
- max. (m)	8	-	-	25.6	-	6.4	-	7.05	6.55	-
Physical form	C	R	R	NV	C	2 x R	2 x R	2 x R	C	R
Baffles	0	0	0	0	0	0	0	0	1-straight	3-straight
Short circuiting	Y	N	Y	N	Y	N	Y	N	N	N
Artificial mixing	N	N	N	N	N	N	N	N	N	N
Intake protection	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Treatment before supply	Y	Y	Y	-	Y	Y	Y	Y	Y	Y

Table 3.1 continued

	Reservoir									
	11	12	13	14	15	16	17	18	19	20
Construction data	1866	1972	1973	1991	c 1982	1984	1937	1965	1978	c 1837
River class	1	1	1a	1a	1a	1	1	-	-	-
Catchment type	A+F	A	A	A	A	A+F	A	-	-	A
Population served	29 000	600 000	600 000	40 000	c 80 000	280 000	12 000	c 30 000	30 0002	150 000
Abstraction rate (Ml d^{-1})	54	227	120-180	16	40	35	11	10	60	40
Storage capacity (days)	7	<1	7-10	<1	<1	6	-	-	7	7
Mean retention time (days)	1	-	-	<1	<1	6.5	6	15	-	7
Volume (Ml)	54.5	32	1214	9	25	231	65.5	234	540	320
Surface area (ha)	1.4	-	-	-	-	8.75	2.17	6.7	7.3	4
Depth - mean (m)	3.86	-	-	-	-	2.64	3	3.5	7.39	-
- max. (m)	-	-	-	-	-	-	-	4.8	12	7.31
Physicalform	C	R	NV	R	C	O	IR	R	IR	O
Baffles	1-spiral	N	N	N	N	Y-1 bent	N	N	N	N
Short circuiting	N	-	Y	N	Y	N	Y	N	Y	N
Artificial mixing	N	N	N	N	N	-	N	N	N	N
Intake protection	Y	-	Y	Y	Y	N	N1	only NO3	Y	Y
Treatment before supply	Y	Y	Y	Y	Y	Y	Y	Y	N	Y

Key to Table 3.1

A - agricultural	I - industrial	F - forestry	NO_3 - nitrate
R - rectangular/4 sided	NV - natural valley	C - circular/oval	IR - irregular
N - no	Y - yes	- no data	c - circa

Table 3.2a Summary of responses to questionnaire

	Water company							
	1	2	3	4	5	6	7	8
Nº of Bankside systems	1	2	0	0	1	1	1	1
- future intentions								
- no plans	-	*	-	*	-	-	-	-
- plans	-	-	1	-	upgrade	-	1	-
Risk assessment	H	-	-	L-M	M	-	-	M-H
closures per year	2	18	-	0	2-5	3	0.04	<0.2
av length of closure (hrs)	3-24	-	-	0	<24	8.5-85	-	<24
Importance of BS for:								
- pollution risk/safeguarding supply	-	-	-	-	*	*	-	-
- smoothing out quality	-	*	*	-	-	-	-	-
- storage capacity	-	-	-	-	-	*	-	*
- economic pumping regime	-	-	-	-	-	-	-	-
- not important	-	-	-	*	-	-	-	-
Role of pollution risk assessment	-	-	-	I	I	VI	-	I
Role of intake protection	E	I	I	I	risk dependent	-	-	I
Role of catchment control	E	routine	I	I	VI	-	-	some
Role of advanced H_2O treatment	E	pesticides and NO_3	pesticides	I	taste/odours and final defence	-	-	isolated problems
Role of cost-benefit analysis	I	-	routine	-	E	-	none	-
Effects of tighter controls	costs<	treatment<	treatment<	costs<< benefit<	large	costs<	-	large
Role of emergency treatment	negated by BS	-	-	none	none	-	-	I
Future need of BS	E	-	confidence< but expensive	negated by BI	-	-	-	depends on CBA

Table 3.2a continued

	Water company 9	10	11	12	13	14	15
Nº of Bankside systems	1	1	0	3	4	1	1
- future intentions							
- no plans	-	-	-	*	*	*	-
- plans	-	-	1	-	-	-	1
Risk assessment	L	L	H	L	-	-	-
closures per year	0	0	0.4	2	<2	-	none due to pollution
av length of closure (hrs)	0	0	<24	1-96	<<24	12-72	-
Importance of BS for:							
- pollution risk/safeguarding supply	*	-	-	-	*	-	*
- smoothing out quality	-	-	*	-	-	-	-
- storage capacity	*	*	-	*	*	-	-
- economic pumping regime	-	-	-	*	-	-	-
- not important	-	-	-	-	-	-	-
Role of pollution risk assessment	I	E	-	-	-	VI	I
Role of intake protection	I	risk dependent	-	-	advance warning	E	not relevant
Role of catchment control	I	NRA's role	-	-	limited use	E	limited
Role of advanced H_20 treatment	low qual. H_20 and pollutions	last resort	-	-	not relevant	I	expensive, not relaible
Role of cost-benefit analysis	none	routine	-	-	-	Routine	Routine
Effects of tighter controls	use of low qual. H_20>	costs<	-	-	BS allows standards to be met	not important	-
Role of emergency treatment	not recommended	none	-	-	none	none	-
Future need of BS	need>	negates BI + IP	-	-	H with IP	I - long term	H

Table 3.2b Summary of responses to questionnaire

	Water company							
	1	2	3	4	5	6	7	8
Major threat								
- nitrates	-	-	-	-	-	-	*	-
- farm/sewage/ammonia	*	-	*	-	-	-	-	-
- oil	-	-	*	-	-	*	-	-
- road/rail	-	-	-	-	-	-	-	-
- other chemicals	-	-	*	*	*	-	-	-
- saline intrusion	-	-	-	-	-	-	-	-
% pollution incidents								
- nitrates	2	24	-	-	-	-	-	-
- ammonia	4	16	-	-	-	-	-	47
- oil	55	21	-	-	-	88	-	20
- other chemicals	30	40	-	-	-	-	-	33
- unclassified	9	-	-	-	-	12	-	-

Table 3.2b continued

	Water company						
	9	10	11	12	13	14	15
Major threat							
- nitrates	-	-	-	-	-	-	*
- farm/sewage/ammonia	*	*	*	*	*	*	-
- oil	-	-	-	-	-	-	-
- road/rail	-	-	-	*	*	-	-
- other chemmicals	-	-	-	-	-	*	-
- saline intrusion	-	-	-	-	-	-	*
% pollution incidents							
- nitrates	-	-	-	-	-	-	-
- ammonia	-	-	-	-	-	-	-
- oil	-	-	-	-	-	-	-
- other chemmicals	-	-	-	-	-	-	-
- unclassified	-	-	-	-	-	-	-

Key:

H	-	high	M	-	medium	L	-	low
E	-	essential	VI	-	very important	I	-	important
<	-	increased	>	-	decreased			

CBA	-	cost benefit analysis
BS	-	bankside storage
BI	-	bankside infiltration
IP	-	intake protection
NRA	-	National Rivers Authority
-	-	no opinion/disagreement
*	-	in agreement

The literature indicates that short term storage of water (typically up to seven days) not only allows time for a water quality problem to be detected and remedial measures taken, it also generally leads to an improvement in the bacteriological and virological quality of the water. Significant reductions in the number of coliforms, sulphide reducing and mesophilic bacteria occur: however, similar reductions could also be achieved by applying a small dose of chlorine. Short term storage also promotes the deposition of suspended solids thereby potentially reducing the cost of treatment. Storage also results in the concentration of contaminants associated with suspended solids, such as iron and manganese, being reduced (through settlement), providing that thermal stratification does not subsequently occur. The bottom sediments in stratified waters may become anoxic causing these contaminants to go back into solution. The concentrations of iron and manganese in dissolved form will be unaffected by storage.

Biochemical oxygen demand tends to show a general reduction on storage but this is probably also due to the settlement of particles which could be removed by clarification and filtration. Biodegradation of some organic compounds within the reservoir may occur. Ammonia tends to decrease on storage partially due to nitrification by algae whereas the pH of the raw water tends to increase on storage, this is most noticeable in summer, due to the direct uptake of carbon dioxide in photosynthesis altering the carbonic equilibrium. Water colour is generally unaffected by storage unless the volume of water is large enough to even out peaks and troughs that may occur. Organic chemicals which are resistant to biodegradation can cause taste and odour problems which are difficult to remove if the water is treated immediately after abstraction; short-term storage reduces such problems.

In deep reservoirs (greater than about 5 m) thermal stratification can occur providing clear, warm epilimnotic waters which are an ideal habitat for phytoplankton. Similarly short circuiting can produce pockets of relatively stagnant water in which phytoplankton may multiply. Excessive growth may lead to reduced DO and increased BOD in the outlet water.

3.2 Protection of supply

Bankside storage is undoubtedly beneficial with respect to being able to close the intake during a pollution incident in the river. However, if the pollutant enters the reservoir undetected, there would still be an element of safety through dilution or containment of the contaminant. It also enables the closure of an intake when the source water is of low quality. Poor water quality can be caused not only by pollution incidents but also due to heavy rain which brings about high turbidity, ammonia (from storm discharges) and nitrate levels.

In 1980 the Department of the Environment estimated that approximately 6000 pollution incidents were notified in England and Wales each year causing 100 intake closures annually.

Water Company A estimate that their intake on a river in the north west of England is closed up to 30 times a year (in many cases on a precautionary basis) of which 2 to 5 per annum are major incidents. For most of these incidents intake closure is only for 24 hours, for the major incidents closure could be up to three days.

Water Company B has one intake on which an intake protection system has recently (in last two years) been installed. There is no bankside storage. The assessment of risk of closure was put as low to medium, with one intake closure expected every five to ten years. They have at present no record of any pollution events occurring.

Water Company C constructed a bankside reservoir in an old gravel workings five years ago which they use for additional raw water storage capacity. Since the installation of the system, they have had two incidents which have led to closure, both for a few hours only.

Water Company D have detailed records of the number of pollution incidents occurring on the two rivers supplying one of their reservoirs. In 1987 on one of the rivers there were six reported incidents, two of which lead to intake closure, and on the other eight, five of which lead to closure. One incident lead to both intakes being closed. Information on the length of time which intakes needed to be closed in general has not been recorded.

Water Company E has 30 river abstractions, one of which has a bankside storage reservoir which has four days storage capacity and has been in operation since the late 1960's. It was installed to smooth out the fluctuations in river quality and to assist the supply of raw water. They have experienced short circuiting and algal growth. In the last 25 years there has only been one major pollution incident which led to closure for 16 days, however better time-of-travel information would have decreased the length of closure. They estimate that on average there are probably 1000 pollution events on one of the rivers each year, two of which would require an intake to be closed for up to two days.

Water Company F has a bankside storage reservoir with three days capacity there have been no recorded pollution incidents since its installation in the early 1900's.

Water Company G has had one bankside storage reservoir since 1966, over the last five years on average there have been approximately three closures per year, coloured and turbid water result in the intake needing to be close one further time per year. So far none of the incidents have been serious.

The South Western Division of Water Company H has four river intakes. They have installed bankside storage systems at three of these, the fourth intake is an old direct intake abstraction point, which takes water just upstream of the bankside storage intake, and is used as an industrial supply. The assessment of risk to the intakes was described as being low to medium, with the major risks being from agricultural pollution and road/rail accidents. Intake closures occur between one and two times a year on three of the rivers and last for between one and four hours. On the other river there are between three and four closures per year generally lasting between six and nine hours but occasionally may last up to four days.

Water Company I do not record the number of pollution incidents that lead to closure. Bankside storage has led them to have a relaxed attitude with respect to closure and as a matter of policy close intakes if there is any suspicion of pollution. Closures normally only last for a few hours.

Water Company J have 17 intakes, of which ten have bankside storage facilities and seven go to treatment directly. Only one of these offers short term storage. This reservoir was built in 1965 for emergency storage and to improve water quality. There have been very few pollution incidents, less than ten, which have led to intake closure since its construction.

Water Company K has one bankside storage reservoir. It was constructed in the late 1830s. In the last four years there have been 179 pollution incidents on the supplying river, ten of which have led to intake closure. The duration of closure has varied between 12 and 72 hours. In addition to these a further 15 incidents have led to partial closure of the intake.

Water Company L commissioned a reservoir in 1972 to preserve water quality and offer protection against pollution as well as enabling pumping flexibility. It allows selective abstraction from the river offering protection against high nitrates, high turbidity and saline intrusion. The intake has been closed on several occasions as a precaution but there have not been any pollution events in recent years. The length of closure is variable but can be between three and four days.

Two major incidents occurred on the River Stour in the 1970's. The first occurred in 1973 when thousands of tomato plants were seriously affected by weed killer which was present in water which had been transferred from the Ely Ouse. The second was in 1975 when dyestuff intermediates were accidentally released. This resulted in the intake being closed for two weeks; however, this length of closure was partially due to a miscalculation resulting in the intake being closed too early. Although a few days bankside storage was inadequate to deal with these two major incidents, through having a well integrated supply network it was possible to divert water from other reservoirs in order to maintain supplies (Slack and Burfield 1978).

In the Northumbrian region the worst incident in recent years was the spillage of approximately 4000 gallons of flux oil causing the closure of river intakes for about three days.

From the pollution events recorded it would appear that three days storage is sufficient to protect the supply against the majority of incidents. Although incidents did occur which caused the intake to be closed for more than three days these were rare and generally could have been shortened if better time-of-travel information had been available.

In terms of improving quality the need for bankside storage should reduce as the NRA improve the quality of the river water and introduce catchment management; however this will have no effect on accidental, unforeseen pollutions. This is further expanded in Section 5.

In order to provide an adequate level of protection at the minimum cost it is necessary to undertake a pollution risk assessment (Appendix B) and review the availability of other sources which could be used in an emergency.

Several companies were keen to point out that catchment control was the domain of the NRA and one company felt that the need for bankside storage should decrease as the NRA improve the quality of the water but that they could be useful in increasing the public's confidence in the quality of the potable water.

3.3 Smoothing of water quality variations and blending

Examples have been found where the water within bankside storage reservoirs has been blended with other, usually higher quality, sources of water. This has enabled the intake to remain open even though the abstracted water by itself would be unsuitable for drinking (in terms of meeting standards).

Water Company D provides an example where conjoint use of bankside storage (with two different river intakes) and other sources helps to maintain supplies and treated water quality. Here low nitrate borehole water is frequently blended with high nitrate (above the 50 mg l^{-1} N-NO_3 drinking water standard) river/reservoir water such that the standard is complied with in the final treated water. This flexibility in source and supply means that their river intakes need to be closed less frequently than otherwise would be the case. For example, in 1987 the nitrate limit was exceeded for 73 (of 191 the monitored) days at one of the two intakes into Langford reservoir, and 115 (of the 190 monitored) days at the other. However, because of the conjoint use of water the intakes had only to be closed for approximately nine and three of those days, respectively. As would be expected the nitrate problem largely occurs during the winter/early spring period.

Water Company C, in particular, thought that an important role of bankside storage was to smooth out fluctuations in water quality, especially increases in turbidity after rain events. Maintaining an even quality of raw water enables them to provide a constant level of treatment and a quality of water that meets the required standard.

A reservoir in Water Company E's catchment was constructed in the early 1960s to smooth out fluctuations. It has also been used to protect and maintain the potable water supply, the largest event occurred following a fire at an adhesives factory which polluted the river for some time.

The experimental treatment plant which was built at Pecq on the River Seine, which included a 24 hour settling tank, was found to be very effective at preventing sudden peaks of turbidity in the raw river water being passed onto the treatment works (Rizet and Cauhape 1975).

3.4 Operational aspects

Operationally there may be the opportunity to use multiple river intakes, and an example has been found where water is abstracted from two rivers either simultaneously or individually. This allows selective use of the raw water and has enabled supply to be maintained for a greater proportion of time than would have been otherwise possible. In addition, there would be the possibility of using multiple offtakes possibly at different depths or at different points around the outfall. Some bankside storage reservoirs also have mixing systems such as air mixers or may prevent short-circuiting by the use of baffles.

Water in bankside storage may be used as a prime source of raw water or may be blended with different quality water to maximise supply sources and to meet water quality standards. They may also act as strategic sources of water.

3.5 Design aspects

One of the design decisions to be made would be on the flow and mixing characteristics of the reservoir. The main choice would be between inducing fully mixed conditions, plug flow or partially mixed conditions. In a fully mixed system the incoming water is distributed throughout the reservoir and arrives rapidly at the outlet. Plug flow occurs when incoming raw water is uniformly distributed in a vertical cross-section near the inlet and then advances at a steady rate between the inlet and outlet.

The advantage of fully-mixed conditions would be the achievement of maximum dilution of any pollutant that inadvertently got into the reservoir. Fully-mixed conditions would also induce a more even water quality distribution with time in the outlet water from a variable raw water supply. A disadvantage would be a lack of time delay between the intake and outlet, and the treatment works may well be exposed to contamination before the problem was identified.

Plug flow would ensure a maximum time delay but would tend to induce a smaller dilution (compared to fully-mixed reservoir) of any pollutant, and the smoothing effect on water quality would be potentially less. It would in practice be very difficult to design a naturally fully mixed system and most of the examples obtained from the water industry would best approximate to partially mixed systems. Indeed the only examples of plug flow reservoirs were four Scottish Reservoirs. In partially mixed reservoirs it would be important to prevent short-circuiting which would cause unexpectedly high concentrations of pollutants to arrive at the intake and might induce dead-zones in which algae may proliferate (e.g. blue greens).

The degree to which the water in a bankside reservoir is mixed will depend principally on the degree to which the surface is exposed to wind shear and the magnitude of this shear. Also of importance is the surface to depth ratio; shallower reservoirs (with a depth of around 5 m or less) will exhibit a greater degree of wind-induced mixing than deeper reservoirs whose lower-layers will be relatively unaffected by turbulent water movements. In addition, in winter when winds speeds are high and more prolonged, mixing will be more sustained than in summer when winds are generally light and temperatures such that thermal stratification may be established in the reservoir. Under these latter conditions it is very likely that water entering the reservoir at or near the surface, and at a similar temperature, will mix only with the upper, warmer layer of water in the reservoir.

From previous field experiments conducted for the Department of the Environment (White and Davis 1978) it was shown that, depending on the wind speed and direction, the degree of mixing as revealed by dilution of tracer and velocity-field measurements was very variable. It was clear that if well-mixed conditions were desirable in bankside reservoirs then this could only be achieved all the year round by designing systems to achieve this.

There are several ways in which a bankside reservoir can be artificially mixed ranging from mechanical pumps to air-diffuser techniques. The principle of all these methods is to continuously pump water from the lower layers to the surface. For bankside systems where water is pumped from the river into the reservoir there is a further method available for mixing which employs the use of a nozzle on the inlet pipe. The inclined nozzle is located near the bed of the reservoir and forces the incoming water to behave as a jet entraining water from the main body of the reservoir as it rises to the surface. This type of system is used successfully on a number of large pumped-storage reservoirs such as Farmoor reservoir near Oxford.

WRc's experience of air-diffuser mixing in bankside reservoirs has shown that well-mixed conditions can be easily achieved using a submerged perforated-pipe connected to a compressed air system located in the treatment works (Davis and Nixon 1978). The perforated pipe is generally manufactured from suitable plastic pipe (high density polythene) having a bore of 50 mm and containing a series of 1 mm diameter holes along its upper side. This pipe is then submerged in the middle of the reservoir with the length of perforated-pipe section depending on the size of the reservoir.

For a reservoir in south east England (volume 135 000 m^3), studies in 1978 and unpublished further investigations employed perforated-pipe lengths of 30 m and 90 m. Compressed-air flow rates ranged from 7 $l\ s^{-1}$ to 45 $l\ s^{-1}$ of free air delivered at a pressure just sufficient to overcome the static head in the reservoir. The results showed that there was no appreciable difference in mixing efficiency between the different perforated-pipe systems used, as determined by injecting tracer into the reservoir and monitoring its dilution, and in each case the reservoir behaved as a well-mixed system.

As described above, it has been demonstrated (Davis and Nixon 1978) that short-circuiting can be prevented by appropriate mixing systems. The use of mixing systems as a possible control of algal blooms has been discussed further in Section 3.1. Where there has been historical problems with regards to excessive algal growth then pretreatment small volume contact tanks have been designed where phosphorus precipitation occurs.

3.6 Other information and views

3.6.1 General

Three water companies indicated that bankside storage was most important for safeguarding supplies against accidental spills, three others gave their primary role as smoothing out water quality and six for their storage capacity. One company thought bankside storage was not important and considered it an unnecessary expense and felt that intake protection monitors alone were adequate. Another company felt that intake protection would remain a feature, and are expecting the sensitivity and range of sensors to improve. They felt that bankside storage was a longer term option to provide further protection and quality improvement.

3.6.2 Future plans

Most of the water companies who replied to the questionnaire had no future plans for bankside storage, however four companies were considering plans to build new bankside storage reservoirs and another was planning to upgrade an existing system. One company felt that all companies should be thinking in the long term as regards to the building of bankside storage reservoirs, especially since there are periods of time when abstraction is not possible, for example during the nitrate season (October - March). Southern Water propose to construct three bankside storage lakes alongside the River Blackwater which joins the River Test just downstream of the river abstraction point. The total holding capacity of the lakes will be 2000 Ml. Southern Water needs raw water storage to provide an alternative source of supply if there is a pollution in the River Test and to meet the forecasted increase in demand (Institute of Environmental Assessment 1992).

3.6.3 Pollution risk

Pollution risk assessment was generally seen as an important step for assessing the appropriate level of protection and for undertaking representative cost benefit analyses for potential reservoirs.

Associated with this it was generally thought that intake protection systems were important for river intakes to minimise the risk, but the level of protection needed was dependent on the catchment and hence the risk assessment. Catchment control was generally considered to be important but it was thought to be under the responsibility of the NRA and had only limited scope as all risks could not be eliminated, for example from spillages from highways.

3.6.4 Treatment

Views on the role of advanced treatment varied greatly. Two companies thought that it was or would be invaluable for the control of background pollutants such as those causing taste and odour problems. Another thought it only of real use for isolated pollution incidents due to the expense, whereas another saw it as being essential to obtain the quality of water now required. Many companies have had to introduce activated carbon anyway for the removal pesticides to meet current standards. Others are looking at tertiary treatment to remove nitrates and phosphates. Another view was that advanced treatment was beneficial if catchment control is ineffective and enables the use of poorer quality water.

3.6.5 Cost-benefit

Three companies indicated that a cost-benefit analysis had not been undertaken for their bankside system, another company said more were needed whatever the cost. Two said it was a routine component of their operations, and three others indicated that it was essential or important for any major investment. One company had considered installing bankside storage reservoirs on three river abstractions but had decided against them because the large volume of water abstracted per day would have necessitated very large reservoirs, and because if a pollutant enters the reservoir the NRA do not want the contaminated water back. One company thought that bankside storage systems could not be justified on costs alone.

3.6.6 Drinking water standards

Most expected that tighter controls, for example through the introduction of more stringent standards, would increase their costs, some thought dramatically. One thought that there would be little return from the very small increase in quality however an additional effect would be minimisation of the use of poor quality river water.

One view was that the future need for bankside storage should reduce as the NRA introduces catchment control but it could be useful for increasing confidence. A further view was that bankside storage could diminish the need for bankside infiltration and intake protection. Another company thought that customer acceptability and public health implications were a greater driving force than EC regulations.

3.6.7 East Worcestershire Water Company case study

One Water Company has recently assessed the possibility of developing a new source works which might include the use of raw water storage. They presently have no surface abstractions but rely on groundwater supplies. The NRA has proposed a licence which allocates the annual resource into a restricted summer abstraction when the river flow is regulated and a larger winter abstraction when natural river flows can meet requirements. Such an allocation of supplies would require borehole supplies to be increased above the average yield in summer and reduced below the average yield in winter. Such conjunctive use of aquifer and river resources would conserve supplies necessary for regulation and allow more abstracters to be supported regulation sources.

The risk of intake closure was also assessed: it was predicted that closure of the intake would be necessary to avoid abstraction of either polluted water or water of high turbidity. This assessment was arrived at through examination of NRA records and through discussions with the NRA and other water abstracters. In general most pollution incidents appear to have been short (less than a day) but a few could lead to intake closure for two or three days. An industrial source was identified as a potential source of pollution though no incidents had been reported. It was concluded that they would need to plan for possible closure of the intake for periods of up to three days at any time of year. During emergencies supplies from the bankside reservoir could be augmented from boreholes: this could include periods of high turbidity.

Other constraints on the company would also affect the decision as to whether to install bankside storage or not. For example, the NRA proposed to reduce the average abstraction from the relevant aquifers in order to ensure that abstractions did not exceed aquifer recharge. They presently receive a large supply of raw water from another water company. This supply would become uneconomical in a few years time as they were likely increase the charge for the water.

4. THE USE AND ROLE OF BANKSIDE INFILTRATION

Bankside infiltration systems may take the form of either wells or reservoirs excavated in the vicinity of a river. Both designs are actively pumped and are fed from the river and by the interception of groundwater flowing towards the river. The proportion of water coming from each source is dependent on the distance from the river and the water table. They may be used independently or in combination.

Bankside infiltration would only be considered to be true bankside infiltration (compared to a groundwater, borehole source) when the proportion of river water to groundwater in the abstracted water is high.

4.1 Survey of experience

Little published or unpublished information has been found on the operational experience of bankside infiltration systems, the main example found being that of Amsterdam Municipal Water Works. In the UK there are only a few examples of use of bankside infiltration, for example, for emergency purposes near Peterborough in 1976. Water Company M have two 'gravel bed' lakes which the hydrologists believe are infiltration fed. The lakes are used for the dilution of pollution pulses and water with high nitrate levels.

The Amsterdam dune infiltration system works through the recharge of the aquifers with pre-treated Rhine river water. Its main advantages are described to be:

- smoothing and improving the quality of the river water through mixing with ground water;
- storage of water for emergencies
- improvement of the quality of the infiltrated water by subsoil biological, physical and chemical processes.

In the Amsterdam system the improvement in the quality of the infiltrated water occurs immediately after it has penetrated into the layer of sand. During this stage most of the free oxygen is used in breaking down organic matter. There is an improvement in taste and a reduction of the ammonia and nitrate content at this stage. The chemical oxygen demand and phosphate content may also considerably decrease. However the ability to remove phosphates has been significantly decreased by the installation of the coagulation plant at the intake.

4.2 Bankside infiltration model

The quality of water abstracted from bankside infiltration wells or bankside infiltration reservoirs will, under certain circumstances, be adversely affected by a pulse of pollution travelling along a river. There was no information relating to this in the literature or from operational experience. Therefore, the relationship between the quality of the abstracted water and that of the river was simulated using a mathematical model (Appendix C). In the model simulation it was was assumed that a slug of pollutant passed along the river over a day. The quality of the water abstracted will be related to the quality of the river water and of the groundwater in proportion to the contributions to the well output from the river and from groundwater.

In an under-utilised aquifer (where there is a greater proportion of groundwater) the maximum concentration, expressed as a fraction of the concentration in river water, falls off rapidly as the distance between the well and the river is increased. Aquifer type has an important influence on the predictions, with the relatively low transmissivity sandstones giving rise to the greatest river influence. For chalk and gravel aquifers no pollution will reach the well at distances greater than about 80 m.

In the case of an over-utilised aquifer the abstraction rate is high and the regional groundwater gradient low so that river water provides a relatively high proportion of groundwater abstraction. These conditions would apply to catchments in which a high proportion of the total groundwater recharge is abstracted. The maximum pollutant concentration is much more significant even for wells remote from the river. Sandstone again gives the highest concentrations, and even the highly transmissive gravels show a significant level of pollution in pumping wells at up to 1 km from the river.

Bankside infiltration reservoirs can be filled by water seepage either from the river or from groundwater flowing towards the river. The impact of river pollution on water quality in the reservoir will be determined by the relative contributions to seepage from the river and from groundwater. It was again assumed that a pollution pulse of one days duration passed along the river in the vicinity of the reservoir.

5. THE NEED FOR BANKSIDE STORAGE AND BANKSIDE INFILTRATION

5.1 Standards and legislation

The legal requirement of the water supply company is to provide water of a quality that complies with all relevant standards. The level of the standards and potential changes to them will be of prime concern when operational and treatment options are considered. Two options are the use of bankside storage and infiltration systems. The main legislation and standards associated with the supply of drinking water are fully discussed in Appendix D.

5.1.1 European Directives

Two EC Directives currently cover the quality of water used for potable abstraction, thereby indirectly affecting the viability of bankside storage and infiltration. These are the Directive concerning the quality required of surface waters intended for the abstraction of drinking water in the Member States 75/440/EEC (the Surface Water Directive, CEC 1975) and the Directive relating to the quality of water intended for human consumption 80/778/EEC (the Drinking Water Directive, CEC 1980). The former is primarily concerned with the quality of surface waters with regard to abstraction and levels of treatment required. It is implemented in UK law in the Surface Waters (Classification) Regulations (HMSO 1989a) which prescribe a classification system for inland waters in England and Wales. This classifies waters used for abstraction for drinking into three classes, DW1, DW2 and DW3, which reflect the mandatory values in Annex II of the Directive. Regulation 23 of the Water Supply (Water Quality) Regulations 1989 (HMSO 1989b) also requires that the provisions of the Directive apply to abstractions. The Surface Waters (Classification) (Scotland) Regulations (HMSO 1990) prescribe an identical system for Scotland.

The Drinking Water Directive (CEC 1980) has been implemented in the UK as part of the Water Act 1989 (HMSO 1989c). Detailed implementation of the provisions contained in the Act for drinking water quality are laid down in the Water Supply (Water Quality) Regulations 1989 (HMSO 1989b) and the Water Supply (Water Quality) Amendment Regulations 1989 and 1991 (HMSO 1989d, 1991a). These regulations lay down the frequency of sampling and the parameters which need to be analysed. The actions to be taken if the standards are exceeded are laid down in a guidance document entitled 'Safeguarding the Quality of Public Water Supplies' (HMSO 1989e).

The Drinking Water Directive (CEC 1980) may be modified because of recent developments in water treatment and scientific understanding, as well as practical experience by both water companies and governmental authorities. Any increase in the stringency of the standards may stimulate interest in the use of bankside storage and infiltration systems since these two systems are reported to help reduce levels of many parameters, including suspended solids, micro-organisms and metals. However, it appears unlikely that the Commission will amend the Directive at present and it would probably take at least 5 years for any changes to be included in a modified Directive.

5.1.2 Eureau

Eureau (The European Water Suppliers Association) has recently submitted, to the Commission, proposals for modifications of the Drinking Water Directive. Changes proposed by Eureau involve different areas of the Directive and include the choice of parameters, actual values, compliance rules and monitoring of compliance. The changes proposed by Eureau are unlikely to have a significant impact on the need for bankside storage and infiltration systems.

A parameter which if it is amended might have a significant impact on the storage of water in bankside reservoirs is the presence of algae. At present, the algal parameter is included in the Drinking Water Directive as a footnote but it may become a more precise parameter requiring additional control where water is stored in a reservoir. Regulation 3.(3).(a) of Water Quality Regulations requires that water does not contain any element, organism or substance (whether or not a parameter) at a concentration which would be detrimental to public health; this may be considered adequate to cover these changes. Taste and odour parameters which can be influenced by the presence of algae are not expected to be modified and existing treatments can eliminate this problem (e.g. activated carbon). Much would depend on developments on the occurrence and toxicology of substances produced by blue-green algae in particular. The major toxins appear to be the microcystin group of compounds, anatoxin-a and lipopolysaccharides. The toxicology of these compounds is incomplete but evidence to date suggests that any regulatory level for microcystins in particular, is likely to be considerably less than 50 ug l^{-1}. There is some evidence that microcystins may operate through a mode of action which would also be consistent with tumour promotion. This is currently under investigation and potentially has a high public profile, particularly if linked to eutrophication. Some blue-green algae are also associated with taste and odour problems and it should therefore be a practical requirement to manage reservoirs to prevent growth of these algae. The question which remains is whether this will be sufficient to also manage any problems with toxins.

5.1.3 World Health Organization

The World Health Organisation (WHO) will publish its review of the guideline values for a number of parameters in drinking water in Spring 1993. These proposed revisions were submitted to the Task Group for a decision in September 1992. Any proposals to revise WHO guidelines may increase the pressure to change individual standards in the Directive, but it is more likely that the Commission will encourage the Member States to comply with the new guidelines than directly modify the Directive. The revised values of the guidelines, once adopted, are likely to be taken into consideration by the UK government and the Drinking Water Inspectorate will probably encourage the water companies to comply with the new guidelines.

5.1.4 Concluding comments

Although discussions are in progress concerning modification of the Drinking Water Directive, it is unlikely that it will be amended in the foreseeable future. WHO guidelines could potentially have a significant impact on the use of bankside storage and infiltration. For example, if parameters such as disinfection by-products are regulated, there will be pressure to find a suitable and cost-effective treatment, which potentially may involve bankside systems.

The replies to the questionnaires indicated that it is generally felt amongst water companies that if tighter controls are put in place the cost of treatment would dramatically increase the costs with only a small increase in quality. However it would minimalise the use of poor quality water.

5.2 Protection of intakes and supply

A common theme emerging from the response to the questionnaire was the responsibility of the NRA in ensuring that river water was of adequate quality for abstraction for drinking water. It is the responsibility of the water suppliers to ensure that the treated water conforms to drinking water quality standards. As such the NRA would designate a river or lake as being suitable for 'Use' as a potable abstraction supply. Once designated the NRA would be responsible to ensure that water quality complied with the appropriate standards to safeguard that supply.

The NRA is developing the use of catchment management plans in controlling both diffuse and point sources of pollution with the long term aim of improving the general level of water quality within catchments. These plans might include the definition of land uses and assessment of pollution loads arising from these. Associated with this are new controls to reduce the amount of pollution arising from farming activities. To this end the Government has introduced regulations to set minimum standards for the construction of silage, slurry and agricultural fuel oil stores. The regulations also enable the NRA to make farmers improve existing installations where there is a risk of pollution. Action under these regulations should greatly reduce the number of pollution incidents in the agricultural sector from structural failures. Once it has completed its consideration of the pollution risks which need to be tackled, the Government intends to introduce similar regulations for industrial fuel oil and chemical stores. Such regulations would also potentially reduce some of the risk from accidental spillages of chemicals etc.

A number of NRA Regions (e.g. South West and Thames Regions) are actively assessing the risks in their river catchments. Studies not only include the identification of potential sources of pollution but also the collection of data on river times-of-travel under different river flow regimes. The latter would be used to predict travel times to water intakes and other sensitive points along the river.

The River Dee has probably the most reported case history of pollution incidents affecting potable intakes. This has resulted in the formation of a river management structure that involves the water suppliers and the NRA. A comprehensive river quality monitor network has been established to detect pollutants in the river. A model is then used to predict the time of travel and dispersion of the pollutant along the Dee. Using the information from the management model the appropriate actions are then instigated.

Many NRA Regions have water quality monitors deployed along their most important rivers to detect changes in water quality. Along many rivers these are supplemented by water quality monitors deployed by the Water Company, these range from standard chemical monitors to more sophisticated multi-parameter monitors which might also include a fish monitor. A number of examples were found from the questionnaires where the tripping of a fish monitor would lead to the immediate closure of a river intake. It was also generally found that communications between the NRA and the suppliers, when it came to warnings of pollution in the rivers, were good.

A group of Water Companies has recognised the importance of intake protection by commissioning research to produce, and subsequently evaluate, a manual of procedures for identifying and minimising the risks of pollution of raw water sources (surface and groundwater).

5.3 Cost benefit analysis

A detailed analysis of the cost-benefit of bankside reservoirs (using defined parameters) has been undertaken and is reproduced in full in Appendix E. The main findings of that analysis are reported in this section.

In order to assess the benefits of providing bankside storage reservoirs, only the effects of storage on the performance and marginal decreases in operating costs of water treatment processes were considered. The effects of storage on the capital cost of treatment plants were not considered since it was assumed that any perceived potential treatment facility needed would be constructed any way.

The analysis considered the following:

- Three water treatment plant sizes: 10 Ml d^{-1}, 30 Ml d^{-1}, and 70 Ml d^{-1};

- Two types of reservoir: clay-cored totally bunded reservoirs (CBR) and reservoirs constructed other than by simple excavation with special attention paid to creating an impervious structure or special bunded reservoir (SBR);

- Three sizes of reservoir for each size of treatment works: one day, seven days, and fourteen days storage. Although the remit was to consider storage for upto 7 days, 14 days storage has been included here to give a more complete picture, and because length of storage should be based on the assessment of risk;

- The effects of spillages or poorly controlled use of substances e.g. phenol, sewage (causing an increase of ammonia), pesticides and petrol or diesel fuel resulting from road accidents on water quality;

- Sudden changes in water quality e.g. high nitrate concentrations, or high colour and turbidity following heavy rain.

What has not been costed is the operational cost penalty if supply to a treatment works is stopped by a pollution incident. The cost penalty includes costs due to:

- fixed costs (labour, heating, lighting, maintenance, capital repayments);
- cost of the public relations exercise;
- costs of providing supplies from elsewhere, and;
- the costs of removing poor quality water that enters the supply system.

Nowadays the infrastructure exists for most supply areas for importation from other areas. Therefore, the cost penalty of using that facility is the cost of pumping.

The estimated capital cost for a clay bunded reservoir ranged from £0.75M for one day storage at a supply of 10 Ml d^{-1} to £10.04M for a similar type of reservoir with seven days storage at a supply of 70 Ml d^{-1}. The comparable costs for a special bunded reservoir were £2.25M and £30.24M, respectively. An alternative to storage of water for when intake closure is necessary is importation from another source. Comparing the capital costs of importation with that of bankside reservoirs, it was found that the costs of providing 20 and 50 km pipelines are approximately the same as for a 7 and 14 day clay bunded reservoirs respectively. Under these distances it might therefore be more cost-effective to import water rather than construct a bankside reservoir.

For most bunded reservoirs depth is optimised with respect to cost. This means that greater or lesser depth than the cost-optimum can be constructed at greater cost per unit volume treated. It also follows that surface to volume ratio is also a function of volume stored and therefore governed by minimum cost of reservoir construction.

Since reservoir dimensions are defined to achieve minimum cost, there is little scope to alter shape substantially enough to govern retention or mixing characteristics. The ability to control these will be mainly through the positioning and use of inlets and offtake. The most important requirement is to minimise short circuiting otherwise the purpose of the reservoir will be defeated. One of the greatest problems at a water works is encountered relatively frequently with direct river abstraction, and that is coping with very rapid changes in quality such as those experienced following heavy rain. In trying to cope the operator can spend considerable effort, often relatively unsuccessfully. Attenuation of the magnitude of or dampening the speed of change in quality makes the operator's life easier and coping with severe changes in the river much cheaper.

Algal growth within the reservoir might occur and this will require extra treatment for instance by fitting microstrainers. An alternative approach to dealing with algae is to prevent their growth during storage by reducing phosphate concentration. This might be done by dosing metal-ion coagulant (aluminium sulphate or ferric sulphate) to the raw water entering the reservoir such that precipitation takes place either in the reservoir or in a preliminary treatment basin, reservoir or lagoon. Whilst it would not be cheaper than providing and using microstrainers it should be more effective and reliable.

Storage of waters in reservoirs will reduce the turbidity (perhaps by 50%, depending upon the quiescence of the water body and other factors). This might result in reduction of coagulant dose. The savings in chemicals are less than 0.2 pence per m^3 treated. There will be indirect cost savings from reduction in sludge formation and treatment and less frequent backwashing of rapid gravity filters. At slow sand filter works, turbidity reduction during storage will result in a reduced frequency of sand cleaning.

This study was by no means exhaustive, as it has not included the effects of bankside storage on the potential saving in operational manpower (by balancing out the river water quality, treatment is easier as peaks and troughs are eliminated) as compared with extra time needed for reservoir management. Other costs such as dealing with the public due to the interruption of supply, and supply from other sources were not considered.

The cost estimates show that in general the capital cost of bankside storage exceeds the potential savings it provides in the pollution cases considered. Savings might be achieved with bankside storage where the risk of pollution incidents is considered to be high, to the extent that provision had to be made to import water; or, if there were, for example, at least three pollution cases per year and each time the activated carbon was exhausted and replaced then clay-bunded reservoirs of seven days storage might be the cheaper option. Savings also might be achieved with small reservoirs (one day storage) if the plants use activated carbon as part of their treatment. The risk of pollution incidents is considered to be high, to the extent that provision had to be made to import water.

Only four of the water companies returning questionnaires supplied information on the costs involved in running a bankside storage reservoir. The first estimated that the capital investment involved in converting an old gravel workings pit into a reservoir with a mean retention time of 18 hours was between £5M and £6M and the operational costs are £120 000 pa. The second referred to a reservoir in a natural basin with a mean retention time of three days, no information on capital costs was available but the operational costs, including abstraction from the river, are in the order of £443 000 pa. The third company estimated that capital investment was £675 000 for the rectangular concrete tank, with a storage capacity of less than one day which they built 18 months ago and the running costs are £1000 per annum. The final company gave the capital cost of the reservoir contract for their 15 day storage reservoir as being £316 916 in 1965. The reservoir originally had a 30 day storage capacity. A comparison of costs of bankside storage and water treatment is included in Appendix E.

Bankside infiltration can achieve a level of treatment similar to slow sand filtration, how similar depends on various factors. Bankside infiltration reduces turbidity and therefore microbiological contaminants. Parameters such as ammonia, nitrate, organic pollutants etc. will be reduced depending on factors that affect microbiological activity such as dissolved oxygen concentration, temperature, time of passage etc.

Bankside infiltration can be set up in a number of ways depending partly upon the nature of the river-side geology and could include: infiltration galleries under and alongside the river, a series of wells into river valley gravels near the river, or reconstruction of the river bank to be relatively pervious in order to feed adjacent wells. Costs are therefore not readily estimated. It may also be feasible to abstract from a reservoir by bankside infiltration. It is probable that an infiltration scheme would be more expensive than microstraining but do a better job, and be cheaper than slow sand filtration but not perform as effectively.

5.4 Procedure for assessing need

In developing a new river water supply the main objective would be to achieve a drinking water of the required quality as cost-effectively as possible. There would be a decision process or procedure involved in meeting these objectives. A suggested procedure is illustrated in Figure 5.1.

The first consideration would be the average quality of the river. This would naturally generate or identify a number of options for treatment and/or operational aspects of the treatment works. These possible options are illustrated in Figure 5.2. The robustness of the generated options would then be tested. Robustness could be expressed in terms of meeting constraints on the water company, and in coping with the variability in water quality and the risk of quality deterioration.

Constraints would include: legal requirement to meet drinking water standards; the need for continuity of supply; the robustness of treatment; financial constraints; and customer satisfaction.

Legal constraints: All options would have to ensure that water was of an acceptable quality. Variability of the river quality would have to be assessed. Potentially there would be episodic changes in quality due to rain events or from accidental spills. To some extent the occurrence of episodic changes in quality might have a predictable or seasonal component e.g. the company may know that nitrates are going to be high in March. Consideration would also have to be given to how the standards and legislation may change. Legal constraints would also include the obtaining of an abstraction licence from the NRA who would need to consider factors such as minimum river flows, sustainable abstraction rates and other uses of the river, before granting a licence.

Continuity of supply: An important consideration would be the continuity and security of supply which would lead to customer satisfaction. The number of days a year the intake might be closed and for how long would also be assessed. The location of alternative supplies for emergency or for blending would also be considered.

Robustness of treatment: The level of treatment required for average river quality and for the predictable changes around that average would also be considered. Again this would involve some sort of assessment of risk of deterioration of quality. Whether to design spare capacity into the works or not and the reliablility of the technology behind the treatment method e.g. for the removal of nutrients would also have to be considered.

Financial constraints: The cost of any new intake or works would inevitably be paid for by the customer, the option must, therefore, be cost effective. OFWAT would also need to be assured that undue charges were not to be passed onto the consumer.

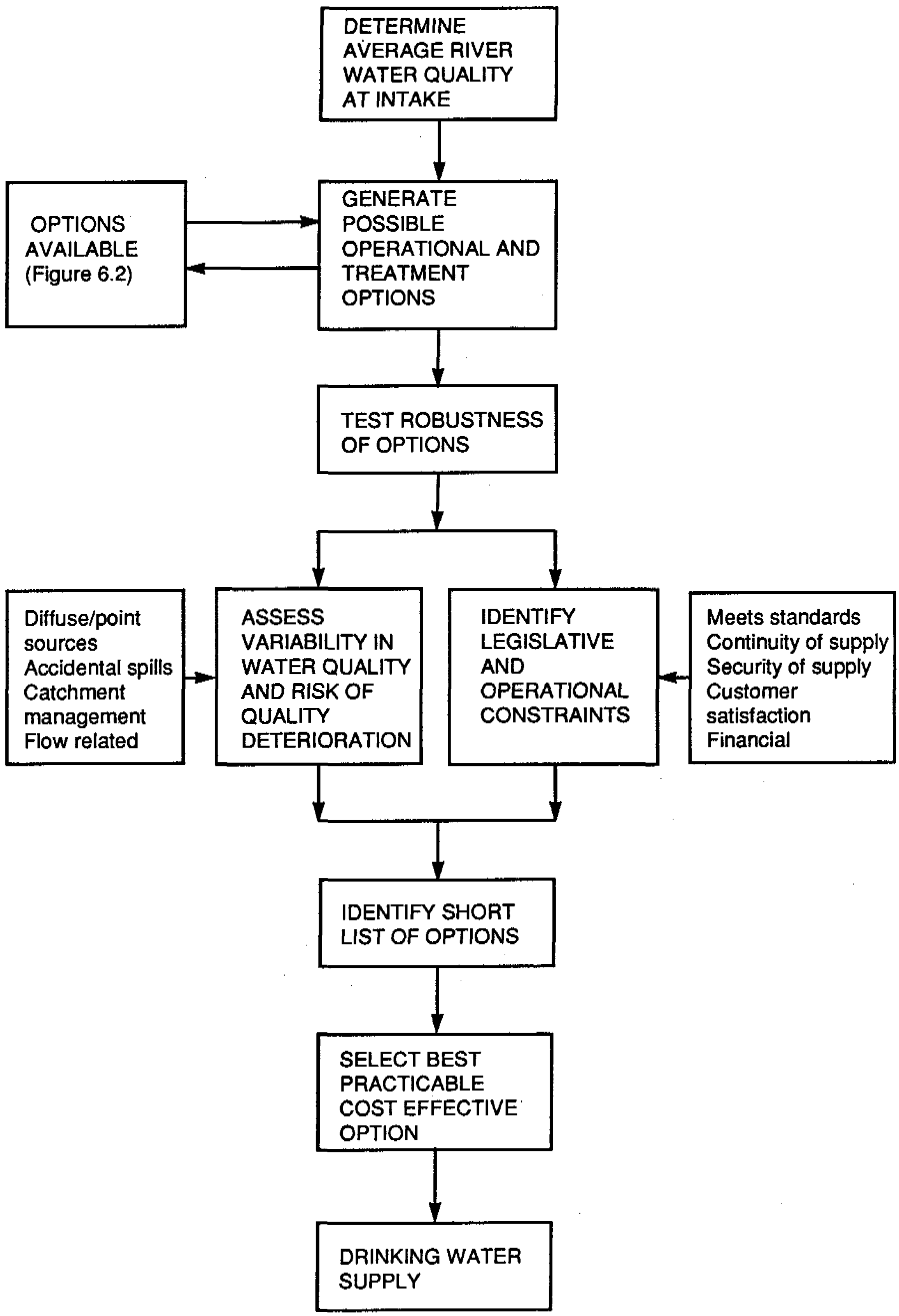

Figure 5.1 Assessment of the need for bankside storage or bankside infiltration.

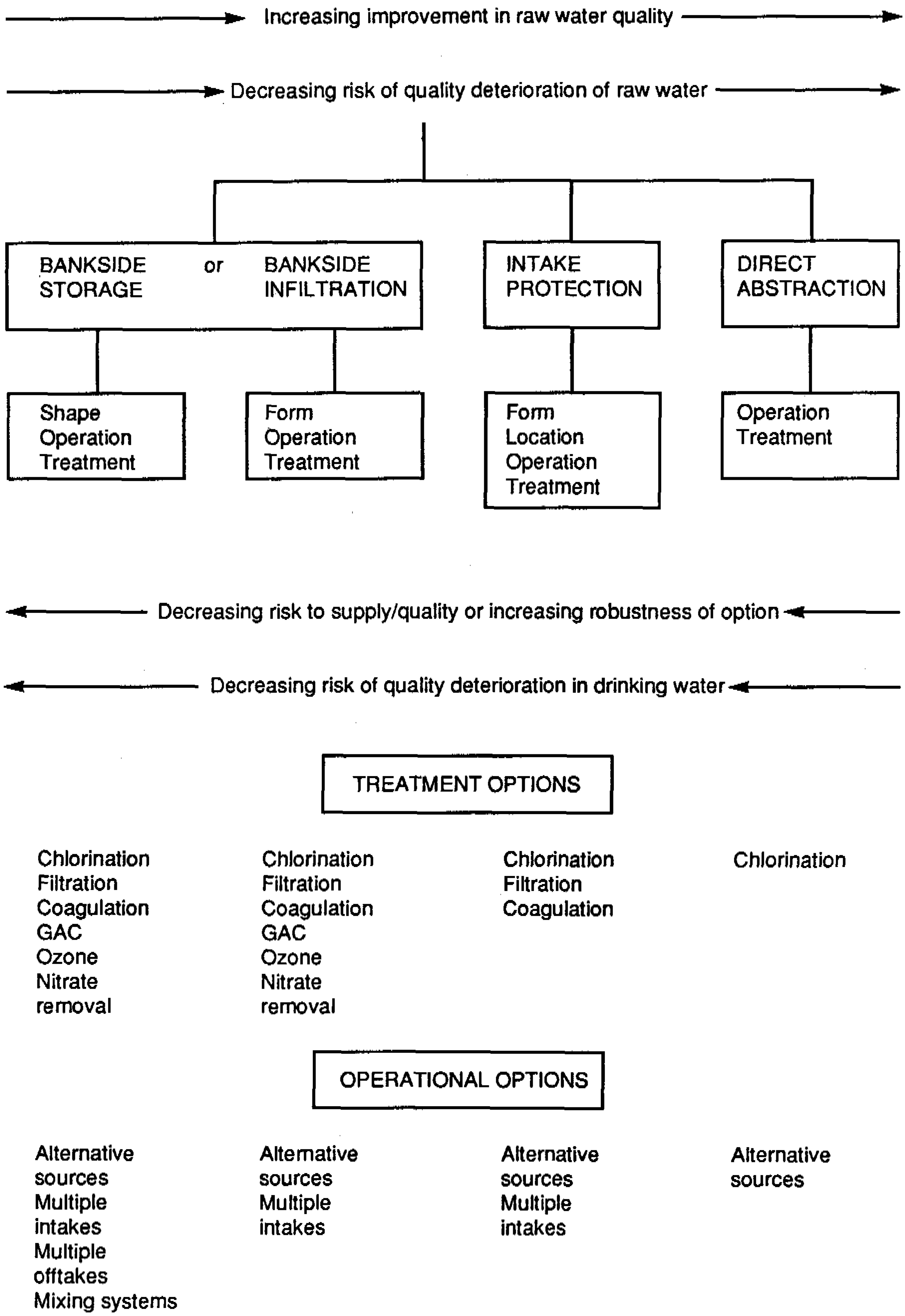

Figure 5.2 Treatment and operational options for river water intakes.

Customer satisfaction: The customer would have to be satisfied with the quality of the drinking water, particularly if standards of service were to be defined in the Citizens Charter.

Robustness would include the ability and capability of the options to cope with variations in water quality. The latter may be brought about by point or diffuse sources of pollution (such as storm sewage discharges and nitrates respectively) or accidental spills. Many changes in water quality may also be river flow related such as increases in turbidity. The presence of a catchment water quality plan to control and/or improve river water quality may also affect the robustness of an option.

The consequence of insufficient robustness would potentially lead to failure to meet standards, the loss of supply, a decrease in security of supply and an increase in customer dissatisfaction. Robustness may also be expressed as a risk to the supply. The generated options would have to reduce the risk to zero or to an acceptable level close to zero. If the risk is not reduced then new options would have to be generated and tested in the procedure again. Once risk had been reduced to the desired level then there would be a preferred or selected option.

The main risks associated with deterioration of river quality would be failure to meet quality standards and loss of water supply leading to customer dissatisfaction. Also influencing the treatment option would be standards arising from national and EC legislation, and how secure is the preferred option in relation to potential changes in existing standards.

As mentioned previously the main treatment and operational options available to the water companies are illustrated in Figure 5.2. The options for intake design and/or protection include bankside storage reservoirs, bankside infiltration or direct abstraction. These three options may or may not involve the use of some form of intake protection system or monitor. The choice of using these basic options in some way relates to raw water quality e.g. direct abstraction without any detention of water or intake protection may be possible in high quality rivers. There would also be sub-options relating to different ways of operating the system e.g. mixing in reservoirs to induce fully mixed conditions and the use of alternative sources for emergencies or blending.

There are also treatment options which would be considered when considering the robustness or risk to the intake. Thus for high quality, low risk water may just involve chlorination whereas for many lowland rivers there may not be much scope for different options as river water may require pesticide and/or nutrient removal to meet standards with or without the use of bankside storage and/or bankside infiltration.

There would also be choices associated with the design and shape of the reservoir or infiltration system. These are illustrated in Figure 5.3 and could form the basis of a classification scheme for such options, for example, reservoirs may range from natural basins to rectangular to serpentine shapes. Another primary consideration is whether to design for plug flow or fully mixed conditions. Several reservoirs could also be connected in a series arrangement this would induce plug flow conditions.

Classification

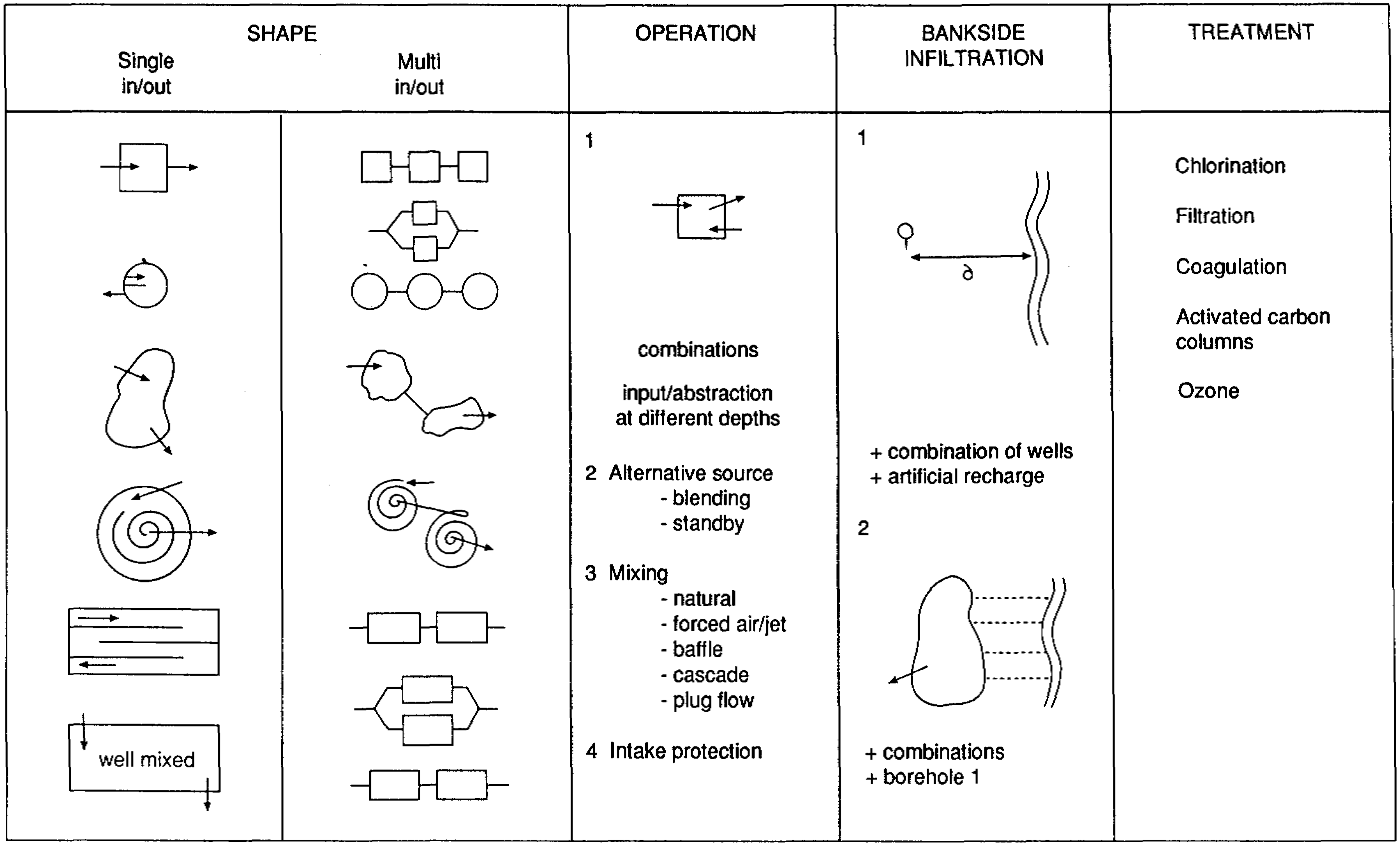

Figure 5.3 Classification chart of bankside storage reservoirs and bankside infiltration systems

6. COMPARISON OF BANKSIDE STORAGE AND BANKSIDE INFILTRATION

Table 6.1 summarises the main advantages and disadvantages of bankside storage reservoirs and infiltration systems. These are discussed under broad headings in the following section.

Table 6.1 Summary of the main advantages and disadvantages of bankside storage reservoirs and bankside infiltration systems

Bankside storage reservoir	Bankside infiltration well
Can be blended	Can be blended
Variations in water quality are smoothed by large dilution in reservoir	Dilution and smoothing are less
Able to close intake	Can not stop ingress of pollutant if ground water is contaminated
Gives a time delay	Gives a time delay
Pollutant can be contained	Harder to contain pollutant
Short circuiting can be a problem	Short circuiting is less likely to be a problem
Algal problems	No algal problems
Can release contaminants back into the water	Redissolution of contaminants is not likely
Improvement in physico-chemical and biological quality	Improvement in physico-chemical and biological quality
Zooplankton can become prolific	Zooplankton do not proliferate

6.1 Changes in water quality

Both bankside reservoir storage and bankside infiltration would be expected to result in some improvement in water quality with respect to suspended solids and associated contaminants such as heavy metals, taste and odour, ammonia, chemical and biochemical oxygen demand, and biological quality. The improvement in quality through bankside infiltration has been reported to be similar to that achieved by slow sand filtration. However, filtration efficiency will be very dependent on the substrate in the infiltration system. The information on the improvement in quality due to bankside infiltration has been gathered from the dune system in Amsterdam which is based on sand; improvement in gravel systems are likely to be very different. A disadvantage of the Amsterdam system is that the water can become coloured when it passes through layers of peat and humic matter within the dunes.

Storage of nutrient rich river water in bankside storage reservoirs has been found to stimulate excessive algal production in some cases. This has lead to problems in treatment and potentially increased costs. Algal problems when they have occurred have been overcome operationally by inducing better mixing or by adding additional treatment (e.g. microstrainers or phosphorus precipitation). Bankside infiltration does not have such algal problems and might be expected to filter out algal biomass. Zooplankton may also become prolific in bankside storage reservoirs which can cause problems if they get into the filter systems. However, they can also be beneficial in helping to combat algal growth and in aiding purification.

6.2 Smoothing out variations in quality and blending

Water from both bankside storage reservoir and bankside infiltration wells can be blended with water of higher quality to produce a larger volume of water of an adequate quality. Bankside infiltration would naturally blend groundwater and river water anyway, the resultant quality of abstracted water being dependent on the respective quality of the groundwater and river water, and the relative contribution of each to the abstracted water.

Both would be expected to smooth out variations in river water quality. The extent of smoothing in bankside infiltration would depend on the relative contributions of groundwater and river water to the abstracted water, and on the storage capacity of the system. Bankside storage reservoirs would be expected to achieve a consistent level of smoothing as long as short-circuiting was not a problem.

6.3 Protection of potable supply

If a pollutant enters a river and is detected before it reaches the intake to a bankside storage reservoir, it is possible to shut the intake thereby preventing the pollutant entering the reservoir. In a bankside infiltration system the intake can also be closed by the cessation of pumping. However, where the aquifer is naturally fed by the river it is possible that the pollutant may also contaminate the ground water. In the case of bankside infiltration there would also be no stored supply to draw on while the pollutant passed the intake, and alternative supplies would have to be sought.

Water entering a bankside storage reservoir undergoes a large dilution, dilution in a bankside infiltration well system will generally be less and is very dependent on the overall catchment utilisation of groundwater. This could be very important if a large amount of pollutant entered the intakes to the respective systems.

If a pollutant enters a bankside storage reservoir and is detected, it can be contained within it and, although not without difficulty, can be disposed of if necessary. If the groundwater in a bankside infiltration system becomes contaminated containment of the pollutant would be a lot harder, and might have to be pumped 'clean'.

There is normally a time delay in bankside storage reservoirs before a pollutant which has entered the reservoir undetected reaches the outlet. If the reservoir is monitored there is a good chance that the problem will be detected before the outlet water becomes contaminated. Although, if a similar incident occurs in a bankside infiltration well system, there will still be a time delay before the pollutant reaches the borehole, it is less likely that the contaminant will be detected.

Short-circuiting can be a problem in bankside reservoirs particularly when a pollutant arrives at the offtake sooner and at higher concentrations than might be expected. Short-circuiting may also lead to the formation of stagnant zones in which algae may proliferate. Short-circuiting would not be expected to occur in bankside infiltration systems; the time of travel of pollutants from the river to the abstraction point would be dependent on the nature of the substrate and on the pumping rates.

6.4 Conjoint use of bankside storage and infiltration

Bankside infiltration reservoirs can be thought of as a form of conjoint bankside storage and bankside infiltration and have many of their respective advantages. If a pollutant enters the river pumping can be stopped, however if the groundwater is polluted the pollutant may still eventually get into the reservoir. If the ground water is polluted it could take a long time to remove it from the source.

If a pollutant does get into the reservoir it will be diluted and the time delay before the pollutant reaches the outlet will enable containment and mitigation of the event however short circuiting and its associated problems may be experienced.

The water quality should benefit greatly from first being filtered and then from storage, however if the water becomes coloured in the filtration stage it will not be rectified by storage only diluted and evened out.

It would probably only be economic to use conjoint bankside storage and infiltration where there is a readily available gravel pit beside a river which is also fed naturally by groundwater.

6.5 Optimum characteristics for bankside reservoirs

In the case of bankside storage this would be almost exclusively based on the economics of building the reservoir. The relationship between depth and volume stored would be governed by the relative costs of moving excavated material outwards and of constructing height into the embankment or bund, and would mean for most bunded reservoirs that depth is optimised with respect to cost. This means that greater or lesser depth than the cost-optimum could be constructed at greater cost per unit volume treated. It also follows that surface to volume ratio is also a function of volume stored and, therefore, governed by minimum cost of reservoir construction.

For reservoirs consideration might also be given to attainment of well mixed systems to minimise the potential problems arising from short-circuiting and to maximise the smoothing of quality variations in the river water. Combined with this might be the need to minimise algal production.

7. CONCLUSIONS

1. A literature review of bankside storage and bankside infiltration systems showed that only very limited information exists relating to water quality aspects of storage. Very little information was available on bankside infiltration systems. However the storage of water would be expected to improve the bacteriological and virological quality of the water, allow the deposition of suspended solids and reduce the concentration of contaminants associated with the sediments, such as iron and manganese. In some bankside reservoirs there would be the possibility of excessive algal production through the impoundment of nutrient rich water. This can be controlled by minimising the input of nutrients and by the design of appropriate retention times, suitable depths and the prevention of short circuiting which could induce relative dead zones within the reservoir in which algae may multiply.

2. A questionnaire was distributed throughout the UK water industry to gather operational experience on the use of bankside storage and bankside infiltration systems. There are differing opinions on the usefulness of bankside storage. Responses to the questionnaire varied from the opinion that bankside storage is an essential asset to the view that there is no need for such a system if adequate intake protection monitors are installed on the river. Most of the existing bankside storage reservoirs are used for storage of water for strategic purposes, however several companies also use them for blending supplies and smoothing out variations in the water quality. Strong views were expressed in responses to the questionnaire on the need for effective catchment management to control point and diffuse source of pollutants; protection against accidental spills was also recognised as an important issue which would need to be included in any assessment of pollution risk.

3. Little evidence on the quality changes occurring during storage in bankside reservoirs was available from the water undertakings who responded to the questionnaire. Information gathered through the literature search indicated that improvement in quality due to storage is mostly associated with the settlement of suspended solids. However, if short circuiting occurs algal blooms and the re-dissolution of chemicals bound to the sediments can occur thereby causing a deterioration in quality.

4. Experimental data shows that bankside reservoirs, unless specifically designed as plug flow systems, will exhibit some degree of short circuiting depending principally on the prevailing wind speeds and direction. If this is considered to be a problem then artificial-mixing systems can be employed to ensure that the reservoir behaves as a well-mixed system. Under these circumstances any pollutant which enters the reservoir will undergo maximum dilution within the reservoir.

5. Cost estimates show that in general the capital cost of bankside storage exceeds the potential savings it provides in the pollution cases considered. Only where small reservoirs are considered (one day storage) might savings be achieved if the treatment plant uses granulated activated carbon as part of its treatment. If there were, say, at least three pollution cases per year and each time the granulated activated carbon was exhausted and was replaced, then savings might be achieved

with clay-bunded reservoirs of seven-days storage. However, if the risk of pollution incidents is considered to be high to the extent that provision has to be made to import water, then bankside storage may be the cheaper and more preferable option.

6. The capital costs of providing 20 and 50 km pipelines for the importation of water (as an alternative to bankside storage) are approximately the same as for a 7 and 14 day clay bunded reservoir respectively. The use of bankside storage when alternative sources are at greater distances might become more cost-effective.

7. Bankside infiltration would be expected to give comparable levels of treatment to slow sand filtration. Bankside infiltration would be expected to reduce turbidity and therefore microbiological contaminants. Ammonia, nitrate and organic pollutants will be reduced depending on factors that affect microbiological activity such as dissolved oxygen concentration, temperature and time of passage.

8. Bankside infiltration can be achieved in a number of ways depending partly upon the nature of the riverside geology and could include: infiltration galleries under and alongside the river, a series of wells into river valley gravels near the river, or reconstruction of the river bank to be relatively pervious in order to feed adjacent wells. Costs are therefore not readily estimated. It is probable that an infiltration scheme would be more expensive than microstraining of water from a surface source but would be more efficient, and would be cheaper than slow sand filtration but not perform as effectively.

9. For bankside infiltration systems the concentration of pollutant in the abstracted water relative to that in the river water will vary with time as the pollution pulse passes, and will depend on the rate of abstraction, the regional groundwater gradient and the transmissivity of the aquifer.

10. In an under-utilised aquifer where the abstraction rate is relatively low and the regional groundwater gradient is high, only a small proportion of the abstracted water is drawn from the river. The maximum concentration, expressed as a fraction of the concentration in river water, falls off rapidly as the distance between the well and the river is increased. Aquifer type has an important influence on the predictions, with the relatively low transmissivity sandstones giving rise to the greatest river influence. For chalk and gravel aquifers it is unlikely that pollution will reach the well at distances greater than about 80 m.

11. In an over-utilised aquifer the abstraction rate is high and the regional groundwater gradient is low so that river water provides a relatively high proportion of groundwater abstraction. The maximum concentration of the pollutant is much more significant even for wells remote from the river. Sandstone again gives the highest concentrations, and even the highly transmissive gravels show a significant level of pollution in pumping wells at up to 1 km from the river.

8. RECOMMENDATION

The need for bankside storage or infiltration systems can only be sensibly assessed on a site-by-site basis. There are many factors influencing the choice of system including intake protection facilities, enhanced treatment, costs and the extent of pollution control procedures within the catchment. A procedure for assessing the need for such systems has been described and should be considered for practical application.

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APPENDIX A - REVIEW OF LITERATURE ON BANKSIDE STORAGE AND INFILTRATION SYSTEMS

A1. INTRODUCTION

WRc has been commissioned by the Department of the Environment (DOE) to undertake a one year feasibility study on bankside storage systems and infiltration systems for the protection of supplies from river abstractions, considering the advantages and disadvantages of such installations taking into account the costs involved. An integral part of this study was to review the published and available unpublished literature, from the UK and abroad, to extract references to obtain information on quality improvements and the use of bankside storage reservoirs to maintain supplies during pollution incidents affecting the source.

Extensive literature searches were undertaken including searches of an American and a German database. The amount of available literature relating to the water quality aspects of bankside storage has been found to be fairly limited, and that relating to bankside infiltration very limited, therefore information relating to water quality aspects in other types of short term storage reservoirs has been included where relevant, since the use of the reservoir has little effect on the biological and physico-chemical processes taking place. Bankside storage is undoubtedly beneficial with respect to being able to close the intake during a pollution incident and allowing dilution or containment of a contaminant to take place. It also appears to affect some of the physico-chemical qualities of the water; however with respect to self purification its effects seem to be limited to those associated with settlement. Some adverse effects can also be attributed to storage such as algal and zooplankton blooms and the risk of contaminants being released back into the environment from anoxic sediments.

A2. DESIGN OF BANKSIDE STORAGE SYSTEMS

Bankside storage reservoirs can be designed to be perfectly mixed systems or to have plug-flow. In a perfectly mixed system the incoming water is instantaneously distributed throughout the reservoir and immediately arrives at the outlet. In reality there is a time delay before the incoming water reaches the outlet. In a plug-flow system the incoming water is uniformly distributed in a vertical cross section near the inlet, and then advances at a steady rate between the inlet and the outlet, with the mean retention time equalling the nominal retention time. In practice a small amount of dispersion always occurs (White and Davis 1978).

The advantage of a well mixed system is that the concentration of a pollutant at the outlet should never exceed the amount of pollutant divided by the volume of water in the reservoir. The disadvantage is that the pollutant rapidly reaches the outlet, this is not a problem if the diluted concentration is below the accepted tolerance level. In a plug-flow system the concentration at the outlet may exceed the acceptable tolerance level but the time delay before it reaches the outlet should enable suitable containment action to take place. For a bankside reservoir with a nominal retention time of a few days the worst situation that can arise is when no warning is given of an undesired substance entering the reservoir. In this situation the concentration of the pollutant will be minimised when the reservoir behaves as a well mixed system: however it will be problematic if the mixed concentration exceeds the tolerance level.

A3. ADVANTAGES OF BANKSIDE STORAGE

A3.1 Closure of intake

The first reason, given by the Steering Committee, for the need for the provision of bankside storage reservoirs was to permit closure of the intake in the event of an accidental pollution. Slack and Burfield (1978) reported the undoubted benefit afforded to Essex Water Company by the ability to close the intake during periods of unfavourable water quality. Poor water quality can be caused not only by pollution incidents but also due to flooding which brings about high turbidity, ammonia and nitrate levels. They listed various forms of pollution which had occurred in Essex Rivers in recent years where bankside storage had been useful, these included oil, crude sewage, preservatives, cyanide and skimmed milk spillages. On the River Rhine, due to the densely populated and industrialised catchment, accidental pollution incidents are a real threat to water treatment works. To protect the Berenplaat Treatment Works, Holland, water abstracted from the Rhine is first passed through Berenplaat reservoir (Rook 1975, Hrubec and de Kruijf 1983).

A3.2 Dilution of polluted waters

The Steering Committees second reason for the provision of bankside storage was to enable the dilution of polluted water entering the intake. There is little literature available on the effectiveness of bankside storage reservoirs during pollution incidents. Nixon and Belcher (1983) simulated pollution events on Cantref and Beacons reservoirs. They found that in Cantref Reservoir, under northerly wind conditions, it took 28 hours for the tracer to be detected in the outlet water thus indicating that the reservoir afforded some protection against a pollution incident. The outlet water had a dye concentration equivalent to a pollutant concentration of 0.9 mg l^{-1} per tonne but the dye never became fully mixed. In Beacons Reservoir the tracer was first detected only 2.5 hours after addition. Its maximum concentration, equivalent to a pollutant concentration of 2 mg l^{-1} per tonne, occurred 3.5 hours after addition. Short circuiting caused the rapid detection of a relatively high concentration of tracer however the remainder of the dye became fully mixed within 60 hours. In both reservoirs higher levels of the simulated pollutant would have reached the treatment works if a surface outlet had been used, in Cantref it would have taken the tracer only 13 hours to reach the outlet. The First Annual Report of the Water Quality Steering Committee also pointed out that there was a need to balance out water quality variations in the river. An experimental treatment plant has been built at Pecq on the River Seine which includes a 24 hour settling tank. It has been found that this tank is effective at preventing sudden peaks of turbidity in the raw river water being pass onto the treatment works (Rizet and Cauhape 1975).

Bankside storage reservoirs with a seven day storage capacity may be inadequate to deal with major pollution incidents. Two such incidents occurred on the River Stour in the 1970's. The first occurred in 1973 when thousands of tomato plants were seriously affected due to weed killer which was present in water which had been transferred from the Ely Ouse. The second was in 1975 when dyestuff intermediates were accidentally released. This resulted in the intake being closed for two weeks however this was partially due to a miscalculation resulting in the intake being closed too early. Although a few days bankside storage was inadequate to deal with these two major incidents, through having a well integrated supply network it was possible to divert water from other reservoirs in order to maintain supplies (Slack and Burfield 1978).

A3.3 Self purification

The final reason the Steering Committee gave for the provision of bankside storage was self-purification. Rizet and Cauhape (1975) found that short term storage dramatically reduced the faecal coliform count and that SO_2 reducing clostridia and mesophilic bacteria counted at 20 and 37 °C were reduced in a 100 to 1 ratio. Slack and Burfield (1978) also noticed a large reduction in coliform counts after storage of 3-4 days; however, they pointed out that this also could be achieved by a small dose of chlorine. The effectiveness of short term storage compared to chlorination needs to be evaluated for viral counts. Lester *et al.* (1971) found that five days storage in the online purification lake resulted in a 96% reduction in coliforms and a 94% reduction in *Escherichia coli.*

The River Rhine receives effluents with high loadings of organic pollutants. Many of these compounds are resistant to biodegradation. This results in taste and odour problems which are difficult to remove if the water is treated immediately after being abstracted from the river (Rook and Oskam 1972). Berenplaat reservoir is effective in removing taste and odour along with suspended solids and the associated heavy metals.

Rizet and Cauhape (1975) found that short term storage was effective at removing suspended solids, Rook and Oskam (1972) reported that 90% of suspended solids were removed in Berenplaat reservoir in the first two weeks of storage. The literature available suggests that self-purification due to short term storage appears to be closely related to the settlement of particulate matter, achieving a significant decrease in pollutants associated with suspended solids but there being little change in the determinands in solution. Rook (1975) and Rook and Oskam (1972) found that the reduction in suspended solids was accompanied by a decrease in organic matter and a substantial decrease in iron and manganese content along with a reduction in heavy metals, pesticides and mineral oil absorbed to the suspended matter (Rook 1975). Lester *et al.* (1971) found that the total BOD decreased on storage but that the soluble organic matter and TOC only decreased a little, further indicating that the reduction was due to the settlement of associated suspended solids. They also found that there was a decrease in the total levels of zinc and copper but not in their soluble levels, and that the concentration of nickel, which was mostly in solution, did not change very much. In contrast to Rook (1975) he found that the pesticide level was unaffected by storage. Slack and Burfield (1978) found that self purification due to short term storage was of little value. Although the organic parameters, such as BOD and PV, showed a general improvement with storage this was probably due to the settlement of coarse particulate matter which can be removed easily by clarification and filtration. They noticed the inability of short term storage to bring about improvement in water quality was most marked in cold conditions. Similarly the treatment works which receives water from Berenplaat reservoir includes coagulation and filtration stages which are more effective at removing suspended solids than the reservoir (Rook 1975, Rook and Oskam 1972). However they concluded that Berenplaat reservoir was useful for removing volatile organic micro-pollutants and taste and odour compounds. Similarly Rizet and Cauhape (1975) found that the settling tank at the experimental plant on the Seine at Pecq led to an improvement in the clarity of the water only.

A4. EFFECTS OF STORAGE ON PHYSICO-CHEMICAL PARAMETERS

Short term storage seems to have some effect on the physico-chemical parameters of the water. The pH of the stored water tends to be strongly alkaline due to the direct use of CO_2 in photosynthesis altering the carbonic acid equilibrium. The increase in pH on storage is most noticeable in summer (Slack and Burfield 1978, Rook 1975, Rook and Oskam 1972).

Lester *et al.* (1971) found that the dissolved oxygen (DO) content increased as the water passed through the purification lake in summer, sometimes becoming supersaturated. In winter the DO decreased. He pointed out that the raised DO in summer was very beneficial as it coincided with the the occurrence of low DO values in the river. Conversely Woods *et al.* (1984) found that in the purification lake there was an overall daily reduction in DO, in the order of 1 mg l^{-1}, due to the oxygen demand exerted by the sludge. He also found that during the summer months that the purification lake was good at smoothing out the diurnal variations of DO in the river.

Ammonia tends to decrease on storage, this is partially due to nitrification by algae. The amount of removal increases with temperature and residence time. (Rizet and Cauhape 1975, Rook 1975, Rook and Oskam 1972). Lester *et al.* found that there was little change in the amount of ammoniacal nitrogen in winter but in summer the concentration decreased due to algal growth. He found that there was a slight reduction in the in the nitrate concentration and that nitrification did not occur.

Rizet and Cauhape (1975) found that the temperature in the river and settling tank tend to follow seasonal changes, with there being little difference between the values for the river and settling tank and only 1 or 2 ^{o}C more variation in the shallow, slow flowing settling tank than the river.

Thermal stratification can become established resulting in the associated problems. The clear, warm waters of the epilimnion provide an ideal habitat for phytoplankton growth.

This can lead to a decrease in DO and a high BOD in the outlet water. Iron and manganese occur in the particulate form in oxygenated waters, however in slow moving bodies they settle out and if DO is low or absent they are reduced to the soluble form. In addition iron and manganese may be dissolved out of the bed rock when oxygen concentrations are low. Soluble iron and manganese are objectionable in concentrations of less than 1 ppm (Churchill 1968). In addition thermal stratification commonly leads to density gradients between pooled and inflowing water which limits mixing. This may result in in a pollutant reaching the outlet having undergone very little dilution.

A5. DRAWBACKS OF BANKSIDE STORAGE

Storage in Berenplaat results in two contrasting effects, firstly self purification, this is especially noticeable in in highly polluted water, and secondly water deterioration due to algal growth. The balance between the two is dependent on temperature, degree of pollution, residence time and turbidity. Rook and Oskam (1972) found that the number of algal cells increases with residence time and temperature but due to the short retention time do not tend to reach the peak of their growth cycles . They also concluded that the virtually complete lack of blue-green algae was probably due to the short retention time. Storage in the Essex bankside storage reservoirs also promoted algal growth. Here the growth could be so prolific that on several occasions it had to be treated with copper sulphate. Storage can also prolong an algal bloom for some time after it has died in the river (Slack and Burfield 1978).

Animals can help reduce algae and diatoms but also have a nuisance value because the larger ones can lead to filter blockage. Penetration of rapid sand filters can lead to colonisation of the distribution system where they are hard to eradicate as they are not affected by permethrin dosing. A large number of animals can also result in an increase in ammonia during storage due the excretion. Rizet and Cauhape (1975) found that during the one month storage at the experimental treatment plant at Pecq that the zooplankton and phytoplankton were in equilibrium.

Short term storage of water may result in the accumulation of a silt layer. This may result in micro-pollution and nutrients being released from the bottom anaerobic layer. However, at Berenplaat it was found that surface sediment layer remained aerobic and the dissolved constituents from the underneath sediment never passed through this layer (Rook 1975).

At the meeting held to discuss the first annual report of the water quality steering committee it was suggested that if a pollutant entered a bankside storage reservoir it could necessitate the emptying of reservoir which would be very laborious. From the experience of Essex Water Company this does not seem to be a likely event since in Essex pollution in a storage reservoir has never required the drainage of that reservoir (Slack and Burfield 1978).

WRc found retention time tended to be considerably less than that expected in both perfectly mixed and plug flow systems due to short-circuiting. In perfectly mixed systems it occurs when a fraction of the inlet water takes a route which doesn't interact with the main body of stored water this may be due to the inlet and outlet being too close together. In plug-flow systems short-circuiting can be caused by the existence of stagnant zones or layers resulting in pollutants arriving at the outlet much earlier than the mean retention time (White and Davis 1978).

The degree of short circuiting that takes place is dependent on the wind direction and strength. In general light or calm wind conditions tend to increase the degree of short circuiting whereas moderate to strong winds tend to have a beneficial effect on the dilution taking place between the inlet and outlet. The correlation between wind direction and short circuiting is very site specific (Lee *et al.* 1978,Belcher *et al.* 1978, White *et al.* 1977, White and Davis 1978).

A6. BANKSIDE INFILTRATION

Amsterdam has been abstracting water from nearby dunes since 1851. In order to replenish the underground source and to prevent the intrusion of salt water it became necessary to recharge the groundwater with Rhine water. The Rhine water is treated at the river abstraction point by coagulation and rapid filtration so that the recharge water is relatively free of all silt, phosphates and heavy metals. Infiltration of the Rhine water is achieved through a system of recharge channels and ponds. The infiltrated water remains in the area for at least two months. The groundwater in the dunes is blended with recharge water in such a way that drinking water of nearly constant composition is obtained.

The main advantages of the dune infiltration scheme are described to be:

- smoothing and improving the quality of the river water through mixing with ground water;
- storage of water for emergencies;
- improvement of the quality of the infiltrated water by subsoil biological, physical and chemical processes.

The velocity of percolation through the dunes is not the same for all of the infiltrated water, therefore, the smoothing of water quality occurs with a lag phase. The smoothing effect is enhanced by the division of the recharge area into five compartments that can be separately fed with river water. By designating specific areas for water of above average quality and controlling the input from the drains, it is possible to obtain water of a relatively constant composition. The composition of the drinking water may be further influenced by mixing it with varying quantities of deep ground water of a very high quality.

Shipping accidents are a frequent occurrence on the Rhine, resulting in the spillage of oil and chemicals into the river. Accidental spills also occur from the many industrial sites situated along the banks of the rivers and in the harbours. Further pollution arises from the effluent from the many industrialised areas and cities along the Rhine and its tributaries. A network of monitoring stations has been set up along the river to provide information on such accidents. The river intake is immediately closed when pollution occurs (Amsterdam Municipal Waterworks 1989). During the drought of 1976 Anglian Water Authority installed an emergency water supply in the Etton area north of Peterborough utilising gravel infiltration systems (alongside the river Witham) with transfer of water from Rutland Water via local rivers and dykes.

In the Amsterdam dune system the improvement in the biological quality of the infiltrated water occurs immediately after it has penetrated into the layer of sand. During this stage most of the free oxygen is used in breaking down organic matter. There is an improvement in taste and a reduction of the ammonia and nitrate content at this stage. The chemical oxygen demand and phosphate content may also decrease considerably. However, the ability to remove phosphates has been significantly decreased by the installation of the coagulation plant at the intake.

The layers of peat and humic matter that occur at various depths and locations in the dunes produce organic compounds and colour. After infiltration and mixing with ground water, the water is pumped to a treatment plant where it is subjected to the following purification processes:

- softening;
- aeration by means of a cascade;
- powdered activated carbon;
- rapid filtration;
- slow sand filtration;
- standby chlorination.

The deteriorating quality of the Rhine water makes it necessary to build more and more sophisticated purification plants; by 1995 ozonation and activated carbon filtration will be incorporated into the system.

A7. CONCLUSIONS

The provision of bankside storage undoubtedly affords benefits with respect to the ability to close the intake in the event of an accidental pollution incident and enabling the dilution of the polluted water that has entered the reservoir; however the benefits of self-purification are limited. The improvement in quality due to short term storage appear to be closely associated with the settlement of suspended solids; with little or no improvement in the levels of contaminants in solution. This degree of improvement is achieved through filtration and coagulation processes in treatment works. The physico-chemical parameters of water are altered on storage of this type. The pH rises making the water more alkaline, the amount of ammonia decreases and the fluctuations in dissolved oxygen which occur in the river are moderated. Storage appears to have little effect on temperature. Algal growth can result in a deterioration of the water's quality, however due to the short retention time this is not generally likely to be a major problem. The number zooplankton also increase on storage which can be problematic if any get into the filtering system. The anaerobic silt from settled solids could release pollutants back into the water.

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APPENDIX B - POLLUTION RISK ASSESSMENT

Pollution risk is compounded of the two main factors:

1. The risk of a particular class of pollution incident reaching an intake without the knowledge of the abstractor.

2. The toxicological or other damage consequences of a particular stock of pollutant getting released into the environment.

The quantitative treatment of 1. in terms of frequency and severity of occurrences is exceedingly difficult, although it can reasonably be attempted for incidents related to transport accidents, where statistics are available, and for commonplace minor pollution incidents where pollution inspectors' records can serve as a basis.

In coping with the risks and attempting to reduce them, much depends on having good operational information, such as rapid response by emergency services and industry, in warning all the downstream water abstractors of any incident.

Another factor is the degree of passive safety built into sites where chemicals are stored and handled: bunds, gully pots, oil traps and detention tanks are examples.

Training is also essential for personnel working at chemical and fuel stores, industrial and commercial premises, as well as for those engaged in the transport and handling of liquid and solid wastes, fuels and chemicals, and for fire and police officers. The training should cover safe handling procedures, prompt communication with water abstractors and clean-up actions.

Clearly where travel times down a river are short, the risk of not being informed of a pollution incident is far greater than where more time is available, and where longer reaches of river are involved, so that any visible evidence, such as dead fish, has a better chance of being noticed and reported before it is too late to act.

The consequential threats, 2. above, are more readily assessed. The original measure of these was PARI (Potential Abstraction Risk Index) as devised by Welsh Water Authority and Bradford University. PARI is derived as follows:

1. The total amount (e.g. stored weight or volume) of a potential pollutant is assumed to discharge directly into a river.

2. The pollutant is fully mixed in a volume of water corresponding to ten minutes of the river's 95% low flow.

3. The mixture arrives at a downstream site without further dilution or dispersion.

4. PARI is the ratio:

$$\frac{\text{concentration derived in step b}}{\text{concentration of toxicity threshold}}$$

where the denominator relates to short term exposure to humans drinking the water.

As a tool for ranking pollution threats, PARI is rather crude. It would be vastly improved by allowing for dispersion, dilution and time factors. The toxicity thresholds used are crucial and WRc has special experience in evaluating these, in regard to drinking water. PARI does not cater for groundwater pollution.

APPENDIX C - THE BANKSIDE INFILTRATION MODEL

The quality of water abstracted from bankside infiltration wells or bankside infiltration reservoirs will, under certain circumstances, be adversely affected by a pulse of pollution travelling along a river. The relationship between the quality of the abstracted water and that of the river may be determined by using mathematical models of the river and associated aquifer. Such models can be precisely constructed and carefully calibrated for specific localities to give accurate simulations of this relationship. In the present study models have been used to give general indications of the interaction between river water quality and the quality of the abstracted water using typical ranges of the controlling parameters.

C1. BANKSIDE INFILTRATION WELLS

As a general case it was assumed that a well is pumping from a uniform aquifer at a constant rate, and is located close to a straight river in hydraulic continuity with groundwater in the aquifer. The water abstracted from the well will be derived either directly from the river or from the interception of groundwater flow towards the river. Whatever the proportions of abstraction coming from the two sources the flow in the river will be diminished by an amount equal to the rate of abstraction from the well. On the other hand, the quality of the water abstracted will be related to the quality of the river water and of the groundwater in proportion to the contributions to the well output from the river and from groundwater. This proportion may be estimated with the aid of a simple mathematical model of the river/aquifer system. It was assumed for modelling purposes that a pulse of pollution would persist in the river in the vicinity of the well for a period of one day.

The concentration of pollutant in the abstracted water relative to that in the river water will vary with time as the pollution pulse passes, and will depend on the rate of abstraction, the regional groundwater gradient and the transmissivity of the aquifer. Figures C1 and C2 show results from the model for the two extreme cases of an under-utilised aquifer (Figure C1) and an over-utilised aquifer (Figure C2). In the first case the abstraction rate is relatively low and the regional groundwater gradient is high so that only a small proportion of the abstracted water is drawn from the river. These conditions would apply in catchments in which only a small proportion of the total groundwater recharge is abstracted. The maximum concentration, expressed as a fraction of the concentration in river water, falls of rapidly as the distance between the well and the river is increased. Aquifer type has an important influence on the predictions, with the relatively low transmissivity sandstones giving rise to the greatest river influence. For chalk and gravel aquifers no pollution will reach the well at distances greater than about 80 m.

In the second case the abstraction rate is high and the regional groundwater gradient low so that river water provides a relatively high proportion of groundwater abstraction. These conditions would apply to catchments in which a high proportion of the total groundwater

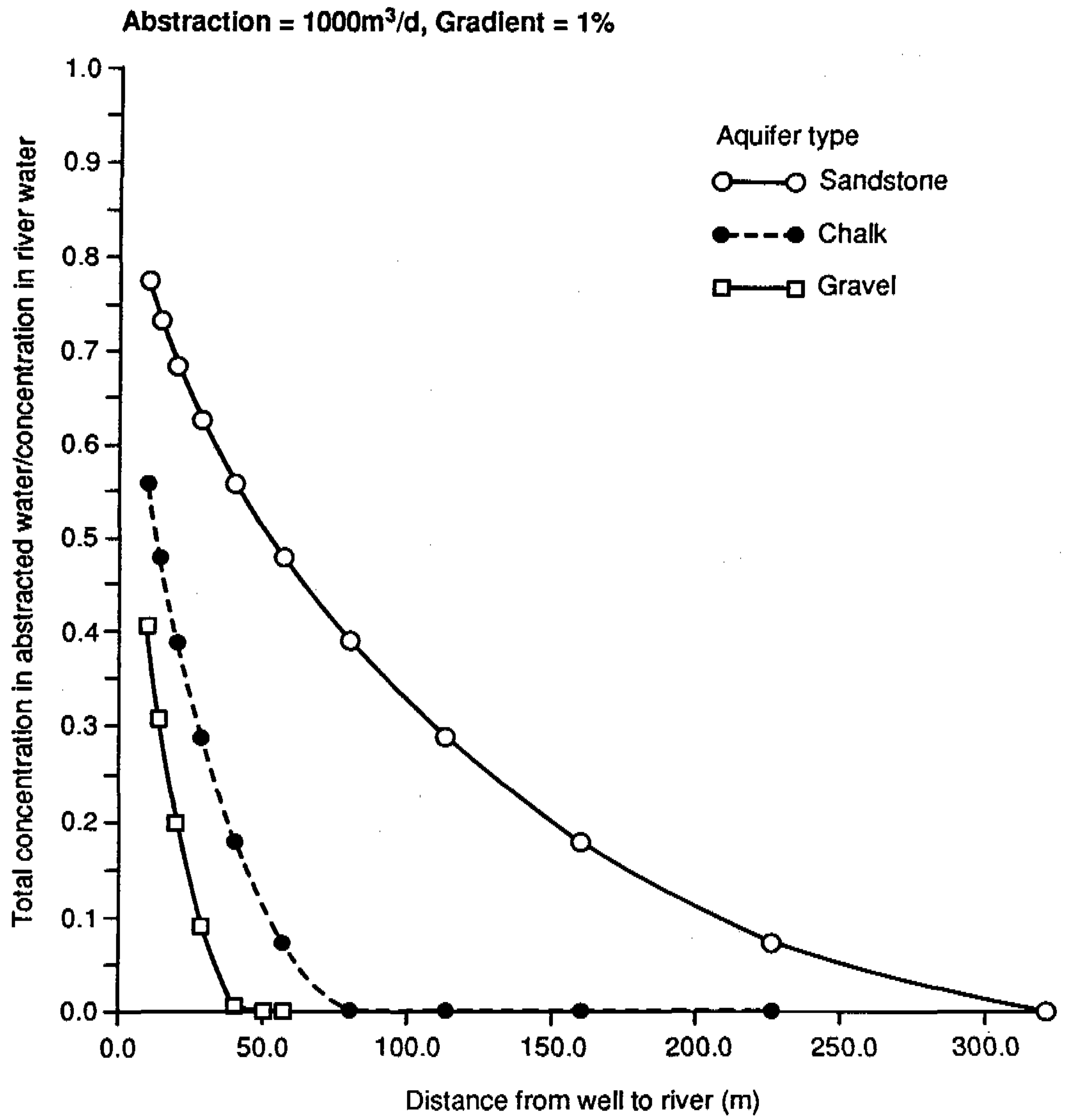

Figure C1 Predicted concentrations in a bankside infiltration well in an under-utilised catchment

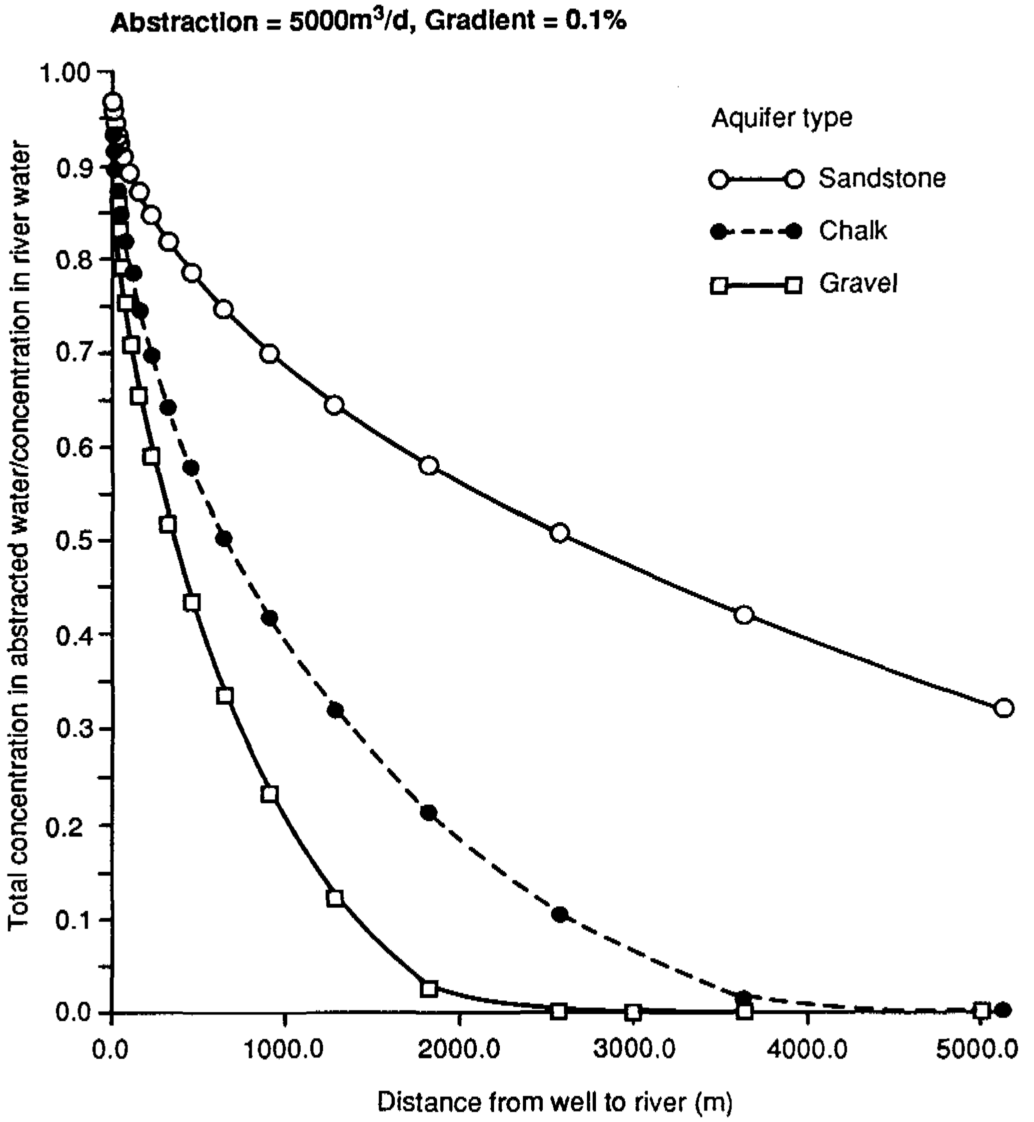

Figure C2 Predicted concentrations in a bankside infiltration well in an over-utilised catchment

recharge is abstracted. The maximum concentration (Figure C2) is much more significant even for wells remote from the river. Sandstone again gives the highest concentrations, and even the highly transmissive gravels show a significant level of pollution in pumping wells at up to 1 km from the river.

C2. BANKSIDE INFILTRATION RESERVOIRS

A similar model study was undertaken for bankside infiltration reservoirs which can be filled by water seepage either from the river or from groundwater flowing towards the river. The latter is equivalent to the interception of groundwater flow by bankside infiltration wells. The impact of river pollution on water quality in the reservoir will be determined by the relative contributions to seepage from the river and from groundwater. As with the case of the bankside infiltration wells it was assumed that the total seepage would equal the total rate of abstraction from the reservoir. The model equations for the bankside infiltration reservoir problem differ from those for bankside infiltration wells however, and the model results do not depend on aquifer transmissivity. Instead, the results of the model simulations may be plotted as maximum relative concentration versus equivalent days of infiltration time as in Figure C3. The latter takes into account both reservoir volume and the rate of abstraction. It was again assumed that a pollution pulse of one days duration passed along the river in the vicinity of the reservoir. The results depend the fraction of seepage into the reservoir derived from the river, as shown. This fraction will depend on local conditions, and will tend to be lower in under-utilised catchments.

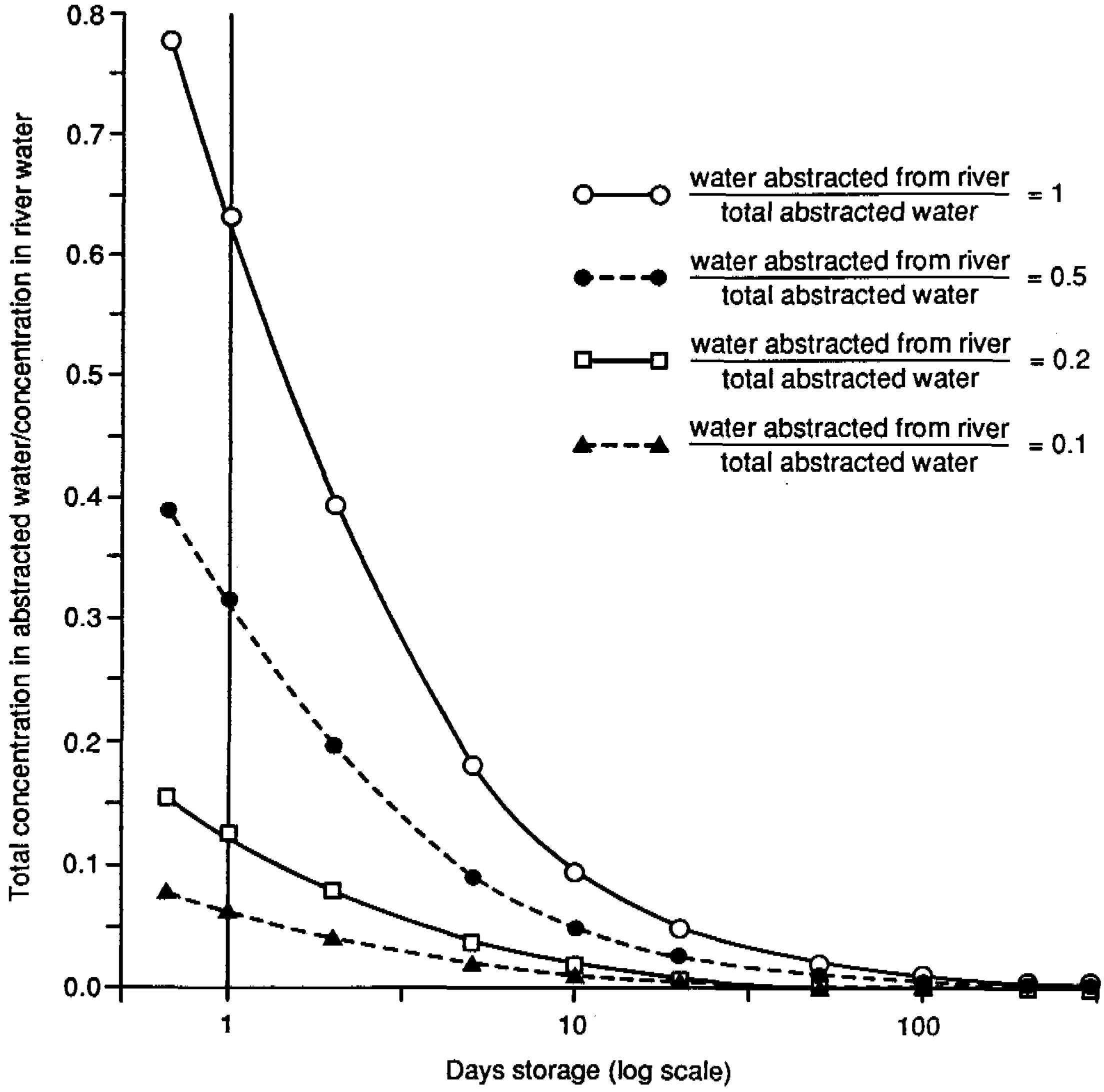

Figure C3 Predicted concentrations in a bankside infiltration reservoir

APPENDIX D - ASSESSMENT OF EC (AND UK) PROSPECTIVE POLICIES AND THE CONSEQUENCES ON THE VIABILITY OF BANKSIDE STORAGE/INFILTRATION

Bankside storage of raw water before treatment is recognised as a useful tool to safeguard drinking water supplies against accidental pollution. This document reviews future EC and UK policies concerning drinking water and assesses their potential impact on the viability of such systems.

D1. EXISTING LEGISLATION

There are two EC Directives which are relevant when considering the quality of water used for drinking water abstraction and hence the viability of bankside storage. These are the the Directive concerning the quality required of surface water intended for the abstraction of drinking water in the Member States 75/440/EEC (Surface Water Directive, CEC 1975) and the directive relating to the quality of water intended for human consumption 80/778/EEC (Drinking Water Directive, CEC 1980).

D1.1 Surface Water Directive

Standards for the abstraction of surface waters for drinking water are reported in the Surface Water Directive (CEC 1975). Annex II of the Directive specifies three categories of raw water treatment according to the achievement of guideline and mandatory standards for 46 physical, chemical, and biological parameters as listed in Table D1. The three water treatment categories are:

1. Simple physical treatment (A1 treatment);
2. Normal physical and chemical treatment and disinfection (A2 treatment);
3. Intensive physical and chemical treatment and disinfection (A3 treatment).

The Directive is implemented in UK law in the Surface Waters (Classification) Regulations (HMSO 1989a) which prescribe a classification system for inland waters in England and Wales. This classifies waters used for abstraction for drinking into three classes, DW1, DW2, and DW3, which reflect the mandatory values in Annex II of the Directive. Regulation 23 of the Water Supply (Water Quality) Regulations 1989 (HMSO 1989b) also requires that the provisions of the Directive apply to abstractions. The Surface Waters (Classification) (Scotland) Regulations (HMSO 1990) prescribe an identical system for Scotland.

D1.2 Drinking Water Directive

The principal Directive on the quality of drinking water for human consumption is the Drinking Water Directive (CEC 1980). This has been implemented in the UK as part of the Water Act 1989 (HMSO 1989c). Detailed implementation of the provisions contained in the Act for drinking water quality are laid down in the Water Supply (Water Quality) Regulations 1989 (HMSO 1989b) and the Water Supply (Water Quality) Amendment Regulations 1989 and 1991 (HMSO 1989d, 1991a). These regulations lay down the frequency of sampling and the parameters which need to be analysed. The actions to be taken if the standards are exceeded are laid down in a guidance document entitled 'Safeguarding the Quality of Public Water Supplies' (HMSO 1989e). This document also describes the analytical detection limits and analytical quality controls which must be achieved. For parameters not included in the water supply regulations, guideline values are derived, if appropriate, using a method based on the ADI (acceptable daily intake) of the compound, an average daily intake of water and the relative exposure to the compound from drinking water and other sources. This is the type of procedure used in the derivation of WHO guidelines.

D2. RECENT DEVELOPMENTS

D2.1 Modifications to the Drinking Water Directive

Due to recent developments in water treatment and scientific understanding as well as practical experience by both water companies and governmental authorities, the Drinking Water Directive (CEC 1980) may be modified. Any increase in the stringency of the standards introduced in the Drinking Water Directive, may stimulate interest in the use of bankside storage and infiltration systems since these two systems are reported to help reduce levels of many parameters, including suspended solids, micro-organisms and metals. However, it appears unlikely that the Commission will amend the Directive at present and it would probably take at least five years for any changes to be included in a modified Directive.

Eureau (The European Water Suppliers Association) has recently submitted, to the Commission, proposals for modifications of the Drinking Water Directive. Changes proposed by Eureau involve different areas of the Directive and include the choice of parameters, actual values, compliance rules and monitoring of compliance.

The Eureau proposals to revise the Directive may lead to a number of changes, for example:

- the elimination of some parameters not relevant to the quality of drinking water (e.g. silica);
- the elimination of parameters already covered by other parameters (e.g. total hardness covered by calcium and magnesium);

- the addition of some parameters (e.g. disinfection by-products),
- the subdivision of the parameters into those relating to health, comfort/aesthetic criteria, microbiology, and operations (relevant only for water supply systems but not necessary for judging the safety and acceptability of drinking water and thus not requiring a MAC (Maximum Acceptable Concentration) value);
- the modification of some standards (e.g. lead standard),
- the change in the rules for assessing compliance (e.g. monitoring requirement according to the type of parameters);
- adequate protocols in case of MAC exceedance;
- separate legislation to deal with the problems of pollution.

The parameter which if it is amended would have the most significant impact on the storage of water in bankside reservoirs is the presence of algae. At present, the algal parameter is included in the Drinking Water Directive (CEC 1980) as a footnote but it may become a more precise parameter requiring additional control where water is stored in a reservoir. Regulation 3.(3).(a) of the Water Quality Regulations requires that water does not contain any element, organism or substance (whether or not a parameter) at a concentration which would be detrimental to public health, this may be considered adequate to cover these changes.

Some concern has also been expressed over the indirect effects of algae. For example, the presence of excess algae can lead to the development of anaerobic conditions and the re-dissolution of iron and manganese. However treatment processes can remove these organisms or compounds from the water. The release of algal by-products is also of concern and may be the subject of new parameters for organics. Taste and odour parameters which can be influenced by the presence of algae are not expected to be modified and existing treatments can eliminate this problem (e.g. carbon).

The phenol parameter which currently specifies total phenols (Eureau has proposed that this should apply to individual compounds), could be a cause of concern for reservoir waters.

No change in the nitrate parameter is proposed. The storage of water offers the opportunity to use fluctuations in the nitrate concentration in surface water to dilute the concentration in stored water to below the required level.

The changes proposed by Eureau are unlikely to have a significant impact on the need for bankside storage and infiltration systems.

D2.2 Revisions of the WHO Guidelines

Recent proposals to revise WHO guidelines for drinking water quality may increase the pressure to change individual standards in the Directive, but it is more likely that the

Commission will encourage the Member States to comply with the new guidelines than directly modify the Directive.

WHO is working on revision of guideline values for a number of parameters in drinking water (Table D.2). These proposed revisions will be submitted to the final Task Group for a decision in September and will be published in Spring 1993. The addition of new parameters such as disinfection by-products (Table D.3) and the revision of pesticide parameters (Table D.4) could both have an impact on bankside storage and bankside infiltration. This is because bankside storage is reported to reduce suspended solids in water such as humic acid which is responsible for the presence of toxic by-products in case of disinfection of water and bankside infiltration system is reported to help to reduce pesticide concentrations in water.

The parameters for drinking water quality set in the UK legislation and currently under consideration for revision by WHO guidelines are reported in Table D.5. At this stage detailed information on the likely modifications are not available.

D2.3 The Nitrate Directive

The recently adopted Directive on nitrate pollution from agricultural sources (91/676/EEC (CEC 1991)) sets the same criterion for nitrate as the drinking water Directive, namely a maximum admissible concentration of 50 mg l^{-1} (NO_3). The main requirement of the directive is the designation of zones vulnerable to water pollution from nitrogen compounds. The Directive is intended, for example, to safeguard surface freshwaters, in particular those intended for the abstraction of drinking water, which contain or may contain more than the concentration of nitrates laid down by the relevant provisions of Directive 75/440/EEC, from pollution by nitrates from agricultural sources. The directive intends to reduce discharges of nitrate by controlling agricultural practices. The Water Resources Act 1991 (HMSO 1991) makes provision in England and Wales for the designation of water protection zones and nitrate sensitive areas.

Although bankside storage and bankside infiltration may reduce the level of nitrate in water, the Nitrate Directive is not relevant to the need for these two systems.

D3. CONCLUSIONS

Although discussions are in progress concerning modification of the Drinking Water Directive, it is unlikely that it will be amended. The Commission might give more freedom to Member States according to the subsidiary principle and to encourage them, for example, to comply with new WHO guidelines. WHO guidelines could potentially have a significant impact on the use of bankside storage and infiltration, for example, if parameters such as disinfection by-products become regulated, there will be pressure to find a suitable and cost-effective treatment, which may involve and bankside systems.

The recent Nitrate Directive is unlikely to have any significant impact on the need for bankside storage and infiltration systems.

Table D1 Standards laid down in the UK Drinking Water Regulations (HMSO 1989a). Prescribed concentrations or values

Item	Parameters	Units of measurement	Concentration or value (maximum unless otherwise stated)
1.	Colour	mg l^{-1} Pt/Co scale	20
2.	Turbidity (including suspended solids)	Formazin turbidity units	4
3.	Odour (including hydrogen sulphide)	Dilution number	3 at 25 °C
4.	Taste	Dilution number	3 at 25 °C
5.	Temperature	°C	25
6.	Hydrogen ion	pH value	9.5 5.5 (minimum)
7.	Sulphate	mg SO_4 l^{-1}	250
8.	Magnesium	mg mg l^{-1}	50
9.	Sodium	mg Na l^{-1}	150
10.	Potassium	mg K l^{-1}	12
11.	Dry residues	mg l^{-1}	1500 (after drying at 180 °C)
12.	Nitrate	mg NO_3 l^{-1}	50
13.	Nitrite	mg NO_2 l^{-1}	0.1
14.	Ammonium (ammonia and ammonium ions)	mg NH_4 l^{-1}	0.5
15.	Kjeldahl nitrogen	mg N l^{-1}	1
16.	Oxidizability (permanganate value)	mg O_2 l^{-1}	5
17.	Total organic carbon	mg C l^{-1}	No significant increase over that normally observed
18.	Dissolved or emulsified hydrocarbons (after extraction with petroleum ether): mineral oils	µg l^{-1}	10
19.	Phenols	µg C_6H_5OH l^{-1}	0.5
20.	Surfactants	µg l^{-1}	200
21.	Aluminium (as lauryl sulphate)	µg Al l^{-1}	200
22.	Iron	µg Fe l^{-1}	200
23.	Manganese	µg Mn l^{-1}	50
24.	Copper	µg Cl l^{-1}	3000
25.	Zinc	µg Zn l^{-1}	5000
26.	Phosphorus	µg P l^{-1}	2200
27.	Fluoride	µg F l^{-1}	1500
28.	Silver	µg Ag l^{-1}	10(ii)

(ii) If silver is used in a water treatment process 80 may be substituted for 10

Table D1 continued

Item	Parameters	Units of measurement	Maximum concentration
1.	Arsenic	$\mu g\ As\ l^{-1}$	50
2.	Cadmium	$\mu g\ Cd\ l^{-1}$	5
3.	Cyanide	$\mu g\ CN\ l^{-1}$	50
4.	Chromium	$\mu g\ Cr\ l^{-1}$	50
5.	Mercury	$\mu g\ Hg\ l^{-1}$	1
6.	Nickel	$\mu g\ Ni\ l^{-1}$	50
7.	Lead	$\mu g\ Pb\ l^{-1}$	50
8.	Antimony	$\mu g\ Sb\ l^{-1}$	10
9.	Selenium	$\mu g\ Se\ l^{-1}$	10
10.	Pesticides and related products:		
	(a) Individual substances	$\mu g\ l^{-1}$	0.1
	(b) total substances[(i)]	$\mu g\ l^{-1}$	0.5
11.	Polycyclic aromatic hydrocarbons[(ii)]	$\mu g\ l^{-1}$	0.2

(i) The sum of the detected concentration of individual substances.
(ii) The sum of the detected concentrations of fluoranthene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene and indeno[1,2,3-cd]

Item	Parameters	Units of measurement	Maximum concentration
1.	Total coliforms	number/100 ml	0
2.	Faecal coliforms	number/100 ml	0
3.	Faecal streptococci	number/100 ml	0
4.	Sulphite-reducing clostridia	number/20 ml	≤ 1
5.	Colony counts	number/1 ml at 22 °C or 37 °C	No significant increase over that normally observed

Table D1 continued

Item	Parameters	Units of measurement	Maximum concentration or value
1.	Conductivity	$\mu S\ cm^{-1}$	1500 at 20 °C
2.	Chloride	$mg\ Cl\ l^{-1}$	400
3.	Calcium	$mg\ Ca\ l^{-1}$	250
4.	Substances extractable in chloroform	$mg\ l^{-1}$ dry residue	1
5.	Boron	$\mu g\ B\ l^{-1}$	2000
6.	Barium	$\mu g\ Ba\ l^{-1}$	1000
7.	Benzo 3,4 pyrene	$ng\ l^{-1}$	10
8.	Tetrachloromethane	$\mu g\ l^{-1}$	3
9.	Trichloroethene	$\mu g\ l^{-1}$	30
10.	Tetrachloroethene	$\mu g\ l^{-1}$	10

Item	Parameters	Units of measurement	Maximum concentration or value
1.	Total hardness	$mg\ Ca\ l^{-1}$	60
2.	Alkalinity	$mg\ HCO_3\ l^{-1}$	30

Table D2 Chemicals under consideration for inclusion in the current revision of the WHO guidelines for drinking water quality (WHO 1988)

Organics

(i) Chlorinated organics

a. Chlorinated alkanes
   1. carbon tetrachloride
   2. 1,2-dichloroethane
   3. 1,1,1-trichloroethane
   4. dichloromethane
   5. 1,1-dichloroethane

b. chlorinated ethenes
   1. 1,1-dichloroethene
   2. 1,2-dichloroethene
   3. trichloroethene
   4. tetrachloroethene
   5. vinyl chloride

c. chlorinated benzenes

(ii) Aromatic hydrocarbons

a. benzene, lower alkyl benzenes and vinyl benzene
   1. styrene
   2. toluene
   3. xylene
   4. ethyl benzene
   5. benzene

b. polycyclic aromatic hydrocarbons (b(a)p)

(iii) Disinfection by-products, including trihalomethanes (see Table 3)

(iv) Pesticides (see Table D4)

(v) Miscellaneous organics
   acrylamide
   plasticisers:
   -diethylhexylphthalate
   -diethylhexyladipate
   hexachlorobutadiene
   epichlorohydrin
   EDTA
   NTA
   organo-tin compounds

Table D2 continued

Inorganics
(i) health-related inorganics and aesthetic/organoleptic aspects

aluminium	iodine
ammonia	iron
antimony	lead
arsenic	manganese
asbestos	mercury
barium	molybdenum
beryllium	nickel
boron	nitrate and nitrite
bromate	oxygen dissolved
cadmium	pH level
chloride	selenium
chromium	silver
colour	sodium
copper	sulphate
cyanide	taste and odour
fluoride	temperature
hardness	tin
hydrogen sulphide	total dissolved solids
	turbidity
	uranium
	zinc

(ii) Disinfectants
residual chlorine
chlorine dioxide, including chlorite and chlorate
chloramines

Microbiology/biology

Radioactive Materials

Table D3 Disinfection by-products under consideration for revision of the WHO guidelines for drinking water quality (WHO 1991a)

a. Trihalomethanes
   1. chloroform
   2. bromoform
   3. dichlorobromethane
   4. dibromochloromethane
   5. bromodichloromethane

b. chloramines
   1. monochloramine
   2. dichloramine

c. chlorophenols

d. haloacetonitriles
   1. dihaloacetonitriles: dibromoacetonitrile (dban), dichloroacetonitrile (dcan)
   2. trichloroacetonitrile (tcan)

e. formaldehyde
   chloroacetate
   chloropicrin (trichloronitromethane)
   cyanogen chloride
   dichloroacetate
   trichloroacetate
   1.1-dichloropropanone
   iodine
   3-chloro-4-dichloromethyl-5-hydroxy-2(5h)-furanone (mx)
   trichloroacetaldehyde monohydrate

Table D4 Pesticide substances under consideration for revision of the WHO guidelines for drinking water quality (WHO 1988, 1991b)

aldicarb	alachlor
aldrin/dieldrin	carbofuran
atrazine	2,4-d
bentazon	DDT
chlordane	1,2-dibromo-3-chloropropane
chlortoluron	mcpa
1,2-dichloropropane	methoxychlor
1,3-dichloropropane	metolachlor
1,3-dichloropropene	molinate
ethylene dibromide	pendimethalin
heptachlor,-epoxide	propanil
hexachlorobenzene	pyridate
isoproturon	simazine
lindane	trifluralin
permethrin	other chlorophenoxy acetic acid herbicides (excluding 2,4-D, mcpa): dichlorprop, 2,4-DB, 2,4,5-T, silvex, mecoprop, MCPB

2,4-D = 2,4-dichlorophenoxyacetic acid

Table D5 Prescribed parameters for drinking water quality (HMSO 1989a)

Parameters	Notified in the EC Directive	Under consideration for revision by WHO guidelines
colour	yes	proposed
turbidity	yes	proposed
odour	yes	proposed
taste	yes	proposed
temperature	yes	proposed
hydrogen ion	yes	proposed
sulphate	yes	proposed
magnesium	yes	no
sodium	yes	proposed
potassium	yes	no
dry residues	yes	no
nitrates	yes	proposed
nitrite	yes	proposed
ammonium	yes	proposed
kjeldahl nitrogen	yes	no
oxidizability	yes	dissolved oxygen
total organic	yes	no
carbon dissolved or	yes	no
emulsified HC phenols	yes	no
surfactants	yes	no
aluminium	yes	proposed
iron	yes	proposed
manganese	yes	proposed
copper	yes	proposed
zinc	yes	proposed
phosphorus	yes	no
fluoride	yes	proposed
silver	yes	proposed
arsenic	yes	proposed
cadmium	yes	proposed
cyanide	yes	proposed
chromium	yes	proposed
mercury	yes	proposed
nickel	yes	proposed
lead	yes	proposed
antimony	yes	proposed
selenium	yes	proposed
pesticides	yes	proposed (see Table D2)

Table D5 continued

Parameters	Notified in the EC Directive	Under consideration for revision by WHO guidelines
polycyclic aromatic HC	yes	proposed
total coliforms	yes	microbiology/biology
faecal coliforms	yes	microbiology/biology
faecal streptococci	yes	microbiology/biology
sulphite-reducing clostridia	yes	microbiology/biology
colony counts	yes	microbiology/biology
conductivity	yes	no
chloride	yes	proposed
calcium	yes	no
substances extractable in chloroform	yes	no
boron	yes	proposed
barium	yes	proposed
benzo 3,4 pyrene	no+	proposed
tetrachloromethane	no	proposed
trichloroethene	no	proposed
tetrachloroethene	no	proposed
total hardness	yes	proposed
alkalinity	yes	no

HC = hydrocarbons
\+ = not as individual compound

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APPENDIX E - COMPARISON OF COSTS OF BANKSIDE STORAGE AND WATER TREATMENT

E1. INTRODUCTION

Bankside storage of river water sources for potable supply provides a measure of protection to treatment works by:

- providing intake protection and closure without interruption of treatment,
- balancing out river water quality variations, and
- improving the quality.

These benefits are offset by the additional cost of bankside storage. There may also be occasions where some deterioration of water quality occurs during bankside storage, notably as a result of algal growth.

Improvement of quality with respect to *ammonia, turbidity, colour and microbiological* contaminant levels by storage could be equivalent to the difference between the raw water categories A1 and A2 (of the Surface Water Directive). Similarly, improvement in quality with respect to ammonia and organic pollutants could be equivalent to the difference between categories A2 and A3. Increase in algal populations could also be equivalent to the difference between categories. Thus it may be reasonable to compare the difference in costs of treating such categories. However, it is believed that the categories are used very broadly and designers of treatment works probably consider the worst conditions (because of the need to achieve 100% compliance for water quality at consumers' taps) and it is unlikely that the presence of a reservoir would alter their decisions.

In order to assess the benefits of providing bankside storage reservoirs, only the effects of storage on the performance and marginal decreases in operating costs of water treatment processes should be considered. The effects of storage on the capital cost of treatment plants will not be considered since it is assumed that any perceived potential treatment facility needed will be constructed any way.

Two types of reservoirs were considered for this assessment, clay-cored totally bunded reservoirs (CBR) and reservoirs constructed other than by simple excavation with special attention paid to creating an impervious structure or special bunded reservoir (SBR). Three sizes of reservoir were considered for each size of treatment works: one day, seven days, and fourteen days storage, although the remit of this report was to consider storage for upto seven days, fourteen days storage has been included here to provide a more complete picture.

Three water treatment plant sizes were chosen: 10 Ml d^{-1}, 30 Ml d^{-1}, and 70 Ml d^{-1}.

The pollution cases most frequently encountered and which are considered in this study are spillages or sudden changes in quality causing short term deterioration. Examples of contaminants arising from spillages or poorly controlled use are phenol, sewage (causing an increase of ammonia), pesticides, and petrol or diesel fuel resulting from road accidents. Examples of sudden changes are high nitrate concentrations, or high colour and turbidity following heavy rain.

Reservoir prices were derived from cost functions in TR61 (WRc 1977). They were updated to Q1 1991, using the index for the cost of labour in civil engineering construction, as in the Baxter indices. Equipment and material costs were obtained from suppliers.

What has not been costed is the operational cost penalty, if supply to a treatment works is stopped by a pollution incident. The cost penalty includes costs due to: fixed costs (labour, heating, lighting, maintenance, capital repayments), cost of the public relations exercise, costs of providing supplies from elsewhere and the costs of removing poor quality water that enters the supply system. Nowadays the infrastructure exists for most supply areas for importation from other areas. Therefore, the cost penalty for using that facility is just the cost of pumping.

E2. COSTS OF RESERVOIRS

The estimated capital costs of reservoirs shown in Table E1 include the costs of pumping plant and pumphouse in million pounds sterling. The costs of pump operation are excluded since it is assumed that the lift by pumping is necessary anyway. These prices with a discount rate of 5% over 30 years expressed as pence per m^3 of treated water are as shown in Table E2, assuming actual output is equal to design capacity. The effect on costs to different levels of utilisation has not been examined nor has the cost of intake protection for reservoirs been identified.

Table E1 Estimated capital costs of water storage, £M

Capacity	10 Ml d^{-1}		30 Ml d^{-1}		70 Ml d^{-1}	
Storage days	CBR	SBR	CBR	SBR	CBR	SBR
1	0.75	2.25	1.62	4.82	2.84	8.34
7	2.65	8.15	5.62	17.12	10.04	30.24
14	4.25	13.05	9.02	27.22	15.94	48.24

Depth of reservoir as a design parameter is related in general to size of reservoir (volume stored). Reference should be made to (Figure 11.14, page 200, WRc, 1977) the relationship between depth and volume stored. This relationship is governed by the relative costs of moving excavated material outwards and of constructing height into the embankment or bund, and means for most bunded reservoirs that depth is optimised with respect to cost. This means that greater or lesser depth than the cost-optimum can be constructed at greater cost per unit volume treated. It also follows that surface to volume ratio is also a function of volume stored and therefore governed by minimum cost of reservoir construction.

Table E2 Unit cost of water storage, p m^{-3}

Capacity	10 Ml d^{-1}		30 Ml d^{-1}		70 Ml d^{-1}	
Storage days	CBR	SBR	CBR	SBR	CBR	SBR
1	1.34	4.01	0.96	2.86	0.72	2.12
7	4.72	14.51	3.34	10.17	2.56	7.70
14	7.57	23.30	5.36	16.17	4.06	12.28

CBR - clay bunded reservoir
SBR - special bunded reservoir

Since reservoir dimensions are defined to achieve minimum cost, there is little scope to alter shape substantially enough to govern retention or mixing characteristics. The ability to control these will be mainly through the positioning and use of baffles, inlets and offtake. The most important requirement is to minimise short circuiting otherwise the purpose of the reservoir will be defeated. Short circuiting can be minimised by providing plug flow. However, whilst plug flow can be argued to be a desirable characteristic, it is virtually impracticable except by having storage provided by three or more reservoirs with flow in series.

Consequently, the best characteristic that can be achieved in practice is a partly-mixed system with some plug-flow to minimise short-circuiting. The ideal is to be able to construct a reservoir to have specified retention and other hydraulic characteristics that produce the desired physical, chemical and biological processes that improve water quality or otherwise attenuate quality extremes. Then it would be possible to determine the reservoir capacity needed in relation to the possible magnitude of deterioration of the source or sources. Geological, geographical and financial constraints may hinder the realisation of this ideal.

However, there should be some scope to collate existing knowledge, if this has not already been done, to produce basic rules that go some way to operational improvements.

A generalisation of retention characteristics would be useful to examine potential attenuation of short term peaks in raw water quality which in turn could be used to identify to what extent a cost benefit might be realisable through less robust water treatment. In the case of step deterioration of quality, modelling can predict how much time the operator has available before action must be taken to cope with that change, given that further minor adjustments to works operation will no longer be adequate. The greater the magnitude of the step change then the sooner action must be taken.

One of the greatest problems at a water works is encountered relatively frequently with direct river abstraction, namely coping with very rapid changes in quality, such as occur after heavy rain. In trying to cope the operator can spend considerable effort, often relatively unsuccessfully. Attenuation of the magnitude of or dampening the speed of change in quality makes the operator's life easier and coping with severe changes in the river much cheaper.

E2.1 Importation of water

When intake closure is necessary an alternative to using stored water is importation from another source. Table E3 presents approximate costs of importation from 20 and 50 km. The capital repayment cost is incurred whether or not the pipeline is used or not. The pumping cost (operating cost of overcoming headloss only at the design capacity) is the additional operating cost for ten days pumping per year. If the capital costs in this table are compared with Table E2 it will be seen that the costs of providing 20 and 50 km pipelines are approximately the same as for a 7 and 14 day clay bunded reservoirs respectively. (It may be useful to refer to a similar exercise (Gregory and Sheiham 1981) that compared the costs of treatment, storage and importation as solutions for control of nitrate levels in drinking water, to which the above costs of importation relate.)

Table E3 Unit costs of water pumped from another area, p m^{-3}

Capacity	10	30	70	Ml d^{-1}
20 km				
Capital cost	4	2.5	1.7	p m^3
Pumping cost	0.11	0.11	0.11	p m^3
50 km				
Capital cost	8.3	5.1	3.6	p m^3
Pumping cost*	0.27	0.27	0.27	p m^3

* = marginal cost for ten days pumping per year

The estimated costs of importing do not include any penalty or otherwise for extra costs that might be incurred with exploiting another source, nor whether the imported water is raw or treated. This and the other simple comparisons have not taken into account factors such as environmental and social impact during and after construction and the recreational value of larger reservoirs.

E3. POLLUTION INCIDENTS

Two examples of pollution incidents were considered. The first was organics pollution in the raw water source (for example phenol spillage or excess pesticides in the river) which will call for the use of Granular Activated Carbon (GAC), the other was excess ammonia which will affect the chlorine demand. Other effects considered were the possibilities of algal growth in the reservoir and the reduction in raw water turbidity.

E3.1 Effects of organics pollution on GAC

GAC is used to adsorb organic pollutants that are not easily removed by coagulation, sedimentation and sand filtration processes. Under normal conditions, a GAC filter is designed for an empty bed contact time of 15 minutes, and the carbon is exhausted and needs regeneration typically after one year. The price of new carbon and the regeneration costs are shown in Table E4.

Table E4 Estimated costs for GAC

Output (Ml d^{-1})	10	30	70
Carbon (tonnes)	52.5	157.5	364.5
Price for new carbon (£K)	79	237	547
Regeneratoin costs (£K per year)	39.5	118.5	273.5
Regeneration costs (p m^{-3})	1.08	1.08	1.08

The regeneration costs are independent of plant size as the amount of carbon required is proportional to flow rate. If the pollution incident causes a complete exhaustion of the carbon bed, the extra costs per regeneration are about 1.08 p m^{-3} of treated water.

E3.2 Effects of ammonia pollution

In case of ammonia increases in raw water (discharge of sewage effluent) the chlorine demand will increase until ammonia concentrations return to their typical values (assume the effect lasts three days). The cost of extra chlorine consumption for a three day period (assuming an increase in chlorine demand of 5 mg l^{-1} due to an increase of 1 mg l^{-1} ammonia) for plants running at 10, 30 and 70 Ml d^{-1} is about 0.003 p m^{-3} of treated water.

E4. ALGAL GROWTH

Algal growth within the reservoir might occur (although the probability of algal blooms during 7 to 14 days storage is generally low), and this will require extra treatment, for instance by fitting microstrainers. Capital costs of microstrainers (Weir Pumps Limited) including civil engineering construction, washwater pumps, pipeworks, valves, variable speed drives, penstocks, and installation are given in Table E5, expressed as pence per m^3, with a discount rate of 5% over 30 years.

Table E5 Estimated costs for microstrainers, p m^{-3}

Output (Ml d^{-1})	10	30	70
Cost (p m^3)	0.39	0.22	0.16

An alternative approach to dealing with algae is to prevent their growth during storage by reducing phosphate concentration. This might be done by dosing metal-ion coagulant (aluminium sulphate or ferric sulphate) to the raw water entering the reservoir such that precipitation takes place either in the reservoir or in a preliminary treatment basin, reservoir or lagoon. As a first approximation, the total amount of coagulant used for this, plus treatment of water drawn from the reservoir should be very similar to that used for treatment when the raw water feed is not dosed with coagulant. However, when coagulant is dosed in two such stages, the total dosage is likely to be greater than when dosed only in normal treatment, whilst the cost of other chemicals used will be similar. For an ecologically acceptable and operationally convenient strategy, such a phosphate precipitation scheme should be adequately engineered. This may need to be achieved by providing large concrete, horizontal flow, settling basins to minimise the amount of coagulant-derived solids entering the reservoir, and from which settled solids can be removed easily for dewatering and disposal off site. Much of the cost of this should be offset by reduced costs of the eventual treatment. Whilst this pre-treatment approach would not be cheaper than providing and using microstrainers, it should be more effective and reliable.

E5. EFFECTS OF TURBIDITY REDUCTION

Storage of water in reservoirs reduces the turbidity (perhaps by 50%, depending upon the quiescence of the water body and other factors). This might result in reduction of coagulant dose. The savings in chemicals are less than 0.2 pence per m^3 treated (assuming ferric sulphate salts with 12.5% w/w as Fe cost £54.4 per tonne as delivered, and an average reduction in demand by 3 mg Fe l^{-1}). There will be indirect cost savings from reduction in sludge formation and treatment and less frequent backwashing of rapid gravity filters. At slow sand filter works, turbidity reduction during storage will result in a reduced frequency of sand cleaning.

At works where sludge treatment is costly (approximately 20% of treatment costs), savings of about 1 p m^{-3} of treated water might be achieved.

Typically the filtration rate of a rapid gravity filter is 7 m h^{-1}; the backwash rate is 30 m h^{-1} for ten minutes; a backwash would be needed every 24 hours. The effect of storage in a reservoir could be to reduce the backwash by 50%: in such a case the savings would be about 0.15 p m^{-3} of treated water (assuming the cost of washwater to be 10 p m^{-3}).

For a slow sand filter, it is assumed that the filtration rate is 0.3 m h^{-1}, and that six scrapings are done per year. It takes a team of five men to scrape 500 m^2 h^{-1}. If the storage reduces the need for scraping by 50%, then the savings are about 0.008 p m^{-3} of treated water. Turbidity removal before slow sand filtration could also be achieved using microstrainers as a pretreatment and the figures on the previous table can be used to compare storage and microstraining as pretreatments before slow sand filters.

The treatment achieved by bankside infiltration is similar to slow sand filtration. How similar it is depends on various factors. Bankside infiltration reduces turbidity and therefore microbiological contaminants. Parameters such as ammonia, nitrate and organic pollutants will be reduced depending on factors that affect microbiological activity such as dissolved oxygen concentration, temperature and time of passage. Bankside infiltration can be set up in a number of ways depending partly upon the nature of the riverside geology and could include: infiltration galleries under and alongside the river, a series of wells into river valley gravels near the river, or reconstruction of the river bank to be relatively pervious in order to feed adjacent wells. Costs are therefore not readily estimated. It may be feasible to abstract from a reservoir by bankside infiltration. It is probable that an infiltration scheme would be more expensive than microstraining but would do a better job of improving water quality; conversely it would be cheaper than slow sand filtration but would not perform as effectively in water quality terms.

A reduction of turbidity or colour might contribute to a smaller chlorine demand (in addition to that associated with ammonia) in prechlorination. The cost saving arising from this, however, is only of the order of 0.001 p m^{-3}, which will be insignificant relative to the cost of storage or reduction in chlorine demand due to reduced ammonia concentration.

When coagulation of raw water is carried out prior to storage to precipitate phosphorous, then this will also contribute to improvement in turbidity, microbiological quality and possibly colour. This adds another dimension to the possible options for comparison. In some circumstances it may allow, for example, treatment of stored water to be by slow sand filtration rather than coagulation.

E6. COMMENTS

The above estimates of costs are summarised in Table E6, and Figures E1 and E2.

Table E6 Summary of estimated unit costs, p m^{-3}

Output ($Ml\ d^{-1}$)	10		30		70	
Storage (days)	CBR	SBR	CBR	SBR	CBR	SBR
1	1.34	4.01	0.96	2.86	0.72	2.12
7	4.72	14.51	3.34	10.17	2.56	7.70
14	7.57	23.30	5.36	16.17	4.06	12.28
Importation						
Capital						
20 km	4.0		2.5		1.7	
50 km	8.3		5.1		3.6	
Operating	10 days pumping per year					
20 km			0.11			
50 km			0.27			
Savings on GAC regeneration	Assuming pollution incident exhausts all the carbon, savings are 1.08 p m^{-3}					
Microstrainers	0.39		0.22		0.16	
Savings on chemicals	Less coagulant and chlorine is required due to reservoirs, savings are 0.103 p m^{-3}					
Savings on sludge treatment	On sites where sludge treatment is costly, savings of 1 p m^{-3} can be achieved					
Savings on backwash water	Backwash frequency is reduced due to reservoirs, savings are 0.15 p m^{-3}					
Slow sand filters	Reduced scrapings, savings are 0.008 p m^{-3}					

Notes

CBR = clay bunded reservoir
SBR = special bunded reservoir

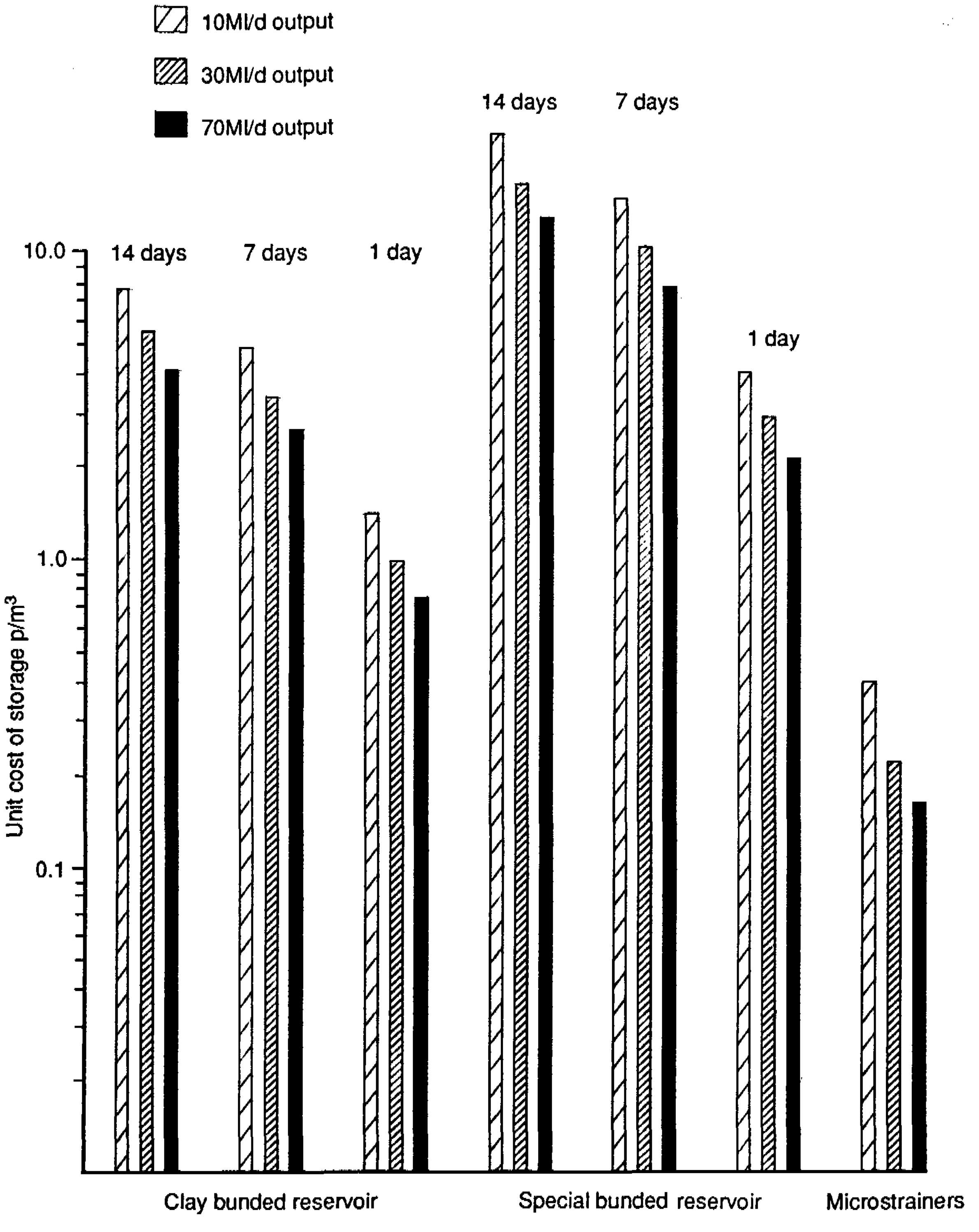

Figure E1 Summary of estimated costs of storage

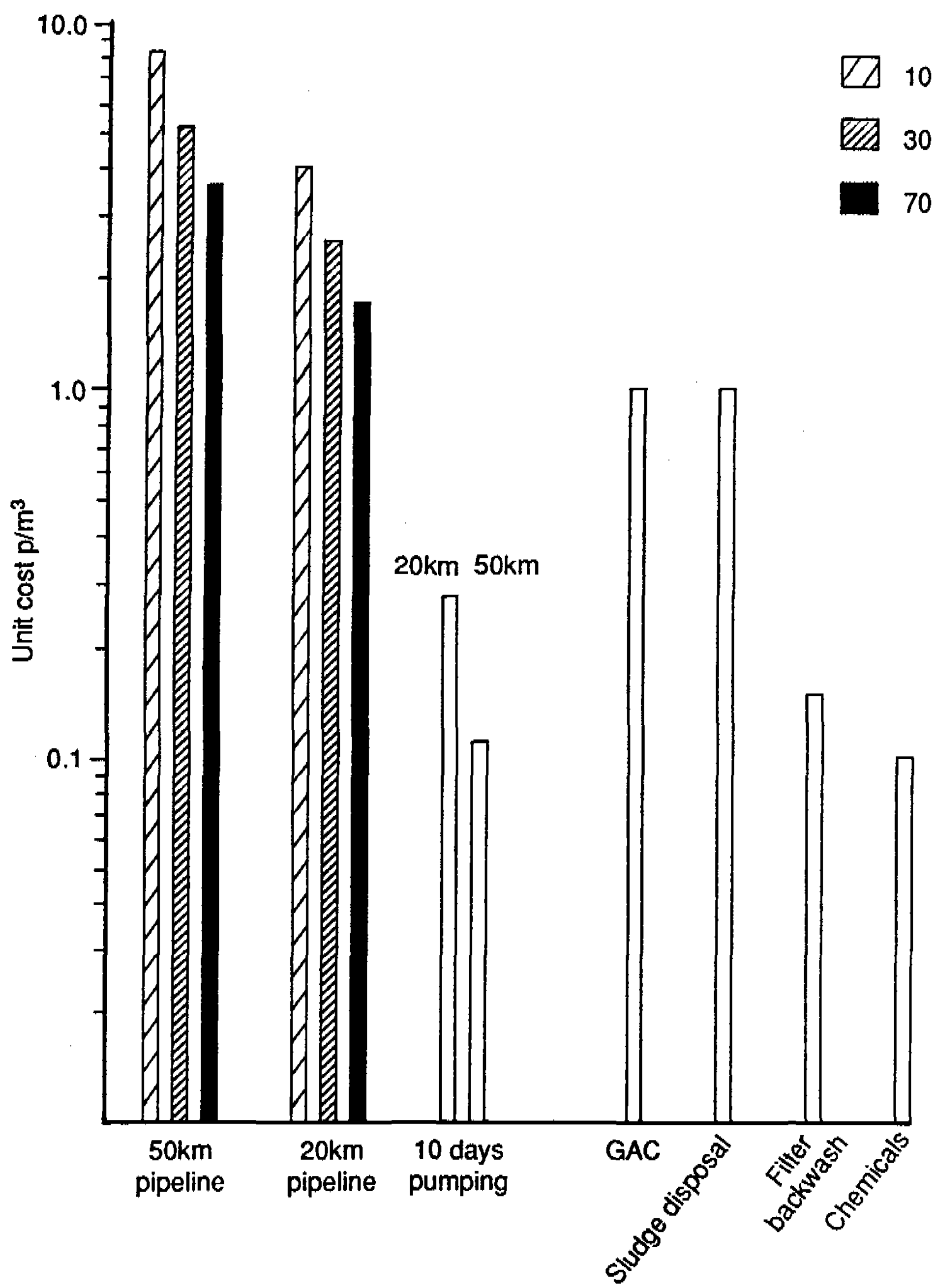

Figure E2 Summary of estimated costs of alternatives to storage

This study is by no means exhaustive, as it has not included the effects of bankside storage on the potential saving in operational manpower (by balancing out the river water quality, treatment is easier as peaks and troughs are eliminated) as compared with extra time needed for reservoir management. Other costs such as dealing with public due to interruption of supply and supply from other sources were not considered.

Other indices than the Baxter Indices could have been used to update the costs to 1991. However, the differences in costs arising between indices are very small compared to the differences between costs of storage and treatment and would not have altered the conclusions.

It is emphasised that the costs given are estimates only and the confidence limits may be equivalent to at least multiplication or division by 1.5. Actual costs for any particular scheme and the differences between costs of the options will depend upon individual circumstances.

E7. CONCLUSIONS

The cost estimates show that in general the capital cost of bankside storage exceeds the potential savings it provides in the pollution cases considered. Only where small reservoirs are considered (one day storage) might savings be achieved if the plants use activated carbon as part of their treatment and sludge treatment is expensive. If there were, say, at least three pollution cases per year and each time the GAC was exhausted and was replaced (a total cost of more than 3.2 p m^{-3}), then savings might be achieved with clay-bunded reservoirs of seven days storage capacity. However, if the risk of pollution incidents are considered to be high to the extent that provision had to be made to import water, then bankside storage may be the cheaper and more preferable option.

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APPENDIX F - PROVISIONAL LIST OF SURFACE WATER ABSTRACTION POINTS IN ENGLAND AND WALES

NRA Region/ Water Company	Number of intakes	Treatment level of raw water			
		A1	A2	A3	UC
Southern Region					
Southern Water	9	-	9	-	-
West Kent Water	3	-	3	-	-
Mid-Kent Water plc	1	-	1	-	-
Mid-Sussex Water	1	-	1	-	-
Eastbourne Water Company	5	-	5	-	-
East Surrey Water plc	1	-	1	-	-
Portsmouth Water plc	1	-	1	-	-
Northumbrian Region					
Northumbrian Water Ltd	10	-	10	-	-
Newcastle and Gateshead Water plc	8	-	8	-	-
Sunderland and South Shields Water plc	4(2)	-	4(2)	-	-
Welsh Region					
Welsh Water	121	42	79	-	-
Wrexham and East Denbighshire Water Company	20	6	14	-	-
Chester Waterworks Company	1	-	1	-	-
North West Water	3	-	3	-	-
Severn Trent Water Ltd	2	1	1	-	-
Wessex Region					
Wessex Water	14(3)	2(3)	12	-	-
Bristol Water plc	4	-	4	-	-
West Hampshire Water Company	1	-	1	-	-
Bournemouth and District Water Company	2	-	2	-	-
Wessex Water	3	3	-	-	-
South West Water	(4)	(4)	-	-	-

NRA Region/ Water Company	Number of intakes	Treatment level of raw water			
		A1	A2	A3	UC
North West Region					
North West Water	102	30	72	-	-
Severn Trent Region					
Severn Trent Water Ltd	21(9)	2	18(9)	1	-
North West Water	4	4	-	-	-
South West Region					
South West Water	53	33	19	-	1
Wessex Water	1	-	1	-	-
Anglian Region					
Anglian Water plc	21	-	21	-	-
Tendring Hundred Waterworks Company	1	-	1	-	-
Suffolk Water Company	5	-	5	-	-
Essex Water Company	6	-	6	-	-
Thames Region					
Thames Water Utilities	36(4)	-	36(4)	-	-
North Surrey Water Ltd	3	-	3	-	-
Three Valleys Water Company	1	-	1	-	-
Yorkshire Region					
Yorkshire Water	52(5)	48(4)	4(1)	-	-
York Waterworks plc	1	-	-	1	-
Northumbrian Water Ltd	1	-	1	-	-
Severn Trent Water Ltd	2	-	2	-	-
Totals	524(27)	171(11)	350(16)	2	1

Bracketed entries refer to the number and classification of abstraction points not yet agreed for inclusion in the final list.
Treatment levels as described in the EC Surface Water Directive.
UC = unclassified