WS ATKINS

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In October 1995 WS Atkins were appointed by the National Rivers Authority (Anglian Region) to undertake an Operational Investigation into the potential hydrological effects of demand management. In April 1996 the NRA joined HMIP and the Waste Regulatory Authorities to form the new Environment Agency. Although regionally funded, the project complements a national EA sponsored R & D initiative relating to demand management.

Whilst the potential benefits of demand management are generally recognised in the context of water supply, this has often been accompanied by an assumption that demand management will also be of benefit to the water environment as a whole. This has led to considerable debate in which the view has been expressed that the effects on the water environment of demand management are sometimes bad, sometimes neutral and sometimes good.

Since there are significant cost implications of implementing demand management, EA Anglian are keen to ensure that their own efforts to encourage the implementation of such measures are based on a clear understanding of the issues and are targeted in the most effective manner. It is against this background that this project has been commissioned, and it has the dual aim of improving the understanding of the issues involved and providing the EA with a practical means of assessing the hydrological impacts of demand management.

The project is structured in two stages *viz* Project Definition and Full Report. The necessity for the Project Definition Stage reflects the uncertainty regarding the scope and feasibility of the work involved. It's purpose is to establish the best approach to the project and to develop a clear and viable methodology for meeting the overall project objectives. This report describes the work undertaken during this first stage and provides an outline of the proposed methodology and resourcing for the Full Report Stage.

The work undertaken to date comprises:

- ***Agreement of approach*** - agreement of initial geographical focus (Anglian Region) and hydrological focus (hydrology of urban water supply and returns).

- ***Data Review*** - review of the nature and availability of data for the Anglian Region, specifically four urban supply zones (Bedford, Northampton, Cambridge and Southend).

- ***Development of a Water Balance Model*** - as the study progressed a framework was developed in order to address the range and complexity of the issues involved. This essentially comprises a conceptual model of the urban water supply system within which the issues and data requirements can be assessed, prioritised and quantified.

To date, the water balance model has only been used on a limited scale and it has yet to be subject to any rigorous sensitivity analysis. However, within the context of these limitations, the initial model runs indicate the following:

- Reductions in household demand and leakage both have the potential to significantly reduce abstraction rates and consumptive use.

- Reducing household demand will have a much greater effect on effluent returns than reducing leakage.

- The effects of demand management on abstraction rates, consumptive use and the magnitude of effluent returns are independent of the abstraction and return combination.

- The demand management scenarios applied have only a very limited effect on river flows downstream of the urban use and return cycle.

Based on the initial findings, and the potential of the model, the proposed methodology for the Full Report Stage can be summarised as follows:

- ***Hypothesis Testing*** - the model will be used to test a series of hypotheses which cover the main hydrological issues under consideration. This will include a process of sensitivity testing to identify which factors (e.g. consumptive use; leakage returns; locations of abstraction and effluent returns) have the most significant impact on the main outputs from the model (e.g. abstraction rates; river flows before and after abstraction or return). A probabilistic approach will also be applied to try and take account of uncertainty relating to the model inputs by expressing the key outputs as a probabilistic range of values.

- ***Application of the Model*** - having established the model as a means of assessing the potential hydrological impacts of demand management, the methodology will be applied using data from the four zones in Anglian Region identified above, if made available. This will examine the effects of factors such as geology on the nature and location of returns and the relative location of abstraction and returns on river flows in these specific urban supply zones.

  In addition the model will be used to link up a number of different supply zones to form a hypothetical catchment model. This will allow the assessment of the potential cumulative hydrological effects which might be realised when demand management is applied to several different supply zones within a catchment. For example, leakage to groundwater might constitute a loss to river flow in a single supply zone, but would represent a gain to river flow in a supply zone further down the catchment.

- ***Development of the Model as an Assessment Tool*** - the potential for applying the model to specific urban supply zones and catchments will be assessed, and the limitations involved with this approach will be clearly identified. If significant potential exists, the best means of "packaging" the model for general use by the EA will be considered.

1.0 INTRODUCTION

1.1 Aim of the Project

In October 1995 the Anglian Region of the NRA appointed WS Atkins to undertake a research project into the potential hydrological effects of "demand management" on the environment. In April 1996 the NRA joined HMIP and the Waste Regulatory Authorities to form the new Environment Agency. The EA's intention is that the study will complement existing research being undertaken by EA/UKWIR into the economics of demand management, and that the two projects combined will improve the framework within which the EA can best implement and target their demand management policies.

It is widely acknowledged that in terms of water supply, demand management will generally be of benefit in situations where resources are insufficient to meet demand either now or in the future. There remains some debate, however, regarding the extent to which demand management will address other water resource issues such as problems associated with low river flows and groundwater levels. To date, there has often been a general assumption that the projected reductions in water use as a consequence of demand management will result in environmental improvements. However, the projections have generally been on a regional scale, with little work being undertaken to establish how, in reality, such reductions will translate to a local scale in a variety of differing hydrological situations. Some have suggested that on a more local scale demand management will, in many circumstances, have little or no impact on these "environmental" problems, and that in some instances there may be an adverse impact.

The EA Anglian Region are keen to ensure that this issue is examined in more detail, and in sponsoring this project have defined its objective in the Project Brief as being "to focus the EA's demand management efforts to where they will be of greatest benefit to the water environment" (Appendix A).

Within this context, this study is primarily directed towards identifying and, where possible, quantifying the key hydrological impacts of implementing demand management measures. If this can be achieved, or at least a methodology developed to facilitate this process, the EA would be better equipped to target appropriate demand management initiatives.

1.2 Project Structure

Although the project is sponsored directly by Anglian Region, it is intended that the final outputs are of national rather than regional relevance. In the initial stages of the project, the focus will be directed toward case studies and issues within Anglian Region, with the intention of establishing principles that are applicable within a wider context. There will then be the potential to widen the focus during the latter part of the project.

The project as a whole is comprised of two stages, which are defined by the EA in the Project Brief as follows:

Stage 1: Project Definition

- review the problem and overall objective of the project
- produce an outline methodology to enable the overall objective to be achieved
- propose a detailed work plan and specification for Stage 2
- provide a detailed evaluation of the staff resources and timescales for each category of work required to implement Stage 2

Stage 2: Full Report

- develop the proposals of Stage 1 into a detailed methodology
- carry out the detailed work plan defined in Stage 1
- recommend how and where the EA can best harness demand management to maximise the benefit to the water environment

This document reports the work undertaken during the Project Definition Stage, and describes how this has been used to develop an appropriate methodology for the Full Report Stage. The methodology and work plan for Stage 2 are both described but will be subject to review by the EA prior to their implementation.

2.0 DEVELOPMENT OF DEMAND MANAGEMENT

2.1 Development of a Demand Management Policy

The issue of water supply and availability has been the subject of increasing public concern during the 1990's. Whilst several factors have contributed towards this, the water shortages and restrictions to supply experienced by a significant proportion of the population during one or more of the summers of 1988 to 1992, and more recently in 1995, has been the major catalyst in propelling the issues involved high up the political, economic and social agendas.

Since their formation in 1989, the National Rivers Authority, sought to highlight the issues involved, and their views became increasingly influential in the public debates which ensued. One of the main tenets of the NRA's argument was that for too long the planning of water supply and usage in England and Wales has had insufficient regard for the limitations of the resources that are actually available, and for the potential effects of depleting those resources. In a number of cases, the over-utilisation of water resources is perceived to have led directly to problems of low river flows and the drying out of wetland habitats, with significant impacts on fish populations, flora and fauna.

Under Section 19 of the Water Resources Act 1991 the NRA were required to conserve, redistribute or otherwise augment water resources and secure their proper use. These duties are now the responsibility of the new Environment Agency. In 1991 the NRA started to direct increasing effort towards acquiring a greater understanding of the factors that were driving the demand for water and how these might be controlled or managed. An extended period of investigation and policy formulation followed, culminating in September 1995 with the publication of 'Saving Water', a consultation report detailing the NRA's approach to water conservation and demand management.

'Saving Water' essentially comprises an analysis of demand management issues, an examination of the need to implement demand management measures, and the exposition of a series of demand management initiatives. It is based on the principle that water is a precious and finite resource and needs to be treated and managed as such, and suggests that this has not previously been the case in the U.K.

2.2 Principal Demand Management Initiatives

In 'Saving Water', several routes to reducing demand are identified. These are as follows:

- *Leakage control* - this has been a low priority within the water industry in the past and is an area in which there is perceived to be considerable scope for reducing water into supply at relatively low cost.

- *Selective Domestic Metering* - this is considered to be an important demand management option, with a range of trials indicating that wide scale metering would lead to significant reductions in average and peak demands.

- *Water Saving Technology* - the use of such technology has created significant savings in industry and there is the potential for the increased use of water efficient appliances in the home to have a similar effect on household consumption.

- *National Co-ordination, Research & Development and Education* - these comprise three different "priority programmes" , but all are directed at increasing education of consumers in the need to conserve and carefully manage water resources. The aim is also to inform consumers of the means through which this can be achieved, including the need to change habits as well as technology.

2.3 Research Programme for Demand Management

Whilst the principles underlying demand management are being increasingly acknowledged, there is still significant debate concerning the extent to which such measures should be employed, their cost implications, and the significance of the benefits that can be realised through such measures i.e. the debate essentially concerns the likely costs (financial and other) and the potential benefits. For this reason it is recognised within the EA that there needs to be both clear understanding and clear communication of these issues, and this has prompted the initiation and sponsorship of an extensive integrated research programme. The EA sponsored programme includes the following projects:

- *Water Consumption and Conservation in Buildings*
- *Effective Methods of Water Saving Education*
- *Water Saving in Industries Dependent on Direct Abstraction*
- *Abstraction Incentive Charging*
- *Autonomous Technologies*
- *Economics of Demand Management*

This research project forms part of this overall programme and is essentially aimed at obtaining a greater understanding of the potential hydrological effects of demand management. Whilst it will avoid any detailed analysis of the cost implications of the demand reductions examined, the results may be used by the EA/UKWIR project team for this purpose as part of their study on the economics of demand management.

3.0 APPROACH TO PROJECT DEFINITION STAGE

3.1 NRA Input

A "Project Start-up" meeting was held with the NRA on 31 October 1995, and further progress meetings were held on 5 December 1995 and 6 February 1996. NRA input and review was provided from Anglian Region (David Evans - Water Resources Planning Manager) and from the NRA's Demand Management Centre (David Howarth).

3.2 General Principles

At the initial project meeting several principles were agreed which, in conjunction with the brief, have provided a framework within which the nature and direction of the study have been developed. These are as follows:

- Due to the number and potential complexity of the issues involved, a clear focus on the primary objectives of the project needs to be maintained in order to ensure that the final outputs are relevant and useful.

- The project is a regional rather than national research initiative and will concentrate primarily on particular concerns within Anglian Region. However, comment from a national perspective will be included where appropriate.

- The scope of the project relates to the "hydrological" effects of demand management (e.g. changes in river flows or groundwater levels). It does not extend to assessments of the environmental significance of these effects, or to the economics involved. Within the context of this report, therefore, the "effects" of demand management implies hydrological effects unless otherwise specified.

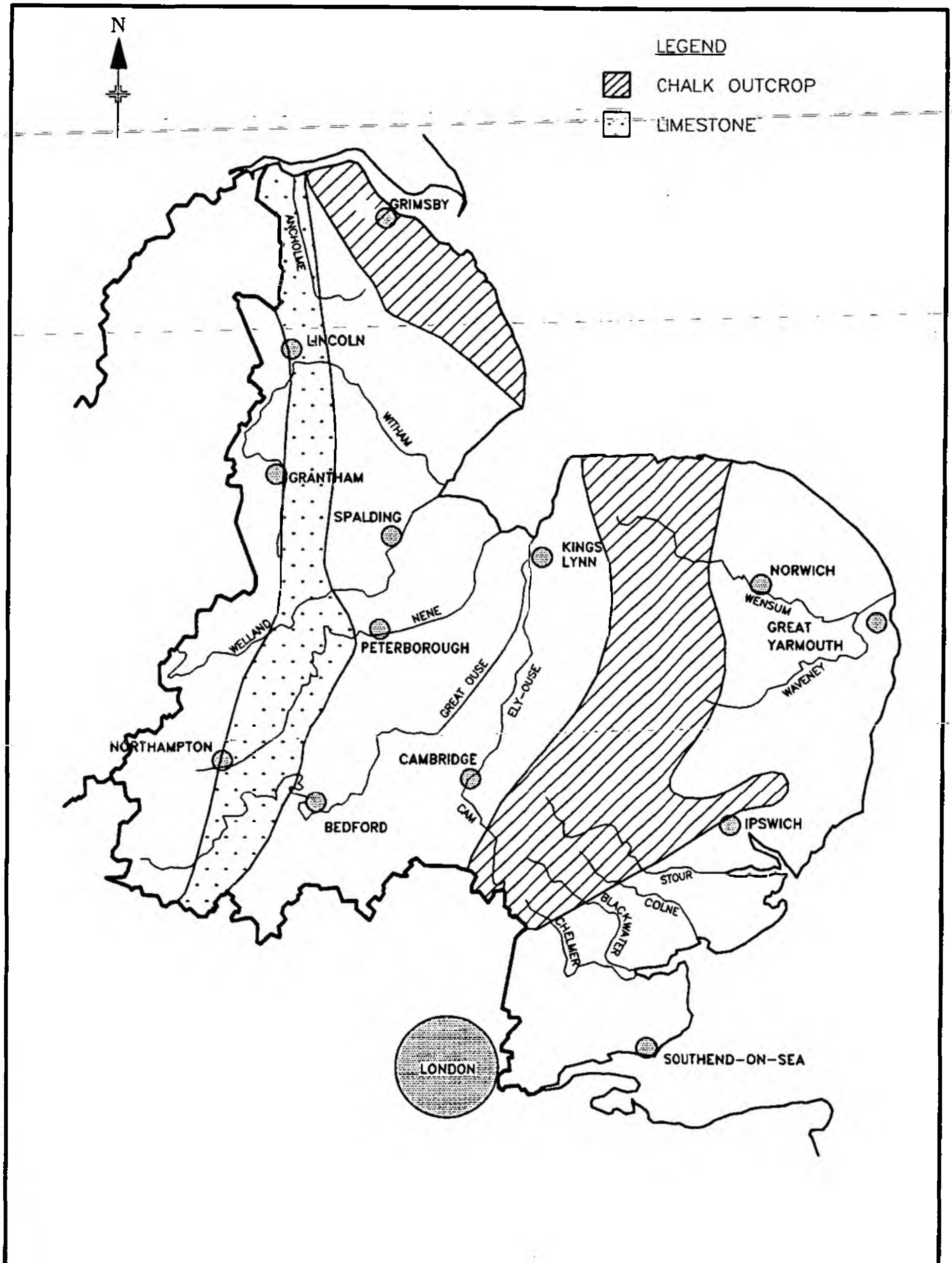
3.3 Scope for the Study of Demand Management in Anglian Region

The boundary of Anglian Region, and the main rivers, towns and aquifers are shown on Figure 1. The Water Resources Strategy document issued by NRA Anglian in 1994 concludes that there is generally limited scope for restricting water use through demand management, since in such a dry region much has already been done to limit water use. This view was reflected in the initial project discussions with the NRA, and several factors were identified which have served to direct the scope of the study within the Anglian Region. These are as follows:

- There is limited scope for considering the effects of demand management on spray irrigation, since many of the existing licences are already under-utilised.

- The use of irrigation "slackers" in the fens is difficult to control or quantify and the NRA indicated that it would be best to exclude this from the study.

- Industrial demand is of only limited significance in Anglian Region, and has generally fallen due to increasing use of waste minimisation techniques, a



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NRA ANGLIAN REGION

Figure 1

01/03/96 - 13:50---SG File-G:\AK194B\194B-A tendency toward light industries and the impact of recession.

3.4 Agreement of Approach

On the basis of the above, and the original Project Brief, it was agreed that the primary focus of the study would be the hydrology of urban water use and the potential effects of demand management on the abstractions and subsequent return of water. Although this would initially focus on the four urban schematics provided in the Brief (Bedford, Northampton, Cambridge and Southend), with each being developed using real data, the scope would then be widened to examine other combinations of abstraction and return.

Having established this initial focus for the project, efforts were directed toward identifying the nature and availability of information required, and developing a framework within which this information could be assessed, prioritised and utilised. This process is described in the sections below.

3.5 Review of Relevant Information

The following sources were targeted:

- NRA
  - NRA Anglian Water Resources Strategy
  - Catchment Management Plans
  - Guidelines (e.g. irrigation)
  - Demand Management Studies (e.g. 'Saving Water')
- Water Companies
  - Meetings with Essex & Suffolk Water and Cambridge Water concerning available data for the Southend and Cambridge supply zones. Both Companies expressed their willingness to co-operate and have since provided a range of useful information.
  - Discussions with Anglian Water concerning the Bedford and Northampton supply zones. To date, Anglian Water have had difficulty identifying a suitable supply zone with sufficiently discrete inflows and outflows, but it is hoped that such an area can be found as the project progresses.
  - Anglian Water's ongoing "Study of Domestic Consumption" (SODCON) will form the basis of a review of consumptive and non-consumptive domestic use.
- General
  - literature search of existing studies on household consumptive use (yielded very little)

- literature search for studies of leakage from distribution systems

- literature search for studies on water uptake by vegetation in urban areas, particularly water use by trees (yielded only very limited information)

- discussions with Forestry Commission regarding water uptake by trees in urban areas

3.6 Development of a Conceptual Model

The two stage structure of the project reflects uncertainty regarding the nature and feasibility of developing an effective methodology for assessing the impacts of demand management on the hydrology of urban water supply and returns. This is due in part to the range, variability and interdependence of the factors controlling the urban water cycle, and in part to doubts as to whether meaningful data can be obtained and/or generated (i.e. there are significant "unknowns").

In view of the above, the main efforts in the Project Definition Stage have been directed at the development of a methodology which is simple enough to be viable but of sufficient complexity to be meaningful.

The approach taken is based on the development of a conceptual model which will be used to identify the key processes and factors involved in the urban water cycle without the need, at least initially, for extensive data. The key processes and factors will be identified through an iterative process of sensitivity testing.

As part of the development and assessment of the model, which is a hypothetical water balance model, the following key tasks were established:

- Identify the principal factors influencing the magnitude of consumptive losses in the system and establish realistic ranges for such losses.

- Identify the principal factors influencing the nature and magnitude of the returns of distribution losses within the system.

- Develop the four specific schematics included in the original project. Where possible, this should use real data provided by Anglian, Cambridge and Essex Water Companies.

- Undertake an initial range of sensitivity analyses to identify the elements of the conceptual model which have the most significant effect on abstraction volumes, effluent returns or river flows.

- Test a range of hypotheses using the conceptual model in order to determine the potential hydrological effects of demand management, and the key factors which control the significance of those effects.

The intention has not necessarily been to complete each of the above tasks, but to extend each to a level at which the viability and validity of extending and developing the model to test the hypotheses defined in Section 3.7 can be assessed. On this basis, the nature, extent and relative priority of additional work required can be established.

3.7 Definition of Hypotheses

The five hypotheses below have been defined as part of the project, and cover a range of issues which have been the subject of debate both within and outside the NRA, but have yet to be the subject of systematic analysis. The intention is to use the water balance model and other available data to undertake such an analysis, and to test the validity of each hypothesis using a quantitative approach wherever possible.

The aim of the hypothesis testing is not to produce simple 'yes'/'no' answers, but rather to establish the circumstances in which each hypothesis is true or false, the extent to which it is true or false, and the principal factors which affect this assessment. By this means the hypotheses will provide a structured mechanism for questioning the output from the water balance model.

The hypotheses are as follows:

H1: *Demand management will increase river flows at times of average and peak demand.*

H2: *The effect of demand management on river flows will depend on the location of the original abstraction and the effluent return.*

H3: *Demand management will provide a saving of groundwater resources at times of average and peak demand.*

H4: *Demand management will have a greater effect on groundwater resources than on river flows.*

H5: *Reducing leakage will have a greater hydrological impact than reducing domestic demand.*

4.0 HYDROLOGY OF URBAN WATER USE

4.1 Urban Water Use and Return Examples

Four urban water use and return examples were included within the Project Brief as follows (Appendix A):

1) Inland river abstraction and inland return downstream (e.g. Bedford).

2) Inland river abstraction and inland return upstream (e.g. Northampton).

3) Tidal limit abstraction and tidal limit return (e.g. Southend).

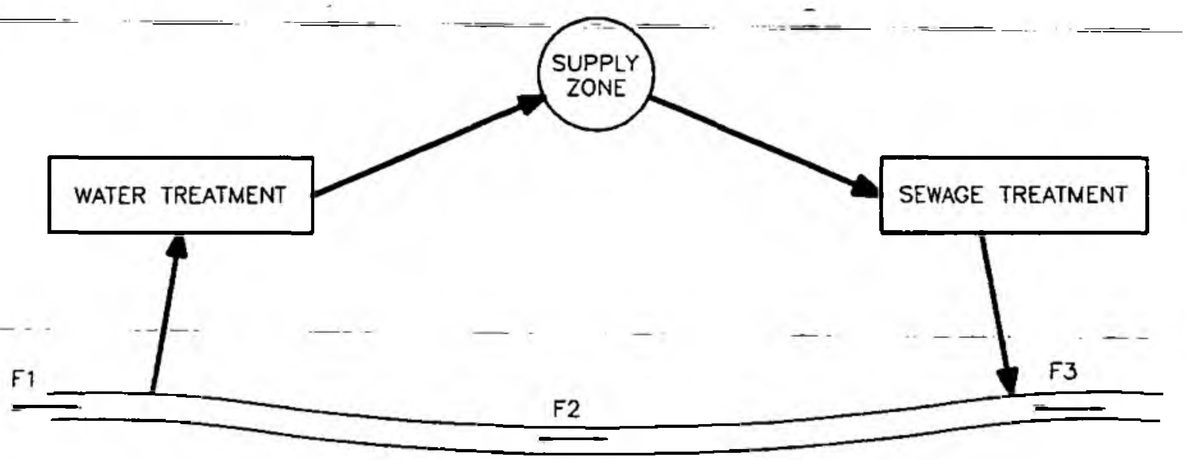
4) Groundwater abstraction and inland return (e.g. Cambridge)

In addition to the above there will also be other urban use and return examples. NRA Anglian requested that WS Atkins should identify other cases including those which may not be applicable to the Anglian Region. A total of nine examples have been identified for consideration, as listed in Table 1 and illustrated by Figure 2A/2B/2C. At this stage of the study only single catchment systems have been considered, without water transfers from other river or groundwater systems, as this would significantly increase the complexity and number of examples. However, it is intended that catchment transfers will be considered at a later stage.

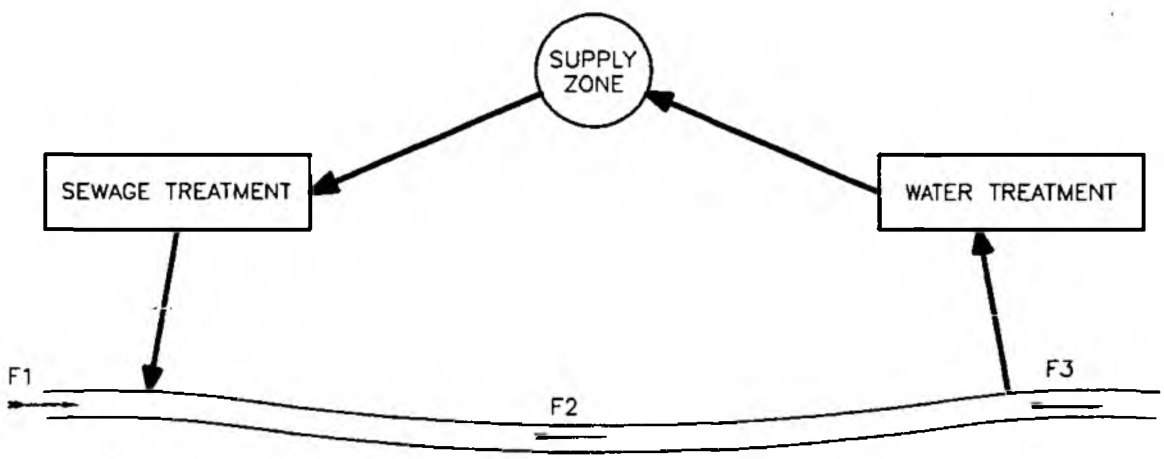
Table 1: Principal Combinations of Water Sources and Effluent Return

Example	Water Source	Effluent Return
1	Inland River	Inland River Downstream of Abstraction (eg Bedford)
2	Inland River	Inland River Upstream of Abstraction (eg Northampton)
3	River at Tidal Limit	River at Tidal Limit or Sea Outfall (eg Southend)
4	Groundwater	Inland River Downstream of Abstraction (eg Cambridge)
5	Groundwater	Inland River Upstream of Abstraction
6	Groundwater	River at Tidal Limit or Sea Outfall
7	Inland River	River at Tidal Limit
8	River at Tidal Limit	Inland River
9	Onstream Reservoir	Inland River

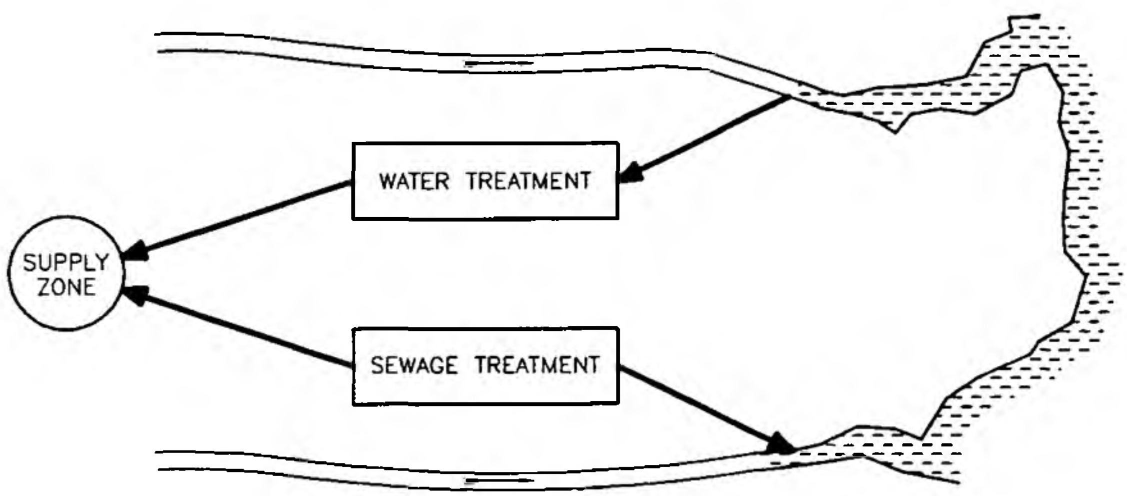
1. INLAND ABSTRACTION AND INLAND RETURN DOWNSTREAM



2. INLAND ABSTRACTION AND INLAND RETURN UPSTREAM



3. TIDAL LIMIT ABSTRACTION AND TIDAL RETURN



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HYDROLOGICAL CYCLE OF URBAN USE AND RETURN ABSTRACTION AND EFFLUENT RETURN EXAMPLES

Figure 2A

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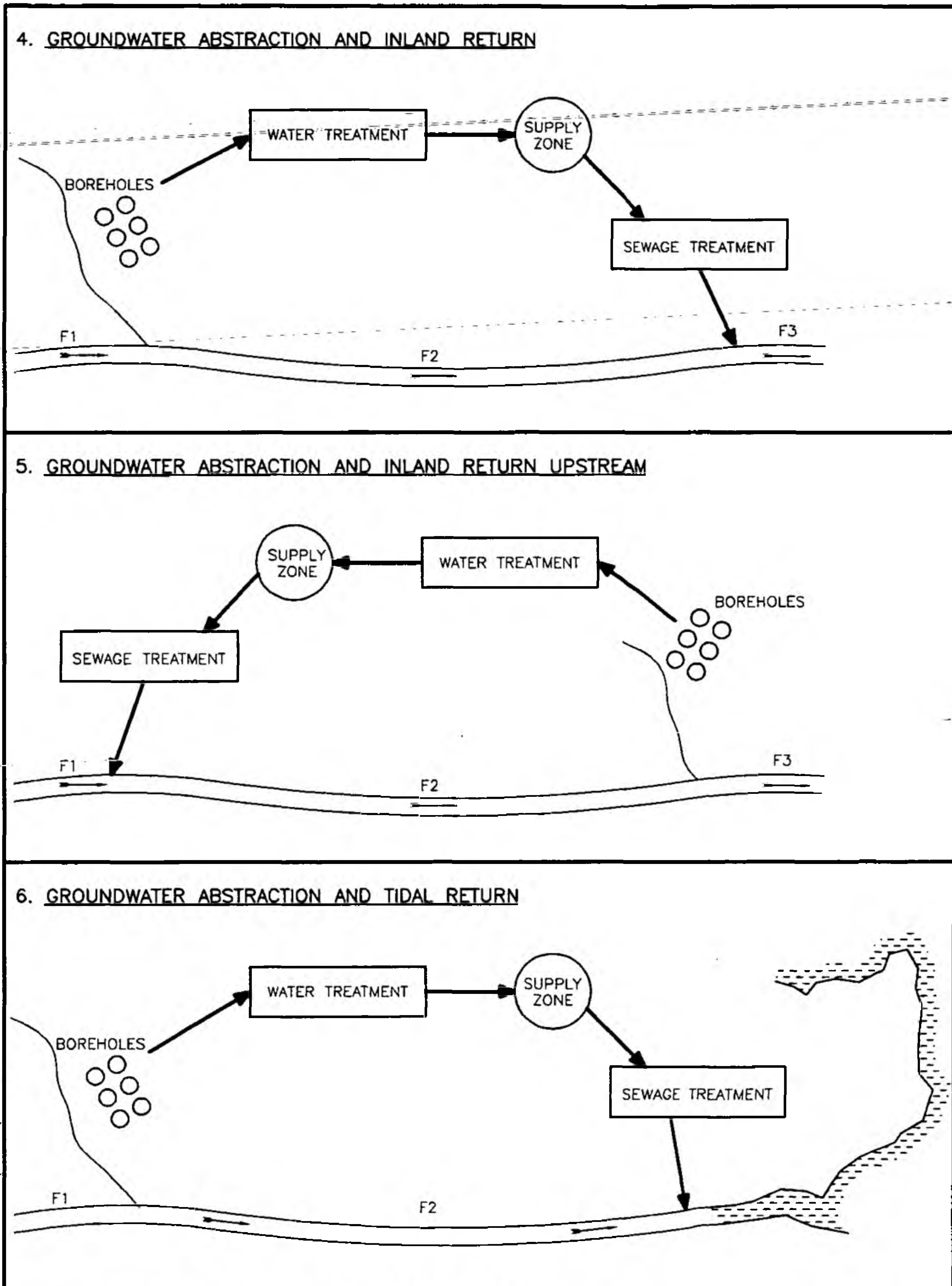

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HYDROLOGICAL CYCLE OF URBAN USE AND RETURN
ABSTRACTION AND EFFLUENT RETURN EXAMPLES

Figure 2B

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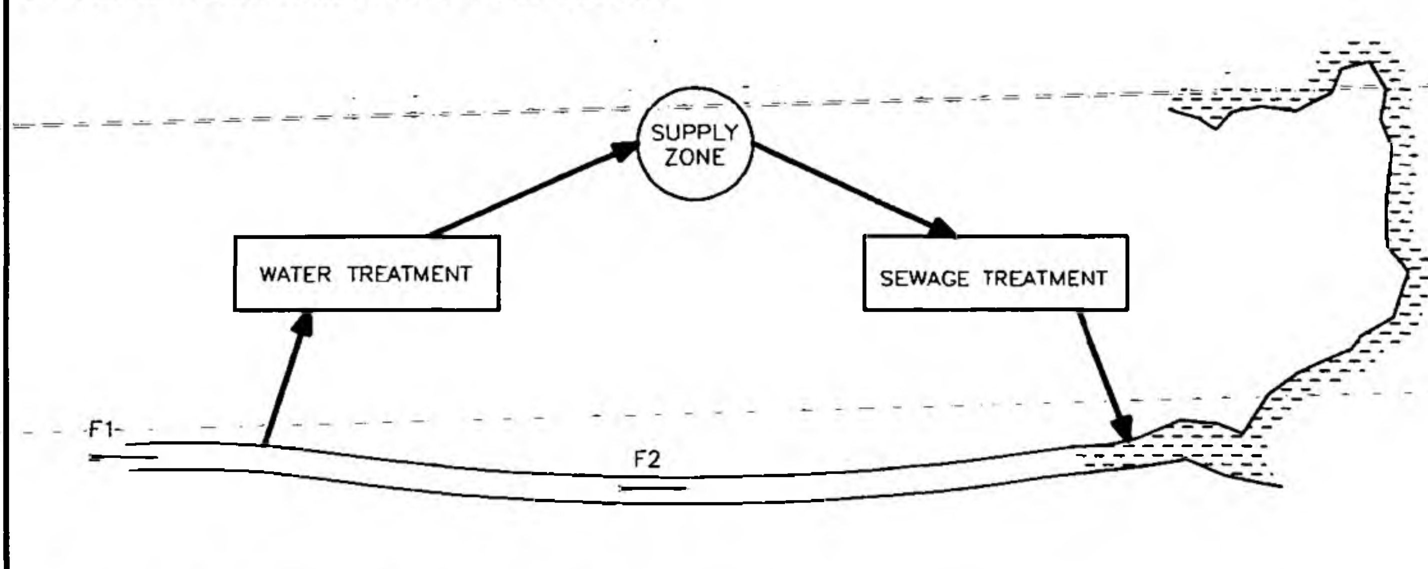
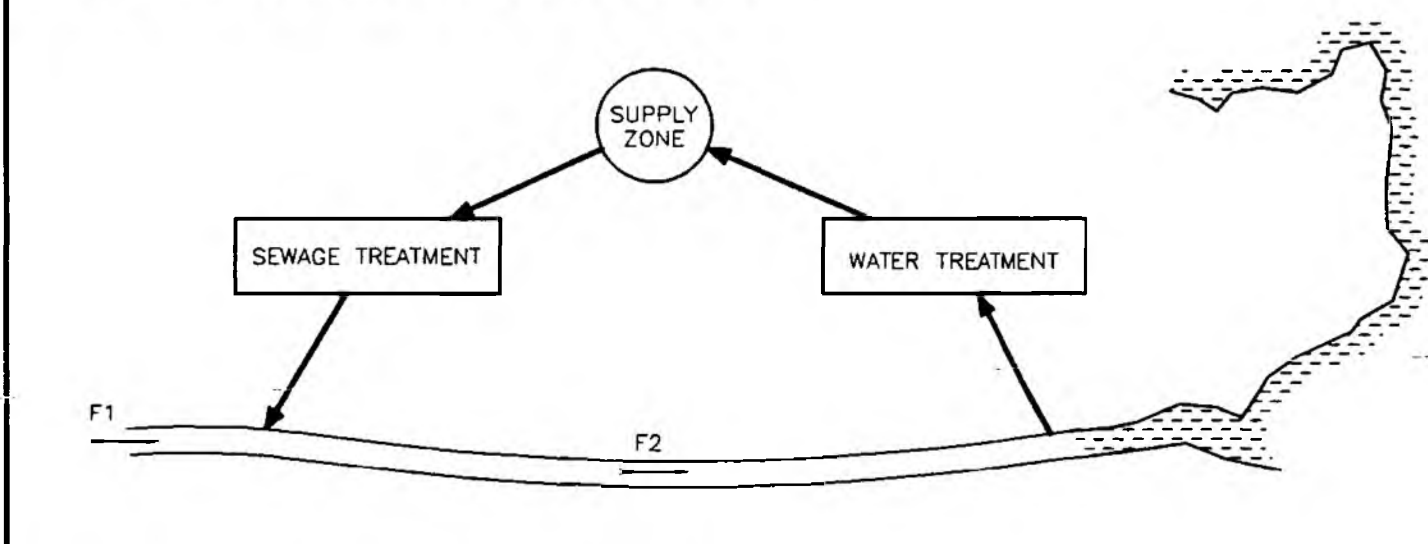
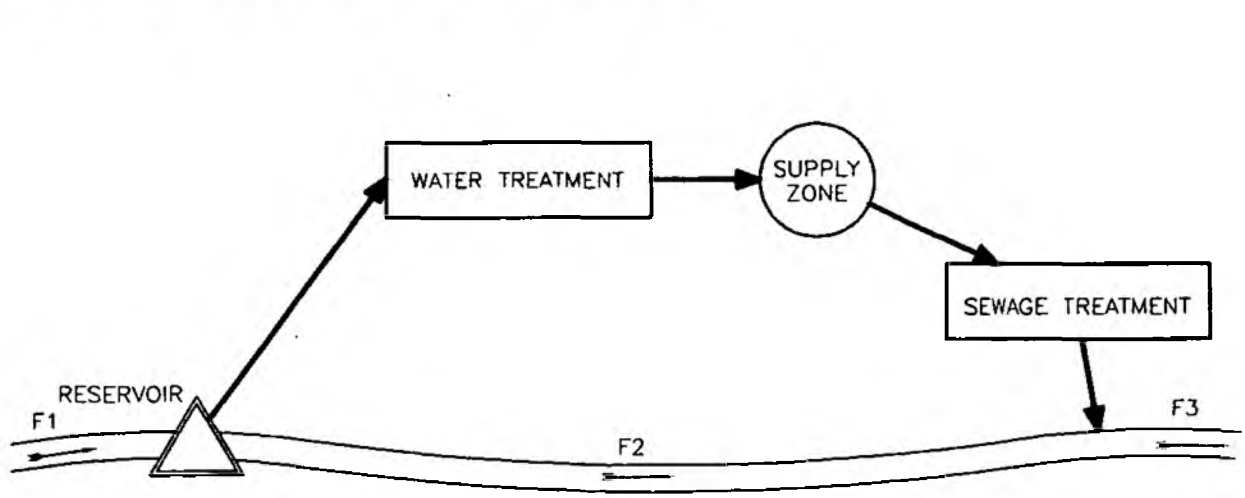
7. INLAND ABSTRACTION AND TIDAL RETURN



8. TIDAL LIMIT ABSTRACTION AND INLAND RETURN



9. ONSTREAM RESERVOIR AND INLAND RETURN



WS/Atkins	HYDROLOGICAL CYCLE OF URBAN USE AND RETURN ABSTRACTION AND EFFLUENT RETURN EXAMPLES	Figure 2C

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4.2 General Schematic

The urban use and return examples included in Table 1 have been used to produce a general schematic showing the identified water sources and effluent returns (Figure 3). The schematic also illustrates the various components of consumptive use and leakage. Each element of the schematic is summarised as follows:

Water Sources (S)

The water sources include direct surface water abstraction from rivers, groundwater abstraction, and reservoir storage.

- Surface Water
  - Upstream of Effluent Return (SRU)
  - Downstream of Effluent return (SRD)
  - Tidal Limit (SRL)
- Groundwater
  - Upstream of Effluent Return (SGU)
  - Downstream of Effluent return (SGD)
  - Tidal Limit (SGL)
- Reservoir Storage
  - Upstream of Effluent Return (SSU)
  - Downstream of Effluent return (SSD)
  - Tidal Limit (SSL)

Consumptive Use (C)

Consumptive use is defined in 'Saving Water' as " use of water that is not returned either directly to an aquifer or to a river via a sewage works'. This is generally where water is lost through evaporation, transpiration and process losses such as sludge disposal. The consumptive uses included in the schematic are as follows:

- Water Treatment (CWT) i.e. evaporation and process losses
- Household (CH) i.e. evaporation and transpiration losses
- Non-household (CNH) i.e. evaporation and process losses
- Sewage Treatment (CST) i.e. evaporation and process losses
- Leakage (CL) i.e. evaporation and transpiration losses

Leakage (L)

Leakage occurs from the supply pipe network, from trunk mains and distribution pipework, and also from the sewerage system. There may also be some leakage from

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HYDROLOGICAL CYCLE OF URBAN USE AND RETURN SCHEMATIC OF ABSTRACTION AND EFFLUENT RETURN

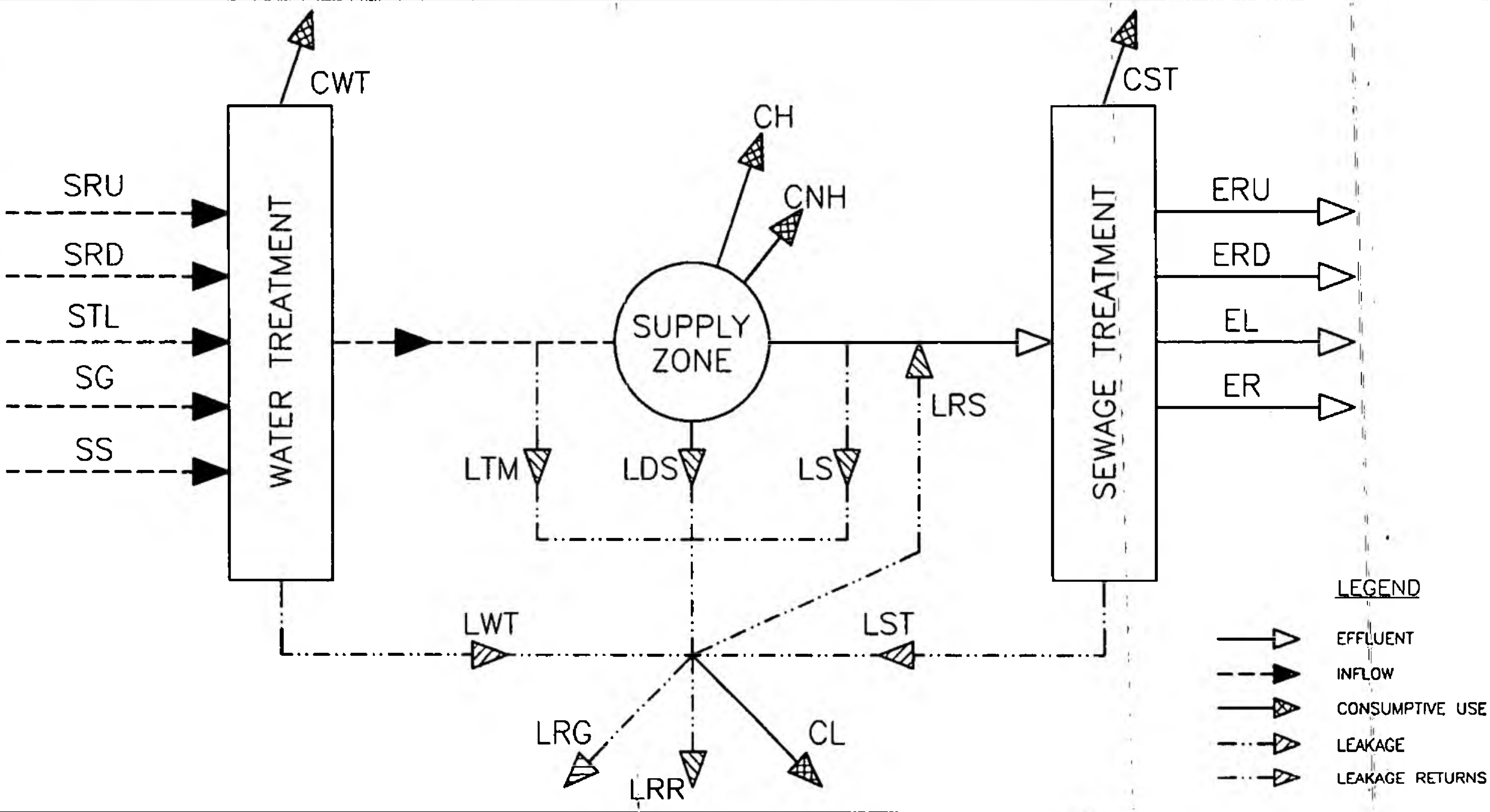


Figure 3

WATER SOURCE (S)

SRU – SURFACE WATER ABSTRACTION SOURCE UPSTREAM OF EFFLUENT RETURN

SRD – SURFACE WATER ABSTRACTION SOURCE DOWNSTREAM OF EFFLUENT RETURN

STL – TIDAL LIMIT SURFACE WATER ABSTRACTION SOURCE

SG – GROUNDWATER SOURCE

SS – RESERVOIR STORAGE

EFFLUENT RETURN (F)

ERU – EFFLUENT RETURN UPSTREAM OF SURFACE WATER ABSTRACTION

ERD – EFFLUENT RETURN DOWNSTREAM OF SURFACE WATER ABSTRACTION

EL – EFFLUENT DISCHARGE TO TIDAL LIMIT OR SEA

ER – EFFLUENT RETURN TO RIVER (RIVER NOT USED FOR ABSTRACTION)

CONSUMPTIVE USE (C)

CWT – WATER TREATMENT CONSUMPTIVE USE

CH – DOMESTIC DEMAND CONSUMPTIVE USE

CNH – COMMERCIAL DEMAND CONSUMPTIVE USE

CL – CONSUMPTIVE USE OF TOTAL LEAKAGE

CST – SEWAGE TREATMENT CONSUMPTIVE USE

LEAKAGE (L)

LWT – LEAKAGE FROM RAW WATER STORAGE AND WATER TREATMENT WORKS

LTM – TRUNK MAINS LEAKAGE

LDS – DISTRIBUTION SYSTEM LEAKAGE

LS – SEWERAGE LEAKAGE

LST – SEWAGE TREATMENT WORKS LEAKAGE

LEAKAGE RETURNS (LR)

LRG – LEAKAGE RETURN TO GROUNDWATER

LRR – LEAKAGE RETURN TO RIVER

LRS – LEAKAGE INFILTRATION TO SEWERAGE

water and sewage treatment works. The various components of total leakage included in the schematic are as follows:

- Water Treatment Works (LWT)
- Trunk Mains (LTM)
- Distribution System (including customer supply pipes) (LDS)
- Sewers (LS)
- Sewage Treatment Works (LST)

Leakage Returns (LR)

Leakage which is not lost through consumptive use is returned to the system by means of infiltration to sewers, migration to surface water streams and rivers, or infiltration to groundwater. The leakage returns shown by the schematic are as follows:

- Infiltration to Sewers (LRS)
- Leakage Returns to Groundwater (LRG)
- Leakage Returns to River (LRR)

Effluent Returns (E)

Effluent from sewage treatment works is returned either to rivers, inland or to the tidal limit, or to the sea. The various return cases included in the schematic are as follows:

- Upstream of Surface Water Abstraction (ERU)
- Downstream of Surface Water Abstraction (ERD)
- Tidal Limit or Sea (EL)
- Other Inland River (ER)

5.0 DEVELOPMENT OF WATER BALANCE MODEL

5.1 Water Balance Examples

A water balance spreadsheet model (Lotus 1-2-3 Release 5) has been developed for the hydrological urban use and return cycle in order to assess the effects of various demand management options and the sensitivity of the model towards various parameters. Models have been constructed for the first four examples listed in Table 1, which correspond with the four examples in the Project Brief. Although at this stage the models have been based on hypothetical data, it is envisaged that real data will be used when the model has been developed further. Models for the remaining five examples in Table 1 will also be constructed during the Full Report stage.

5.2 Model Construction

Each of the identified elements of the urban use and return cycle illustrated in Figure 3 and described in Section 4.2 have been included within the water balance model.

At this stage, for comparative purposes, abstraction rates have been assumed to be 50% of river flows for each selected example. The proportion of abstraction to river flow will of course be varied as the model is developed, and the effect of reducing surface abstraction to 25% of river flow has been considered as part of the initial sensitivity testing.

Several assumptions have been made during the construction of the model for the level of consumptive-use, leakage levels, and household and non-household demands, and these are explained in the sections below.

5.3 Consumptive Use

Water Treatment (CWT) - Consumptive use at water treatment works will be due to evaporation and sludge disposal. For the UK, evaporation rates of 2mm/day are typical and this value has been incorporated into the spreadsheet model with a conservative assumed surface water area of $10,000m^2$. As expected the model illustrates that evaporation losses at treatment works are insignificant in terms of total flow. The amount of water lost through sludge disposal is dependent on the type of sludge process adopted but this is unlikely to exceed 1% of inflow to the works.

Non-household Use (CNH) - Consumptive use of non-household demand is very dependent on the type of process used. Evaporation losses are likely to be quite high for heavy industry such as power generation but low for a lighter industry. An assumed value of 10% has been adopted for the spreadsheet model at this stage of the study.

Household Use (CH) - Consumptive use of household demand is due to evaporation losses resulting from internal use such as cooking and washing, and external use such as car washing and garden watering. Garden watering will also result in transpiration losses. In order to try to quantify household consumptive use a spreadsheet has been developed based on the component data available from the Anglian Water "Study of Domestic Consumption" (SODCON). Two scenarios have been assumed, an average demand case with low garden watering, and a peak demand case with high garden watering. For the average demand case the consumptive use was estimated to be in the order of 5%. This increased to around 15% for the peak demand case due to increased evaporation and transpiration losses resulting from increased garden watering. The spreadsheet output is included in Appendix B.

An assumed household consumptive use figure of 10% has been used for the water balance model at this stage of the study. A figure of 5% has also been considered as part of the initial sensitivity testing exercise (see Table 4).

Sewage Treatment (CST) - Consumptive use at sewage treatment works will be due to evaporation and process losses. As with water treatment works evaporation losses are insignificant. Water lost through sludge disposal is again dependent upon the type of process involved but is unlikely to exceed 2% of inflow to the works.

Leakage (CL) - This term essentially covers uptake by urban vegetation of water derived from leakage. On the basis of a review of available literature, and discussions with the Forestry Commission Research Station at Alice Holt in Hampshire, it appears that CL is likely to be minimal but there are no data available to substantiate this. Although this will be reviewed further as part of the second stage of the report, a fixed value of 10% has been used in each of the modelled examples to date. As part of the same review and discussions, it has also become apparent that in only a few exceptional circumstances, particularly in urban areas, will reductions in leakage cause significant water stress to trees. In view of this, the potential for reductions in leakage to cause water stress to trees will not be investigated any further in stage two.

5.4 Leakage

Total Losses

For the purposes of the water balance model the term 'total losses' includes all leakage from the supply pipework network including trunk mains leakage, distribution pipework leakage and leakage from customers supply pipes. Leakage varies depending principally upon the supply pressures, age and type of pipe materials, topography and the leakage control policies of individual Water Companies. For the water balance model, total losses have been assumed as 25% of average demand at this stage of the study.

Sewage Leakage (LST) - Less robust data are available concerning leakage from sewers. This is dependent on the age and type of pipe material, the ground conditions and depth to the water table. At this stage of the study a leakage level of 5% of sewage flows has been assumed for the water balance model. Further work to establish a realistic range of sewage losses will be carried out during the Full Report Stage.

Water Treatment and Sewage Treatment Works Leakage - An estimate of 1% of inflow has been assumed for leakage from water treatment and sewage works.

5.5 Leakage Returns

Infiltration of supply system leakage to sewers (LRS) - The rate of infiltration to sewers from supply system leakage is dependent on many factors including the condition of the sewerage pipework system, the proximity of leakage from water mains, and the permeability of the soil. At this stage of the study an infiltration rate of 10% of supply system leakage has been assumed for the water balance model. Further work to establish a realistic range for this leakage component will be carried out during the Full Report Stage.

Leakage Returns to Groundwater (LRG) and Rivers (LRR) - Leakage which is not accounted for through consumptive use (evaporation and transpiration), or returned to the sewage treatment works via infiltration to the sewerage network, is either returned to groundwater or to surface water streams and rivers (*via* interflow, land drains or surface water drains which discharge direct to surface water courses). In some circumstances, leakage will be returned to the sea.

The distribution of leakage returns to groundwater and surface water is dependent upon local geology. In areas with strata of low permeability, most leakage would be expected to migrate to local streams and watercourses and hence ultimately return to the river environment. Conversely, in areas with permeable strata, the majority of leakage which is not lost through consumptive use or returned to sewage treatment works would be expected to infiltrate to groundwater storage. This may ultimately return to the river further downstream as baseflow outside the urban supply zone under consideration.

At this stage, the model has assumed impermeable geology with all leakage, excluding consumptive use and infiltration to sewers, returning to surface water sources without any return to groundwater. Initial sensitivity analyses have also been undertaken where 50% of available leakage was assumed to return to groundwater, and 50% to surface water sources.

5.6 Household and Non-household Demand

The proportion of household and non-household demand varies depending on the individual supply area considered. For the water balance model at this stage, a typical distribution has been assumed in which household demand accounts for 70% of water delivered, excluding supply system leakage. Non-household demand accounts for the remaining 30%.

5.7 Demand Management Options

In order to assess the hydrological effects of demand management on river flows and groundwater abstraction the following scenarios were applied to the water balance model.

Reduced household demand through domestic metering

Reductions in average household demand of 5%, 10% and 15% have been assumed for metered properties. The model assumes a meter penetration figure for households of 70%.

However, although the water balance model assumes that reduced household demand is due to domestic metering, it is acknowledged that the adoption of water saving technology, and/or education of customers to use water more wisely, may result in reduced household demand without metering.

Reduced Supply System Leakage

Reductions in leakage from 25% of average demand to 20%, 15%, and 10% have been considered.

6.0 SUMMARY OF DATA REVIEW AND INITIAL MODEL RUNS

This section summarises the initial conclusions to date, resulting from the data review, model construction and preliminary analyses undertaken during the Project Definition Stage. It is important to understand that the data upon which these conclusions have been based have yet to be the subject of any rigorous sensitivity analysis.

6.1 Data Review and Model Construction

Appendix C contains model output, and summaries of key variables are provided in Table 2. The initial conclusions are presented below:

- Reductions in household demand and leakage both have the potential to significantly reduce abstraction rates and consumptive use.

- The effects of demand management on abstraction rates, consumptive use and the magnitude of effluent returns are independent of the abstraction and return combination.

The effects of the demand management scenarios on river flows are summarised by Table 3 for the flow and return examples 1 and 2. Initial conclusions are as follows:

- The demand management scenarios have only a limited effect on river flows downstream of the urban use and return cycle.

- Demand management has a more significant effect on the river flows between the point of abstraction and effluent return.

6.2 Recommendations

Conclusions arising from the data review and model construction process have been summarised and are presented as recommendations for inclusion in the Full Report Stage: The approach to the Full Report Stage is detailed in Chapter 7.

- The study will primarily focus on the hydrology of urban water use and return. This is considered to be the most effective means of assessing the hydrological effects of demand management on a sufficiently localised scale.

- The model will initially be used to represent hypothetical water balances for various urban supply zones and to identify the relative importance of the various factors which affect the water balance.

- The primary purpose of the model is to establish principles and, where possible, quantify the impact of key factors (e.g. leakage levels, geology, reduced domestic demand) rather than to accurately model actual urban supply zones. However, where feasible, attempts will be made to apply the model to specific zones using data obtained from the Water Companies.

- It appears at this stage that there are very little field data upon which to substantiate a value or range of values for the consumptive use of leakage. Sensitivity testing of the model will be used to establish its potential significance, and the results of this process will determine the extent to which the subject is pursued in the Full Report Stage.

- Apart from the hydrological effects, one of the original aspects of the study was to investigate the possibility that leakage reduction in urban areas might cause significant water stress to trees which had become reliant on leakage for their water supply. Discussions with the Forestry Commission have indicated that in only a few exceptional circumstances might trees be reliant on leakage and that in the majority of these cases the rooting systems would almost certainly adapt in order to tap other sources of supply. It is also clear that there is no basis upon which to identify these situations in advance. No further research will be undertaken into this subject within the context of this project.

6.3 Initial Sensitivity Analysis

The initial sensitivity analysis simply comprised examining the effect of modifying three of the model components in turn for Example 2 (Inland Abstraction & Inland Return Upstream). The modifications were to the surface water abstraction (reduced from 50% to 25% of upstream river flow), domestic consumptive use (reduced from 10% to 5%) and leakage returns to the river (reduced from 100% to 50%). The water balance outputs are presented in Appendix D and a summary of the results is shown in Table 4.

Table 2 - Summary of Water Balance Results for Urban use and Return Examples 1 to 4. Abstraction, Effluent Returns and Consumptive Use.

	Demand Management Option						
	Initial Value	Reduction in Household Demand for metered properties			Total Distribution Leakage		
		5%	10%	15%	20%	15%	10%
Abstraction (Units of flow)	50.00	49.10	48.20	47.30	47.60	45.10	42.70
Effluent Return (Units of flow)	31.60	30.90	30.20	29.40	31.40	31.20	31.00
Total Consumptive Use (Units of flow)	6.20	6.10	6.00	5.90	6.00	5.70	5.50

Table 3 - Summary of Water Balance Results for Urban use and Return Examples 1 to 2. Effects on River Flows.

	Demand Management Option						
	Initial Value	*Reduction in Household Demand for metered properties*			*Total Distribution Leakage*		
		5%	*10%*	*15%*	*20%*	*15%*	*10%*
Example 1 - Inland Abstraction and Inland Return Downstream (Units of flow)							
River Flow Upstream of Abstraction	100.00	100.00	100.00	100.00	100.00	100.00	100.00
River Flow Downstream of Abstraction	50.00	50.90	51.80	52.70	52.40	54.90	57.30
River Flow Downstream of Effluent Return	93.80	93.90	94.00	94.10	94.00	94.30	94.50
Example 2 - Inland Abstraction and Inland Return Upstream (Units of flow)							
River Flow Upstream of Effluent Return	100.00	100.00	100.00	100.00	100.00	100.00	100.00
River Flow Downstream of Effluent Return	143.80	143.00	142.20	141.40	141.60	139.40	137.20
River Flow Downstream of Abstraction	93.80	93.90	94.00	94.10	94.00	94.30	94.50

Table 4 - Summary of Water Balance Sensitivity Analysis Results for Urban use and Return Example 2.

	Demand Management Option						
	Initial Value	*Reduction in Household Demand for metered properties*			*Total Distribution Leakage*		
		5%	*10%*	*15%*	*20%*	*15%*	*10%*
a) Reduced Surface Water Abstraction (Units of flow)							
Abstraction	25.00	24.60	24.10	23.70	23.80	22.60	21.30
Effluent Return	15.80	15.40	15.10	14.70	15.70	15.60	15.50
Total Consumptive Use	3.10	3.10	3.00	3.00	3.00	2.90	2.80
River Flow Upstream of Effluent Return	100.00	100.00	100.00	100.00	100.00	100.00	100.00
River Flow Downstream of Effluent Return	121.90	121.50	121.10	120.70	120.80	119.70	118.60
River Flow Downstream of Abstraction	96.90	96.90	97.00	97.00	97.00	97.10	97.20
b) Reduced Domestic Consumptive Use (Units of flow)							
Abstraction	50.00	49.10	48.20	47.30	47.60	45.10	42.70
Effluent Return	32.80	32.00	31.30	30.50	32.60	32.40	32.20
Total Consumptive Use	5.00	4.90	4.80	4.80	4.70	4.50	4.20
River Flow Upstream of Effluent Return	100.00	100.00	100.00	100.00	100.00	100.00	100.00
River Flow Downstream of Effluent Return	145.00	144.20	143.40	142.50	142.80	140.60	138.40
River Flow Downstream of Abstraction	95.00	95.10	95.20	95.20	95.30	95.50	95.80
c) Reduced Leakage Returns to River (Units of flow)							
Abstraction	50.00	49.10	48.20	47.30	47.60	45.10	42.70
Effluent Return	31.60	30.90	30.20	29.40	31.40	31.20	31.00
Total Consumptive Use	6.20	6.10	6.00	5.90	6.00	5.70	5.50
River Flow Upstream of Effluent Return	100.00	100.00	100.00	100.00	100.00	100.00	100.00
River Flow Downstream of Effluent Return	137.70	136.90	136.20	135.40	136.50	135.30	134.10
River Flow Downstream of Abstraction	87.70	87.80	88.00	88.10	88.90	90.20	91.50

7.0 METHODOLOGY FOR FULL REPORT STAGE

The proposed methodology for the Full Report Stage will comprise five steps which are detailed below.

Step 1: Extend conceptual model to all nine hypothetical schematics

The first step will be to produce base spreadsheet models for the nine combinations of abstractions and effluent returns defined in Section 4.1.

Step 2: Hypothesis Testing

This step will constitute the majority of the analytical and assessment work, with the model being used to address hypotheses H1 - H5 defined in Section 3.7. The aim will be:

- to identify the nature and magnitude of potential hydrological effects
- to describe the circumstances in which such effects will occur (e.g. seasonal effects, geology, different combinations of abstraction and returns)
- to establish the relative impact of different forms of demand management

The scope of this work will comprise a combination of sensitivity testing and probabilistic assessment as explained below.

Sensitivity Testing

This is effectively an iterative process through which the range of factors governing the model will be varied in turn in order to establish their relative importance in terms of their effect on the key outputs from the model. This process will be undertaken for each of the nine combinations of abstraction and effluent return.

The main factors to be examined will be as follows:

a) Ratio of current abstraction volumes to current river flows upstream of abstraction

b) Partition of leakage returns between groundwater and surface water

c) Household demand as a proportion of total demand

d) Leakage levels

e) Household consumptive use

Of the above, only factors c), d) and e) are directly affected by the implementation of demand management initiatives. The key is therefore to establish both the magnitude of the effect of demand management on each factor and the relative importance of those factors in determining the outputs from the model. For example, if demand management significantly reduces household demand, but the level of household demand is of little significance compared with the other four factors, there is unlikely to be any significant hydrological impact. However, if leakage levels are a key factor, then even moderate reductions may have a significant hydrological impact.

The key outputs from the model for the nine hypothetical schematics are shown in the table below.

SCHEMATIC	KEY MODEL OUTPUT		
	Abstraction volume	**River flow between abstraction and effluent return**	**River flow downstream of abstraction and effluent return**
1	✔	✔	✔
2	✔	✔	✔
3	✔	✗	✗
4	✔	✔	✔
5	✔	✔	✔
6	✔	✔	✗
7	✔	✔	✗
8	✔	✔	✗
9	✔	✔	✔

Probabilistic Assessment

As indicated previously, one of the difficulties in undertaking a meaningful analysis of the issues involved is that of the 'unknowns' (i.e. variability in components such as upstream river flows or abstraction rates). The spreadsheet model on its own is too rigid to address this uncertainty, since each of the above factors, as well as each output, are represented by single values.

In order to address this, a probabilistic assessment will be undertaken. This will initially use an event decision tree analysis but will extend to the use of a Monte Carlo iterative scheme if required. Essentially, components for which there is significant uncertainty are represented by a distribution of values, with the distribution being defined by specifying maximum credible and minimum credible values and a most likely (e.g. mean) value. The intention will be, for example, to generate a distribution of abstraction reductions arising from demand management for a specific schematic which takes account of the variability in river flows, abstraction rates, domestic demands and consumptive use.

A full review of the project findings will be undertaken at the end of this step, with an Interim Report, including initial conclusions, being passed to the EA/UKWIR research team involved with the 'Economics of Demand Management' project.

Step 3: Application of the Model to Specific Schematics

In addition to characterising the effects of demand management using the hypothetical model, the model itself will be applied to the specific case studies highlighted in the original brief (i.e. Cambridge, Southend, Bedford and Northampton). The aim of this exercise would be to assess the applicability of the technique in real situations and to identify the limitations that would need to be addressed if it were to be developed as a predictive tool for use by the EA.

Additional co-operation will be sought from Cambridge, Essex and Anglian Water Companies in order to facilitate this process.

Step 4: Development of Hypothetical Catchment Model

Initial indications from the hypothetical water balances suggest that in most circumstances the hydrological impacts of demand management may be limited. However, this takes no account of the cumulative effect that might be realised on a scale that extends beyond a single urban supply zone. To investigate the potential for such cumulative effects, a hypothetical catchment model will be constructed which combines the four case study schematics (i.e. for a hypothetical river flowing from Northampton to Bedford to Cambridge and finally to Southend on the coast).

Step 5: Adaptability of the Model for use as a Predictive Tool

The aim of this final step is to identify how the methodology used within the project might be adapted for use as an assessment tool by the EA. In this context, issues such as ease of use, data requirements and data interpretation will be considered, as will the means through which the methodology could be effectively "packaged" for general use.

Project Review

At the end of the study, the results and conclusions will be reviewed within the context of both regional and national developments in demand management. Additional consideration will also be given to potential water quality impacts and the degree to which turning hydrological changes into potential environmental benefits will depend on other factors (e.g. abstraction strategy employed by the Water Companies).

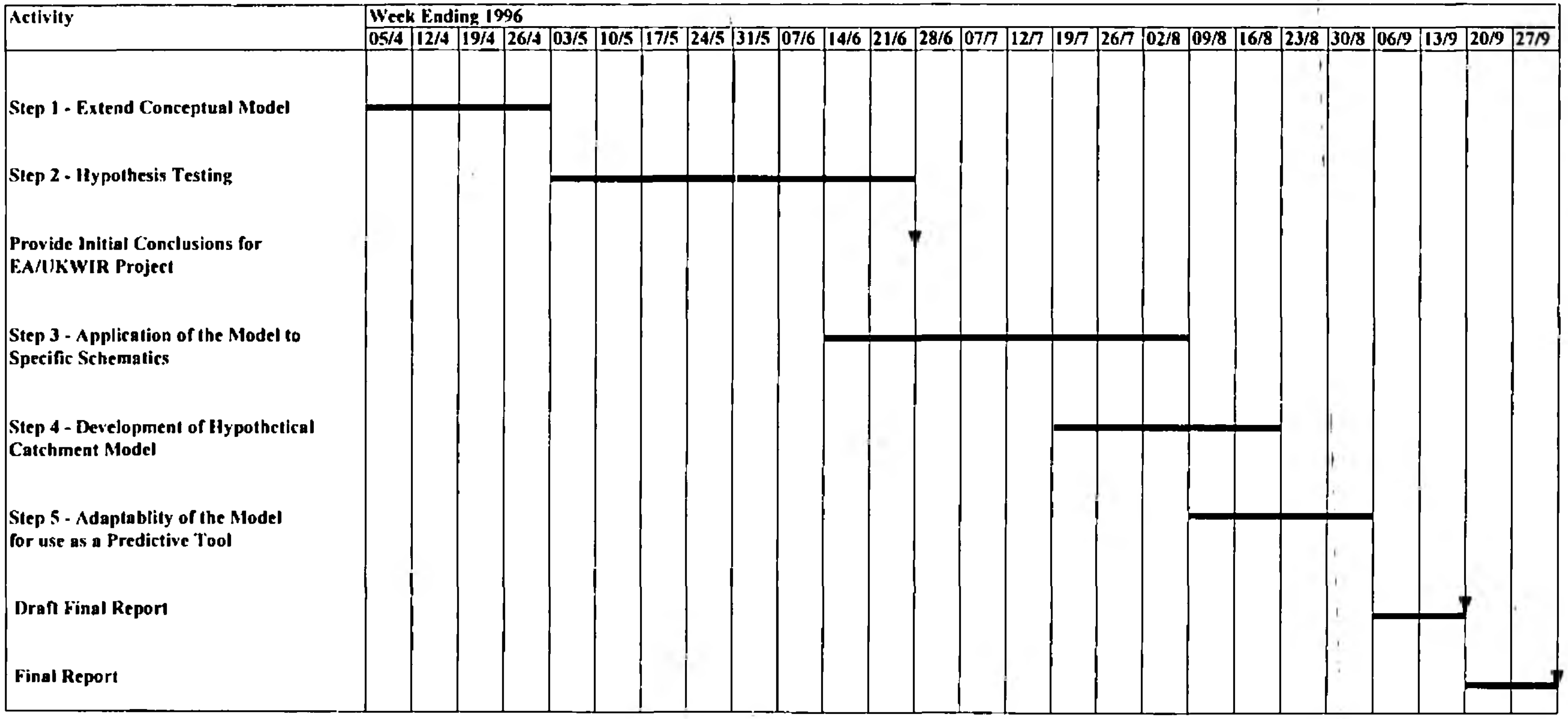
8.0 PROGRAMME, RESOURCING AND COSTS

8.1 Programme

The programme for the second stage is shown on the attached sheet. It is envisaged that this will commence at the beginning of April and, on this basis, that it will be completed by the end of September 1996. At the request of the EA, however, initial conclusions from Step 2 will be made available to the EA/UKWIR research team by the end of June 1996.

8.2 Staff Resourcing

The project will continue to be managed by Mike Woolgar with the bulk of the work being undertaken by Jim Leat and Philip Sutherland along with graduate support. Specialist input on the probabilistic approach to the water balance model will be provided by Neil Cullen (*cv* included in Appendix E). Rob Gray will continue to act as the Review Engineer.



THE HYDROLOGICAL EFFECTS OF DEMAND MANAGEMENT ON THE ENVIRONMENT
FULL REPORT STAGE

APPENDIX A
Project Brief

THE HYDROLOGICAL EFFECTS OF DEMAND MANAGEMENT ON THE ENVIRONMENT

Project Number OI 583
Tender Number I194

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14 August 1995

Project Manager: David Evans

NATIONAL RIVERS AUTHORITY

BACKGROUND INFORMATION

The National Rivers Authority (NRA) was established in 1989 with statutory responsibilities and powers in relation to *pollution control, water resources, flood defence, fisheries, recreation, conservation and navigation* in England and Wales. To ensure that the best ways of protecting, improving and managing the water environment are used, the NRA also undertakes an extensive research and development programme. Consequently, the NRA is widely recognised as the strongest environmental protection agency in Europe.

Structured into eight Regions (based broadly on the geographical coverage of the Water PLC's) the NRA employs 7,500 staff and has total operating costs of some £430m of which almost £300m reflects revenue and capital expenditure on goods and services. IN April 1996, the Authority will form, with HMIP and Waste Regulatory bodies, the new Environment Agency.

The Anglian Region, covering an area from the Humber to the Thames, proposes to engage a Consultant by competitive tender to carry out the task of identifying and quantifying the hydrological effects of demand management on the environment.

The overall objective of the project is to focus the NRA's demand management efforts to where they will be of greatest benefit to the water environment. This is explored further in Schedule 5.

The NRA (and others) are enthusiastic in their efforts to 'save' water; but no-one questions what it is being saved from.

Neither leakage nor profligate use destroy water, they only result in moving it from one place or time to another. The effects on the water environment of such movements may be sometimes bad, sometimes neutral and sometimes good. Where they are perceived to be good there is no environmental case for demand management and where they are perceived to be bad there is such a case. Where they are neutral there may or may not be a case. The project will identify which is which, and quantify where possible.

Areas where 'wasting' water can actually do some environmental good include those inland where the effect is to boost low river flows, giving higher summer flows, increasing dilution, and supporting downstream abstraction. Neutral areas may include those where demand is met from the tidal limit of a river; in such areas the effect of 'waste' may be just to move water from one point of entry to the sea to another.

4. Demand management is also questionable where its purpose is to defer new developments (such as well designed reservoirs or river regulations) which themselves may offer net environmental benefit.

5. The NRA advocates demand management by all water users to the extent which is economically justified. By this we mean to the point where the costs of saving water match those of making more available, taking account of all the costs and benefits-financial, social and environmental. Water Companies may be expected to act according to their financial costs. It is for NRA to ensure that the environmental costs are included.

6. By August 1996 a UKWIA/NRA project "The Economics of Demand Management" will provide a framework that will allow consideration of all costs and benefits for resource developments and demand management options. This will facilitate the identification of those options with the lowest societal cost. The framework will be consistent with current NRA policy to advocate demand management where it is economic to do so and where it generates a net environmental benefit.

7. The current project will complement that project by identifying, and where possible quantifying the benefit of demand management, which may take two forms:-

   a) Deferring (or eliminating) water resource developments whose net effect is environmentally bad, and/or

   b) Reducing abstractions whose net effects are environmentally bad.

8. Category a) is very site specific, particularly as regards potential reservoirs. Therefore the project just seeks guidance in general terms under this category. (eg. are boreholes and pipelines environmentally neutral? Are reservoirs `good' or `bad'? Which categories of development warrant most pressure for demand management on environmental grounds?)

   Category b) may be more amenable to generalised research. It is intended that the majority of the project will focus on this aspect.

   It is expected that the contract will be awarded in September 1995 and intended that the project will be completed by September 1996.

1. **Objectives**

1.1 The overall objective of the project is to focus the NRA's demand management efforts to where they will be of greatest benefit to the water environment. This is explored further in Section 2.

1.2 Specific objectives are identified in sections 2.1 and 2.2.

2. **Scope of Work**

The project is to be comprised of two stages.

2.1 Project Definition Stage

The specific objectives of the Project Definition Stage are to:-

- Review the problem and overall objective of the project
- Produce an outline methodology to enable the overall objective to be achieved.
- To propose a detailed work plan and specification for the Full Report Stage.

The Project Definition Report will provide a detailed evaluation of the staff resources, and timescales for each category of work required to implement the Full Report Stage.

2.2 Full Report Stage

The Full Report Stage is subject to Section 3.2.3, and its objectives are to:-

- develop the proposals of the Project Definition Stage into a detailed methodology.
- carry out the detailed work plan defined by the Project Definition Stage
- Conclude with recommendations as to how and where the NRA can best harness demand management to maximize benefit of the water environment.

2.3 Approach

The effects of demand management on abstractions, and subsequent returns, of water may be addressed by the following steps.

a. Categorise the major types of water source, for example;
   - groundwater, direct
   - groundwater, via river regulation
   - river, direct
   - river, via river regulation
   - river, via reservoir
   - river at or near tidal limit, direct
   - river at or near tidal limit, via reservoir
   - other?

b. In each case, identify in broad terms the effect of abstraction (not returns, yet) on:
   - river flow
   - estuary flow
   - groundwater levels, hence effects on wetlands
   - water quality
   - other?

c. Identify what typically happens to water abstracted for:
   - pws
   - power generation
   - other industry
   - spray irrigation
   - other agriculture

   ie. explore and categorise the ways in which water is `consumed' (in the sense of being artificially transferred, directly or indirectly, to the atmosphere); and the ways and places to which it is returned, directly or indirectly, to the fresh water environment or to the tidal environment.

   This step lends itself particularly to schematic presentations. See Figures 1&2.

d. Identify in broad terms only, any impact upon freshwater quality (eg. from contamination of leakage in urban areas).

e. In each case quantify the effects in percentage terms.

f. Combine c and e to identify in broad terms the net effect of abstractions upon rivers, estuaries and groundwater for various permutations of source, use and location of return. Simplify the permutations as much as possible having regard to the actual occurrence of combinations of source and destination of water within the Anglian Region. Comment, if appropriate on the possible occurrence elsewhere in England and Wales, of significant combinations of source and destination not represented in Anglia.

g. Summarise the various demand management techniques, the percentage 'savings' which each can achieve and the order of costs involved. This information will be provided by the NRA Demand Management Centre (DMC) and other published work - no new 'fieldwork' is needed.

h. Combine f and g to identify in broad terms the effect of demand management measures in the various circumstances.

i. Apply the techniques to particular case studies (perhaps those illustrated in Figures 1&2).

j. Deduce what demand management measures, in which circumstances, will offer best value for money in terms of environmental benefit.

2.4 The following considerations should be made:

a. Differentiation between areas where resources are plentiful (say Rutland demand zone), and where they are tight (say Essex).

b. Seasonal factors in abstractions and returns.

c. Consideration of the cost of demand management versus the cost of development should be avoided. This is already covered by DMC and by OFWAT.

d. Social aspects should also be avoided.

e. Where demand management is beneficial (eg sensitive groundwater areas), its effect may be suppressed because water companies will still use their cheaper sources first, and these tend to be the environmentally sensitive ones. (eg 'saving' water in Grimsby will reduce Trent-Witham-Ancholme transfers; not Northern Chalk abstraction - unless somebody pays the difference). How to take account of this factor?

f. It should not be forgotten that all unconfined groundwater abstractions may affect wetlands and this may be an over-riding factor, irrespective of where water is returned.

2.5 Consultation

The Consultant will need to establish early contact and confer with the NRA Demand Management Centre (DMC) at Worthing, the other 7 NRA Regions, and several representative water companies.

3. **Project Information**

3.1 Information Sources

Much of the demand management data required are already collated by the DMC and NRA Anglian Region; no field work is envisaged for the Project Definition stage of the project.

3.2 Programme

3.2.1 It is expected that this consultancy will be awarded to the successful tenderer in September 1995.

3.2.2 The Project Definition stage of the project is to be completed within 3 calendar months from the date of appointment. The Full Report Stage is to be completed within 9 calendar months of the completion of the Project Definition stage.

3.2.3 The NRA will review the Project Definition stage of the project and reserves the right to terminate the engagement at the end of the Project Definition stage and not proceed to the Full Report stage. If the engagement is terminated, the consultant will be notified by the client within 2 weeks, after the end of the Project Definition stage.

3.2.4 Four draft copies of each report at both the Project Definition and Full Report stages will be presented to the Project Manager for approval at least three weeks before the issue of the definitive report. The draft, with any suggestions for corrections and amendments, will be returned to the Consultant by the Project Manager within two weeks of receipt of the draft.

3.2.5 The structure of the definitive reports shall be determined during the progress meetings (Section 3.3.2).

3.2.6 Five bound copies, one unbound copy and a copy on disk in Wordperfect 5.1(or 5.2) format of the definitive reports for both the Project Definition and Full Report stages will be presented to the Project Manager at the end of each stage.

3.3 Administration

3.3.1 For the purposes of this engagement the Consultant's contacts within the NRA will be:

Project Executive:	Graham Wilson, Regional Water Resources Manager
Project Manager:	David Evans, Water Resources Planning Manager
Project Team:	Andy Turner, Assistant Engineer (Water Resources)
	Martin Smalls, Regional R&D Scientist

All of the above are based at

Kingfisher House,
Goldhay Way,
Orton Goldhay,
Peterborough. PE2 5ZR. (Tel. 01733 371811)

NRA Demand Management Centre: David Howarth at the following address;

NRA Southern Region,
Guildbourne House,
Chatsworth Road,
Worthing,
West Sussex. BN11 1LD. (Tel. 01903 820692)

3.3.2 Progress meetings will be held, at intervals to be agreed between the NRA and the Consultant, throughout the duration of the project. The consultant should allow for eight such meetings within his tender (3 in the Project Definition stage and 5 in the Full Report stage). These meetings will take place at Kingfisher House, Peterborough, or other agreed location. Brief written progress reports summarising work completed and projected, consultancy fees/expenses incurred to date, outstanding contractual matters etc., will be submitted to the Project Manager every month for the Project Definition stage, every two months for the Full Report stage and at least one week before each progress meeting.

3.3.3 The Project Definition stage report will include a detailed evaluation of the staff resources and timescales for each category of work required to implement the Full Report Stage of the consultancy.

3.3.4 The Authority will only award a contract for the Project Definition Stage. The Full Report Stage may be awarded following consideration of the results of the Project Definition Stage.

3.3.5 Prior to the award of the Full Report Stage the Authority will review the tendered Target Fee. The Target Fee may be renegotiated into a Fixed Fee in the light of the findings of the Project Definition report by the mutual consent of both parties but any renegotiated Fee shall be based upon the fee rates submitted with the original tender. If at this stage either party feels that the original tendered Target Fee is unrealistic and a renegotiated Fixed Fee can not be agreed, then either party may terminate the contract. NRA will then re-consider the project before deciding whether or not to tender the remaining work.

4. **Ownership of Documents**

4.1 All documents, papers and data collected as part of the projects will be handed over to the NRA on completion or termination of the contract.

4.2 The consultant may, with the prior written consent of the NRA, publish with due acknowledgement to the NRA any learned papers, articles, photographs or other illustrations relating to the task.

4.3 Copyright of all documentation will be vested in the NRA (see contract conditions).

5. **The Proposal**

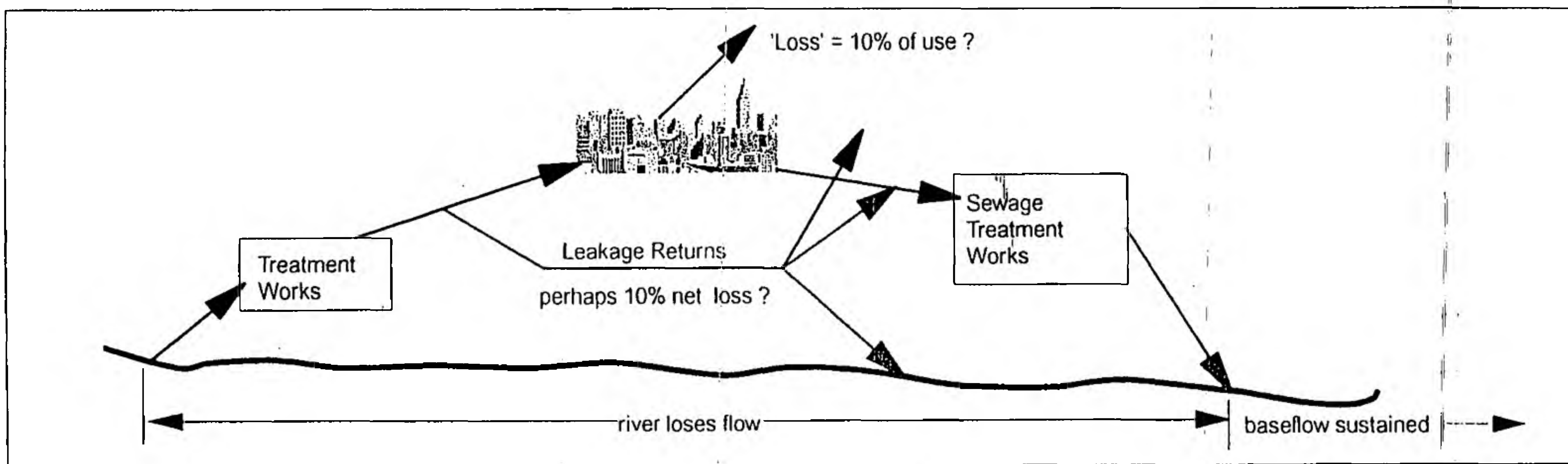
5.1 Each tenderer for this consultancy shall submit with their tender three clear and concise bound copies of a detailed proposal to the NRA. One copy should be clearly marked 'Master'. The proposal will set out how they would undertake the project, and shall provide such supporting information as is necessary to demonstrate sufficient understanding of the task and their ability to undertake the project and to enable the NRA to properly assess and evaluate their proposal. The supporting information shall include details of their:-

- Overall appreciation of the task.
- Proposed approach and methodology.
- Proposed project organisation, management and staffing (including curricula vitae) and project base location.
- Quality Assurance system.
- Detailed programme of work.
- Audited Accounts for the last 2 years (summary only).

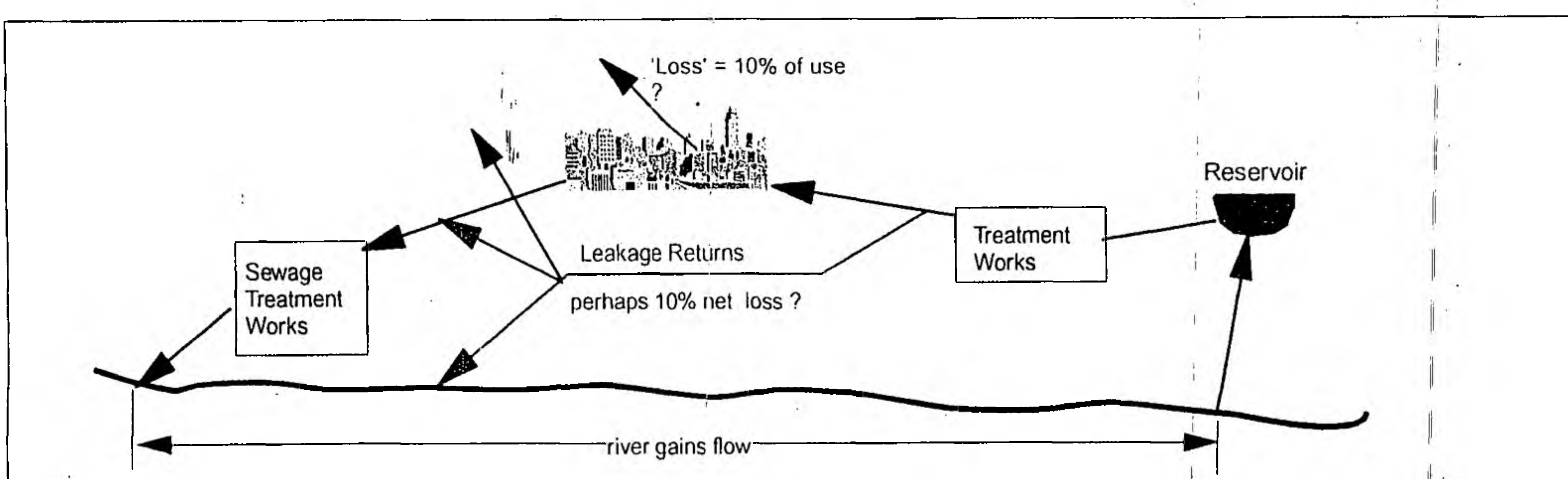
Figure 1:

SOME SCHEMATICS OF WATER USE AND RETURN

1. River Abstraction & Inland Return, Downstream (eg.Bedford)



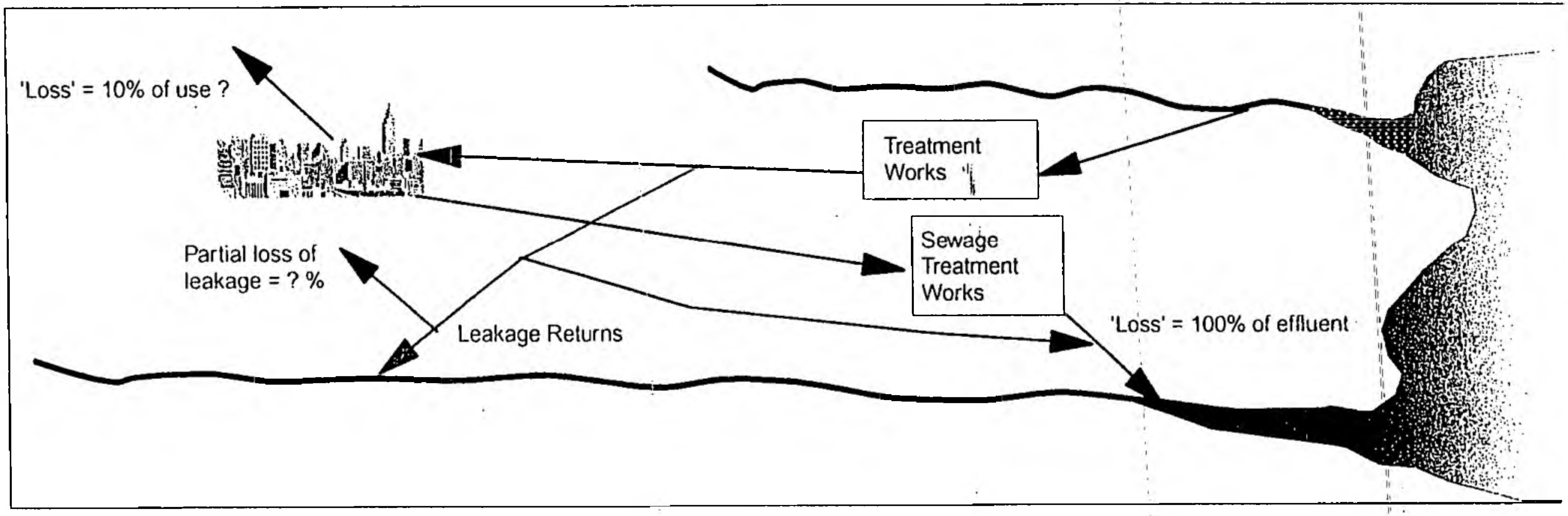
2. River Abstraction & Inland Return, Upstream (eg. Northampton)



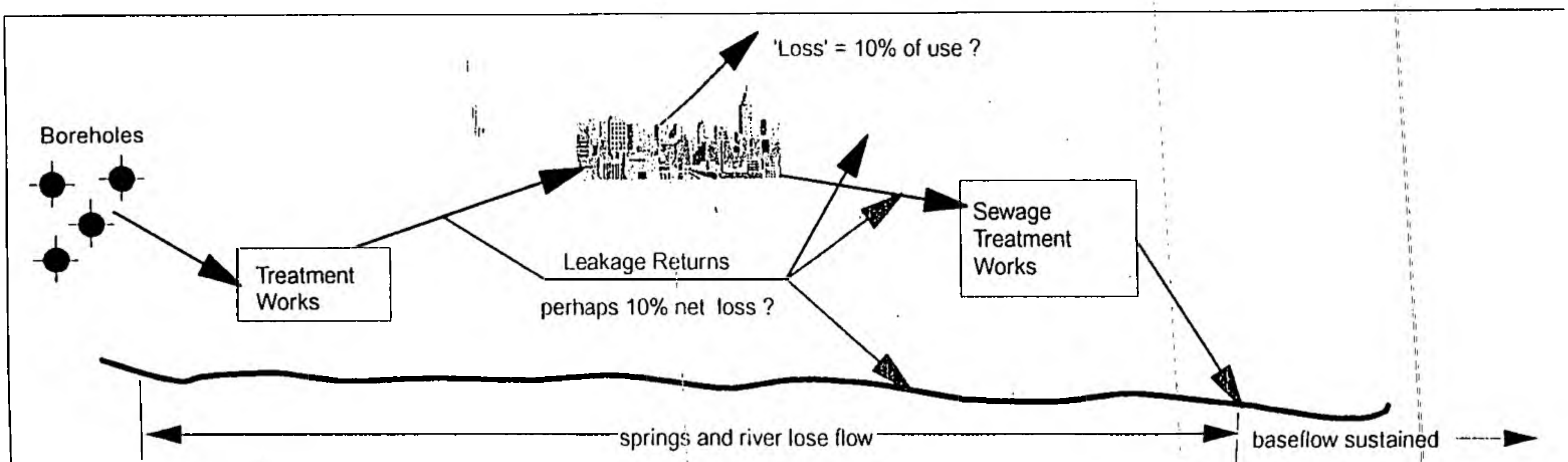
SOME SCHEMATICS OF WATER USE AND RETURN

Figure 2:

3. River Abstraction & Tidal Return (eg. Southend)



4. Groundwater Abstraction & Inland Return (eg. Cambridge)



APPENDIX B

Domestic Consumptive Use Spreadsheet

Assessment of Household Consumptive Use

a) Average Demand

Type of Water use	Percentage of Total Use (%)	Volume l/h/d	Percentage of Volume Evaporated (%)	Volume Evaporated (l)
Toilet	**33.00**	**47.9**	0	0.00
Baths	**13.00**	**18.9**	1	0.19
Showers	**4.00**	**5.8**	1	0.06
Washing Machines	**21.00**	**30.4**	1	0.30
Kitchen Sink	**16.00**	**23.2**		
washing up	9.60	13.9	1	0.14
cooking	3.20	4.6	25	1.16
drinking	1.60	2.3	0	0.00
kettle	1.60	2.3	2	0.05
Wash Hand Basins	**9.00**	**13.05**		
washing face/hair	4.50	6.5	1	0.07
washing hands	1.80	2.6	1	0.03
cleaning teeth	1.35	2.0	0	0.00
drinking	1.35	2.0	0	0.00
Dishwashers	**1.00**	**1.4**	1	0.01
Outside Taps	**3.00**	**4.35**		
car washing - hose	0.15	0.2	50	0.11
car washing - manual	0.15	0.2	50	0.11
lawn sprinkling	1.20	1.7	80	1.39
hose watering	1.20	1.7	80	1.39
other	0.30	0.4	50	0.22
Total	100	145		5.2

Percentage of Evaporation 3.6

b) Peak Demand

Average l/h/d = 145
Peak l/h/d = 174

Type of Water use	Percentage of Total Use (%)	Volume l/h/d	Percentage of Volume Evaporated (%)	Volume Evaporated (l)
Toilet	**27.50**	**47.9**	0	0.00
Baths	**12.50**	**21.8**	1	0.22
Showers	**5.00**	**8.7**	1	0.09
Washing Machines	**17.50**	**30.4**	1	0.30
Kitchen Sink	**14.17**	**24.65**		
washing up	8.50	14.79	1	0.15
cooking	2.83	4.93	25	1.23
drinking	1.42	2.47	0	0.00
kettle	1.42	2.47	2	0.05
Wash Hand Basins	**8.33**	**14.50**		
washing face/hair	4.17	7.25	1	0.07
washing hands	1.67	2.90	1	0.03
cleaning teeth	1.25	2.17	0	0.00
drinking	1.25	2.17	0	0.00
Dishwashers	**0.83**	**1.4**	1	0.01
Outside Taps	**13.92**	**24.21**		
car washing - hose	0.70	1.21	50	0.61
car washing - manual	0.70	1.21	50	0.61
lawn sprinkling	5.57	9.69	80	7.75
hose watering	5.57	9.69	80	7.75
other	1.39	2.42	50	1.21
Total	100	174		20.1

Percentage of Evaporation 13.8

APPENDIX C
Water Balance Model Output

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 1 - Inland Abstraction and Inland Return Downstream

Ref.	Calculation	Water Use	Average Demand (Ml/d)	a) Domestic Metering — Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
				5%	10%	15%	20%	15%	10%
		WATER TREATMENT							
a)		(SRU) - Surface Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
b)		*Evaporation Losses - (Assume surface area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.6	0.5	0.5	0.6	0.6	0.6	0.4
d)	(b+c)	*(CWT) - Consumptive Use*	0.6	0.6	0.5	0.5	0.6	0.5	0.5
e)	(a*1%)	*(LWT) - Leakage*	0.6	0.5	0.5	0.6	0.6	0.5	0.4
f)	(a-d-e)	Outflow	49.0	48.1	47.2	46.3	46.6	44.2	41.8
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses (25% of average demand)	12.2	12.2	12.2	12.2	9.8	7.3	4.9
h)	(f-g)*30%	Non Household Use - (30 % of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply - (70% of water delivered)	25.7	24.8	23.9	23.0	26.7	25.7	25.7
k)	(j*70%)	*metered (assume 70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(j*30%)	*unmetered (assume 30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(j*10%)	*(CH) consumptive use - 10% of household demand*	2.6	2.5	2.4	2.3	2.6	2.6	2.6
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	33.0	32.3	31.5	30.7	33.1	33.1	33.2
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.6	1.6	1.5	1.7	1.7	1.7
p)	(g*10%)	*(LRS) Infiltration to sewers- (10% of Leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	32.6	31.9	31.1	30.4	32.4	32.2	32.0
r)	(q*2%)	*Process Losses*	0.7	0.6	0.6	0.6	0.6	0.6	0.6
s)		*Evaporation - Surface Water Area 1 ha*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.7	0.7	0.6	0.6	0.7	0.7	0.7
u)	(q*1%)	*(LST) - Leakage*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
v)	(q-t-u)	(ERD) - Outflow/Return to river	31.6	30.9	30.2	29.4	31.4	31.2	31.0
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage	13.6	13.4	13.4	13.3	11.3	9.0	6.8
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.3	1.3	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	12.1	12.1	12.0	12.0	10.1	8.1	6.1
a1)	(z*0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Abstraction (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(a)	(SRU) - Surface Water Abstraction (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
d1)	(50-c1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.3
e1)	(d1/50*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
f1)	(b1-c1)	(F2) - River Flow Downstream of Abstraction (Ml/d)	50.0	50.9	51.8	52.7	52.4	54.9	57.3
g1)	(b1-c1)/b1*100	Decrease in River Flow (%)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
h1)	(z)	(LRR) - Leakage Return to River (Ml/d)	12.1	12.1	12.0	12.0	10.1	8.1	6.1
i1)	(v)	(ERD) - Effluent Return (Ml/d)	31.6	30.9	30.2	29.4	31.4	31.2	31.0
j1)	(31.6-v)/31.6*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
k1)	(f1+h1+i1)	(F3)-River Flow Downstream of Effluent return	93.8	93.9	94.0	94.1	94.0	94.3	94.5
l1)	(b1-k1/b1*100)	Decrease in River Flow (%)	6.2	6.1	6.0	6.9	6.0	5.7	5.5
		CONSUMPTIVE USE							
m1)	(d+i+m+t+y)	Total Consumptive Use (Ml/d)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
n1)	(m1/c1)/100	Consumptive Use as % of Abstraction (%)	12.5	12.6	12.4	12.4	12.6	12.7	12.8
o1)	(6.2-m1)	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.4	0.3	0.5	0.8
p1)	(o1/6.2)*100	Percentage Reduction in Consumptive Use (%)		1.9	3.8	5.8	4.0	8.1	12.1

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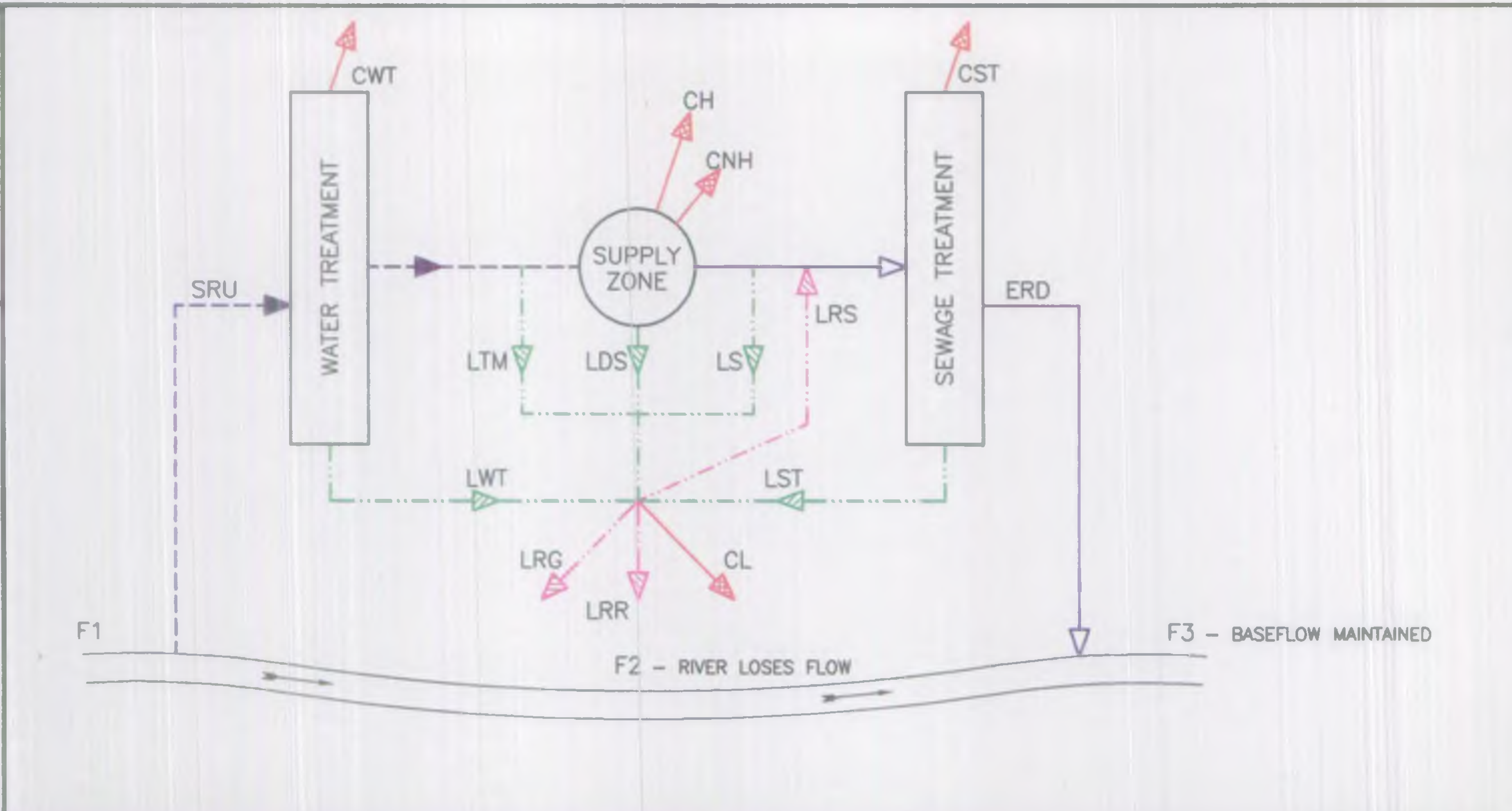

HYDROLOGICAL CYCLE OF URBAN USE AND RETURN
SCHEMATIC OF INLAND ABSTRACTION AND INLAND RETURN DOWNSTREAM

Figure 4

WATER SOURCE (S)

SRU – INFLOW FROM SURFACE WATER ABSTRACTION UPSTREAM OF EFFLUENT RETURN

EFFLUENT RETURN (F)

ERD – EFFLUENT RETURN DOWNSTREAM OF SURFACE WATER ABSTRACTION

CONSUMPTIVE USE (C)

CWT – WATER TREATMENT CONSUMPTIVE USE
CH – DOMESTIC DEMAND CONSUMPTIVE USE
CNH – COMMERCIAL DEMAND CONSUMPTIVE USE
CL – CONSUMPTIVE USE OF TOTAL LEAKAGE
CST – SEWAGE TREATMENT CONSUMPTIVE USE

LEAKAGE (L)

LWT – LEAKAGE FROM RAW WATER STORAGE AND WATER REATMENT WORKS
LTM – TRUNK MAINS LEAKAGE
LDS – DISTRIBUTION SYSTEM LEAKAGE
LS – SEWERAGE LEAKAGE
LST – SEWAGE TREATMENT WORKS LEAKAGE

LEAKAGE RETURNS (LR)

LRG – LEAKAGE RETURN TO GROUNDWATER
LRR – LEAKAGE RETURN TO RIVER
LRS – LEAKAGE INFILTRATION TO SEWERAGE

LEGEND

EFFLUENT
INFLOW
CONSUMPTIVE USE
LEAKAGE
LEAKAGE RETURNS

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 2 - Inland Abstraction and Inland Return Upstream

Ref.	Calculation	Water Use	Average Demand (Ml/d)	Demand Management Option: a) Domestic Metering — Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
				5%	10%	15%	20%	15%	10%
		WATER TREATMENT							
a)		(SRD) - Surface Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
b)		*Evaporation Losses - (Assume surface area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.5	0.5	0.5	0.5	0.6	0.5	0.4
d)	(b+c)	*(CWT) - Consumptive Use*	0.5	0.5	0.5	0.5	0.5	0.5	0.6
e)	(a*1%)	*(LWT) - Leakage*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
f)	(a-d-e)	Outflow	49.0	48.1	47.2	46.3	46.6	44.2	41.8
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses (25% of average demand)	12.2	12.2	12.2	12.2	9.8	7.3	4.9
h)	(f-g)*30%	Non Household Use (30% of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply (70% of water delivered)	25.7	24.8	23.9	23.0	26.7	26.7	25.7
k)	(j*70%)	*metered (70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(j*30%)	*unmetered (30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(j*10%)	*(CH) consumptive use - 10% of household demand*	2.6	2.5	2.4	2.3	2.6	2.6	2.6
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	33.0	32.3	31.6	30.7	33.1	33.1	33.2
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.6	1.6	1.6	1.7	1.7	1.7
p)	(g*10%)	*(LRS) Infiltration to sewers- (10% of dist. leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	32.6	31.9	31.1	30.4	32.4	32.2	32.0
r)	(q*2%)	*Process Losses*	0.7	0.6	0.6	0.6	0.6	0.6	0.6
s)		*Evaporation - (assume surface area of 1ha)*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.7	0.7	0.6	0.6	0.7	0.7	0.7
u)	(q*1%)	*(LST) - Leakage*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
v)	(q-t-u)	(ERU) - Outflow/Return to river	31.6	30.9	30.2	29.4	31.4	31.2	31.0
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage (excluding infiltration)	13.6	13.4	13.4	13.3	11.3	9.0	6.8
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.3	1.3	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	12.1	12.1	12.0	12.0	10.1	8.1	6.1
a1)	(z *0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Effluent Return (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(z)	(LRR) - Leakage Return to River (Ml/d)	12.1	12.1	12.0	12.0	10.1	8.1	6.1
d1)	(v)	(ERU) - Effluent Return (Ml/d)	31.6	30.9	30.2	29.4	31.4	31.2	31.0
e1)	(31.6-v)/31.6*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
f1)	(b1+c1+d1)	(F2) - River Flow Upstream of Abstraction (Ml/d)	143.8	143.0	142.2	141.4	141.6	139.4	137.2
g1)	(f1-b1)/f1*100	Increase in River Flow (%)	43.8	43.0	42.2	41.4	41.6	39.4	37.2
h1)	(a)	(SRD) - Surface Water Abstraction (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
i1)	(50-h1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.3
j1)	(d1/100*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
k1)	(f1-h1)	(F3) - River Flow Downstream of Abstraction	93.8	93.9	94.0	94.1	94.0	94.3	94.5
l1)	(f1-k1)/f1*100	Decrease in River Flow (%)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
		CONSUMPTIVE USE							
m1)	d+i+m+t+y)	Total Consumptive Use (Ml/d)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
n1)	(m1/c1)/100	Consumptive Use as % of Abstraction (%)	12.5	12.6	12.4	12.4	12.6	12.7	12.8
n1)	(6.2-n1)	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.4	0.3	0.5	0.8
o1)	(n1/6.2)*100	Percentage reduction in Consumptive Use (%)		1.9	3.8	5.8	4.0	8.1	12.1

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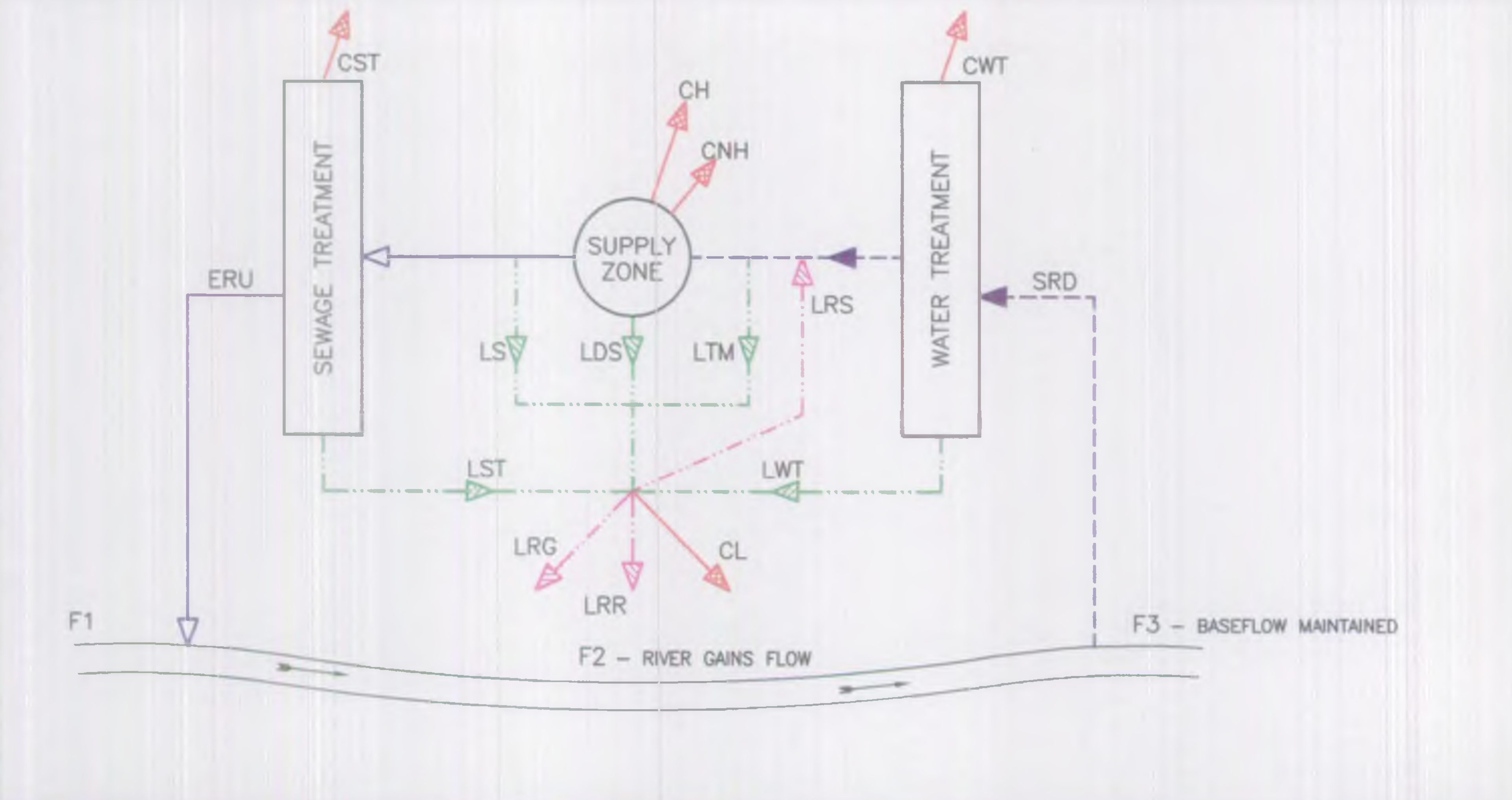
WS Atkins



HYDROLOGICAL CYCLE OF URBAN USE AND RETURN
SCHEMATIC OF INLAND ABSTRACTION AND INLAND RETURN UPSTREAM

Figure 5

WATER SOURCE (S)

SRD – INFLOW FROM SURFACE WATER ABSTRACTION DOWNSTREAM OF EFFLUENT RETURN

EFFLUENT RETURN (E)

ERU – EFFLUENT RETURN UPSTREAM OF SURFACE WATER ABSTRACTION

CONSUMPTIVE USE (C)

CWT – WATER TREATMENT CONSUMPTIVE USE

CH – DOMESTIC DEMAND CONSUMPTIVE USE

CNH – COMMERCIAL DEMAND CONSUMPTIVE USE

CL – CONSUMPTIVE USE OF TOTAL LEAKAGE

CST – SEWAGE TREATMENT CONSUMPTIVE USE

LEAKAGE (L)

LWT – LEAKAGE FROM RAW WATER STORAGE AND WATER TREATMENT WORKS

LTM – TRUNK MAINS LEAKAGE

LDS – DISTRIBUTION SYSTEM LEAKAGE

LS – SEWERAGE LEAKAGE

LST – SEWAGE TREATMENT WORKS LEAKAGE

LEAKAGE RETURNS (LR)

LRG – LEAKAGE RETURN TO GROUNDWATER

LRR – LEAKAGE RETURN TO RIVER

LRS – LEAKAGE INFILTRATION TO SEWERAGE

LEGEND

EFFLUENT

INFLOW

CONSUMPTIVE USE

LEAKAGE

LEAKAGE RETURNS

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 3 - Tidal Abstraction and Tidal Return

Ref.	Calculation	Water Use	Average Demand (Ml/d)	Demand Management Option: a) Domestic Metering — Reduction in Average Domestic Demand of Metered Properties 5%	10%	15%	b) Total Losses (Percentage of average demand) 20%	15%	10%
		WATER TREATMENT							
a)		(STL) - Surface Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
b)		*Evaporation Losses - (Assume area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
d)	(b+c)	*(CWT) - Consumptive Use*	0.5	0.5	0.5	0.5	0.5	0.5	0.5
e)	(a*1%)	*(LWT) - Leakage*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
f)	(a-d-e)	Outflow	49.0	48.1	47.2	46.3	46.6	44.2	41.8
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses (25% of average demand)	12.2	12.2	12.2	12.2	9.8	7.3	4.9
h)	(f-g)*30%	Non Household Use - (30 % of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply - (70% of water delivered)	25.7	24.8	23.9	23.0	25.7	25.7	25.7
k)	(k*70%)	*metered (assume 70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(k*30%)	*unmetered (assume 30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(k*10%)	*(CH) consumptive use - 10% of domestic demand*	2.6	2.5	2.4	2.3	2.6	2.6	2.6
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	33.0	32.3	31.6	30.7	33.1	33.1	33.2
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.6	1.6	1.6	1.7	1.7	1.7
p)	(g*10%)	*(LRS) infiltration to sewers- (10% of dist. leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	32.6	31.9	31.1	30.4	32.4	32.2	32.0
r)	(q*2%)	*Process Losses*	0.7	0.6	0.6	0.6	0.6	0.6	0.6
s)		*Evaporation - (assume surface area of 1ha)*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.67	0.66	0.64	0.63	0.67	0.66	0.66
u)	(q*1%)	*(LST) - Leakage*	0.33	0.32	0.31	0.30	0.32	0.32	0.32
v)	(q-t-u)	(ETL) - Outflow/Return to river	31.6	30.9	30.2	29.4	31.4	31.2	31.0
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage	13.5	13.4	13.4	13.3	11.3	9.0	6.8
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.3	1.3	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	12.1	12.1	12.0	12.0	10.1	8.1	6.1
a1)	(z*0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Abstraction (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)		(STL) - Surface Water Abstraction (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
d1)	(50-c1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.3
e1)	(d1/50*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
f1)	(z)	(LRR) - Leakage Return to River (Ml/d)	12.1	12.1	12.0	12.0	10.1	8.1	6.1
g1)	(v)	(ETL) - Effluent Return (Ml/d)	31.6	30.9	30.2	29.4	31.4	31.2	31.0
h1)	(31.6-v)/31.6*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
i1)	(f1-c1+f1+g1)	(F3)-River Flow Downstream of Effluent return	93.6	93.9	94.0	94.1	94.0	94.3	94.5
j1)	(b1-i1)	Decrease in River Flow to Tide (%)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
		CONSUMPTIVE USE							
k1)	(d+i+m+t+y)	Total Consumptive Use (Ml/d)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
l1)	(k1/c1)/100	Consumptive Use as % of Abstraction (%)	12.5	12.5	12.4	12.4	12.6	12.7	12.8
m1)	(6.2-k1)/100	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.4	0.3	0.5	0.6
n1)	(m1/6.2)*100	Percentage Reduction in Consumptive Use (%)		1.9	3.8	5.8	4.0	8.1	12.1

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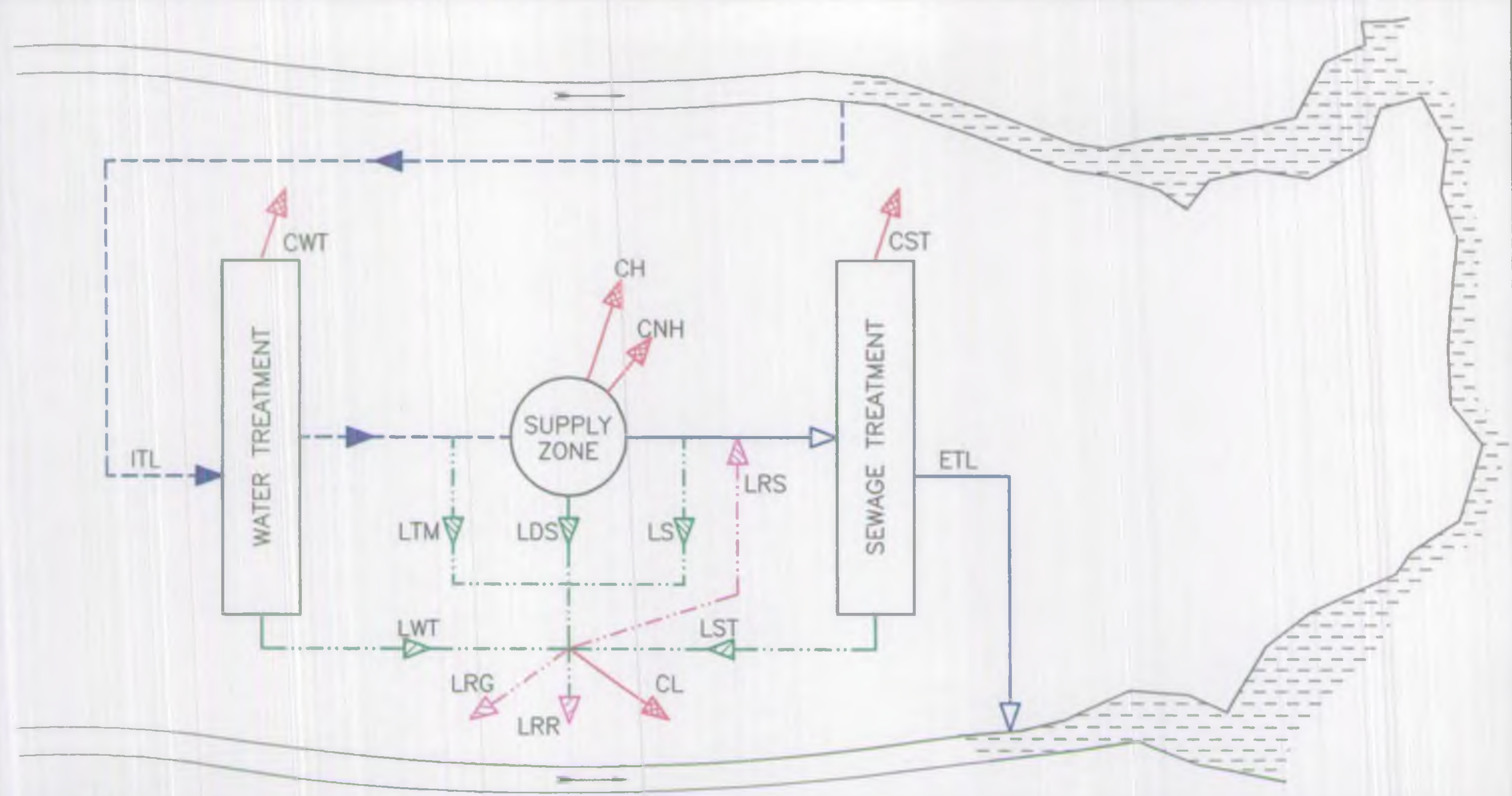
WS Atkins

HYDROLOGICAL CYCLE OF URBAN USE AND RETURN
SCHEMATIC OF TIDAL LIMIT SURFACE WATER ABSTRACTION AND TIDAL RETURN

Figure 6



WATER SOURCE (S)

STL - INFLOW FROM TIDAL LIMIT SURFACE WATER ABSTRACTION

EFFLUENT RETURN (E)

ETL - EFFLUENT DISCHARGE TO TIDAL LIMIT OR SEA

CONSUMPTIVE USE (C)

CWT - WATER TREATMENT CNOSUMPTIVE USE

CH - DOMESTIC DEMAND CONSUMPTIVE USE

CNH - COMMERCIAL DEMAND CONSUMPTIVE USE

CL - CONSUMPTIVE USE OF TOTAL LEAKAGE

CST - SEWAGE TREATMENT CONSUMPTIVE USE

LEAKAGE (L)

LWT - LEAKAGE FROM RAW WATER STORAGE AND WATER TREATMENT WORKS

LTM - TRUNK MAINS LEAKAGE

LDS - DISTRIBUTION SYSTEM LEAKAGE

LS - SEWERAGE LEAKAGE

LST - SEWAGE TREATMENT WORKS LEAKAGE

LEAKAGE RETURNS (LR)

LRG - LEAKAGE RETURN TO GROUNDWATER

LRR - LEAKAGE RETURN TO RIVER

LRS - LEAKAGE INFILTRATION TO SEWERAGE

LEGEND

EFFLUENT

INFLOW

CONSUMPTIVE USE

LEAKAGE

LEAKAGE RETURNS

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 4 - Groundwater Supply and Inland Return

Ref.	Calculation	Water Use	Base Flow (Ml/d)	Demand Management Option: a) Domestic Metering — Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
				5%	10%	16%	20%	15%	10%
		WATER TREATMENT							
a)		(SG) - Ground Water Supply (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
ai)		Evaporation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
b)	(a*1%)	Process losses (Ml/d)	0.5	0.5	0.5	0.6	0.5	0.6	0.4
c)	(b)	(CWT) - Consumptive Use (Ml/d)	0.5	0.6	0.6	0.6	0.6	0.5	0.4
d)	(a*1%)	(LWT) - Leakage (Ml/d)	0.5	0.6	0.5	0.6	0.6	0.5	0.4
e)									
f)	(a-c-d)	Outflow	49.0	48.1	47.2	46.4	46.6	44.2	41.6
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses	12.3	12.3	12.3	12.3	9.8	7.4	4.9
		(25% of average demand)							
h)	(f-g)*30%	Non household Use - (30 % of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply - (70% of water delivered)	25.7	24.8	23.9	23.0	25.7	25.7	25.7
k)	(j*70%)	*metered (assume 70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(j*30%)	*unmetered (assume 30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(j*10%)	*(CH) consumptive use - 10% of household demand*	2.6	2.5	2.4	2.3	2.6	2.6	2.6
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	33.1	32.3	31.5	30.7	33.1	33.2	33.2
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.6	1.6	1.5	1.7	1.7	1.7
p)	(g*10%)	*(LRS) Infiltration to sewers- (10% of dist. leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	32.6	31.9	31.1	30.4	32.4	32.2	32.1
r)	(q*2%)	*Process Losses*	0.7	0.6	0.6	0.6	0.6	0.6	0.6
s)		*Evaporation - assume surface area of 1 ha*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
t)	(r+s)	*(CST) - Consumptive Use*	0.7	0.7	0.6	0.6	0.7	0.7	0.7
u)	(q*1%)	*(LST) - Leakage*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
v)	(q-t-u)	(ER) - Outflow/Return to river	31.6	30.9	30.2	29.5	31.5	31.3	31.1
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage	13.5	13.4	13.4	13.3	11.3	9.0	6.8
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.4	1.3	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	12.2	12.1	12.1	12.0	10.1	8.1	6.1
a1)	(z*0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Abstraction (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(a)	(SG) - Ground Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
d1)	(50-c1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.4
e1)	(d1/50*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
f1)	(b1-c1)	(F2) - River Flow Downstream of Abstraction (Ml/d)	50.0	50.9	51.8	52.7	52.4	54.9	57.4
g1)	(b1-c1)/b1*100	Decrease in River Flow (%)		49.1	48.2	47.3	47.6	45.1	42.7
h1)	(z)	(LRR) - Leakage Return to River (Ml/d)	12.2	12.1	12.1	12.0	10.1	8.1	6.1
i1)	(v)	(ER) - Effluent Return (Ml/d)	31.6	30.9	30.2	29.5	31.5	31.3	31.1
j1)	(31.6-v)/31.6*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
k1)	(f1+h1+i1)	(F2)-River Flow Downstream of Effluent return	93.8	93.9	94.0	94.2	94.1	94.3	94.6
l1)	(b1-k1)/b1*100	Decrease in River Flow (%)	6.2	6.1	6.0	5.8	5.9	5.7	5.4
		CONSUMPTIVE USE							
l1)	(d+f+m+t+y)	Total Consumptive Use (Ml/d)	6.2	6.1	6.0	5.8	5.9	5.7	5.4
m1)	(j1/g1)/100	Consumptive Use as % of Abstraction (%)	12.4	12.4	12.4	12.3	12.6	12.6	12.8
n1)	(6.2-j1)/100	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.4	0.3	0.5	0.8
o1)	(l1/6.2)*100	Percentage Reduction in Consumptive Use (%)		1.9	3.9	6.8	4.1	8.1	12.2

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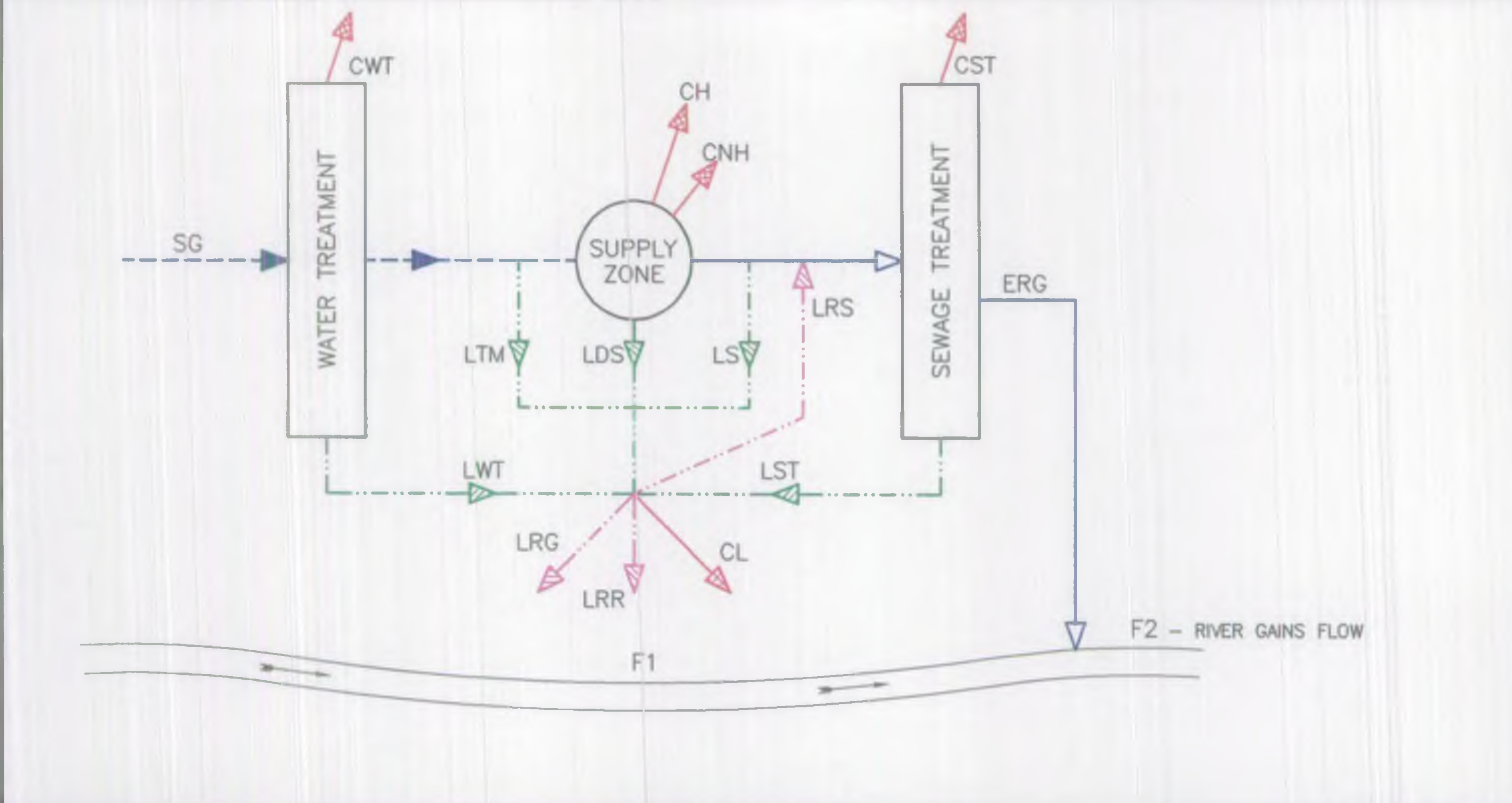
HYDROLOGICAL CYCLE OF URBAN USE AND RETURN
SCHEMATIC OF GROUNDWATER ABSTRACTION AND INLAND RETURN



WATER SOURCE (S)

SG – INFLOW FROM GROUNDWATER SUPPLY

EFFLUENT RETURN (E)

ER EFFLUENT RETURN TO RIVER (RIVER NOT UESD FOR ABSTRACTION)

CONSUMPTIVE USE (C)

CWT – WATER TREATMENT CONSUMPTIVE USE

CH – DOMESTIC DEMAND CONSUMPTIVE USE

CNH – COMMERCIAL DEMAND CONSUMPTIVE USE

CL – CONSUMPTIVE USE OF TOTAL LEAKAGE

CST – SEWAGE TREATMENT CONSUMPTIVE USE

LEAKAGE (L)

LWT – LEAKAGE FROM RAW WATER STORAGE AND WATER TREATMENT WORKS

LTM – TRUNK MAINS LEAKAGE

LDS – DISTRIBUTION SYSTEM LEAKAGE

LS – SEWERAGE LEAKAGE

LST – SEWAGE TREATMENT WORKS LEAKAGE

LEAKAGE RETURNS (LR)

LRG – LEAKAGE RETURN TO GROUNDWATER

LRR – LEAKAGE RETURN TO RIVER

LRS – LEAKAGE INFILTRATION TO SEWERAGE

LEGEND

EFFLUENT

INFLOW

CONSUMPTIVE USE

LEAKAGE

LEAKAGE RETURNS

Figure 7

APPENDIX D
Water Balance Model Output - Sensitivity Analysis

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 2 - Inland Abstraction and Inland Return Upstream

SENSITIVITY ANALYSIS
a) Reduced Surface Water Abstraction

				Demand Management Option					
				a) Domestic Metering Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
Ref.	Calculation	Water Use	Average Demand (Ml/d)	5%	10%	15%	20%	15%	10%
		WATER TREATMENT							
a)		(SRD) - Surface Water Abstraction	25.0	24.6	24.1	23.7	23.8	22.6	21.3
b)		*Evaporation Losses - (Assume surface area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.3	0.2	0.2	0.2	0.2	0.2	0.2
d)	(b+c)	*(CWT) - Consumptive Use*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
e)	(a*1%)	*(LWT) - Leakage*	0.3	0.2	0.2	0.2	0.2	0.2	0.2
f)	(a-d-e)	Outflow	24.5	24.0	23.6	23.1	23.3	22.1	20.9
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses	6.1	6.1	6.1	6.1	4.9	3.7	2.4
		(25% of average demand)							
h)	(f-g)*30%	Non Household Use (30% of water delivered)	5.6	5.5	5.5	5.6	5.5	5.5	5.6
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	0.6	0.6	0.6	0.6	0.6	0.6	0.6
j)	(f-g-h)	Domestic Water Supply (70% of water delivered)	12.8	12.4	11.9	11.6	12.6	12.8	12.6
k)	(j*70%)	*metered (70% of households)*	9.0	8.5	8.1	7.6	9.0	9.0	9.0
l)	(j*30%)	*unmetered (30% of households)*	3.9	3.9	3.9	3.9	3.9	3.9	3.9
m)	(j*10%)	*(CH) consumptive use - 10% of household demand*	1.3	1.2	1.2	1.1	1.3	1.3	1.3
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	16.6	16.1	15.7	16.3	16.5	16.6	16.6
o)	(n*5%)	*(LS) leakage from sewers (5%)*	0.8	0.8	0.8	0.8	0.8	0.8	0.8
p)	(g*10%)	*(LRS) Infiltration to sewers- (10% of dist. leakage)*	0.6	0.6	0.6	0.6	0.6	0.4	0.2
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	16.3	15.9	15.5	15.2	16.2	16.1	16.0
r)	(q*2%)	*Process Losses*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
s)		*Evaporation - (assume surface area of 1ha)*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
u)	(q*1%)	*(LST) - Leakage*	0.2	0.2	0.2	0.2	0.2	0.2	0.2
v)	(q-t-u)	(ERU) - Outflow/Return to river	15.8	15.4	15.1	14.7	15.7	16.6	15.5
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage (excluding Infiltration)	6.7	6.7	6.7	6.7	5.6	4.6	3.4
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	0.7	0.7	0.7	0.7	0.6	0.5	0.3
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	6.1	6.0	6.0	6.0	5.1	4.1	3.1
a1)	(z *0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Effluent Return (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(z)	(LRR) - Leakage Return to River (Ml/d)	6.1	6.0	6.0	6.0	5.1	4.1	3.1
d1)	(v)	(ERU) - Effluent Return (Ml/d)	15.8	15.4	15.1	14.7	15.7	15.6	15.5
e1)	(15.8-v)/15.8*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
f1)	(b1+c1+d1)	(F2) - River Flow Upstream of Abstraction (Ml/d)	121.9	121.5	121.1	120.7	120.8	119.7	118.6
g1)	(f1-b1)/f1*100	Increase in River Flow (%)	21.9	21.5	21.1	20.7	20.8	19.7	18.6
h1)	(a)	(SRU) - Surface Water Abstraction (Ml/d)	25.0	24.6	24.1	23.7	23.8	22.6	21.3
i1)	(150-h1)	Reduction in Abstraction (Ml/d)		0.4	0.9	1.3	1.2	2.4	3.7
j1)	(d1/150*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
k1)	(e1-h1)	(F3) - River Flow Downstream of Effluent return	96.9	96.9	97.0	97.0	97.0	97.1	97.2
l1)	(e1-k1)/e1*100	Decrease in River Flow (%)	3.1	3.1	3.0	3.0	3.0	2.9	2.8
		CONSUMPTIVE USE							
m1)	d+i+m+t+y)	Total Consumptive Use (Ml/d)	3.1	3.1	3.0	3.0	3.0	2.9	2.8
n1)	(m1/c1)/100	Consumptive Use as of Abstraction (%)	12.6	12.6	12.6	12.5	12.7	12.8	13.0
o1)	(3.1-n1)	Reduction in Consumptive use (Ml/d)		0.1	0.1	0.2	0.1	0.3	0.4
p10	(o1/3.1)*100	Percentage reduction in Consumptive Use (%)		1.9	3.8	5.7	4.0	8.0	12.0

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 2 - Inland Abstraction and Inland Return Upstream

SENSITIVITY ANALYSIS
b) Reduced Domestic Consumptive Use

Ref.	Calculation	Water Use	Average Demand (Ml/d)	Demand Management Option: a) Domestic Metering — Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
				5%	10%	15%	20%	15%	10%
		WATER TREATMENT							
a)		(SRD) - Surface Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
b)		*Evaporation Losses - (Assume surface area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
d)	(b+c)	*(CWT) - Consumptive Use*	0.5	0.5	0.5	0.5	0.5	0.5	0.5
e)	(a*1%)	*(LWT) - Leakage*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
f)	(a-d-e)	Outflow	49.0	48.1	47.2	46.3	46.6	44.2	41.8
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses	12.2	12.2	12.2	12.2	9.8	7.3	4.9
		(25% of average demand)							
h)	(f-g)*30%	Non Household Use (30% of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CNH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply (70% of water delivered)	25.7	24.8	23.9	23.0	26.7	25.7	25.7
k)	(j*70%)	*metered (70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(j*30%)	*unmetered (30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(j*5%)	*(CH) consumptive use - 5% of household demand*	1.3	1.2	1.2	1.2	1.3	1.3	1.3
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	34.3	33.5	32.7	31.8	34.4	34.4	34.5
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.7	1.6	1.6	1.7	1.7	1.7
p)	(g*10%)	*(LRS) Infiltration to sewers- (10% of dist. leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	33.8	33.0	32.3	31.5	33.6	33.4	33.2
r)	(q*2%)	*Process Losses*	0.7	0.7	0.6	0.6	0.7	0.7	0.7
s)	-	*Evaporation - (assume surface area of 1ha)*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.7	0.7	0.7	0.6	0.7	0.7	0.7
u)	(q*1%)	*(LST) - Leakage*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
v)	(q-t-u)	(ERU) - Outflow/Return to river	32.8	32.0	31.3	30.5	32.6	32.4	32.2
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage (excluding infiltration)	13.6	13.6	13.6	13.4	11.3	9.1	6.9
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.4	1.4	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*100%	*(LRR) - Leakage Return to River*	12.2	12.2	12.1	12.1	10.2	8.2	6.2
a1)	(z *0%)	*(LRG) - Leakage Return to Groundwater*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Effluent Return (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(z)	(LRR) - Leakage Return to River (Ml/d)	12.2	12.2	12.1	12.1	10.2	8.2	6.2
d1)	(v)	(ERU) - Effluent Return (Ml/d)	32.8	32.0	31.3	30.5	32.6	32.4	32.2
e1)	(32.8-v)/32.8*100	Percentage Reduction in Effluent Return (%)		2.4	4.7	7.1	0.6	1.2	1.8
f1)	(b1+c1+d1)	(F2) - River Flow Upstream of Abstraction (Ml/d)	145.0	144.2	143.4	142.5	142.8	140.6	138.4
g1)	(f1-b1)/f1*100	Increase in River Flow (%)	45.0	44.2	43.4	42.5	42.8	40.6	38.4
h1)	(a)	(SRD) - Surface Water Abstraction (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
i1)	(50-h1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.3
j1)	(i1/50*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
k1)	(f1-h1)	(F3) - River Flow Downstream of Effluent return	95.0	95.1	95.2	95.2	95.3	95.5	95.8
l1)	(b1-k1)/b1*100	Decrease in River Flow (%)	5.0	4.9	4.8	4.8	4.7	4.5	4.2
		CONSUMPTIVE USE							
m1)	(d+i+m+t+y)	Total Consumptive Use (Ml/d)	6.0	4.9	4.8	4.8	4.7	4.5	4.2
n1)	(m1/h1)/100	Consumptive Use as of Abstraction (%)	10.0	10.0	10.0	10.0	9.9	9.9	9.9
o1)	(5.0-n1)	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.2	0.3	0.5	0.8
p1)	(o1/5.0)*100	Percentage Reduction in Consumptive Use (%)		1.5	3.0	4.6	5.0	10.1	15.1

The Hydrological Effects of Demand Management on the Environment

Hypothetical Water Balance Model

Example 2 - Inland Abstraction and Inland Return Upstream

SENSITIVITY ANALYSIS
c) Reduced Leakage Returns to River

				Demand Management Option					
				a) Domestic Metering Reduction in Average Domestic Demand of Metered Properties			b) Total Losses (Percentage of average demand)		
Ref.	Calculation	Water Use	Average Demand (Ml/d)	5%	10%	15%	20%	15%	10%
		WATER TREATMENT							
a)		(SRD) - Surface Water Abstraction	50.0	49.1	48.2	47.3	47.6	45.1	42.7
b)		*Evaporation Losses - (Assume surface area of 2 ha)*	0.04	0.04	0.04	0.04	0.04	0.04	0.04
c)	(a*1%)	*Process Losses - Sludge Disposal*	0.5	0.5	0.5	0.5	0.5	0.6	0.4
d)	(b+c)	*(CWT) - Consumptive Use*	0.5	0.5	0.5	0.5	0.5	0.6	0.5
e)	(a*1%)	*(LWT) - Leakage*	0.5	0.5	0.5	0.5	0.5	0.5	0.4
f)	(a-d-e)	Outflow	49.0	48.1	47.2	46.3	46.6	44.2	41.8
		WATER DEMAND							
g)	(f*25%)	(LTM+LDS)Total Losses (25% of average demand)	12.2	12.2	12.2	12.2	9.8	7.3	4.9
h)	(f-g)*30%	Non Household Use (30% of water delivered)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
i)	(h*10%)	*(CH) - consumptive use - (10%)*	1.1	1.1	1.1	1.1	1.1	1.1	1.1
j)	(f-g-h)	Domestic Water Supply (70% of water delivered)	25.7	24.8	23.9	23.0	25.7	25.7	26.7
k)	(j*70%)	*metered (70% of households)*	18.0	17.1	16.2	15.3	18.0	18.0	18.0
l)	(j*30%)	*unmetered (30% of households)*	7.7	7.7	7.7	7.7	7.7	7.7	7.7
m)	(j*10%)	*(CNH) consumptive use - 10% of household demand*	2.6	2.5	2.4	2.3	2.6	2.6	2.6
		SEWAGE FLOW							
n)	(f-g-i-m)	Sewage Flow	33.0	32.3	31.5	30.7	33.1	33.1	33.2
o)	(n*5%)	*(LS) leakage from sewers (5%)*	1.7	1.6	1.6	1.5	1.7	1.7	1.7
p)	(g*10%)	*(LRS) infiltration to sewers- (10% of dist. leakage)*	1.2	1.2	1.2	1.2	1.0	0.7	0.5
		SEWAGE TREATMENT WORKS							
q)	(n-o+p)	Inflow	32.6	31.9	31.1	30.4	32.4	32.2	32.0
r)	(q*2%)	*Process Losses*	0.7	0.6	0.6	0.6	0.6	0.6	0.6
s)		*Evaporation - (assume surface area of 1ha)*	0.02	0.02	0.02	0.02	0.02	0.02	0.02
t)	(r+s)	*(CST) - Consumptive Use*	0.7	0.7	0.6	0.6	0.7	0.7	0.7
u)	(q*1%)	*(LST) - Leakage*	0.3	0.3	0.3	0.3	0.3	0.3	0.3
v)	(q-t-u)	(ERU) - Outflow/Return to river	31.6	30.9	30.2	29.4	31.4	31.2	31.0
		LEAKAGE							
x)	(e+g+o+u-p)	Total Leakage (excluding infiltration)	13.6	13.4	13.4	13.3	11.3	9.0	6.6
y)	(x*10%)	*(CL) - Consumptive Use of leakage*	1.3	1.3	1.3	1.3	1.1	0.9	0.7
z)	(x-y)*50%	*(LRR) - Leakage Return to River*	6.1	6.0	6.0	6.0	5.1	4.1	3.1
a1)	(z *50%)	*(LRG) - Leakage Return to Groundwater*	6.1	6.0	6.0	6.0	5.1	4.1	3.1
		RIVER FLOW							
b1)		(F1) - River Flow Upstream of Effluent Return (Ml/d)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
c1)	(z)	(LR) - Leakage Return to River (Ml/d)	6.1	6.0	6.0	6.0	6.1	4.1	3.1
d1)	(v)	(ERU) - Effluent Return (Ml/d)	31.6	30.9	30.2	29.4	31.4	31.2	31.0
e1)	(6.1-C1)/6.1*100	Percentage Reduction in Effluent Return (%)		2.3	4.6	6.9	0.6	1.2	1.8
f1)	(b1+c1+d1)	(F2) - River Flow Upstream of Abstraction (Ml/d)	137.7	136.9	136.2	135.4	136.5	135.3	134.1
g1)	(f1-b1)/f1*100	Increase in River Flow (%)	37.7	36.9	36.2	35.4	36.5	35.3	34.1
h1)	(a)	(SRD) - Surface Water Abstraction (Ml/d)	50.0	49.1	48.2	47.3	47.6	45.1	42.7
i1)	(50-h1)	Reduction in Abstraction (Ml/d)		0.9	1.8	2.7	2.4	4.9	7.3
j1)	(h1/50*100)	Percentage Reduction in Abstraction (%)		1.8	3.6	5.4	4.9	9.8	14.7
k1)	(f1-h1)	(F3) - River Flow Downstream of Abstraction	87.7	87.8	88.0	88.1	88.9	90.2	91.5
l1)	(b1-k1)/b1*100	Decrease in River Flow (%)	12.3	12.2	12.0	11.9	11.1	9.8	8.5
		CONSUMPTIVE USE							
m1)	(d+i+m+t+y)	Total Consumptive Use (Ml/d)	6.2	6.1	6.0	5.9	6.0	5.7	5.5
n1)	(m1/h1)/100	Consumptive Use as % of Abstraction (%)	12.5	12.5	12.4	12.4	12.6	12.7	12.8
o1)	(6.2-m1)	Reduction in Consumptive use (Ml/d)		0.1	0.2	0.4	0.3	0.6	0.8
p1)	(o1/6.2)*100	Percentage Reduction in Consumptive Use (%)		1.9	3.8	5.8	4.0	8.1	12.1

APPENDIX E
Curriculum Vitae for Neil Cullen

NAME OF PERSON	N CULLEN	**YEAR OF BIRTH**	1950
NATIONALITY	British	**PROFESSION**	Civil Engineer
POSITION IN FIRM	Senior Group Consultant		

SPECIALISATION

- Risk Assessment
- Public Health
- Economics

QUALIFICATIONS

MA (Cantab) Mathematics/Civil Engineering, Trinity College, Cambridge, UK
Member of the Institution of Civil Engineers
Member of the Chartered Institution of Water and Environmental Management
Member of the Institute of Management

KEY EXPERIENCE

Specialised for the past 5 years in Risk Assessment in the UK Water Industry, with an emphasis on providing cost-effective solutions. He has wide experience of water organisations, including two large water authorities, four consultants, the Water Research Centre and the Drinking Water Inspectorate.

Risk Assessment work includes investigation, advice, reports and training and has widened from Public Health to Water Supply Security, Sludge Incineration processes, bathing beach protection, reservoir location and Design Manual review. He has prepared and presented a number of reports and conference papers on related subjects.

EXPERIENCE IN PRESENT EMPLOYMENT

May 1995 W S Atkins Water, Senior Group Consultant specialising in Risk Assessment and Management.

EXPERIENCE IN PREVIOUS EMPLOYMENT

1992-1995 Babtie Group, Principal Engineer (Special Projects)

Brief included investigation for a regional council of options for treatment and disposal of an unusual combination of domestic and industrial effluents and disposal options; advising on the risk assessment aspects of condition assessment of major aqueducts; developing procedures and software for risk assessment in water distribution systems; liaison with research organisations; development of proposals for future research.

From January-September 1993 was operations co-ordinator at a critical stage in the implementation of a new computerised accounting system being introduced to the Glasgow office for the entire Babtie Group.

Led the Risk Management aspects of a number of projects including:

Dam/Reservoir Risk Assessment for AMP2,
Sludge Incinerator Process Risk Assessment,
Service Reservoir Relocation (reliability study),
Strategic Transfer Link - preliminary study of available data and initial assessment,
Bathing beach protection - review of design proposals for sewerage pumping/treatment scheme,
Dundee Supply Security - RAMP/FMECA study and report,
Decision Analysis as part of independent appraisal of a reservoir location study
Review of Design Manual for Roads and Bridges (Government Deregulation Initiative),
Supply Reliability Estimation - Company-wide matrix study of source-supply and route reliability for AMP2 submission.

1991-92 DoE Drinking Water Inspectorate, London (on secondment from WRc Engineering)

Acting Principal Inspector. Conducted various 'special projects' assignments. These included development and trialling of proposals to review the content and effectiveness of water company programmes to improve the condition and performance of water distribution networks, review and promulgation of the results of a survey of polycyclic aromatic hydrocarbons in drinking water and preparation of internal papers on disinfection system reliability and on policy regarding bankside storage.

1980-1991 WRc Engineering Centre, Swindon

Close involvement in the economics and risk assessment aspects of development of national sewerage rehabilitation strategy. Technical secretary to NWC Sewers and Water Mains Committee. Developed computer applications for sewer information management.

Formed part of team developing user requirement specifications for the database requirements associated with digital mapping/geographic information systems (GIS) for all aspects of water authority management but with particular emphasis on water mains and sewers.

Investigated the economics of water pumping efficiency improvement as part of a project covering the technical aspects of pump refurbishment and replacement.

Developed the application of standard risk assessment and reliability principles and techniques to problems in water supply and sewerage. This included writing a condensed report for DoE on probabilistic risk assessment of embankment dams, leading a project to prepare a methodology for reservoir contingency planning, and constructing and using procedures and computer programs to model the risk of water supply interruptions.

Led a project to produce a methodology for the classification of hazardous areas to avoid explosion or fire as a result of ignition by electrical equipment. This included a survey of potentially hazardous areas in the water industry. The studies were subcontracted to specialist consultants.

Advised on research programmes in asset condition ranking and investment risk assessment. Lectured occasionally on Water Training Association courses connected with the research work listed above.

1978-1980 Water Research Centre, Medmenham

Scientist/Engineer in Operational Research and Economics Division.

Investigation of nature and origin of UK sewer dereliction problem, including national surveys of sewer collapses and blockages and supervision of study in Strathclyde region. Author and technical secretary for production of NWC Manual of Sewer Condition Classification and report on Sewer and Water Main Records. Study and report on Performance and Utilisation of Sewer Jetting Plant.

1976-78 North West Water Authority, Manchester

Assistant Engineer in New Works section. Design and construction of sewage sludge digestion plant. Included devising a method of checking contractor's computer calculations for unbonded prestressed slip-formed water retaining sludge digestion tanks. Prepared computer programs to process tunnel overbreak measurements and to automate the billing of pipework qualities.

1975-1976 Yorkshire Water Authority, Huddersfield

Engineering Assistant. Investigation and design of various small sewage treatment works modifications and sewerage schemes.

1974-1975 Howard Humphreys and Sons (employed by Halifax County Borough)

Continuation of ICE training. Junior Assistant Resident Engineer at Halifax sewage treatment works reconstruction. Reconstruction of new activated sludge aeration plant and sludge heat treatment and pressing plant on piled foundations.

1972-1974 D Balfour and Sons, London

Graduate Engineer under ICE training agreement. Design of sewage treatment and sewage sludge treatment plant and design and supervision of construction of small sewerage schemes.

1971 J and A Leslie and Reid, Edinburgh

Summer vacation site experience. Prepared "as constructed" survey drawings of Grantown Sewage Treatment Works.

1969-1972 Undergraduate at Trinity College, Cambridge University

Studied part 1A and 1B, Part II (General) in civil engineering subjects. Bachelor of Arts degree.

SELECTED PUBLICATIONS

Input to National Manuals

1980 Manual of Sewer Condition Classification (First Edition). NWC/DoE. Joint Author; Editor and Technical Secretary.

1980 Sewer and Water Main Records. NWC/DoE. Technical Secretary.

1983 Sewerage Rehabilitation Manual. WRc/WAA.
Major contributor to definition of strategy and background information.

1989 Planning and Rehabilitation of Water Distribution Systems. WRc/WSA.
Author; (Appendix 1 - Energy cost savings)

Papers

Performance and Utilisation of Sewer Jetting Plant. IPHE Journal, 1980.

The Sewer Dereliction Problem - Evidence from Collapse Studies.
Proceedings of ICE 'Sewerage 81' Conference.

Developments in Sewer Management Information Systems. Paper at BHRA 'Sewerage 84' Conference, re-published in 'Civil Engineering' magazine. Joint Author.

UK Development in Underground Mapping. 'No-Dig 85' Conference.
Presenter. Background work; not author.

Computing - Not Yet Half Way There. IWSA 'Water 2000' Conference, Nice, 1987.

Risk Management and Reservoir Maintenance. IWEM Annual Symposium 'Risk Management in Environment and Water Services'. Re-published in IWEM Journal, December 1988.

Energy Cost Management in Water Supply. British Pump Manufacturers Association Conference, Cambridge, 1989.

New light on the 'black art' of predicting risk. Water Services magazine, June 1994.

WRc Reports

National Sewer Collapse Reporting Scheme - Results and Implications of Initial Analysis.
WRC ER 10E, 1980. Author.

Logical Data Models for Water and Sewerage, WRC, 1985. Author.

Risk Assessment of Earth Dam Reservoirs (SAC9790). Final Report to the DoE, WRc DoE 0002-SW/3.
Published in House of Commons Library. Author.

Risk Assessment in Water Supply and Sewerage. WRC UM 1127. Author.

Levels of Service: Measurement and Operational Implications. WRc/FWR report FR 0080, March 1990.

Hazardous Areas in the Water Industry. A series of reports from a large WRc project: UM 1203-1208. Project Leader.

LANGUAGES

English - Mother Tongue, German basic, Russian basic.

WS Atkins