Handbook for the Assessment of Catchment Water Demand and Use

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Preface

The ***"Handbook for the Assessment of Catchment Water Demand and Use"*** has been produced with funding from the Department for International Development (DFID) of the UK Government under the Knowledge and Research (KAR) programme. The work has been carried out as a collaborative venture between HR Wallingford (UK) and the Department for Water Development, Ministry of Rural Resources and Water Development (Zimbabwe), University of Zimbabwe, University of Zambia and the University of Zululand, South Africa. The Handbook includes a number of case studies that have been undertaken by the various members of the team. Pieter van der Zaag of the University of Zimbabwe has written chapter 2. Chapter 9 is based on the work of D. Kammer of the Department for Water Development in Zimbabwe. This document was produced in May 2003.

The Handbook responds to the growing need to balance supply-side and demand-side approaches to managing scarce water resources in catchments and river basins. It recognises that a plethora of research and methodologies are readily available to assist planners and managers to assess water resource availability in a catchment yet little is available to assist in assessing water demand and use. The Handbook therefore aims to fill this gap by bringing together a range of methodologies, examples of their application, supporting information and key references.

The Handbook is aimed at professionals and practitioners in the southern African region. It provides the user with a range of appropriate methods for estimating water demand and use across a range of water uses including environmental, urban, industrial, rural domestic and agricultural sectors. Guidance on the advantages and disadvantages of different assessment techniques are provided and the texts supplemented by worked examples. Methods suitable for forecasting long-term water demand and use are also included.

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Handbook for the assessment of
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1. INTRODUCTION

The aim of the Handbook is to support professionals and practitioners in sub-Saharan Africa responsible for the management of water resources at a catchment and sub-catchment level. The Handbook provides practical guidance for assessing and forecasting water demands and use for the following sectors:

- Environment;
- Agriculture;
- Rural domestic;
- Urban;
- Industry.

Each of these sectors is covered in a separate chapter as detailed below.

1.1 Structure of the Handbook

The Handbook is structured as follows:

- Chapter 1 provides background on the scope of the Handbook together with important definitions and overview of water resources and water demand in southern Africa;
- Chapter 2 provides an introduction to the principles of managing water at a catchment level;
- Chapter 3 details methods to estimate instream environmental water demands;
- Chapter 4 provides methods of estimating agricultural water demand and use based primarily on techniques recommended by the United Nations (UN) Food and Agriculture Organization (FAO);
- Chapter 5 provides an outline of methods of assessing rural domestic water demand and use;
- Chapter 6 outlines methods to assess industrial water demands and use. Appendix A contains look up tables that provide typical specific water consumption figures for a variety of industries;
- Chapter 7 details methods to assess urban water demand and use including commercial and institutional demands but excluding industrial water demands. Typical per capita water consumption figures for urban areas throughout southern Africa are provided;
- Chapter 8 provides brief details on demand forecasting methods;
- Chapter 9 outlines methods for assessing river transmission losses. Although river transmission losses are not strictly a demand it is important that they are taken into account when allocating water at a catchment level.

1.2 Scope of the Handbook

The driving principle behind the Handbook is the requirement that catchment and water resources managers need to have access to simple and effective tools to estimate water demand and use on a catchment and sub-catchment basis. In the past water resources planning has been supply driven. However, with water resources in arid and semi-arid areas becoming increasing scarce it is important that water demand and use is managed efficiently before new sources of water are developed. To manage water resources effectively, current and future water demand and use for all sectors should be estimated as accurately as possible.

It should be noted that the Handbook is limited to assisting catchment and water resources managers estimate water demand and use at a sub-catchment and catchment level. The

Handbook outlines techniques that are primarily aimed for use in the countries that form the Southern African Development Community (SADC). However, many of the techniques described can be applied in other parts of Africa and the world. A map of the 14 states from which SADC is comprised is shown in Figure 1.1.

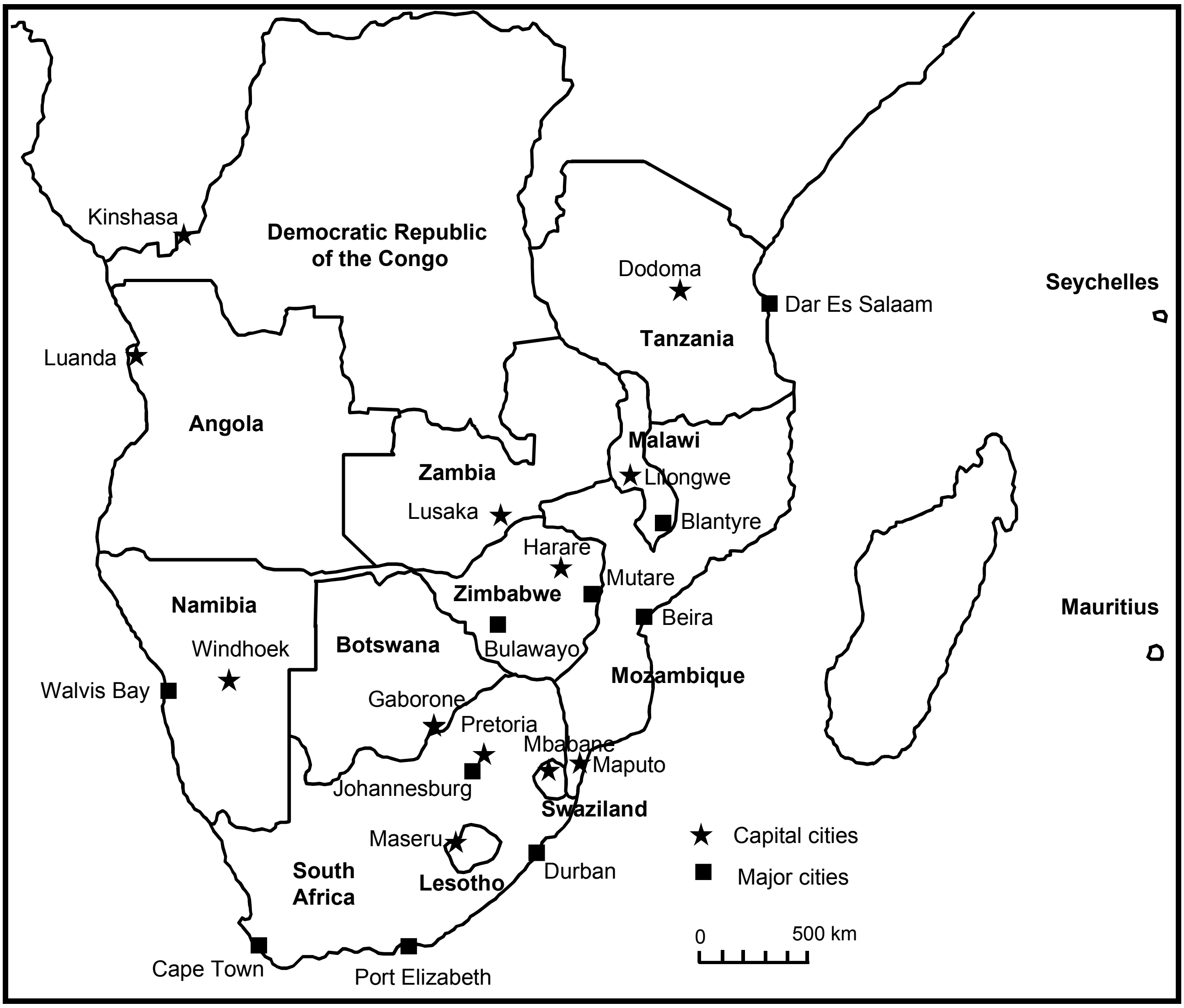

Figure 1.1 Map of the Southern African Development Community (SADC) region

1.3 Definitions of water demand and use

The terms water use and water demand are often used interchangeably. However, these terms have different meanings. In the context of the Handbook the definitions of these terms are given below.

1.3.1 Water use

Water use can be distinguished into three different types. These are:

- **Withdrawals or abstractions** where water is taken from a surface or groundwater source, and after use returned to a natural water body, e.g. water used for cooling in industrial processes that is returned to a river. Such return flows are particularly important for downstream users in the case of water taken from rivers;

- **Consumptive water use** or water consumption that starts with a withdrawal or an abstraction but in this case without any return flow. Water consumption is the water abstracted that is no longer available for use because it has evaporated, transpired, been incorporated into products and crops, consumed by man or livestock or otherwise removed from freshwater resources. Water losses during the transport of water between the points of abstractions and the point of use, (e.g. resulting from leakage from distribution pipes), are excluded from the consumptive water use figure. Examples of consumptive water use include steam escaping into the atmosphere and water contained in final products i.e. it is water that is no longer available directly for subsequent uses;
- **Non-consumptive water use** i.e. the in situ use of a water body for navigation, instream flow requirements for fish, recreation, effluent disposal and hydroelectric power generation.

1.3.2 Water demand

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning. This is because in some cases, especially in rural parts of southern Africa, the theoretical water demand considerably exceeds the actual consumptive water use.

1.4 Overview of water use in southern Africa

There are 14 members of SADC: Angola, Botswana, Democratic Republic of the Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. The SADC region covers an area of almost 6.8 million km^2. Regional estimates put the renewable freshwater resources at an annual average of 650,000 million m^3 distributed in the region's rivers, lakes and aquifers. The sections below give an overview of water use in the SADC region.

1.4.1 Background

The southern African climate varies from tropical rain forests in the north of the region to desert conditions in the south-west. These climatic conditions make rainfall one of the most important climatological elements in the SADC region. Large areas within the SADC region are very dry and cannot support sustainable human existence and agriculture, especially in the south-western parts of the region. A very dry period in the region can result in crop failures, food deficits and, in the extreme, starvation. Rainfall is nearly non-existent in some parts of Namibia. In 1999, for instance, 85% of the country received below average rainfall. This meant that the country could not produce the food it needed. The eastern coastal zones and northern sub-areas (Angola, Malawi, Zambia, Mozambique, Tanzania and parts of Zimbabwe) are relatively wet. In these regions the mean annual precipitation varies from 1,000 mm to 1,600 mm per year, with isolated areas receiving more than 2,000 mm. The high annual evaporation rates, (in some areas as high as 4,000 mm), means that only some 3% to 15% of all rainfall flows to rivers and lakes. Only 360 km^3, out of 600 km^3, are suitable for use in the agricultural, industrial and domestic sectors. Water, therefore, plays an important role in the socio-economic development of the SADC, especially in terms of food production, health, energy and the environment.

1.4.2 Shared river basins within the SADC region

There are fifteen major rivers shared among the continental SADC member-states. All the continental SADC countries share one or more river basins, as noted in Table 1.1. Namibia, for instance, one of the most arid countries in the region, has access to five international river basins. Mozambique shares nine of its rivers with other countries. The Zambezi basin, the largest and probably most crucial in southern Africa, crosses eight countries.

Table 1.1 Shared river basins within the continental SADC states

Country	Number of basins	Name of river basins
Angola	5	Cunene, Cuvelai, Okavango, Congo, Zambezi
Botswana	4	Limpopo, Okavango, Orange, Zambezi
Democratic Republic of the Congo	2	Congo, Nile
Lesotho	1	Orange
Malawi	2	Ruvuma, Zambezi
Mozambique	9	Buzi, Incomati, Limpopo, Ruvuma, Save, Maputo, Pungue, Umbeluzi, Zambezi
Namibia	5	Cunene, Cuvelai, Okavango, Orange, Zambezi
South Africa	4	Incomati, Limpopo, Maputo, Orange
Swaziland	3	Incomati, Maputo, Umbeluzi
Tanzania	3	Nile, Ruvuma, Zambezi, Congo
Zambia	2	Zambezi, Congo
Zimbabwe	6	Buzi, Limpopo, Okavango, Pungwe, Save, Zambezi

Source: Reference 1.1

1.4.3 Water use by sector within the SADC region

Table 1.2 gives broad patterns of water use in southern Africa. Whilst the absence of data on the total volumes of water used in each country prevents detailed comparisons from being made, agricultural water use in each country clearly dominates when compared to the domestic and industrial water use sectors. The high proportion of water used for agriculture suggests that each SADC country rely heavily on food grown within its borders to meet national goals of food security.

Table 1.2 Water use by sector for continental SADC states

Country	Agriculture (%)	Industry (%)	Domestic (%)
Angola	76	10	14
Botswana	48	20	32
Democratic Republic of the Congo	23	16	61
Lesotho	56	22	22
Malawi	86	3	10
Mozambique	89	2	9
Namibia	68	3	29
South Africa	62	21	17
Swaziland	71	8	21
Tanzania	89	2	9
Zambia	77	7	16
Zimbabwe	79	7	14

Source: Reference 1.1

1.4.4 Water scarcity in the SADC region

Table 1.3 presents categories of water scarcity associated with varying levels of water supply per person per year, the typical scales of problems encountered in each category in southern Africa.

Table 1.3 Water scarcity

Water scarcity category and associated problems	Volume of water available (m^3/person/year)
Beyond the "water barrier": continual, wide-scale water supply problems, becoming catastrophic during droughts.	< 500
Chronic water scarcity: continual water supply problems, worse during annual dry seasons; frequent severe droughts.	500 to 1,000
Water stressed: frequent seasonal water supply and quality problems, accentuated by occasional droughts.	1,000 to 1,666
Moderate problems: occasional water supply and quality problems, with some adverse effects during severe droughts.	1666 to 10,000
Well-watered: very infrequent water supply and quality problems, except during extreme drought conditions.	> 10,000

Source: Reference 1.1

Table 1.4 provides estimates of the total water available for each of the continental SADC states on a per capita basis for the year 2000 and 2025. The estimated populations for the year 2025 take into account the likely effects of HIV/AIDS on population growth.

Table 1.4 Water availability for continental SADC states

Country	Total water available (km^3) *	Population in 2000 (millions)	Water per person in 2000 (m^3/person/ year)	Estimated population in 2025 (millions)**	Water per person in 2025 (m^3/person/ year)
Angola	205.0	12.9	15,888	22.0	9,335
Botswana	1.6	1.6	976	2.0	808
Democratic Republic of the Congo	1,019.0	52.0	19,579	114.1	8,930
Lesotho	5.2	2.2	2,412	3.2	1,602
Malawi	17.5	10.8	1,624	16.1	1,089
Mozambique	17.0	20. 0	5,856	28.8	4,066
Namibia	2.7	1.7	1,553	2.6	1,052
South Africa	52.8	43.3	1,220	49.0	1,077
Swaziland	2.8	0.9	3,017	1.3	2,228
Tanzania	80.0	33.7	2,371	63.6	1,257
Zambia	127.0	9.2	13,818	14.9	8,526
Zimbabwe	15.5	13.1	1,182	14.0	1,108

Notes: *This is the surface plus ground water that is generated within the geo-political boundaries of the country each year and excludes water that flows in from neighbouring states. Minor volumes of recycled water are included in the values for water available in South Africa.
**Population growth rates in each country used to estimate the population in 2025 have been adjusted to account for the current prevalence of HIV/AIDS in that country.
Source: Reference 1.1

Table 1.4 indicates that five of the 12 continental SADC countries are water stressed and a further one country (Botswana) is facing a chronic scarcity of water. Table 1.4 also indicates that the water availability per person will significantly decrease by 2025.

1.5 References

1.1 Southern African Development Community (SADC) (1999) *Round Table Conference on the theme "Integrated Water Resources Development and Management in the Southern African Development Community*." http://www.sadcwscu.org.ls/programme/rtc/rtc-II.htm

1.2 IUCN The World Conservation Union (1996) *Water in southern Africa* IUCN – The World Conservation Union (Regional office for southern Africa).

2. AN INTRODUCTION TO THE PRINCIPLES OF MANAGING WATER AT A CATCHMENT LEVEL

2.1 Background

This chapter provides an introduction to some of the issues and principles that need to be addressed when allocating water at a macro-level. The chapter has been written by Pieter van der Zaag of the University of Zimbabwe.

An important purpose of water management is to match or balance the demand for water with its availability, through suitable water allocation arrangements. As detailed in the previous chapters at a catchment and sub-catchment level there is a large number of often conflicting of water uses including:

- Irrigation;
- Domestic use in urban centres;
- Domestic use in rural areas;
- Livestock;
- Industrial use;
- Commercial use;
- The environment (e.g. instream flow requirements for aquatic life and wildlife);
- Institutions (e.g. schools, hospitals);
- Hydropower;
- Cooling (e.g. for thermal power generation);
- Waste and wastewater disposal;
- Fisheries;
- Recreation;
- Navigation.

In many southern African countries there have been significant reforms in the way in which water is managed. One aspect of these water reforms in southern Africa is increased stakeholder participation in water management through catchment management organisations. The roles and responsibilities of catchment managers are discussed below.

2.2 Roles and responsibilities of catchment managers

Catchment planners are mainly concerned with the economic and social development of the catchment and are not normally directly involved with water management. However, in planning the development of a catchment the potential changes in water use and demand, as well as the changes in the water resource, must be considered. Any change in the land use or activities in the catchment affects the water situation and requires decisions to be made about whether and how those changes can be incorporated into the water management strategy for the catchment.

Increasingly, water has become the limiting factor to development either on a catchment level or a national level in many SADC countries. Future development and certainly further growth will, in many cases, rely on the location of a new source (such as through inter-basin transfers) or water saving either through increases in water use efficiency or a change in the catchment development strategy toward less water-intensive economic activities.

Those responsible for catchment planning are usually not directly involved with, or expert in, water management and require support information to make informed development decisions.

Catchment planning is also a dynamic process where development priorities are constantly changing. Consequently, the impact of the development plans on water use are also constantly changing and affect water demands.

The primary components of catchment planning where water management is concerned are:

- To ensure that planned developments do not have an adverse effect on either the hydrology or water quality of the catchment
- To ensure that adequate water resources are available to all water users in all sectors over the development horizon

To implement these primary components, the catchment planner requires knowledge in several areas common to water managers. These include:

(i) Catchment water resources

Catchment development is only feasible if there is sufficient water to support it. Water resources are often now the limiting factor to future development. The potential for new sources or increased storage either within or outside the catchment may also be considered to improve the resource potential if warranted. The schedule for the development of these and other water resources infrastructure must also be considered to ensure that the infrastructure is in place when needed. This should be part of the planning process.

(ii) Water demand forecasts

Water demand forecasts are tied directly with catchment planning and their relationship should be cyclical, as the forecasts are based on expected development and growth in the catchment. As part of demand management, the potential for improving efficiency in distribution or otherwise reducing demands must be assessed as this can make significant differences in the resource potential of the catchment.

(iii) Water allocation policies and strategies

Water allocation policies are directly linked to development planning and may also be cyclical because water allocation policies may result from development policies or vice-versa. Development plans may highlight the need to reconsider allocation policies. For example, where catchment plans lean toward industrial development this may conflict with agricultural water demands and may lead to a reassessment of water allocation to these sectors.

(iv) Reliability requirements

Different economic activities have varying reliability requirements and both the reliability needs of the industries and the ability of the catchment and its water infrastructure to meet the required levels of reliability. The impact of drought and drought alleviation strategies are an aspect of this.

(v) Costs of supplying water and expected returns of the planned development

Especially where water is becoming a limiting factor, the cost of supplying additional water for a development may be prohibitive. These costs may be offset if the value of the industry to the catchment is high. Such costs must be included in the overall catchment plan. Water quality must also be considered within these costs both in terms of supplying water of adequate quality and ensuring that the resulting effluent is acceptable. Water quality standards must also be met.

(vi) Hydrological impacts of planned developments

The hydrological impacts of the development must be fully considered, not just looking at the impacts of a single development, but for the combined effect of all planned development over the entire planning horizon period and including the impact of drought.

(vii) Environmental considerations

The basic flow requirements for rural communities and other unregulated use must be considered in terms of meeting these demands as well as ensuring that the hydrological impacts on these are acceptable. Similarly, minimum flow requirements for environmental or aesthetic needs are also important. Sustainability is the key.

(viii) Source and quality of the information used

The source of the information used and its quality is of great importance. Planning decisions must be based on the best information available and the risks inherent in using that information must be well understood and incorporated into the decision making process. Future monitoring needs should also be considered at this time.

(ix) Water permits

Whatever the planned development for the catchment, water users will need permits for water use and the plans must fit with current permitting policy (though permit policy can also be flexible to accommodate changes in development plans).

The background to many of these components and the importance that estimating water demands accurately plays in managing water at a catchment level are discussed below.

2.3 Balancing supply and demand

There are various ways in which water can be allocated. The challenge is to find an optimal allocation that, firstly, adheres to laid down regulations, and secondly, satisfies the water demand of all users as much as possible. The problem of water allocation can be said to be *"to balance properly between a whole set of obligations:*

- *To international conventions;*
- *To human basic rights for wellbeing of both upstream and downstream societies;*
- *For protection of land productivity;*
- *For delivery of ecological goods and services from both terrestrial and aquatic ecosystems; and*
- *For resilience of ecosystems to both natural and man-made disturbances."* (Reference 2.1).

Water allocation is not generally an issue when water availability far surpasses water demand. In such situations all demands can be satisfied, and in there may be no need for a regulated allocation of water. However, this is not the case for the majority of the catchments in southern Africa. In most catchments in southern Africa water availability is frequently less than the demand for it. It is then necessary to find a suitable allocation of the scarce water.

Water allocation is not only concerned with the physical allocation of water. More broadly it is about satisfying conflicting interests depending on water. These may be functions derived from issues such as the following:

- Water such as navigation (e.g. navigability is often reliant on minimum water levels);
- Hydropower (e.g. a minimum head difference may be required);
- Environment (e.g. many aquatic species will require a certain flow regime or seasonal fluctuations in water level to live and breed);
- Cultural and recreation (availability of water is often necessary for cultural and recreation needs).

Although many of these functions are only to a certain extent consumptive, they can conflict in both their timing and spatial distribution. Flood protection is also a function of the water resources system that relates to the water resources. Flood protection through the construction of storage dams can have a positive impact on water availability for other functions (e.g. hydropower), but can have negative impacts on others (e.g. on the environment). Finding a suitable allocation key for water can be quite complex, since a large number of parameters have to be considered both on the supply and the demand side.

2.3.1 The supply side

On the supply side the generation of water in a catchment area naturally fluctuates, both within years and between years. Water also occurs in different forms that often have different uses. Special reference is made to rainfall and its use as "green water" in agriculture. Green water cannot be allocated in the same way as "blue" water occurring in rivers and aquifers. However, dryland agriculture and other types of land use do influence the partitioning of rainfall into groundwater recharge, surface runoff and soil moisture (i.e. evaporation and transpiration), and hence their availability.

2.3.2 The demand side

There are various parameters that affect demand at a catchment level.

(i) **The demand for water fluctuates**. However, fluctuations in demand are normally much less than those on the supply side. For many types of uses, water demand increases when water availability decreases, such as during the dry season.

(ii) **Many water uses are (partially) consumptive**, meaning that the water abstracted will not return to the water system in the form of "blue water"; consumptive water use typically converts blue or green water into water vapour, which in this form cannot be allocated to other users. Water uses that are non-consumptive allow others to use the water afterwards. Recreational water uses are a typical example. However, some non-consumptive uses alter the time when this water becomes available for other users. A typical example is water used for the generation of hydropower: electricity is needed also during the wet season, and thus water has to be released from dams for this purpose, when demand for it from other sectors may be low. As a result, this water used for electricity generation is unavailable to these potential uses when they need it. The environment is another (partially) non-consumptive user of water; its requirements are frequently out of sync with the needs of other users. (That is precisely why these environmental water requirements are now increasingly being recognised.).

(iii) **Many uses of water generate return flows** that in principle, are available for other uses. However, return flows normally have a lower quality than the water originally abstracted. This may severely limit their re-use. Sometimes the quality of return flows is a hazard to public health and the environment.

(iv) **Different types of water use require different levels of assurance**. For arable (non-perennial) irrigated crops, levels of assurance of 80% (i.e. failure to produce the maximum yield owing to water shortages in one out of five years) may be acceptable.

For urban water supply assurance levels of 96% or higher are the norm (failing in one out of 25 years).

2.4 The legal framework

In many countries water is considered a public good i.e. the water is owned by the citizens of a country, and the government manages this public good on their behalf. Laws and regulations will therefore provide the rules pertaining to the use of this public resource. In countries where water is considered a public good, water allocation may be viewed as the process of converting a public good into a private one. An irrigator, for instance, will apply the water to his/her privately owned crop. The crop will consume a large part of the water, converting it into water vapour and increasing its yield. The irrigator derives direct and private benefit from using a public good, but in so doing denies another person the opportunity to use that water and deriving similar private benefits.

Balancing supply and demand must be done within the established legal framework. A country's water law and subsidiary government regulations will prescribe many aspects of water allocation. Amongst these are:

- Regulation of water for particular uses;
- The use of permits or water rights;
- Prioritisation of hierarchy of different water uses.

2.4.1 Regulation of water for particular uses

Water laws usually prescribe the types of water use that are regulated and those that are not regulated. Regulated water uses require some kind of permit, concession or right. Unregulated water use does not require licences to abstract from or discharge to body of water. Water used for "primary" uses such as the environment or human beings often does not require a permit or water right.

2.4.2 The use of water permits or water right

A water permit or water right typically defines:

- The source of from which the water is abstracted e.g. groundwater, watercourse, reservoir;
- The point of abstraction of the water;
- The purpose for which the water will be used (e.g. irrigation of 500 ha of land).

A permit or right specifies certain conditions under which water use is permitted. A typical condition is that the permit or right is limited in that it does not permit the use of water that infringes on similar rights of others. Another condition frequently specified is that the water should be used beneficially and not be wasted, and that return flows should adhere to certain quality standards. Restrictions may also be placed on the permit during periods of drought.

2.4.3 Hierarchy of water use

Water laws often stipulate the hierarchy of different types of water use; distinguishing between various sectors e.g. primary use (e.g. human consumption), environmental use, industrial use, agricultural use, water for hydropower. In most countries water use for primary purposes has priority over any other type of water use. Some countries also specify a hierarchy of the remaining uses, whereby the most important economic use in that country normally receives a high priority of use. In other countries all uses of water other than for primary (and sometimes environmental) purposes have equal standing. In times of water shortage the amount of water allocated to all non-primary uses will be decreased proportionally, so that all these user share the shortage equally.

The law may provide more detailed stipulations with a direct bearing on the allocation of water. The law may stipulate, for instance, that the allocation of water should be equitable. In some countries, in contrast, the law directs that junior rights may not affect senior rights. In most cases, however, the legal framework does not provide a detailed "recipe" of how the water should be allocated. Water managers therefore have to interpret the more general principles as laid down in the law, and translate these into operational rules for day-today allocation decisions. In many countries the water manager may not even do this without consulting all relevant stakeholders.

2.5 The value of water

The various uses of water in the different sectors of an economy add value to these sectors. Some sectors may use little water but contribute significantly to the Gross National Product (GNP) of an economy. Other sectors may use a lot of water but contribute relatively little to that economy. Table 2.1 gives the contribution of the various sectors of the Namibian economy to its GNP, and the amount of water each sector uses.

Table 2.1 Contribution of various sectors of the Namibian economy to GNP and the quantity of water used by each sector

Sector	Water uses		Contribution to GNP (%)
	Million m^3/year	Percentage (%)	
Irrigation	107	43.0	3
Livestock	63	25.3	8
Domestic	63	25.3	27
Mining	8	3.2	16
Industry and commerce	7	2.8	42
Tourism	1	0.4	4
Total	**249**	**100**	**100**

Source: Reference 2.3

Industry and commerce uses less than 3% of all water used in Namibia, but contribute 42% to the Namibian economy. In contrast, irrigated agriculture uses 43% of all water used, but contributes only 3% to the economy. Care should be taken when interpreting the above data. For instance, it is well known that the agricultural sector typically has a high multiplier effect in the economy, since many activities in other sectors of the economy depend on agricultural output, or provide important input services. The "real" value added by water may thus be underestimated by the type of data given in the table.

The added value of some uses of water are very difficult, if not impossible, to measure. For instance the value of domestic use of water is very difficult to quantify. The value of irrigated use of water is general at least a factor ten less than other types of industrial and commercial uses.

The damage to an economy by water shortage may be immense. It is well known, for instance, that a positive correlation exists between the Zimbabwe stock exchange index and rainfall in Zimbabwe. The drought of 1991/92 had a huge negative impact on the Zimbabwean economy. During the drought of 1991/92, the country's agriculture production fell by 40% and 50% of its population had to be given relief food and emergency water supplies, through massive deep drilling programmes, since many rural boreholes and wells dried up. Urban water supplies were severely limited with unprecedented rationing. Electricity generation at Kariba fell by 15% causing severe load shedding. As a result Zimbabwe's economy contracted by 11%.

Conversely, floods, though often beneficial, can sometimes be devastating. The February 2000 floods killed 800 persons in southern Mozambique. One million people required some form of emergency assistance. About 20,000 cattle drowned and 140,000 hectares of crops were destroyed. Road, rail and irrigation infrastructure was severely damaged. Health centres as well as water supply and sanitation infrastructure in many towns and villages suffered extensive damage, exposing many people to water-borne diseases such as cholera, malaria and diarrhoea. The destruction caused by the floods is estimated at US$ 600 million. Mozambique’s economic growth went down from 10% in 1999 to 2% in 2000.

2.6 Scales and boundary conditions

Any allocation decision potentially has third party effects: it may affect those not immediately involved in the allocation process, either beneficially or detrimentally. A special case, and a very important one, is where downstream users are affected that are located outside the jurisdiction of a given water allocation institution.

Any allocation process that does not encompass the entire catchment runs the risk of being affected by upstream uses and in turn impacting on downstream uses. Since most catchments in southern Africa are simply too large in extent, and often shared by more than one country, the water allocation processes is normally fragmented into sub-catchment areas which form part of the larger catchment. In such cases the allocation process must include boundary conditions; i.e. a specification of water requirements at the inlet and at the outlet of the catchment area under consideration. Even for a catchment area, with its downstream boundary being an estuary, will have to set such boundary conditions so as to minimise salt intrusion, and/or ensure the health of the estuary for environmental, social and/or economic purposes (e.g. for mangrove forests and prawn fisheries).

Boundary conditions are especially important in river basins that are shared by more than one country. If an upstream water allocation institution does not consider the requirements of the downstream country, it may even affect the bilateral relations of the two neighbouring countries. It would be advisable to formalise such boundary conditions in writing and to get them endorsed by all water allocation institutions involved; in a similar manner as how claims of individual water users are formalised in water permits or rights.

The water allocation process should ideally consider both the detailed allocation decisions between individual water users at the local level, as well as the "big picture" allocation decisions covering the entire river basin. Obviously, these different spatial scales require different levels of accuracy and specificity. However, they are both required, since decisions at these different spatial scales affect each other.

Historically, the decision-making process has been iterative, with an initial focus on the smaller spatial scales, especially in heavily committed parts of a basin. With the steadily increasing pressures on our water resources, the interconnectedness between the various parts of the basin have become apparent in many river systems. This has inevitably led to widening the scope of the water allocation process also to the largest spatial scale.

2.7 Issues in water allocation

In this section some important issues directly related to water allocation are briefly discussed. These issues typically cannot be solved overnight. Any stakeholder involved in water allocation, however, must be aware of them.

2.7.1 Defining key concepts

Key concepts used in a country's water allocation system must be very precisely and clearly defined, and be known and understood by the water users. Such key concepts may include:

- The ownership of water;
- Water use;
- Primary uses of water;
- Equity;
- Efficiency;
- The precise rights and obligations conferred with a water permit.

A particularly important issue is the definition of water use, since this basically defines the point where water converts from a public to a private good. Lack of clarity about where exactly this conversion occurs will create confusion, which will directly impact on the effectiveness of the water allocation process. For instance, if a permit holder has lawfully stored water in their dam, has this water already been used and hence is owned by the permit holder or not yet? The South African Water Act (1998) defines water use as taking and storing water, activities which reduce stream flow, waste discharges and disposals, controlled activities (declared activities which impact detrimentally on a water resource), altering a watercourse, removing underground water for certain purposes, and recreation.

2.7.2 Uncertainty

Generally speaking, if a user does not know how much water he or she is entitled to, and how much water is likely to be available at a future time, he or she tends to over-use or hoard water often incurring considerable losses. The allocation of water over different uses should therefore aim to deal effectively with uncertainty and increase the predictability of water available to the various uses. Increased predictability is an important condition that will allow users to use water more efficiently. Even a better understanding of how *unpredictable* water availability is will improve a user's ability to deal with this.

Two types of uncertainty may be distinguished:

- Physical uncertainty;
- Institutional uncertainty.

Physical uncertainty

Physical uncertainty does not so much refer to the stochastic nature of hydrological processes (which is normally quite well understood), but more to the impact of human activities on the hydrological cycle. At the global level, human-induced climate change is a possibility and may have wide-ranging effects, but the specific effects are not yet well understood. At a smaller spatial scale, the effects of land use change on the availability of blue water are difficult to predict. Will a more efficient use of soil moisture for rain fed crop production indeed translate into decreased blue water flows? The link between groundwater and surface water abstraction is more straightforward. However, it is still difficult to predict the precise effect of groundwater abstraction in a given location on the surface water availability somewhere downstream.

The physical uncertainties mentioned here must be acknowledged. If a proper understanding of such processes is lacking, in the first instance conservative estimates should be made on possible impacts of certain interventions. The organisation responsible for water management should then put in place a programme of data collection meant to gradually improve the understanding of these dynamic processes.

Institutional uncertainty

A different type of uncertainty is created by the institutions that are involved in water allocation. If the manner in which such institutions allocate water is unknown to the users or not well understood by them, or seen as haphazard, then users may distrust the allocation process. They will receive the wrong incentives and may, for instance, overstate their water requirements, hoard water or even over-use it.

The institutional system of water allocation should therefore be transparent to users. All users should know the principles and procedures guiding the allocation of water. Moreover, the allocation process must treat all users in the same way. It must also be transparent, and information on permits granted or permits refused must be freely accessible, not only to all water users, but to the wider public as well. A fair and transparent allocation process will enhance the individual users' trust in the process, and will increase their confidence in the worth of their permits/rights to use water. Trust in the allocation process will enhance users willingness to invest in water related infrastructure, and desist from "free-rider behaviour" in times of water scarcity.

2.8 Efficiency and equity

It could be argued that equity, efficiency and ecological integrity should form the pillars of any water management activity. Since water allocation is a major water management activity, and so should inform water allocation decisions. Supposing that the environmental/ecological water requirements are adequately taken care of, by assigning to the environment rights to sufficient water with an acceptable ecological regime, then equity and efficiency remain.

Some people believe that there is a trade-off between the principles of equity and efficiency; i.e. a more efficient allocation system may ignore certain issues of equity, and vice versa, a more equitable allocation system may be less efficient. This is not necessarily true for all situations. Some tentative definitions and some implications for water allocation are briefly explored below.

2.8.1 Equity

Equity can be defined as affording everyone a fair and equal opportunity in the utilisation of the resource according to one’s needs. Equitable access does not necessarily mean access to equal quantities but rather equal opportunity to access water (Reference 2.9). Equity deals with the distribution of wealth or resources among sectors or individuals of society.

2.8.2 Efficiency

Different definitions of efficiency can be used, depending on the objective to be achieved. The reason why efficiency is important is that water is a finite and often scarce resource. Generally, efficiency measures how much one can do with one unit of water. Economic efficiency would then measure the benefits derived from a unit volume of water used. Water use efficiency measures the amount of water actually used for a given use.

At a more abstract level, efficiency can also indicate to what extent the ensemble of technical, legal, institutional, economic and other measures induce efficient use of the scarce water. For instance, certain legal and institutional arrangements may enhance people's willingness to privately invest in water infrastructure, or induce them to waste less water, or pollute less. This will eventually lead to increased water use efficiency as well as increased economic efficiency.

This wider definition of efficiency calls for pricing arrangements that ensure cost recovery of water services. This will not only give the correct signal to water users, namely that water is valuable and should not be wasted, but will also lead to the sustainability of infrastructure and institutions. The wider definition of efficiency also calls for suitable legal arrangements that provide users with sufficient security of water tenure, such that they are willing to invest in water-related infrastructure.

2.8.3 Trade-offs

The principle of economic efficiency is often translated into proper pricing of water services. This may obviously jeopardise the equity principle, in that poorer households may not be able to buy such a service. The fact that poorer households are thus denied access to a basic amount of water may however be extremely costly to society (e.g. in terms of disease, ill health). From a societal perspective it may therefore be highly efficient to provide all households with a very cheap (subsidised) lifeline quantity of water, and to make up the financial shortfall through cross-subsidies. In this manner efficiency and equity in water allocation systems may be achieved.

2.9 Water losses

Reducing water losses often has a high priority in attempting to balance demand with supply. However, water losses should always be carefully and precisely defined. This is because it depends on the scale and the boundaries whether water is considered a loss or not. At the global scale no water is ever lost. At the scale of an irrigation scheme, a water distribution efficiency of 60% indeed means that slightly less than half of the water is lost. Part of this water, however, may return to the river and be available to a downstream user. At the scale of the catchment, therefore, it is the transpiration of crops (40% in this example) that can be considered a loss!

In many situations, and especially in irrigated agriculture, a reduction of water losses may not free up the "saved" water. Even "real" water losses, such as when water is released from a dam through the river bed for a downstream user, may provide an important service (e.g. recharge of aquifers and water for the environment). Once such services are recognised and formalised into permits (or in a "Reserve", as done in South Africa), the water manager may sometimes be able to find solutions that are advantageous to a number of different parties. In other cases, of course, this may not be possible. Analysing water losses should therefore always:

- clarify the scale and boundaries at which the analysis is done
- acknowledge both the consumptive and non-consumptive parts of the water use under consideration
- consider any other type of use (including the environment) that may benefit from the water "lost".

2.10 Water allocation between sectors

Some types of water use add more value than other types. The classic case is the different values attained in the agricultural and urban sectors: the value attained in urban sectors is typically an order of magnitude higher than in agriculture (Reference 2.2). If water is currently used in the agricultural sector, the opportunity cost, i.e. the value of the best alternative use, may be ten times higher, subject of course of "location and the hydraulic connections possible between users" (Reference 2.2). Thus a shift towards the higher value use is often promoted.

Whereas the opportunity cost of water for domestic water use may be highest, the moment availability is higher than demand, the opportunity cost of the water will fall to the next best type of use. It is just not possible to consume all the water at the highest value use. The proper opportunity cost for irrigation water may therefore be only half, or less, than the best alternative use (Reference 2.5). Even then the reliability of supply acceptable to irrigated agriculture is much lower than that for urban water supply: a storage dam yielding x m^3 of water supplied to irrigation at 80% reliability, may yield only 0.5x m^3 (or less, depending on hydrology) for urban water supplied at 95% reliability. The effective opportunity cost of water used for irrigation should therefore again at least be halved. The resulting opportunity cost is thus only a fraction of that some neo-classical economists claim it to be.

Figure 2.1 shows the variation of supply and demand in an imaginary case. It shows that, in general, primary (domestic) and industrial demands, with the highest ability and willingness to pay, require a high reliability of supply, which is normally achieved through relatively large storage provision. Environmental demands are also not the most demanding on the resource. Agricultural water requirements tend to be much higher, fluctuate strongly but also accept a lower reliability of supply.

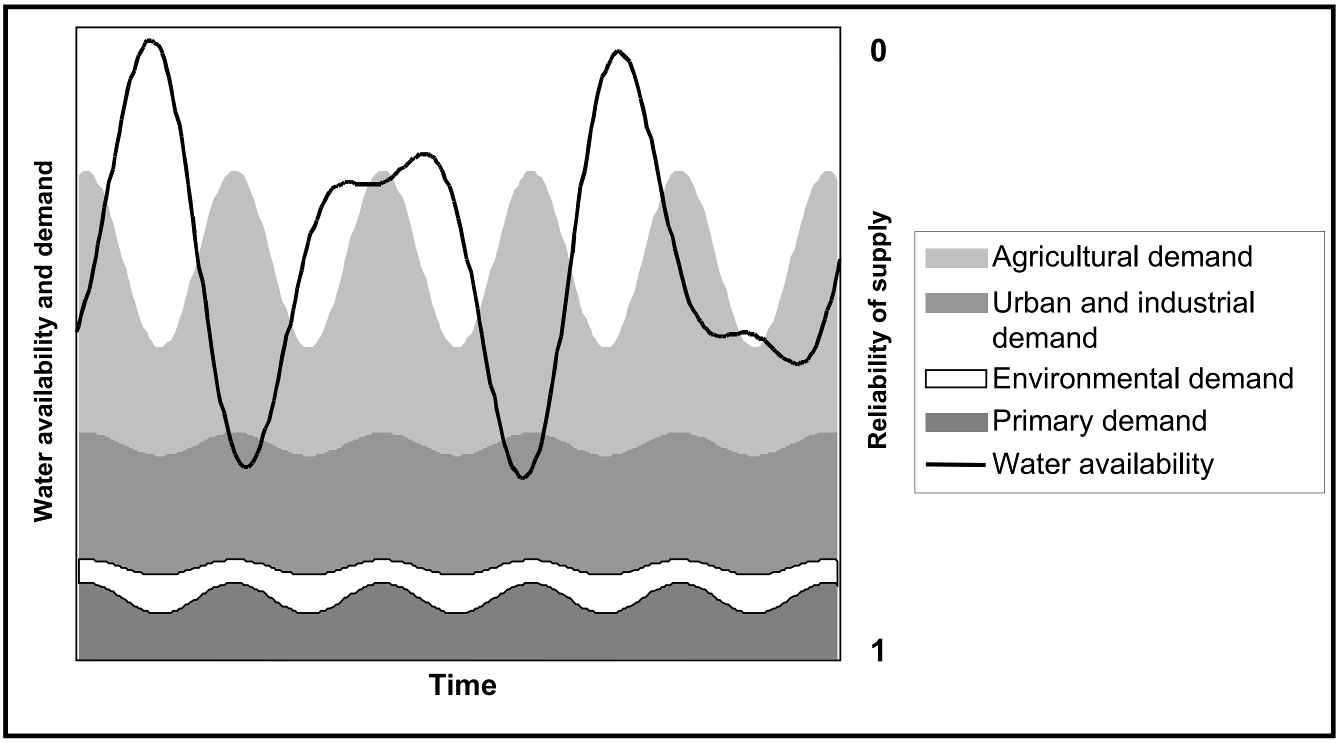

Figure 2.1 Variation of water availability and demand, and reliability of supply

The emerging picture is that the sectors with highest value water uses should have access to water. In many countries these sectors require only 20% to 50% of average water availability, and these demands can easily be satisfied in all but the driest years. In most years much more water will be available, and this water should be used beneficially, for instance for irrigation. There is therefore no need for *permanent* transfers from agriculture to other sectors, except in the most heavily committed catchment areas of the world. What is needed is a legal and institutional context that allows *temporary* transfers of water between agriculture and urban areas in extremely dry years. No market is required to cater for such exceptional situations. A simple legal provision would suffice, through which irrigators would be forced to surrender stored water for the benefit of urban centres against fair compensation of (all) benefits forgone. In those heavily committed catchment areas where permanent transfers of water out of the agricultural sector are required, normally voluntarily negotiated solutions can be agreed, provided the laws allow this to happen.

2.11 Recommendations on water allocation

An important purpose of water management is to match or balance the demand for water with its availability, through suitable water allocation arrangements. The balancing of water demand with water availability is catchment specific and hence there is no one particular method that can be recommended. The balancing of supply with demand will often involve a process of decision making where difficult compromises have to be made. In all cases, the water allocation process requires a sound quantitative understanding of both water availability and water demand. Moreover, the following aspects should receive careful attention, and possible win-win combinations sought:

- The constitutional obligation to provide a basic amount of fresh water to the population;
- The legal (or treaty) obligation to consider downstream requirements beyond the area being considered for water allocation;
- The legal obligation to provide for environmental water requirements;
- Water losses should be analysed considering different spatial scales, and the unintended functions these losses may serve;
- Allocation principles should include clear provisions for (extreme) drought situations;
- Allocation principles should promote water users' willingness to invest in water infrastructure and to improve efficiencies.

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3. ENVIRONMENTAL WATER DEMAND AND USE

3.1 Background

The environment is increasingly being considered a legitimate water user in many SADC countries. As a consequence the water requirement of the environment needs to be estimated. The amount of water that will be allocated to the environment is a decision made by society, and is to some extent arbitrary. The quantity of water allocated to the environment will always be less than what the environment ideally would require, namely the natural, undisturbed, flow regime of a river. Society, therefore has to weigh the potential costs and benefits to the environment and to all other water users, of allocating (or not) a certain amount of water to the environment. In so doing, society accepts a certain modification of the natural environment. This accepted level of modification may differ from river to river, and is sometimes defined in terms of "ecological management classes".

The environmental or instream flow requirement is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the riverine ecosystem in a prescribed state (e.g. pristine, good, satisfactory). However, an environmental instream flow often fulfils a number of different functions. In addition to the ecology of a watercourse there may be a need to recommend instream flow requirements for the following reasons:

- Protection of the rights of other abstractors;
- Navigation;
- Prevention of saline intrusion;
- Dilution of effluent;
- Maintenance of the flood carrying capacity of the channel;
- Cultural and social reasons;
- Prevention of invasive plant species;
- Maintenance of the channel diversity.

There are numerous methods available for the assessment of environmental flows. These are outlined below.

3.2 Environmental flow assessment methods

The environmental flow assessments are used as a method for estimating the quantity of water required. An environmental flow assessment produces one or more descriptions of possible future flow regimes for a river each linked to an objective relating to the condition or the health of the riverine ecosystem. For example the requirement may be stated as “a water depth of at least 50 cm is required throughout the year to provide adequate wetted perimeter for a particular fish species”. Alternatively it may be more complex detailing a comprehensive flow regime that specifies magnitudes, timing and duration of low flow and floods at a number of temporal scales.

There is a range of methods available for assessing instream flow requirements based on:

- Simple hydrological indices;
- Hydrological simulations;
- Consensus and discussion based approaches;
- Historical data analysis;
- Biological response simulation techniques often referred to as habitat simulation methods.

Few, if any, of the approaches available provide a complete solution and hence a wide range of approaches may be appropriate, especially for different levels of planning. The environmental or instream flow requirement for a watercourse is the minimum flow required to enhance or maintain aquatic and riparian life. There are several assessment procedures for determining environmental flows. The decision on which method to use is dependent on the following:

- Type of river (e.g. perennial, seasonal, high base flow, flashy);
- Perceived environmental importance;
- Complexity of the decision to be made;
- Increased cost and difficulty of collecting large amounts of information;
- Severity of different resource developments.

The level of detail required will be case dependent. In many countries a two-tier system is used comprising catchment wide and scoping method for "level-one" studies and more detailed methods for "level-two" studies. Level two studies move away from standard setting (i.e. setting a single minimum flow) and towards an incremental approach (i.e. quantification of varying instream requirements) that enable various management options to be assessed.

Stages in determining the minimum flow requirement may be as follows:

- Outlining of requirements;
- Data collection method;
- Modelling and analysis process, and the use of this information to set an instream flow requirement in a rational manner;
- Use of tools in an active manner (e.g. reservoir releases);
- Follow up monitoring of success and revision of goals.

Knowledge concerning the environmental requirements of rivers is likely to remain incomplete for the foreseeable future. As a consequence there will always be a danger that an instream flow requirement will be set too low, resulting in damage to the riverine environment or too high resulting in potential waste of resources or exploitation of other of other more sensitive water resources. It should also be noted that too much water during natural low flow periods could lead to undesirable changes especially in the arid and semi-arid areas that exist in southern Africa.

The methods discussed in the Handbook are shown below.

Environmental flow assessment methods

Hydrological index methodologies discussed include:

- Tennant method;
- Texas method;
- Flow duration curve method;
- Aquatic base flow method;
- Range of variability approach.

Hydraulic rating methodologies discussed include:

- Wetted perimeter method.

Habitat simulation methodologies discussed include

- Building block methodology

Holistic methodologies discussed include:

- Instream flow incremental methodology.

Each method differs in its data requirements, procedures for selecting flow requirements, ecological assumptions and effects on river hydraulics.

3.3 Hydrological index methods

Hydrological index methods are the simplest type of environmental flow assessment and rely on the use of historical hydrological data for making flow recommendations. These data are usually in the form of long-term, historical monthly or daily discharge records. These are used to determine environmental flow requirements. Hydrological index methodologies are the simplest and least data intense methods estimating instream flows. There are of the order of 15 frequently referenced, hydrological based methods for environmental flow requirements. However, many of these are specific to regions outside of southern Africa. The most commonly used methods include:

- The Tennant (or Montana) method;
- Texas method;
- Annual minima;
- Flow duration curve analysis;
- Range of variability approach.

These methods are discussed below.

3.3.1 The Tennant method

The Tennant method is based on discharge statistics and historical flows. The minimum flow requirement for a watercourse is expressed as a percentage of the mean annual naturalised flow at a specified site. The naturalised flow regime is the hydrological regime of the watercourse with the man-made influences (e.g. abstractions of water, changes in runoff resulting from urbanisation) removed from the flow series. To produce a naturalised flow series flow records are required. This series is then modified to remove man-made influences thus giving a naturalised flow record. There are a number of hydrological textbooks that describe in detail how to go out naturalising a flow series.

The Tennant method was developed to specify minimum flows for watercourses in the mid-western USA. Percentages of the mean annual naturalised flow are specified to maintain the riparian habitat in a particular state e.g. 10% for survival, 30% for a satisfactory healthy ecosystem, 60% to 100% for a pristine ecosystem. It was developed using calibration data from hundreds of watercourses in the USA (Reference 3.24).

There have been several modifications to the Tennant method by various practitioners since it was first used in the USA in 1976. These include the following:

- Modifications for spring runoff;
- Equations to take into account existing flow modifications;
- Modifications to incorporate monthly minimum flow levels.

Where the Tennant method is used the following should be noted:

- The basic method takes no account of flow fluctuations and seasonal effects;
- The method is more suitable to large, perennial watercourses where flow variability is less than for seasonal watercourses;
- No account is taken of the stream geometry;
- Recommendations should be compared to other flow statistics e.g. mean 10 and 30 day naturalised low flows.

The Tennant method could provide a “model” for the development of minimum flow levels at a catchment level for southern Africa. However, to modify the Tennant method so that it can be used in the southern African context would require extensive fieldwork to be undertaken in the region. This would entail both the collection of biological and hydrological data throughout southern Africa to enable relationships between discharge and physical habitat availability and suitability for aquatic biota to be established. The method would also not be applicable for semi-arid and arid regions where watercourses are dry for several months of the year as it is likely to result in flows that are too high.

Advantages of the Tennant method

The main advantages of the Tennant method are:

- It is simple to use;
- Once relationships between discharge and the aquatic environment have been established it requires relatively little data;
- It does not require costly fieldwork to be carried out.

Disadvantages of the Tennant method

The Tennant method has the following disadvantages:

- It does not preserve the natural variability of the watercourse by taking account of daily and yearly variation of flows i.e. the method only prescribes a minimum environmental base flow;
- The naturalised flow regime (i.e. the regime before any anthropogenic influences on the watercourse have occurred) has to be established;

- The method never produces a zero flow recommendation. However, in semi-arid regions where watercourses are naturally dry for some months of some years a zero flow may be appropriate;
- The method is based on fieldwork carried out in the USA. This fieldwork is not applicable to semi-arid regions of the world such as southern Africa. The Tennant method could act as a model for southern Africa, however, this would entail the collection and correlation of both biological and discharge data for the region;
- The relationship between flow and the state of the aquatic ecosystem is poorly established;
- The method is site specific.

3.3.2 The Texas method

This method uses variable percentages of the monthly median flows. The percentages are calibrated to regions with characteristic fauna taking into account results from previous fish inventories and known life history requirements. The Texas method is an advancement over existing preliminary planning methods. This is because it is the first such technique to treat the recommended flow percentage for each month as a variable along with the biological characteristics (e.g., spawning/incubation periods) and regional hydrological characteristics (e.g. highly variable monthly flows with positive skewness) (Reference 3.7).

3.3.3 Flow duration curve analysis

In flow duration curve analysis naturalised or present-day historical flow records are analysed over specific durations to produce curves displaying the relationship between the range of discharges and the percentage of time each of them is equalled or exceeded. For example in some cases the 90 percentile flow (Q_{90}) may be set as the minimum environmental flow. This is the flow that is exceeded 90% of the time. A typical example of a flow duration curve is shown in Figure 3.1. However, to apply such a flow duration curve technique, hydrological flow data are required.

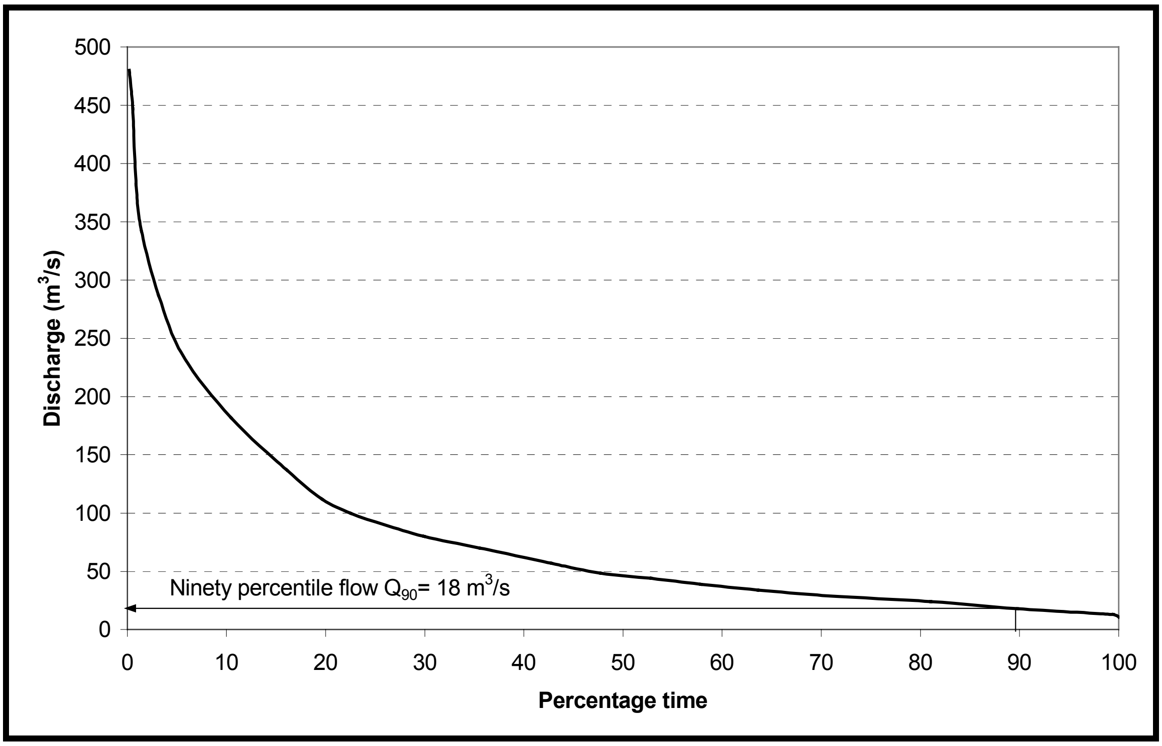


Figure 3.1 Flow duration curve method

3.3.4 Aquatic base flow method

The aquatic base flow method is based on the assumption that the median flow for the lowest flow month is adequate throughout the year for fisheries, unless additional flow is required to meet the needs of spawning and incubation. An example of the method is given below.

Example of the aquatic base flow method

The Lukozi River in Zimbabwe has the following monthly median flows:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow (m^3/s)	14	12	9	8	5	2	1.5	2	3	4	7	13

Using the aquatic base flow method the minimum environmental flow requirement is 1.5 m^3/s.

It should be noted that many rivers in southern Africa are ephemeral and will have no flow during the dry season. For such watercourses the aquatic base flow method will yield a flow of zero. Hence the aquatic base flow method is unlikely to be applicable for many watercourses in the SADC region.

3.3.5 Range of variability approach (RVA)

The range of variability approach is the most sophisticated form of the hydrological index methodologies. It is aimed at providing a comprehensive statistical characterisation of the ecologically relevant features of the flow regime, recognising the crucial role of hydrological variability in maintaining ecosystems. The method is intended to be applied to rivers where protection of the natural ecosystem functioning and conservation of the natural biodiversity are the primary management objectives. The methodology comprises six basic steps, the first of which is the characterisation of the natural range of hydrological variation using a number of ecologically relevant hydrological indices, termed Indicators of Hydrologic Alteration (IHA). These are summarised in Table 3.1.

Table 3.1 Summary of hydrological parameters used in the Indicators of Hydrologic Alteration

IHA statistics group	Regime characteristics	Parameters
Group 1: Magnitude of monthly water conditions	Magnitude Timing	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude Duration	Annual minima and minima 1 day means Annual minima and minima 7 day means Annual minima and minima 30 day means Annual minima and minima 90 day means
Group 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1 day minimum and maximum
Group 4: Frequency and duration of high and low pulses	Frequency Duration	Number of high and low pulses each year Mean duration of high and low pulses
Group 5: Rate/frequency of consecutive water condition changes	Rates of change	Means of all positive differences between daily values Means of all negative differences between daily values

Source: Reference 3.20

The second step is to select management targets for each of the IHA parameters. The fundamental concept is that the river should be managed so that the annual value of each IHA parameter falls within the range of natural variation of that parameter. The management targets should be based on available ecological information. In the absence of adequate ecological information it is recommended that ±1 standard deviation is used as the default for the initial setting of targets.

Step 3 is to use the flow based management targets, known as the Range of Variability (RVA) to set up management rules that will enable the targeted flow conditions in most, if not all, years. Step 4 involves implementing a monitoring programme to assess the ecological effects of the new management system. The fifth step is to characterise the actual stream flow variation using the same hydrologic parameters and compare then to the RVA targets. The final step is to repeat the first five steps incorporating the results of the preceding years' management and any new ecological research or monitoring information to revise either the management system or the RVA targets.

The RVA method requires at least 20 years of flow data. If 20 years worth of data are not available it is usually necessary to extend the record. In some cases hydrological simulation models may be used. The RVA approach was designed to bridge the gap between applied river management and current aquatic ecology theories (Reference 3.20).

3.3.6 Unsuitable historical discharge techniques.

A hydrological technique that is not acceptable for establishing instream flows for fish is the 7 day 1 in 10 year low flow (expressed as 7Q10). This statistic was developed in the USA to ensure wastewater treatment plants did not violate water quality standards during droughts. It does not address instream environmental requirements.

3.3.7 Advantages of hydrological index methodologies

The advantage of hydrological methodologies are as follows:

- They are relatively simple to use;
- They are an appropriate method to use for use at a catchment level for establishing low-resolution estimates of the quantity of water required
- Relatively little site-specific data are needed, in many cases only historical flow records are required;
- It does not require costly fieldwork to be carried out;
- Hydrological indices that are derived from such methods can be incorporated into as sub-components of holistic type methods.

3.3.8 Disadvantages of hydrological index methodologies

The disadvantage of hydrological index methodologies are as follows:

- Although the hydrological index methodologies require a relatively low level of resources per site they require a large amount of field work to be carried out in order to set the various standards and parameters required;
- These methods should only be applied for high level scoping studies.

3.4 Hydraulic methods

Hydraulic methods relate various parameters of the hydraulic geometry of a watercourse channel to discharge. The most commonly used hydraulic method is the wetted perimeter technique.

3.4.1 The wetted perimeter technique

Background

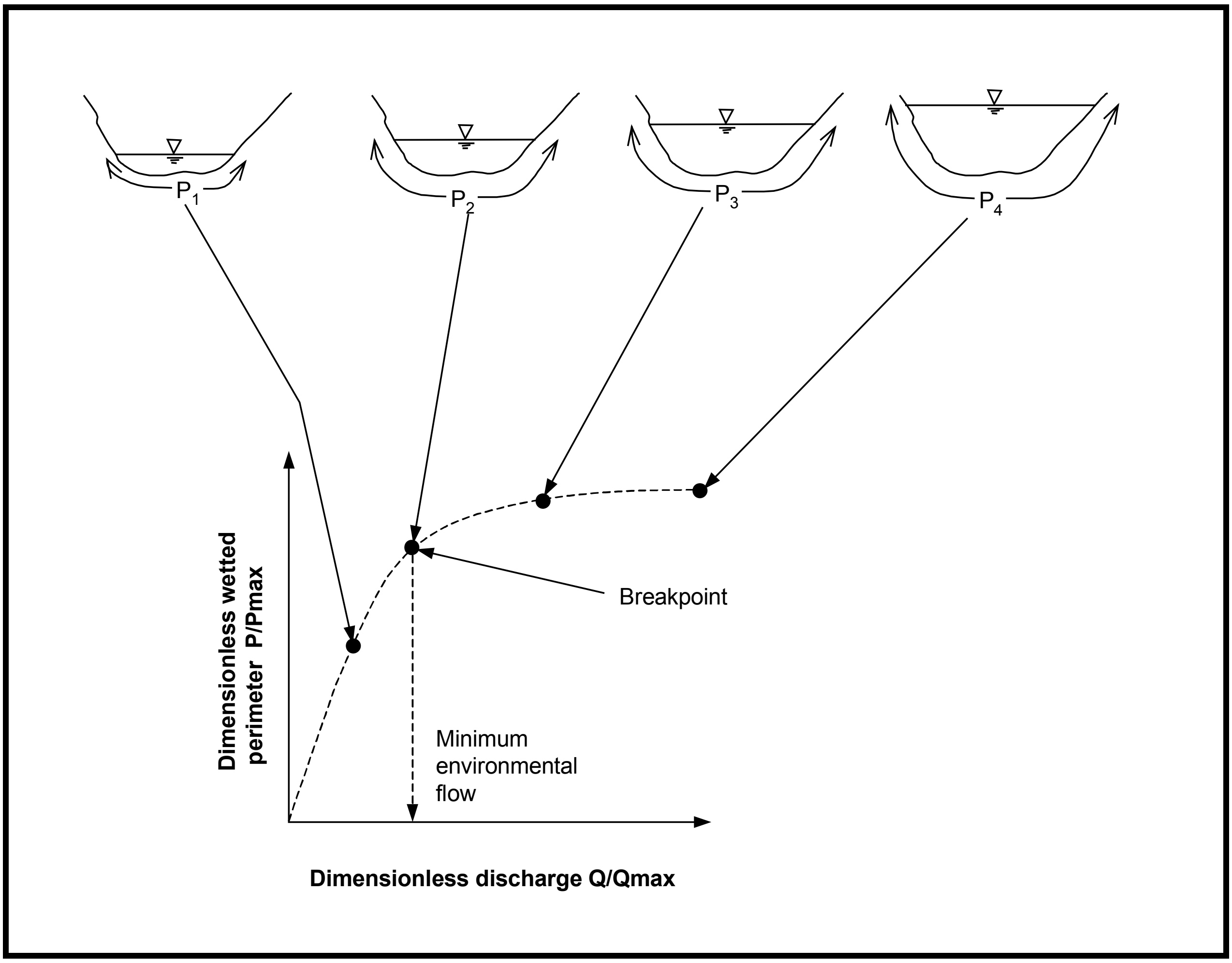
The wetted perimeter method is the simplest of the field survey-based, site-specific techniques that allows the minimum instream flow of a watercourse to be calculated (Reference 3.25). It should be noted that the wetted perimeter technique includes no explicit representation of the aquatic habitat. To establish the minimum environmental flow a wetted perimeter-discharge relationship is generated. The wetted perimeter of a watercourse is defined as the length of the line of intersection of the channel wetted surface with a cross-sectional plane normal to the direction of the flow.

The wetted perimeter-discharge relationship should be generated for watercourse cross-sections that are at riffle sites or at sites where fish passage is likely to be limited. A riffle is an area of shallow rapids in an open stream where a turbulent water surface is induced by obstructions that are wholly or partly submerged. A photograph of a riffle on a South African watercourse is shown in Figure 3.2.

Figure 3.2 Photograph of a riffle on a South African watercourse

The method assumes that preserving the wetted perimeter in critical habitat areas such as riffles, adequate flow will be available to maintain aquatic life. The wetted perimeter method is illustrated in Figure 3.3 and applied as follows:

- The relationship between the wetted perimeter and the discharge of the watercourse at a riffle, or where the passage of fish is limited, is established;
- A non-dimensional graph of wetted perimeter versus discharge is plotted. The values of wetted perimeter and discharge are expressed as a proportion of their maximum value;
- The breakpoint of the curve is established. The breakpoint indicates where small decreases in the flow result in increasingly greater decreases in the wetted perimeter. The breakpoint on the wetted perimeter-discharge curve can be mathematically defined as the point where the curvature of the curve is 45^o. It should be noted that it is not possible to reliably assess the breakpoint by eye. The breakpoint should be taken at the point where the slope of the curve is one ($dy/dx = 1$) (Reference 3.25);
- Compound cross-sections with multiple benches may produce an irregular relationship between wetted perimeter and discharge, and there may be more than one breakpoint. In these cases the lowest breakpoint is usually the most relevant to minimum flow determination;
- Once the breakpoint has been established the minimum instream flow requirement can be estimated.



Source: Reference 3.25

Figure 3.3 Use of the wetted perimeter method to estimate instream flows

An important consideration in site selection is the ease with which the flow through the site can be measured or calculated. Discharge through a riffle is relatively difficult to measure directly with any confidence by manual flow gauging. It is often better to measure the discharge at a nearby site suitable for manual gauging or use readings from a nearby gauging station. These surrogate discharge measurements should be sufficiently close to the site of interest that any losses or inflows between the two sites could be ignored.

It should be noted that compound cross-sections with multiple benches will produce an irregular relationship between wetted perimeter and there may be more than one breakpoint where the slope is unity. The lowest breakpoint is probably the most relevant to minimum flow determination.

Data requirements

- Surveyed watercourse cross-sections at appropriate locations e.g. riffles;
- Measured or generated stage-discharge curve for the surveyed cross-section.

Example of the wetted perimeter method

Current metering has been carried out for a number of discharges for the Hwadzi River in Zimbabwe at a point in the watercourse where the passage of fish is limited. A surveyed cross-section of the Hwadzi River at the point, shown in Figure 3.4, where the discharge measurements have been made is available.

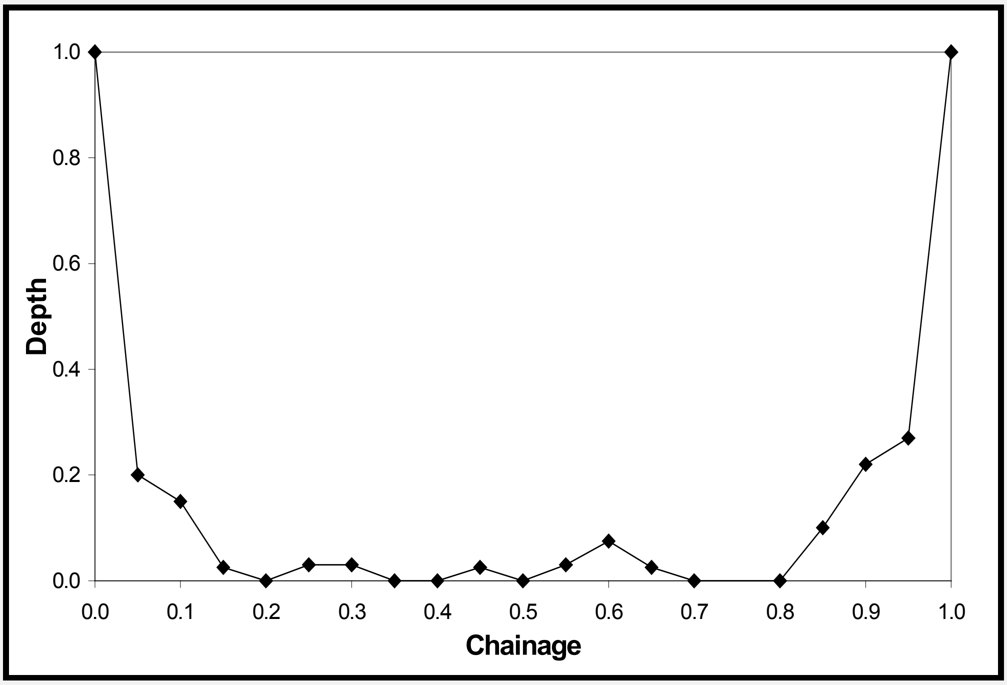


Figure 3.4 Surveyed cross-section of the Hwadzi River

An estimate of the minimum instream environmental flow requirement is made as follows:

(i) A graph of wetted perimeter versus discharge is plotted.
(ii) The wetted perimeter and discharge data are non-dimensionalised with respect to their maximum values.
(iii) A relationship is established between the dimensionless wetted perimeter and discharge. This is shown in Figure 3.5. In this example a curve was fitted and the wetted perimeter was found to be related to the discharge by the equation $P = 0.08\ln Q + 1$.

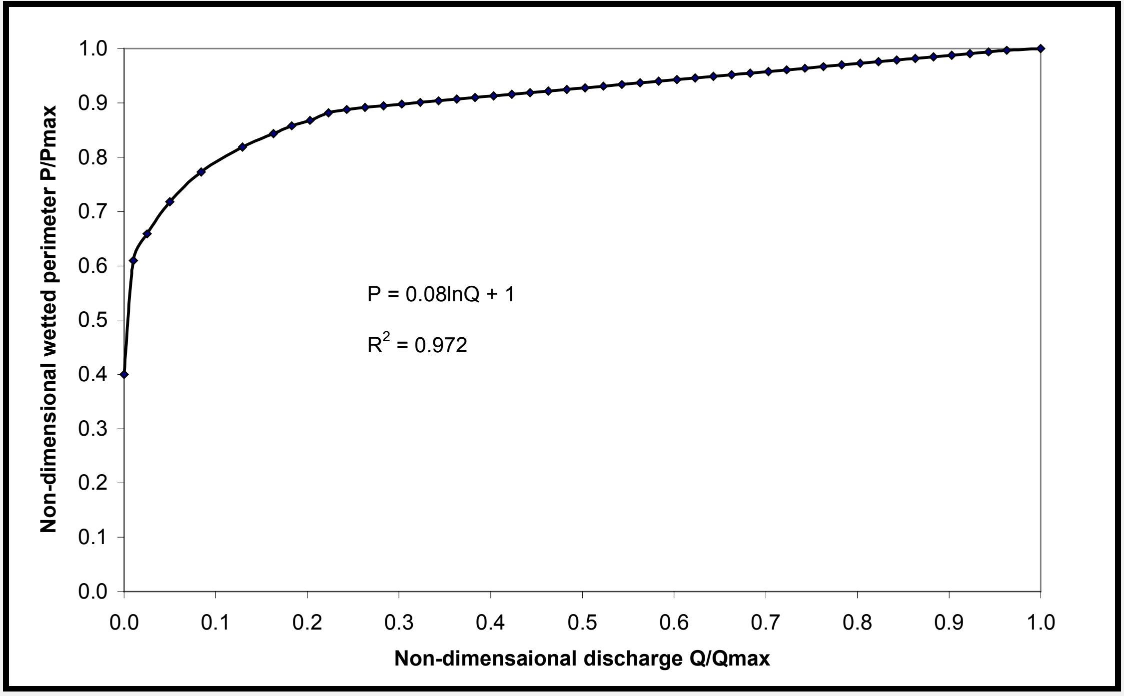


Figure 3.5 **Non-dimensional wetted perimeter versus discharge relationship**

The breakpoint is calculated. The breakpoint is defined by the point on the curve where the gradient is one (i.e. $\frac{dy}{dx} = 1$). Hence given that P = 0.08lnQ + 1 differentiating gives $1 = \frac{0.08}{Q}$. Hence the minimum value of flow to meet the instream flow requirement is:

$Q_{instream} = 0.08Q_{max} = 0.08 \times 16 = 1.3\ m^3/s$

In cases where it is not possible to fit a simple relationship to the data, the slope of the relationship should be calculated for each plotted point until the point where the gradient equals one is established.

Source: Adapted from Reference 3.25

Advantages and disadvantages of the wetted perimeter method

The main advantages of the wetted perimeter method are:

- It is relatively simple to use;
- It requires relatively little data.

Disadvantages of the wetted perimeter method

The wetted perimeter method has the following disadvantages:

- It recommends only a minimum environmental base flow;
- The method is site specific.

3.5 Holistic methods

The most widely used holistic method in southern Africa is the building block methodology. This methodology for determining instream flow requirements is outlined below.

3.5.1 The building block methodology

The building block methodology was developed in South Africa by the Department of Water Affairs and Forestry and various academic institutions (Hughes and Münster 1999). The building block methodology requires the following:

- The total flow volume of the following four building blocks components:
    - Low flows;
    - Habitat maintenance floods;
    - Channel maintenance/Flushing floods;
    - Spawning migration flows;
- Monthly distribution of the four building block components;
- Establishment of the present ecological state (A to F) and future management category (A to D). These are given in Table 3.2.

Table 3.2 Ecological states used in the building block methodology

Class	Description of ecological state
A	Unmodified
B	Largely natural with few modifications
C	Moderately modified
D	Largely modified
E	Natural habitat loss extensive
F	Modifications at a critical level

Source: Reference 3.13

The major objective of the method is to estimate the values of the four building block components as a percentage of the mean annual runoff of the natural flow regime. A building block instream flow study would be carried out as follows:

(i) The monthly naturalised flow series for the site of interested must be established.

(ii) The ecological management class of the site is established with A being an unmodified site and F representing a site that had been modified to a critical level. There are methods for estimating the ecological management status of the site based upon various habitat integrity indices developed in South Africa.

(iii) The flow variability has to be established to summarise the variability within the wet and dry seasons. This is based on the average coefficient of variation (i.e. standard deviation/mean) for the three main wet season months and the three main dry season months (excluding those that have zero mean monthly flows). The actual coefficient of variation (CV) is the sum of these two means. The assumption is that rivers with a high degree of variability in their flow regime will require a lower proportion of their natural mean annual runoff because they are used to experiencing such conditions. Rivers with more reliable flows and less flow variation are assumed to be ecological less well adjusted to frequent extremes in the flow regime.

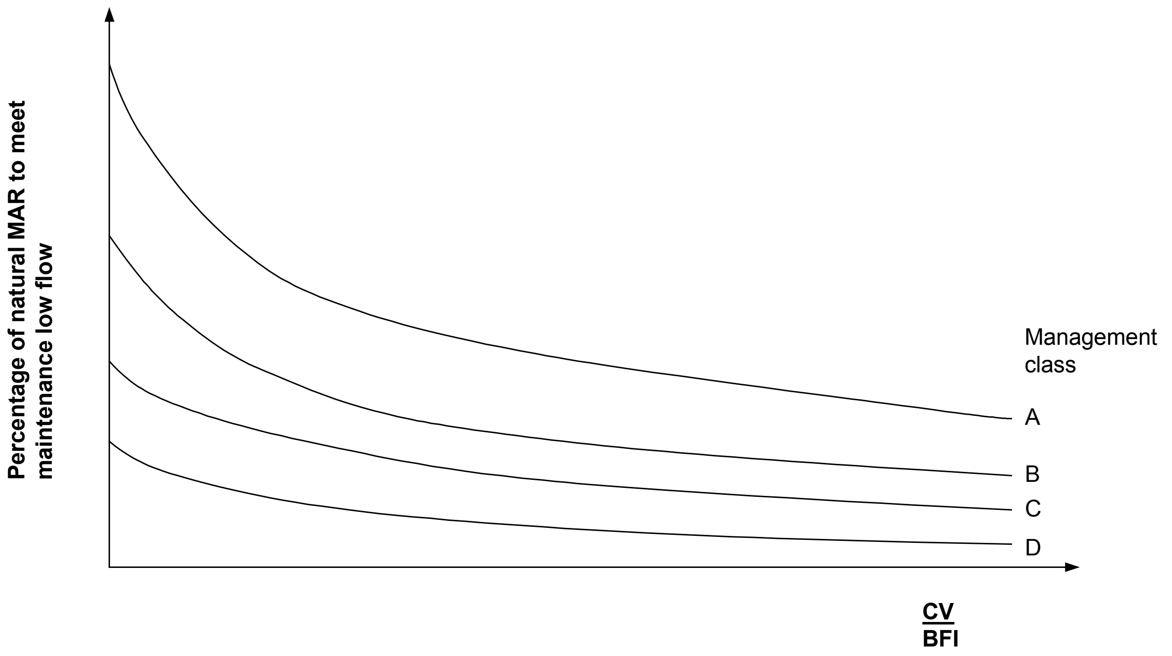
(iv) The base flow is calculated. The base flow index (BFI) is the proportion of the total flow occurring as the base flow. There are various hydrological methods to assess the base flow.

(v) A combined variability index is calculated by dividing the coefficient of variation by the base flow index.

(vi) For particular sub-catchments, curves can be constructed for maintenance low flow estimation and maintenance high flows versus the variability index (CV/BFI) for the four future ecological management classes. A typical set of curves is shown in Figure 3.6.

(vii) The drought low and drought high flows are established.

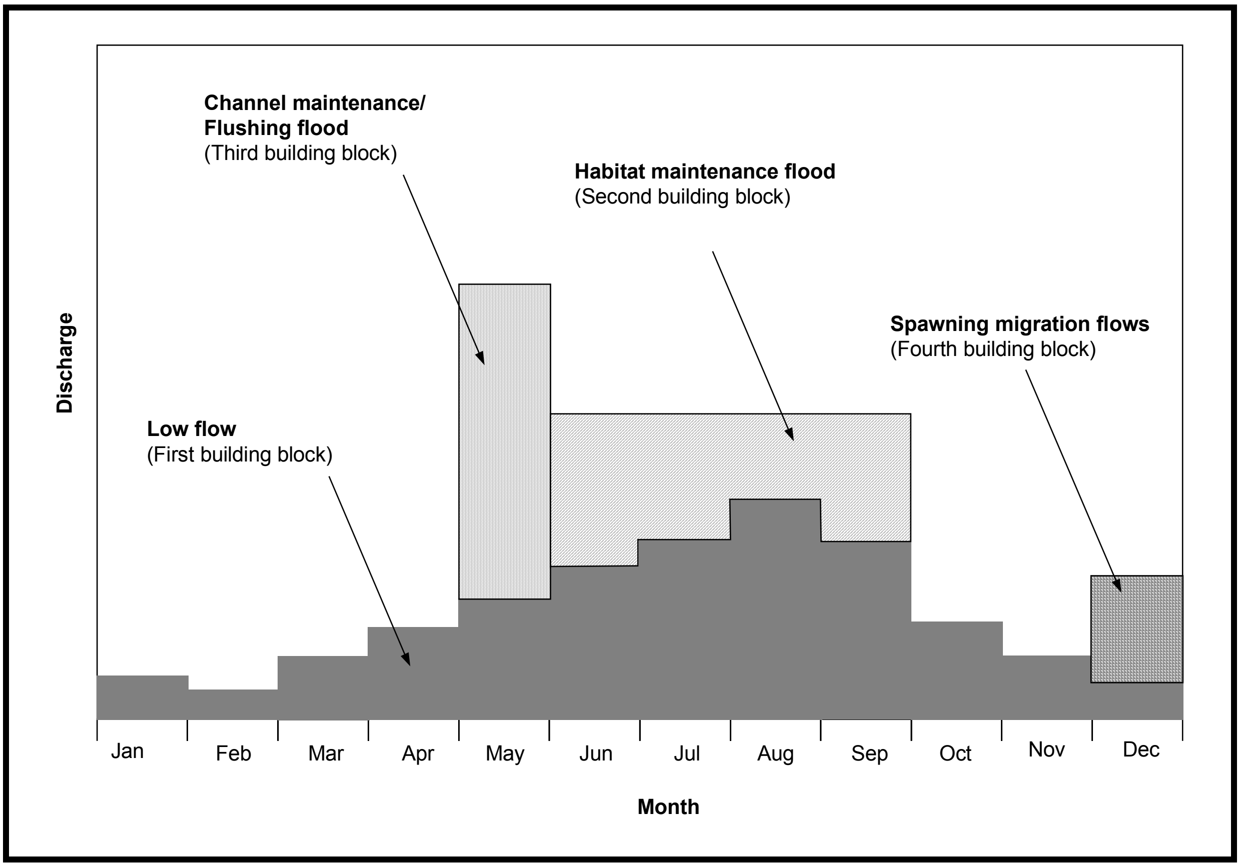
(viii) The monthly distribution of flows is then produced. It should be noted that one of the basic principles of the approach is that a higher proportion of the natural monthly flow is required during the dry months than during the wet months.



Source: Reference 3.13

Figure 3.6 Typical curves to establish the maintenance of low flows

Rhodes University in South African has produced a piece of software to automate the building block methodology. However, this software can only be applied in South Africa, Swaziland and Lesotho. A hypothetical instream flow requirement created using the Building Block Methodology is shown in Figure 3.7.



Source: Reference 3.13

Figure 3.7 Examples of the flow building blocks used in the building block methodology

Advantages of the building block method

The building block methodology has the following advantages:

- It takes into account the monthly flow variability for both high and low flows;
- It has been developed specifically for use in southern Africa;
- The low flow building block can be used to assess preliminary instream flow requirements.

Disadvantages of the building block method

The building block methodology has the following disadvantages:

- It is site specific;
- It requires an estimation of base flow, the natural mean annual runoff and naturalised flows.

3.6 Habitat methods

Habitat rating methods provide the most complex and the most flexible approach to environmental flow assessments. They provide information on how habitats change with flow for instream uses, either biological or recreational. No prior assumptions are made about the state of the natural ecosystem. Changes of physical habitats with stream flow are accounted for and combined with the habitat preferences of a given species to determine the amount of habitat available over a range of stream flow conditions. The result is a curve relating available habitat area and stream discharge. Optimum stream flows for a certain number of species can be ascertained from these curves, and the results can be used as a guide for recommending environmental flows. The most commonly used habitat method is the Instream Flow Incremental Methodology (IFIM). This is discussed below.

3.6.1 Instream Flow Incremental Methodology

The Instream Flow Incremental Methodology (IFIM) is a conceptual framework for assessing the effect of water resources development or management activities on aquatic and riverside ecosystems, and for solving water resources management problems and conflicts that involve the definition of an ecological flow to minimise impacts on ecosystems. IFIM is a collection of analytical procedures and computer models that allows the development of a different approach for each problem and situation. The goal of this method is to relate fish and wildlife parameters to stream discharge in equivalent terms to those used to estimate other beneficial uses of water.

IFIM is based on the assumption that living organisms in running water have their distribution (longitudinally and laterally) controlled by the hydraulic conditions. The decision variable generated by IFIM is the total habitat area with suitable conditions for a species at a particular life stage or for a particular activity (e.g. spawning), computed as a function of discharge. The environmental flow is usually the highest value of a range of minimum flows computed for several species, assuming that this value will be adequate for the preservation of the ecosystem. The target species, one or more, are usually game, commercial, endangered or indicator fish species (Reference 3.19).

IFIM relates changes in the extent of habitats that are available to aquatic species to changes in discharge. This allows instream flow demands to be expressed in the same terms as other water resource demands. The IFIM methodology is usually coupled with the Physical Habitat Simulation System (PHABSIM) model to generate a habitat-discharge relationship. IFIM coupled with PHABSIM can be used to predict changes in almost any environmental parameter that can be quantified in the form of a flow dependent relationship (Reference 3.19).

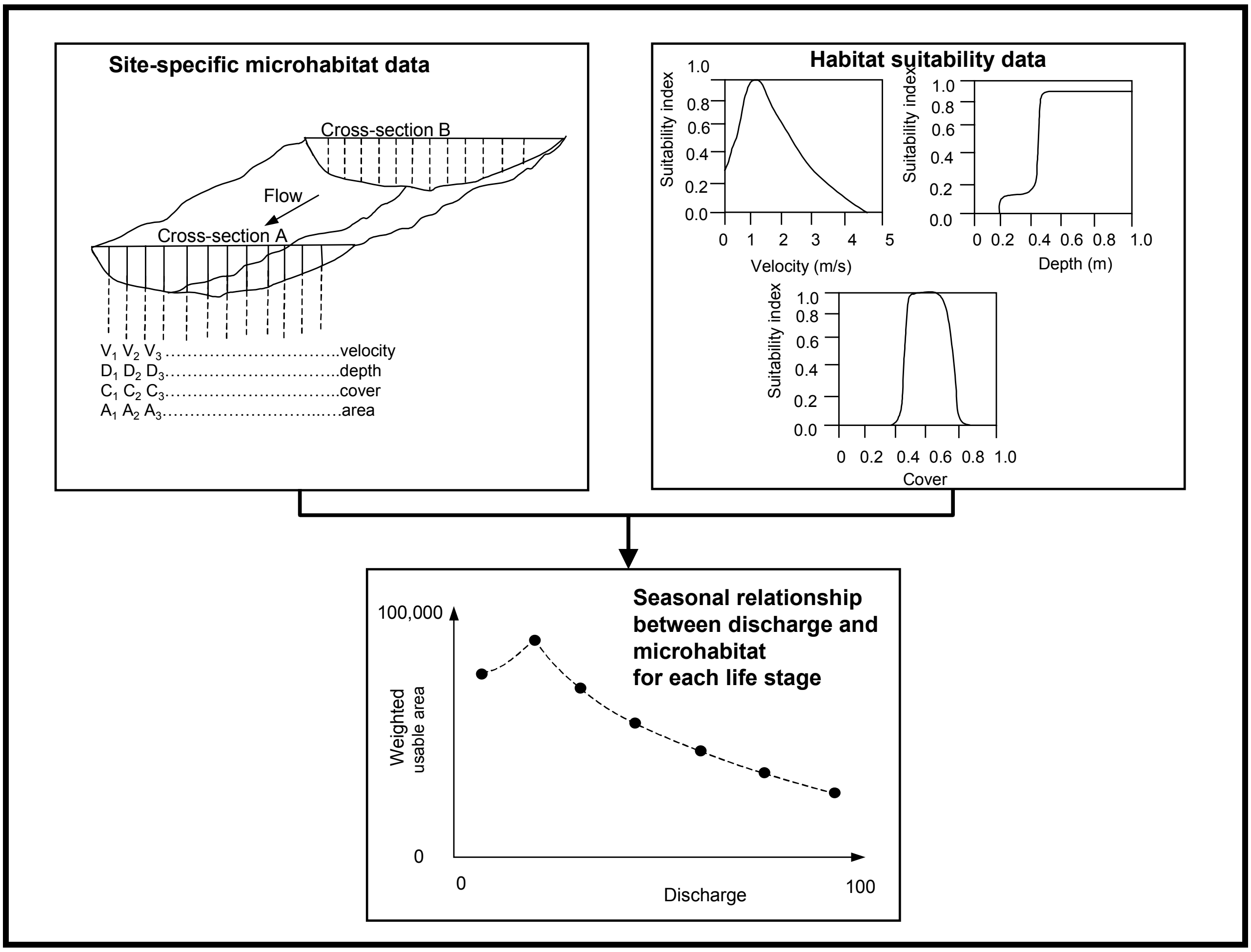
PHABSIM is a collection of computer programs that combine aquatic organisms preferences for velocity, depth and channel conditions to predict habitat availability at various discharge levels. It simulates the relationship between stream flow and available physical habitat (defined by depth, velocity, substrate and cover). For each life stage of the target species, the model requires expressions of the relative suitability for that species of the full range of values taken by these variables. These univariate curves are called habitat suitability indices; they may be derived from existing literature, expert opinion or by sampling techniques such as electro-fishing or snorkelling.

PHABSIM simulates suitable habitats for aquatic species by using depth, velocity and stream channel characteristics to describe local physical niches that are occupied by aquatic species. This method develops a measure of physical habitat called Weighted Usable Area (WUA). The PHABSIM methodology can be summarised as follows:

- The cross-section of the watercourse is divided up into a number of cells;
- Depth, velocity, flow area and cover conditions are measured or simulated for a given discharge;
- Suitability Index Criteria (SI) are used to weight the area of each cell for the discharge;
- The habitat values for each of the cells in the study reach are summed to obtain a single habitat value for the discharge;

- The procedure is repeated for a range of discharges and a graph of Weighted Usable Area (WUA) versus discharge is produced for a particular life stage of the indicator species;
- The WUA is the aggregate product of the Suitability Use Index Criteria (SI) and the area of each stream cell developed using stream gauging techniques. It is calculated as the summation, over all stream cells in a study reach, of the product of cell area and SI for depth, velocity and stream channel characteristic index (cell area x SI depth x SI velocity x SI channel index). It represents a description of the amount of equivalent optimal habitat occurring within a standard length of stream (Reference 3.19);
- Calculating the WUA for numerous discharges allows the relative habitat suitability of a watercourse under different flow conditions to be assessed.

PHABSIM allows changes in habitat resulting from changes in instream flow to be quantified and thus provides answers to "what if" water management questions. Figure 3.8 shows how PHABSIM calculates habitat values as a function of discharge.

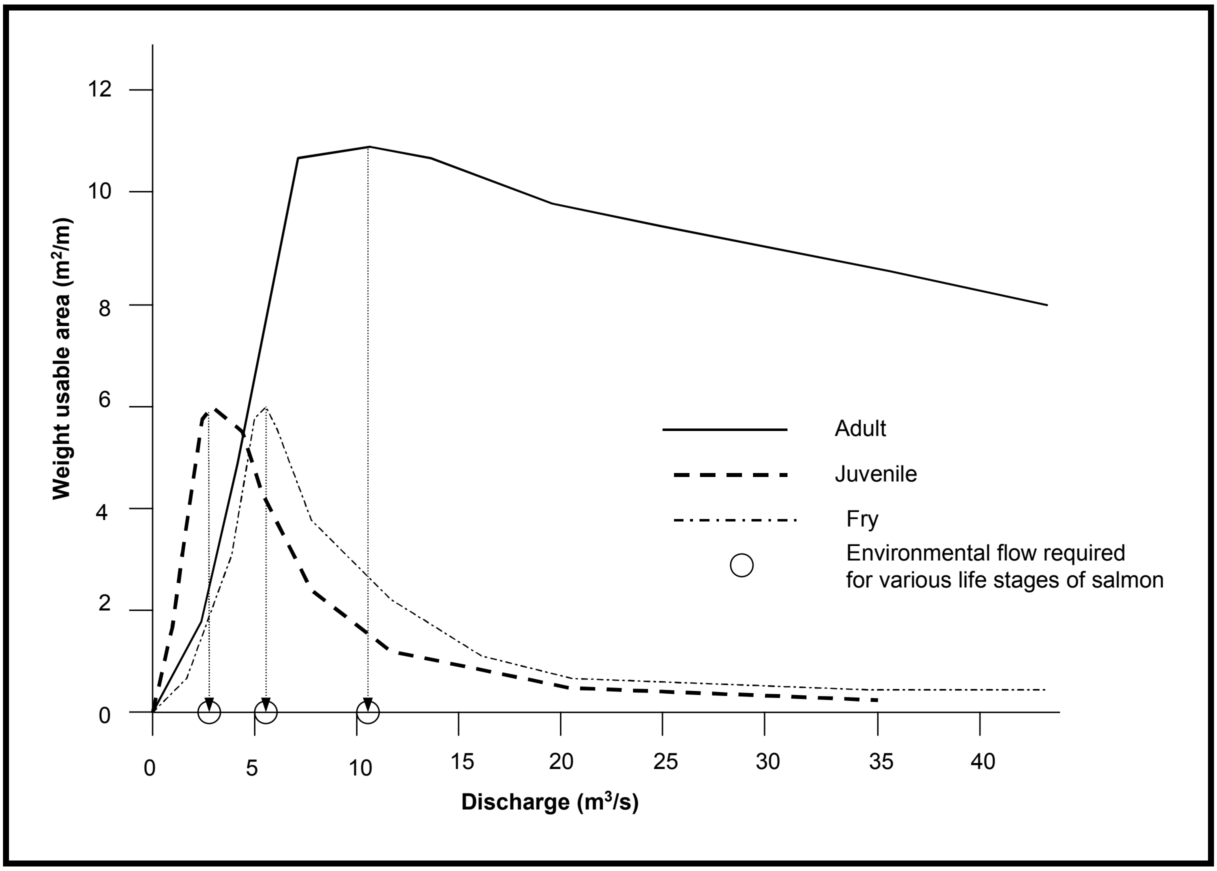


Source: Reference 3.19

Figure 3.8 Conceptualization of how PHABSIM calculates habitat values as a function of the discharge

PHABSIM contains a number of standard, one-dimensional, steady-state, open channel hydraulic models to predict values of depth and velocity at different simulation discharges. These are combined with habitat models to describe Weighted Usable Area (WUA) under a variety of channel configurations and flow management conditions. The use of hydraulic simulation models allows physical habitats to be described for unmeasured discharges. The models require calibration using field data collected at two or more calibration discharges and hence is fairly data intensive. Observations of substrate and cover are recorded using a coding system and are assumed to be independent of discharge. Once calibrated the model can simulate values of microhabitat variables over the full range of discharge within a river reach, combining the results with habitat suitability data to produce WUA versus discharge relationships.

Simulated values of microhabitat variables (from the calibrated hydraulic model) are combined with habitat preference data for each target species for each stage of life. Combining this with a time series of historical flows yields a time series of available physical habitat for each life stage of the target species. An example is shown in Figure 3.9. Using PHABSIM it is possible to simulate habitat curves relating to season and complete life cycles of target species. By relating habitat to discharge, PHABSIM provides a quantitative entity, allowing river ecologists to negotiate prescribed flows in equivalent terms to other water resource demands.



Source: Reference 3.19

Figure 3.9 Example of weighted usable area versus discharge curves for various life stages of a salmon

In summary, PHABSIM predicts the impact of changing flows on fish, invertebrates and macrophytes and predicts physical habitat change and quantifies it in respect of the ecological value of habitat losses/gains. Hydraulic modelling techniques such as PHABSIM require detailed hydraulic and morphological surveys and knowledge of the habitat preferences of the species of interest.

Data requirements

The data requirements to carry out an IFIM study using PHABSIM are dependent upon the level of detail to which the analysis is carried out. A minimum of the following data is required:

- Historical stream flow data;
- Stream flow measurements;
- Channel geometry measurements;
- Indicators of habitat suitability for each species (from literature, expert opinion, field sampling);
- Critical depth of flow per species;
- Critical velocities of flow per species.

In addition the following information may be required:

- Differences in critical indicators over lifetime of species;
- Flow effects on inter-species relations;
- Water quality standards and dilution;
- Local land use;
- Location of potentially polluting industries;
- Pollution types;
- Dilution standards;
- Proximity of agriculture;
- Seasonal variations (emphasis on dry season flows and floods);
- Aesthetic needs and standards;
- Cultural needs and regulations;
- Recreational needs.

Advantages

- If employed correctly IFIM allows the values of every legitimate stakeholder to be taken into account;
- The method takes into account the flow requirements of the indicator species over its entire life cycle;
- An assessment of the natural flow requirement can be made independently of the naturalised flow data.

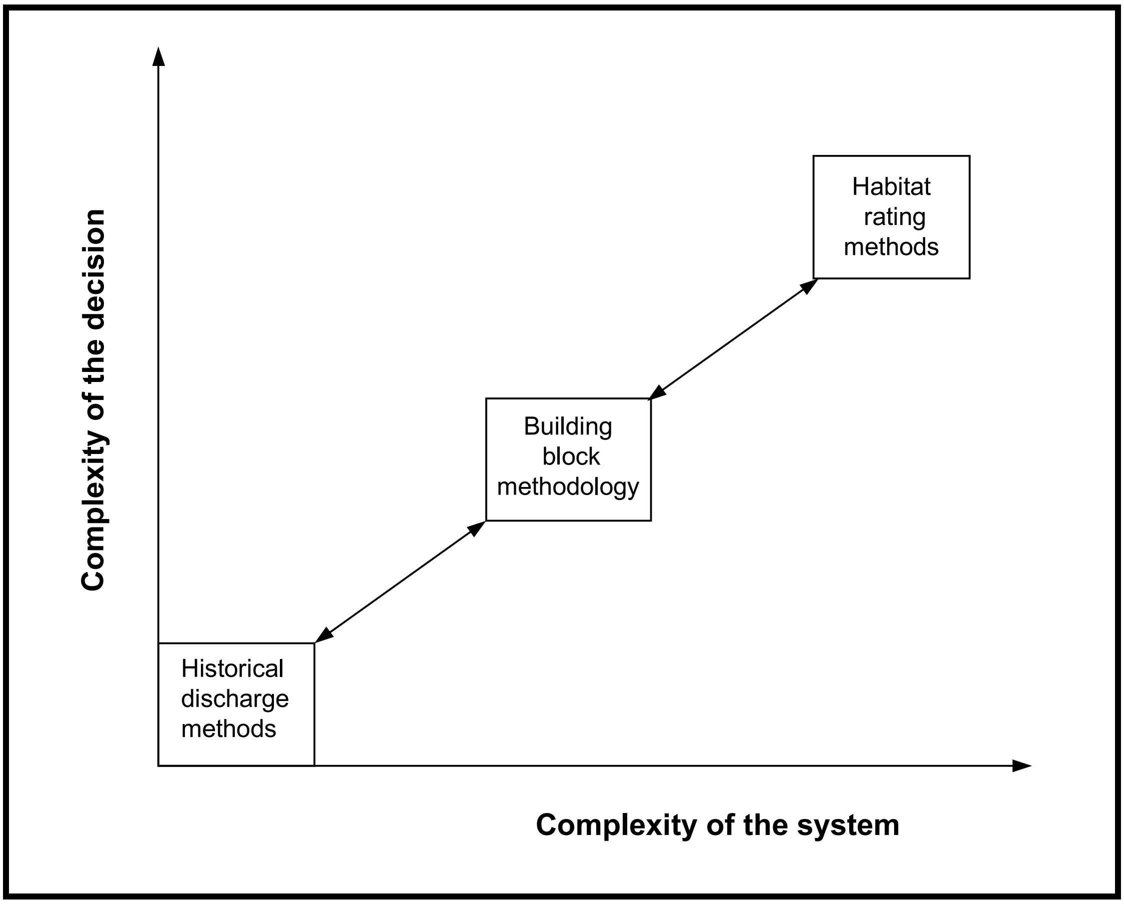
Disadvantages

- It is time consuming and costly to carry out an IFIM study;
- The IFIM techniques have been mainly applied at micro- and meso-habitat levels focusing on one or a few river reaches. There is little experience of using IFIM techniques to assess environmental water demands at a catchment or even a sub-catchment level;
- The method is site specific;
- To implement IFIM requires a multi-disciplinary team with expertise in hydrology, river morphology, water quality, aquatic and terrestrial ecology, carrying out biological field surveys and hydraulic engineering.

3.7 Comparison of the instream flow methods

Historical and hydraulic techniques such as the Tennant Method and wetted perimeter technique are applicable for establishing minimum environmental demands for high level water resources management. It should be noted that these techniques provide an initial “low confidence” estimate. These techniques can be applied rapidly at a large number of sites to provide a first estimate of the likely quantities of water required to maintain the ecology in a given condition. The building block methodology can also be used for rapid assessments. However, in order to use this method for rapid environmental flow appraisals, monthly naturalised flow series are required and a country specific piece of software (possibly based on the one produced by Rhodes University in South Africa) needs to written.

The IFIM method utilising PHABSIM is a commonly used method for more complex decisions e.g. the construction of a hydropower plant or the setting abstractions limits from an ecologically sensitive watercourse. In conclusion there is no one methodology that should be used for establishing the instream flow demand. Figure 3.10 indicates that the choice of the method used is a function of the complexity of the decision to be made and the complexity of the system. To establish the necessary instream flow the practitioner should consider the history and purpose of the various techniques available and must use this knowledge to make an informed choice of the best method to use.



Source: Reference 3.19

Figure 3.10 Spectrum of instream flow methodologies

3.8 Lake level requirements

There are many catchments in southern Africa where freshwater lakes form an important part of the hydrological system. In many cases it will be important to define water level requirements for lakes. A recent study carried out for the Mhlatuze catchment in northern KwaZulu-Natal in South Africa utilised the following method to establish water level requirements for freshwater lakes.

- A Present Ecological State (PES) was allocated to each lake. For each PES an Ecological Management Class (EMC) was prescribed. The PES was described in terms of six classes with A being near pristine and F being irreversibly changed;
- Each lake's importance from a social/cultural and ecological point of view was then established. This was considered when determining the EMC;
- After a process of public consultation the EMC was allocated to each lake. The EMC ranges in classes from A (near pristine) to D (largely modified). Unlike the PES the EMC does not extend to Classes E and F. This is because water resources that are currently in Classes E and F are not considered to represent sustainable systems and must therefore be protected and managed for improvement

For the freshwater lakes to establish a sustainable water level the following is required. A range of water levels needs to be determined for:

- The drought year minimum;
- The maintenance year dry season minimum;
- The management maximum.

Other factors that also need to be determined include:

- Duration and frequency of water levels;
- Maximum rates of drawdown;
- Longer term fluctuations in water level.

The following should then be carried out for the freshwater lake:

- Identify the reference conditions;
- Determine the present operation of the lakes for the provision of water;
- Assess the present state for each of the ecological components;
- Assess the habitat integrity of the system for water body and the littoral/riparian zone;
- Determine the ecological importance;
- Determine the social importance;
- Assess the Attainable Ecological Management Class (AMEC);
- Recommend the EMCs either side of the AMEC and list the flow related and non-flow related activities that would be required to meet these classes;
- Prioritise and list the objectives to attain the AMEC;
- Recommend the water levels required to achieve the AMEC and motivate these levels based on ecological grounds backed up by hydrological records where available;
- Specify the degree of confidence in the recommendations and identify further work required to firm up the recommendations;
- Link the results to the system hydrology to determine realistic assurances of supply for the recommended drought and maintenance year water levels and to extrapolate these levels, through the use of hydrology, to the EMCs on either side of the AEMC.

3.9 Methodologies for assessing ecological flow requirements of wildlife

There has been little research carried out on producing techniques for assessing the ecological flow requirements of wildlife. There are no Stage I or reconnaissance level or guidelines for the assessment of environmental flows. There have been some limited studies carried out to assess the influence of environmental flows on the availability and quality used by birds. There have also been limited cases where the IFIM has been used to assess the flow requirements of semi-aquatic mammals.

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4. AGRICULTURAL WATER DEMAND AND USE

4.1 Introduction

Agriculture is an important activity in southern Africa in terms of food security, economic activity and water use. Irrigated agriculture, moreover, plays a disproportionately important role because it is generally two to three times more productive than rain-fed agriculture, and because irrigation uses approximately 70% of the region's water supplies. It has been estimated that about 1.8 million hectares in the SADC region are under irrigation. This is approximately 7% of arable land in the region. Irrigation is largely reserved for high value crops such as fruits and vegetables, but sugar cane occupies 292,000 ha alone. Other irrigated crops include wheat, rice, cotton, maize, coffee, tea and tobacco. SADC countries rely on irrigation to varying degrees, from 0.5% of agriculture in Botswana to 36% in Swaziland. Table 4.1 provides details of the percentage of irrigated land and water use for continental SADC countries.

Table 4.1 Irrigated land and water use for continental SADC countries

Country	Irrigated area as a percentage of arable area in 1993 (%)	Percentage of total water use (%)
Angola	2.5	76
Botswana	0.5	48
Lesotho	0.9	56
Malawi	1.7	86
Mozambique	4.0	89
Namibia	0.9	68
South Africa	10.3	62
Swaziland	35.8	71
Tanzania	5.0	89
Zambia	0.9	77
Zimbabwe	7.0	79

Source: Reference 4.1

As Table 4.1 illustrates the agricultural sector of SADC has the largest water demand and use owing to crops being grown under irrigation. The irrigation water demand and use can be established from:

- Estimates using empirical formula;
- Measurements of water consumption from flow gauging devices;
- Field measurements of the consumptive use of crops.

Field measurements of water use by crops are complex, time consuming and expensive. Generally irrigation water demands and use are estimated from empirical equations or calculated from readings from flow measurements located on irrigation schemes. Methods for estimating agricultural water demand and use are given in Sections 4.3 and 4.4.

4.2 Overview of irrigated agriculture in the SADC region

Sections 4.2.1 to 4.2.14 provide an overview of irrigation in each of the SADC countries. This overview is based on work carried out by the Food and Agriculture Organization. The land on which water is used primarily for the purpose of agriculture production has been called in the text *water managed areas*. The term *irrigated areas* has been limited to that part of the water managed areas equipped with hydraulic structures: full or partial control irrigation, equipped wetland or valley bottoms and areas equipped for spate irrigation. The difference between the two categories comprises cultivated wetland and valley bottoms without irrigation equipment and recession cropping areas (Reference 4.4).

4.2.1 Angola

The potential for irrigation in Angola is immense and may be in excess of several million hectares. Owing to the civil war in Angola there is a paucity of data on irrigation in Angola. At independence in 1974 it was estimated that there was between 75,000 ha and 80,000 ha irrigated using modern techniques. However, in 1991 this area was estimated to be between 10,000 ha and 30,000 ha (Reference 4.4).

4.2.2 Botswana

Total irrigation potential in Botswana has been estimated to be 39,300 ha, however, once water availability is taken into account this drops to 20,000 ha. This figure includes the area used for flood recession cropping. The total water managed area is 7,881 ha which is 39% of the irrigation potential. Full or partial water control is provided on 1,381 ha which is only 17% of the total water managed area. Of this, 612 ha is irrigated from groundwater and 769 ha from surface water, either by pumping from the Limpopo and other rivers or from storage reservoirs. The major irrigated crops are vegetable, maize, pasture and fodder crops, citrus and cotton. There are some 6,500 ha of flood recession cropping around the Okavango and Chobe enclave, on which mostly maize and millet are planted.

Full and partial control irrigation techniques include 218 ha of surface irrigation (e.g. handwatering, furrow and basin and drag hose) and 1,163 ha under overhead sprinkler (e.g. centre pivot, sprinkler) and 271 ha under drip and micro-sprinkler. Future irrigation development is likely to be on a very limited scale the main constraint being shortage of water and its high opportunity cost (Reference 4.4).

4.2.3 Democratic Republic of the Congo

The irrigation potential in the Democratic Republic of the Congo varies between 4 million hectares and 20 million hectares, depending on the source of the estimate. Owing to the political situation in the Democratic Republic of the Congo over the past two decades it is difficult to obtain reliable figures on the irrigation infrastructure. It is estimated that only some 8,000 ha is actively irrigated.

4.2.4 Lesotho

In the early 1970s the potential for irrigation development in Lesotho was estimated to be some 12,500 ha. Since this time no other survey has been undertaken to assess the total potential in Lesotho. The total water managed area is about 2,722 ha and corresponds to the total equipped area for full or partial irrigation. This area can be divided as follows:

- 203 ha of small schemes (less than 100 ha). Surface and sprinkler irrigation is mainly practised in these schemes which are generally donor sponsored. The main crops are vegetables;
- 2,519 ha of large schemes (more than 100 ha) developed from 1986 onwards. These schemes were equipped for sprinkler irrigation. However, because the schemes never managed to make a profit they are no longer irrigated.

Irrigation development has not been very successful in Lesotho and many schemes have been converted into dryland farming systems. Reasons for the poor performance of irrigation in Lesotho include:

- Using a top-down approach, whereby farmers were informed that their land had been chosen for irrigation development and their plots were consolidated into blocks without prior consultation, resulting in opposition to irrigation development;
- Farmers being expected to provide free labour to the scheme, regardless of the size of the landholding, while their profit share was based on the size of the holding resulting in poor labour productivity;
- Low produce prices.

The most successful irrigation projects in Lesotho have been based on an individual approach to communally owned irrigation schemes where farmers control the on-field crop production activity (Reference 4.4).

4.2.5 Malawi

The total water managed area is about 89,900 ha which is about 56% of the total potential area for irrigation estimated at 161,900 ha. At present 28,800 ha is equipped for full or partial control irrigation. Almost all irrigation is from surface water, either from weirs or by pumping from rivers. There are some small areas (15 ha to 20 ha) along Lake Malawi that are irrigated using groundwater. Irrigation techniques include:

- 15,700 ha of surface irrigation (e.g. furrow and basin);
- 9,000 ha of sugar cane under sprinkler irrigation at Sucoma;
- 2,300 ha of tea, coffee and other crops under sprinkler irrigation;
- 1,000 ha under micro-irrigation.

Some 1,100 ha of surface irrigation are in need of rehabilitation. The cropped area in these full of partial control schemes is 31,500 ha per year. There are three basic categories of farming in the full and partial control irrigation sub-sector:

- Private estates (18,300 ha). These include Sucoma (9,000 ha) and Dwangwa (6,000 ha) sugar estates and Kawalazi estate that have been developed as joint ventures between Government and local and foreign investors;
- Government run small-holder schemes (3,200 ha). These were established by the government to give irrigation opportunities to local farmers.
- Self-help smallholder schemes (6,500 ha). These have usually been designed and constructed by the government with the full support and participation of farmers in each stage of development.

There are also some 61,900 ha of dambo (wetland) areas under rice cultivation (Reference 4.4).

4.2.6 Mauritius

The irrigation sector in Mauritius is primarily focused on sugar cane, which has one of the highest yields in the world. In 1970 the full or partial control irrigated area was 12,000 ha, all for sugar cane. In the late 1980s, half of the full or partial control area was irrigated by sprinkler. The full or partial control irrigated area was estimated to be 16,720 ha in 1987 and 17,500 ha in 1995. The majority of this area was devoted to sugar cane on estates under sprinkler irrigation. In the past groundwater was used as a major source for irrigation of sugar cane plantations. This practice has now ceased owing to the high cost of electricity. There is also a limited area of irrigated land used to produce market garden vegetables.

In recent years there has been an emphasis to move towards water-saving techniques and non-labour intensive system. Surface irrigation systems that have poor efficiency are being replaced by drip or sprinkler (Reference 4.4).

4.2.7 Mozambique

The irrigation potential in Mozambique has been estimated to be some 3,300,00 ha of which 61% lies in the Zambezi Valley, which represents 9% of the cultivable area. In 1993 the area equipped for full or partial irrigation was estimated to be 106,700 ha, only 3.2% of the irrigation potential. This area is divided into small schemes (less than 30 ha), medium schemes, (30 ha to 200 ha) and large schemes. The total area actually irrigated is estimated to cover 45,000 ha i.e. 42% of the equipped area. The main irrigated crops are rice, sugar cane, maize and citrus fruit. Most irrigation schemes are fed by water abstracted from rivers. Basin irrigation for rice and furrow irrigation for maize and vegetables are practised. Sprinkler irrigation is widespread, especially in the sugar and cotton areas.

Irrigation schemes in Mozambique vary from large multi-user schemes (30,000 ha) to small individual schemes (1 ha). In the large schemes, where commercial and family sector irrigation co-exist, water management is almost non-existent. Hydraulic structures do not function, large administrative management bodies have been set up to run the schemes and there is no physical possibility of water control (Reference 4.4).

4.2.8 Namibia

The total water managed area is 8,142 ha. This figure includes 2,000 ha of recession agriculture in the floodplains of the Okavango and Zambezi Rivers mainly used for cultivating maize. In 1992 of the 6,142 ha equipped for irrigation with full or partial control some 886 ha (14%) were irrigated from groundwater and 5,256 ha (86%) utilised surface water either by pumping from the Okavango and Orange Rivers or from storage reservoirs.

The major irrigated crops are maize, lucerne and pasture, wheat and cotton. The irrigation area increased by some 350 ha between 1991 and 1994. Full or partial irrigation techniques comprise 2,950 ha under surface irrigation (basin and furrow), 1,845 ha under centre pivot and sprinkler and 1347 ha under drip and micro-sprinkler.

Although some 3.6 million hectares has soil classified as highly suitable for irrigationbut taking into account water availability the potential for irrigation development is only 45,000 ha. Of this area 8,142 ha is already equipped, 10,000 ha is available for a sugar project in Caprivi and about 27,000 ha is available for development in the rest of the country (Reference 4.4).

4.2.9 Seychelles

Irrigation has been developed in recent years in the Seychelles as a supplementary supply to rain fed crops in cases of water shortages or droughts. Irrigation projects are focused on high value crops such as orchids (Reference 4.4).

4.2.10 South Africa

The potential for full or partial control irrigation development, based on soil and water availability and suitability, is estimated at 1.5 million hectares. The total water managed area is estimated at 1.27 million hectares, consisting only of full or partial control irrigation. Three irrigation techniques are used:

- Surface irrigation comprising furrow, border and basin irrigation are used for 396,000 ha;
- Sprinkler irrigation is used for 660,000 ha;
- Micro-irrigation is applied on 144,000 ha.

Four types of irrigation scheme can be distinguished in South Africa according to the type of management. These are:

- Government Water Schemes that in 1994 covered 329,000 ha and are operated by the Department of Water Affairs and Forestry;
- Irrigation Boards covering 155,000 ha in 1994 that were developed on the basis of legislation that enables groups of private individuals to obtain statutory powers;
- Private schemes that covered 660,000 ha in 1992 and that are irrigated by private farmers;
- Schemes of the Rural Development Programme, located in the former homelands, that cover 70,000 ha.

The main irrigated crops are pasture, wheat, lucerne and irrigated sugar cane. It has been reported that some 110,000 ha of irrigated land is affected is affected by waterlogging or salinization (Reference 4.4).

4.2.11 Swaziland

The potential for irrigation development based on water and soil availability and suitability is estimated to be 90,000 ha. This comprises 47% of the cultivated land. The irrigation sector in Swaziland consists mainly of large private farmers and internationally-owned enterprises. The total water managed area is estimated at 67,400 ha of full or partial control irrigation schemes. These schemes a re of two types:

- Micro- and small schemes (1,000 ha in 1980). These communal, smallholder projects are characterised by individual family holdings of around 0.5 ha. The total size of schemes averages 20 ha;
- Large schemes (66,400 ha estimated in 1990). Furrow irrigation of sugar cane is the most practised system, followed by sprinkler and micro-irrigation of pineapple and citrus fruits. In general water is provided from reservoirs or river diversions (Reference 4.4).

4.2.12 Tanzania

Based on soil and water availability the potential for irrigation development in Tanzania has been estimated to be 828,000 ha which is approximately 2% of the cultivable area. Exact figures for the water managed area are not known. It is estimated to be somewhere between 120,000 ha and 200,000 ha. Most of this is in traditional, small holder schemes. Medium to large schemes cover approximately 20,000 ha to 50,000 ha.

Almost all irrigation schemes are fed by abstraction from rivers. In a few cases storage reservoirs have been constructed. On some of the larger projects sprinkler irrigation is used. The main crops in the large scale irrigation projects is rice. Sugarcane occupies about 10,000 ha of the irrigated area. In some limited areas maize is cultivated (Reference 4.4).

4.2.13 Zambia

The irrigation potential based on water and soil resources has been estimated at 1.4 million hectares. Of this 520,000 ha, including dambo (wetland) and irrigated areas could be economically developed in the future. The total water managed area is some 146,400 ha.

At present some 46,400 ha are equipped for full or partial control irrigation. A total of 61,900 ha of crops are grown annually in these schemes of which only 46,400 are irrigated. The majority of the irrigated area is supplied by surface waters i.e. reservoirs or rivers. There are some 2,500 ha of the irrigated area are supplied by groundwater. Surface irrigation (furrow and basin) is practised on 28,400 ha, there are 17,200 ha under sprinkler and centre pivot and 800 ha fed by drip. Irrigation schemes in Zambia fall into three main categories:

- Commercial estates (18,000 ha). These include both large and small scale companies and commercial farms growing a wide range of high-value crops (e.g. coffee, fruit, vegetables);
- Parastatal and semi-parastatal (12,400 ha). These include large scale farming developments with varying degrees of government control;
- Smallholder (16,000 ha). Of this area 3,669 ha has been established by the government as formal schemes in areas of traditional land tenure. Plots usually occupy 0.5 ha to 1 ha (Reference 4.4).

4.2.14 Zimbabwe

Taking into account soil suitability and water availability the area of land suitable for irrigation has been estimated to be 331,000 ha. Between 1968 and 1990 the irrigated area tripled from 60,000 ha to 191,000 ha, including double cropped areas. Most of the areas that have been developed for full or partial control irrigation are large scale commercial private and parastatal schemes. Small scale schemes cover 9,421 ha, while cultivated wetlands and gardens cover some 20,000 ha. Most water used for irrigation is pumped from regulated rivers or from farm reservoirs. In 1990 it was estimated that 40% of the nine principal crops were produced under irrigation. Major irrigated crops included wheat, cotton, sugarcane, soybean, tobacco and maize.

4.3 Use of empirical equations to calculate irrigation water demand and use

There are two main methods that can be used to establish irrigation demand and use using empirical equations. These are:

- Approximate estimates;
- Detailed estimates.

For most water resources management applications at a catchment and sub-catchment level approximate estimates of irrigation water demand and use should suffice. However, there may be some cases that warrant more detailed estimates. The approximate and detailed procedures for estimating irrigation water demand and use are shown in Figures 4.1 and 4.2 respectively.

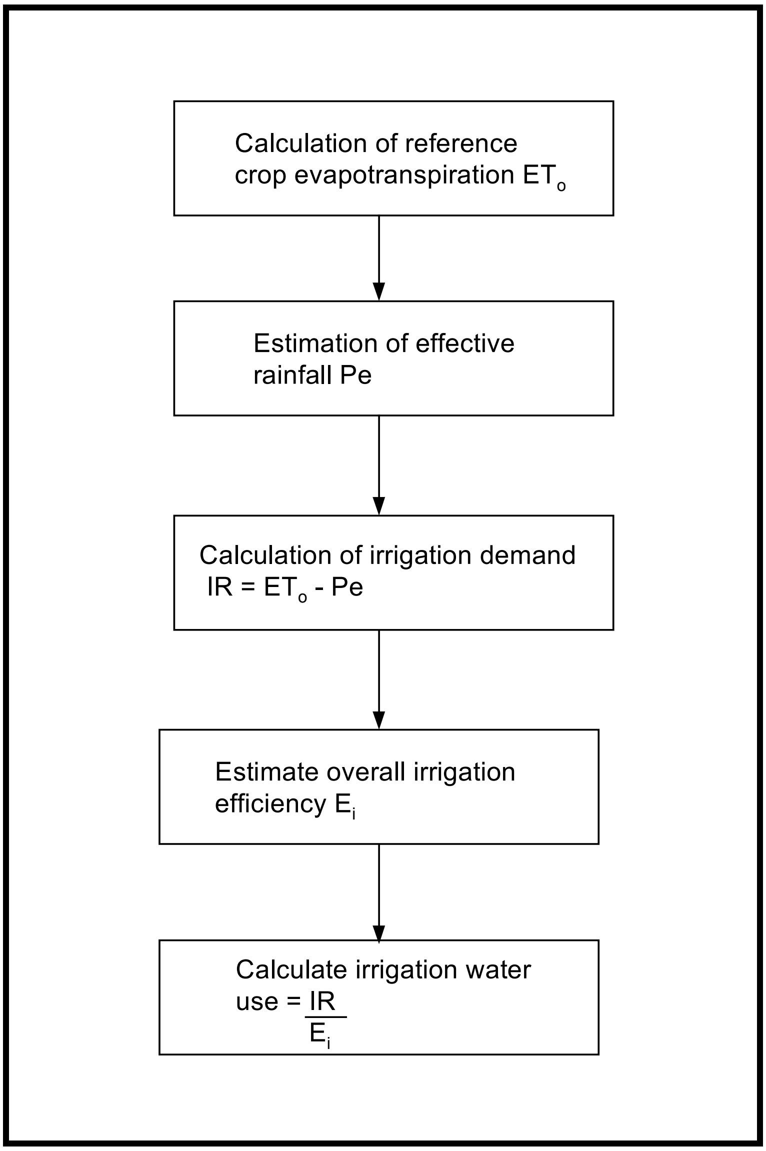


Figure 4.1 Approximate method for estimating irrigation demand and use

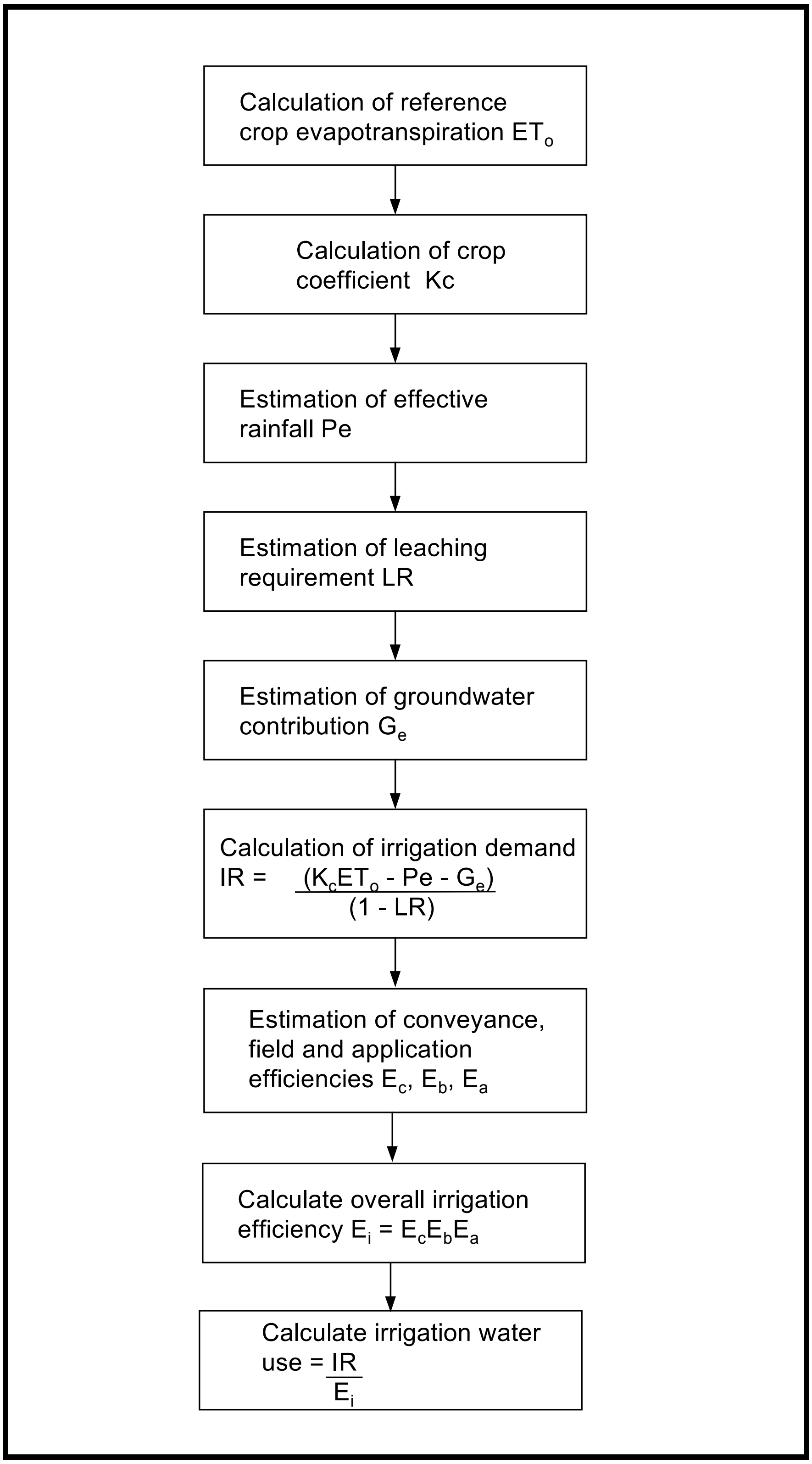


Figure 4.2 Detailed method for estimating irrigation water demand and use

It should be noted that often the greatest uncertainty in determining irrigation water use is the estimation of irrigation efficiency. The overall irrigation efficiency is defined as the ratio of water consumed by crops to the water diverted from the source (e.g. a river or reservoir). The overall irrigation efficiency can vary from 10% to 90% and is heavily dependent on the irrigation technology used, and the operation and maintenance of the irrigation scheme. Figures for irrigation schemes can be estimated from literature or from similar schemes where there are measuring devices. Irrigation efficiency is discussed in Section 4.5.7.

The approximate and detailed methods for estimating irrigation water demand and use are discussed below.

4.4 Approximate method for calculating irrigation water demand and use

The irrigation water demand and use can be estimated approximately at a catchment and sub-catchment level using the following equations:

Irrigation water demand $\mathrm{IR} = (\mathrm{ET_o} - \mathrm{Pe})\mathrm{A}$

Where: $\mathrm{ET_o}$ is the reference crop evapotranspiration for grass;
Pe is the effective rainfall;
A is the area under irrigation.

$$\text{Irrigation water use} = \frac{\mathrm{IR}}{\mathrm{E_i}}$$

Where: IR is the irrigation water demand;
$\mathrm{E_i}$ is the overall irrigation efficiency.

Using the potential evapotranspiration for a reference crop (grass) may cause an upward bias in the estimates of irrigation water demand and use. However, for estimating irrigation water demand and use at a catchment and sub-catchment level it provides a rapid and simple method. Values of reference crop evapotranspiration estimated using the Penman-Monteith method and effective rainfall are available as part of CLIMWAT. CLIMWAT is a climatic database produced by the Food and Agriculture Organization (FAO) of the United Nations that provides data for a total of 3262 meteorological stations from 144 countries throughout the world (References 4.6 and 4.7). An example of an approximate method for estimating irrigation water demand and use is given below.

Example of an approximate method for estimating irrigation water demand and use

An estimate of the water demand and use is required for a 1000 ha sprinkler irrigation scheme close to the town of Karoi in Zimbabwe. Crops are grown throughout the year on the scheme. A similar irrigation scheme in an adjacent sub-catchment is known to have an overall irrigation efficiency of 70%.

An approximate estimate can be made using the reference crop evapotranspiration and the effective rainfall for Karoi taken from the FAO CLIMWAT database. The results of the calculation are shown below.

Month	Reference crop evapotranspiration (mm)	Effective rainfall (mm)	Irrigation requirement (mm)	Irrigation water demand (million m^3)	Irrigation water use (million m^3)
January	124	143	0	0	0
February	109	133	0	0	0
March	127	86	41	0.41	0.59
April	117	34	83	0.83	1.19
May	115	8	107	1.07	1.53
June	102	3	99	0.99	1.41
July	112	0	112	1.12	1.60
August	143	1	142	1.42	2.03
September	177	4	173	1.73	2.47
October	202	14	188	1.88	2.69
November	159	76	83	0.83	1.19
December	133	129	4	0.04	0.06
			Total	**10.32**	**14.74**

4.5 Detailed method of estimating irrigation water demand and use

In order to carry out a detailed estimate of irrigation water demand and use, using empirical formulae, the following information is required:

- Reference crop evapotranspiration;
- Crop type and crop evapotranspiration;
- Cropped area;
- Effective rainfall;
- Soil type and leaching requirements;
- Irrigation efficiencies.

The FAO has produced a piece of software known as CROPWAT which in conjunction with CLIMWAT can be used to carry out detailed calculations to estimate irrigation water demand and use (Reference 4.8). The various components required to carry out a detailed estimation of irrigation water demand and use are discussed below.

4.5.1 Methods of estimating reference crop evapotranspiration

The reference crop evaporation is based on a hypothetical, well-watered grass reference crop with specific characteristics. There are four main methods of estimating reference crop evapotranspiration (ET_o). These are:

- Blaney-Criddle method;

- Radiation method;
- Pan evaporation method;
- Penman-Monteith method.

These methods are briefly discussed below.

Blaney-Criddle method

This method is recommended where the only climatic data available is air temperature (Reference 4.9).

$$ET_o = c[p(0.46T + 8)]$$

Where: T is the mean daily temperature;
c is the empirical adjustment factor depending on minimum relative humidity, sunshine hours and daytime wind estimates;
p is the mean daily percentage of annual daytime hours.

Advantages of the Blaney-Criddle method

The main advantages of the Blaney-Criddle method are:

- It is simple to use;
- It can be used where minimal climatic data is available.

Disadvantages of the Blaney-Criddle method

The main disadvantages of the Blaney-Criddle method are:

- Its validity is limited to areas where temperature is a good indicator of general weather conditions;
- The results can be unreliable for the following conditions:
  - Equatorial regions where temperatures remain fairly constant but other weather parameters change;
  - Small islands and coastal areas where air temperature is affected by the sea temperature having little response to seasonal radiation;
  - High altitudes where mean daily temperatures are relatively low but day time radiation levels are high;
  - Climates with a wide variability in sunshine hours during the transition months (e.g. monsoons);
- It requires extensive local calibration to estimate the value of the empirical factor ‘c’;
- The method should only be used to estimate ET_o for periods of at least one month.

Radiation method

The radiation method is recommended where air temperature and sunshine, cloudiness or radiation is measured, but measurements of wind and humidity are not available (Reference 4.9).

$$ET_o = c(WRs)$$

Where: Rs is the solar radiation in mm/day;
W is a weighting factor dependent on temperature and altitude;

c is an adjustment coefficient dependent on mean humidity and daytime wind conditions.

Advantages of the radiation method

The main advantages of the radiation method are:

- The radiation method generally produces more reliable results than the Blaney-Criddle method;
- It is relatively simple to use;
- For equatorial zones, small islands or high altitudes the method may be more reliable than the Blaney-Criddle method even if measured sunshine or cloudiness data are not available.

Disadvantages of the radiation method

The main disadvantages of the radiation method are as follows:

- The adjustment coefficient c needs to be estimated accurately in order to produce reasonable results;
- The method tends to underestimate evapotranspiration in arid climates;
- The method should only be used to calculate ET_o for periods of at least one month.

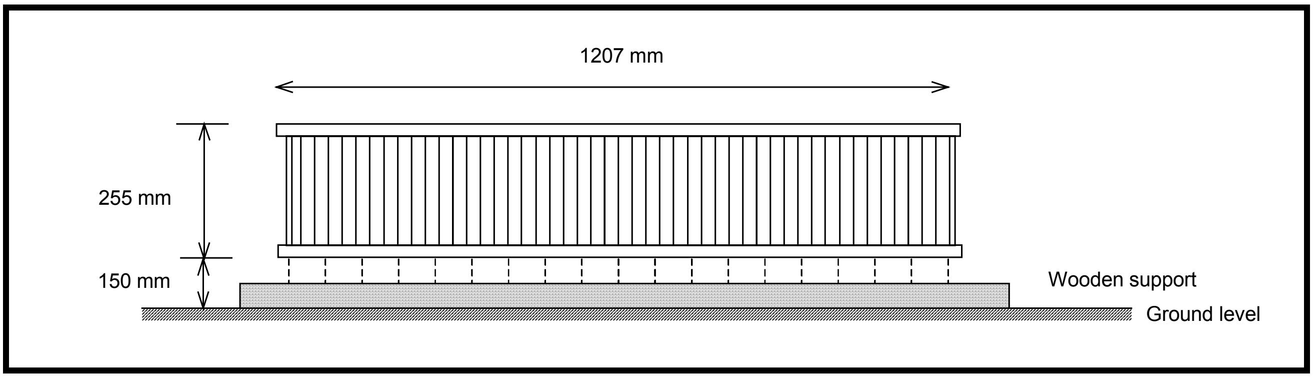
Pan evaporation method

Evaporation pans provide a method by which the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface can be measured. The pan evaporation is related to the reference evapotransipration by an empirically derived pan coefficient as shown in the equation below.

$$ET_o = KpEpan$$

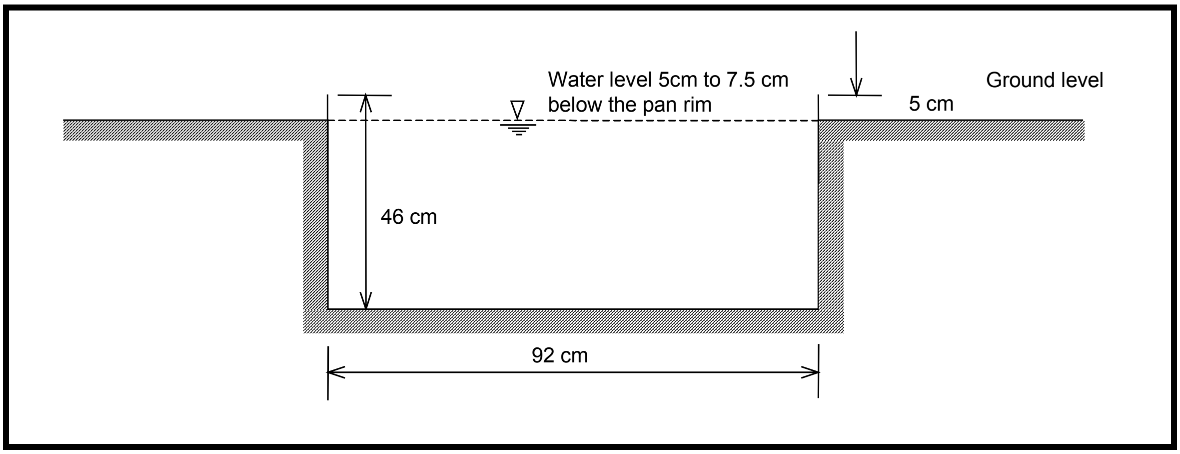
Where: Epan is the pan evaporation in mm/day;
Kp is the pan coefficient.

The value of ET_o produced by the above equation should be compared with results from other evaporation pans and results from the Penman-Monteith equation. There are several different types of pan. The Class A and Colorado pans are two that are most commonly used, these are shown in Figures 4.3 and 4.4 respectively.



Source: Reference 4.9

Figure 4.3 Diagram of a Class A evaporation pan



Source: Reference 4.9

Figure 4.4 Diagram of a Colarado evaporation pan

Advantages of pan evaporation methods

The pan evaporation method has the following advantages:

- Under the correct circumstances the pan evaporation method can be used to predict values of ET_o for periods of ten days or longer;
- Evaporation pans are relatively cheap and simple to set up.

Disadvantages of pan evaporation methods

The pan evaporation method has the following disadvantages:

- The accuracy of the results is dependent upon the type and location of the pan;
- The results of the pan evaporation may be affected by birds drinking from the pan;
- The colour and material of the pan affect the evaporation rate. As a consequence the value of Epan is not constant with time owing to ageing, deterioration and repainting;
- The method is susceptible to microclimatic conditions under which the pans are operating;
- The reliability of the results is dependent upon the frequency of the pan maintenance;
- The method should only be used to calculate ET_o for at least ten days.

Penman-Monteith method

This method is recommended for use wherever possible, providing there is sufficient meteorological data. The reference crop evapotranspiration is calculated from the following equation (Reference 4.9).

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34\,U_2)}$$

Where: R_n is the net radiation at crop surface;
G is the soil heat flux;
T is the average temperature;
U_2 is the wind speed measured at 2 m height;
$(e_a\text{-}e_d)$ is the vapour pressure deficit;
Δ is the slope vapour pressure curve;

γ is the psychrometric constant.

Reference crop evapotranspiration rates in mm/day calculated using the Penman-Monteith method for four African capital cities are shown in Figure 4.5.

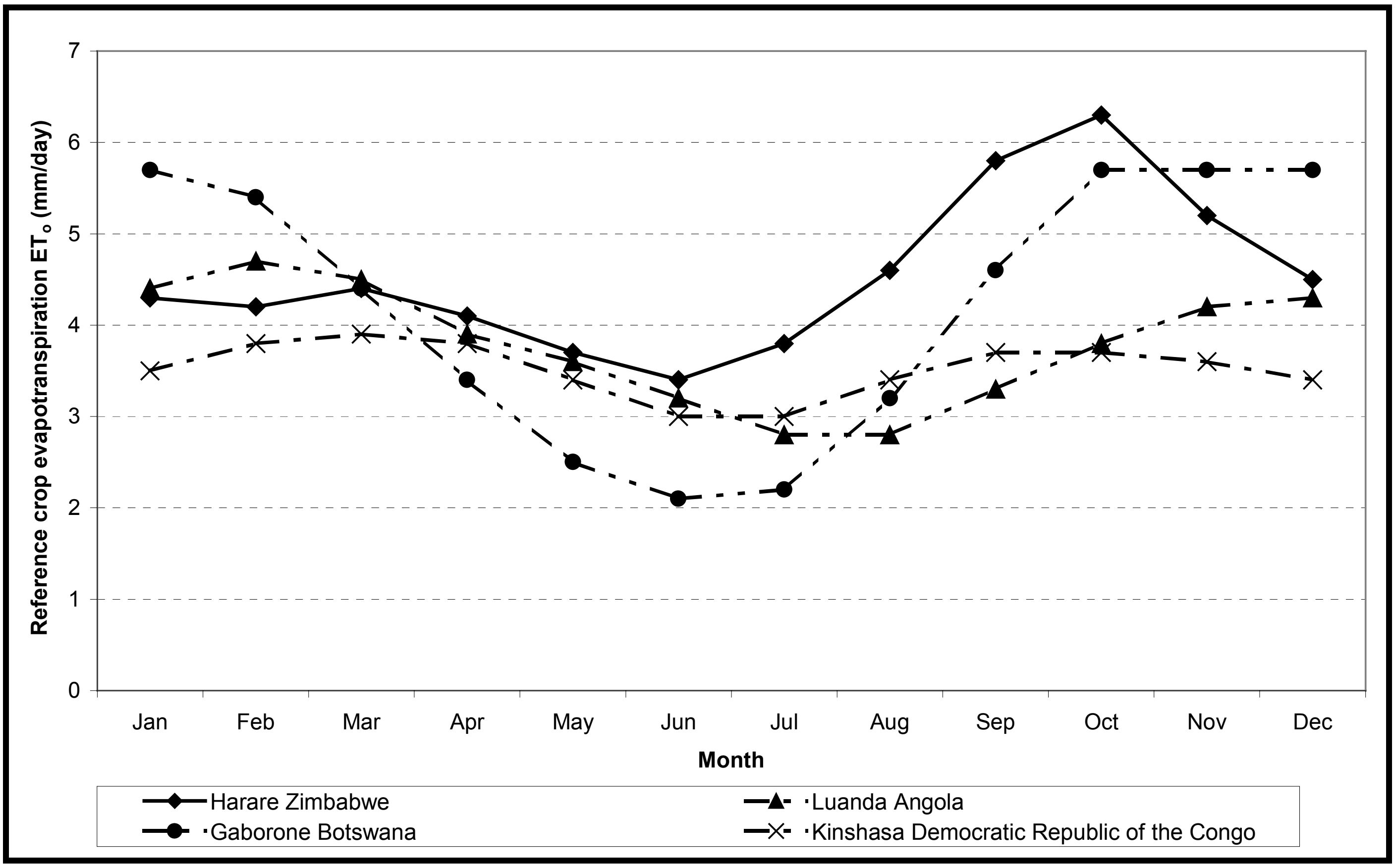


Figure 4.5 Reference crop evapotranspiration calculated using the Penman-Monteith method

Advantages of the Penman-Monteith method

The Penman-Monteith method has the following advantages:

- The Food and Agriculture Organization (FAO) of the United Nations recommend the use of the Penman-Monteith equation as the sole method for the estimation of reference crop evapotranspiration;
- Climatic data and tools to assist with the calculation of ET_o using the Penman-Monteith method are available from the FAO;
- The method can be used to estimate ET_o on a daily basis.

Disadvantages of the Penman-Monteith method

The Penman-Monteith method has the following disadvantages:

- The method requires a considerable amount of climatic data that may not be readily available. However, mean monthly climatic data is available digitally for approximately 3250 climate stations worldwide from the FAO.

Recommended method to estimate reference crop evapotranspiration

The FAO recommends the Penman-Monteith method as the sole method standard method for the computation of ET_o. The use of the Penman-Monteith method does require a reasonable quantity of climatic data. However, advice on the infilling of missing data and the setting up of climate stations is given in FAO Irrigation and Drainage Papers Nos. 56 and 27 respectively. Climate data for over 3000 climate stations in 144 counties is available in a digital format as part of FAO Irrigation and Drainage Paper No. 49. There are also a number of software packages that use the Penman-Monteith method equation to assess reference crop evaporation. The FAO computer program CROPWAT utilises the Penman-Monteith method and a spreadsheet is also available from the FAO to calculate reference crop evaporation.

4.5.2 Estimation of the crop coefficient

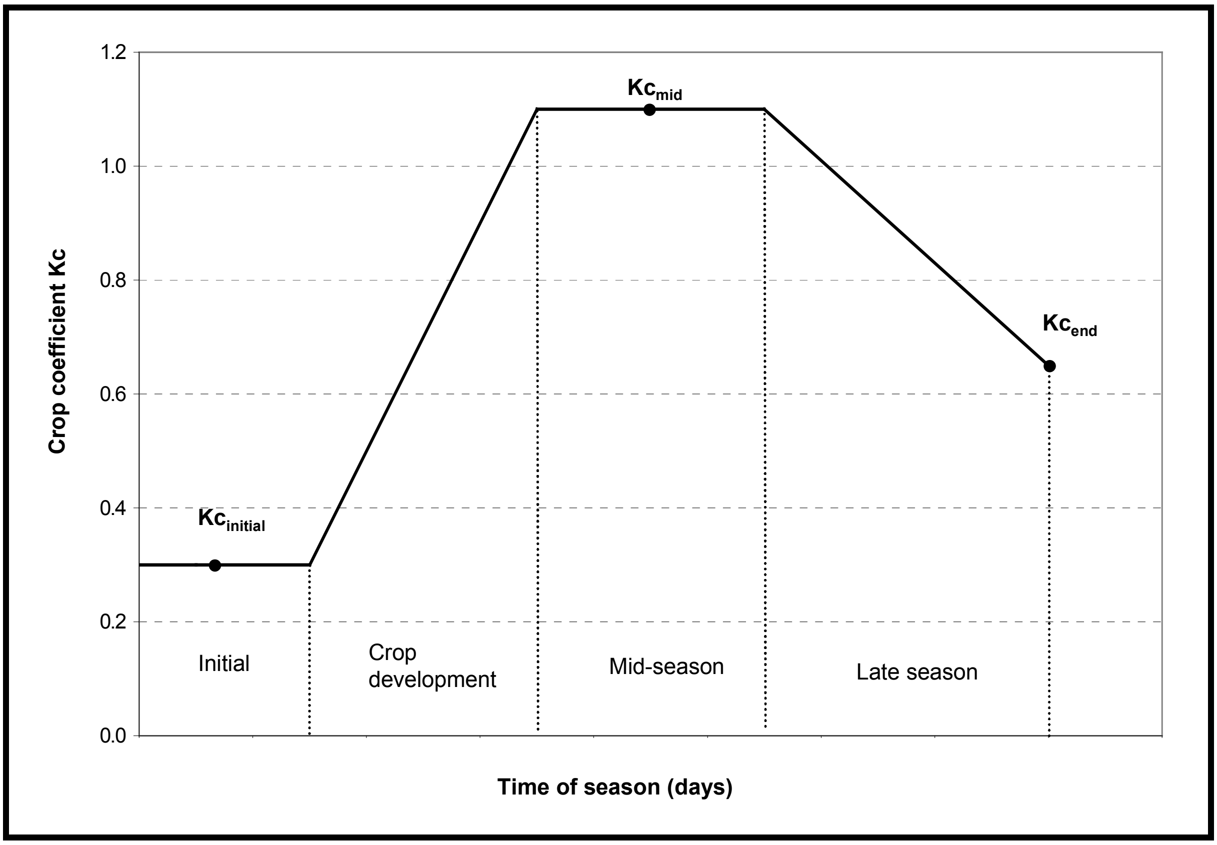
Crop evapotranspiration is the amount of water utilised by a crop under standard conditions i.e. a disease free, well fertilised crop grown in a large field under optimum soil conditions (References 4.9 and 4.10). The crop evapotranspiration ET_{crop} in mm/day is calculated by multiplying the reference crop evapotranspiration ET_o in mm/day by a dimensionless crop coefficient K_c:

$$ET_{crop} = K_c ET_o$$

The crop coefficient is dependent upon the following factors:

- Crop type;
- Climate;
- Soil evaporation;
- Crop growth stage.

A typical crop coefficient curve is shown in Figure 4.6 below.



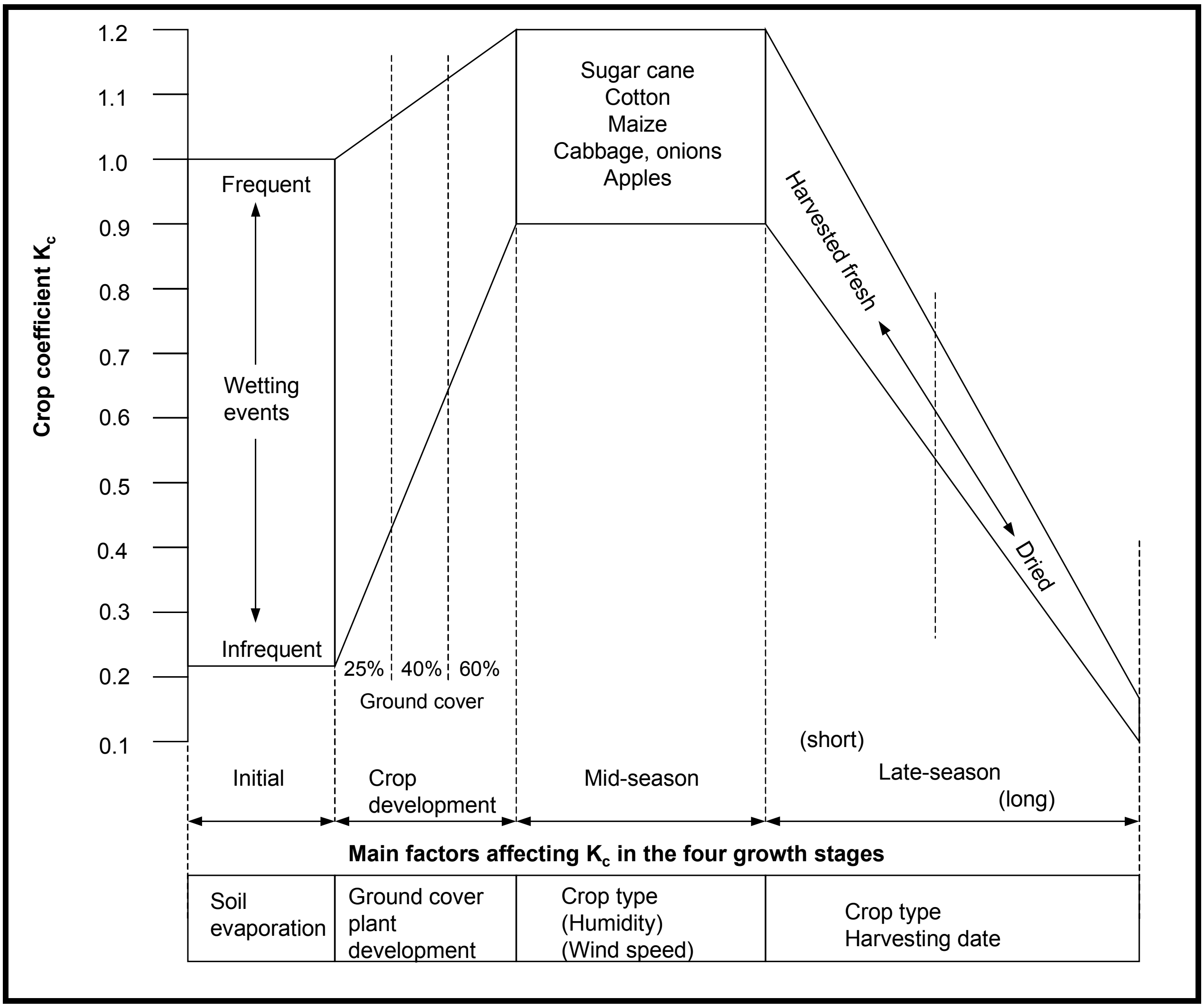
Source: Reference 4.9

Figure 4.6 Typical crop coefficient curve

As Figure 4.6 illustrates, the crop coefficient varies over the growing period of the crop. As the crop develops the ground cover, crop height and the leaf area change. As a consequence the evapotranspiration of a crop will change during its growing period. The majority of crops have four growth stages:

- **Initial stage** when the leaf area is small and the majority of the evapotranspiration is due to soil evaporation;
- **Crop development stage** when leaf area grows from approximately 10% to full ground cover;
- **Mid-season stage** when the crop is reaching maturity;
- **Late season** runs from the start of maturity to the harvest.

Typical ranges of crop coefficient K_c together with the factors that affect the K_c during the life of a crop are shown in Figure 4.7.



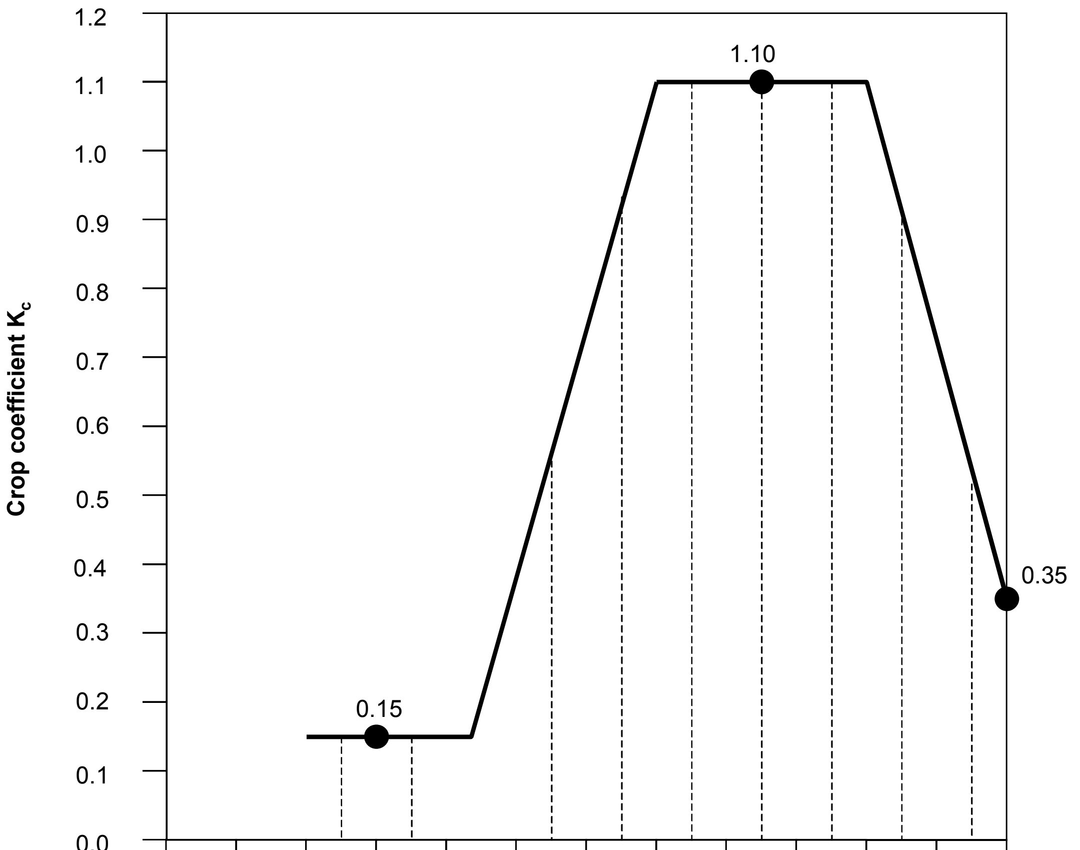
Source: Reference 4.9

Figure 4.7 Typical ranges expected in K_c for four growth stages

A typical crop coefficient curve can be constructed by establishing the values of K_c for the initial, middle and end of the curve. Typical values of the crop coefficients are given in the FAO Irrigation and Drainage Papers Nos. 24 and 56. Crop water requirements can be calculated using CROPWAT, a piece of software available as part of the FAO Irrigation and Drainage Papers No. 46.

Example of a crop water requirement calculation

An example of the construction of a crop coefficient curve is shown in Figure 4.8 below. The calculation has been carried out using ten day periods. The mean crop coefficient for the middle of each of the ten day periods has been calculated. The crop water requirement ET_{crop} in mm/day is calculated by multiplying the crop coefficient by the reference crop evapotranspiration for each ten day period.



	May			June			July			August		
	1	2	3	1	2	3	1	2	3	1	2	3
K_c			0.15	0.15	0.20	0.56	0.91	1.10	1.10	1.10	0.90	0.52
ET_o (mm/day)			3.1	3.5	3.7	4.0	4.2	4.1	4.0	3.9	3.8	3.6
ET_c (mm/day)			0.5	0.5	0.7	2.2	3.8	4.5	4.4	4.3	3.4	1.9

Source: Reference 4.9

Figure 4.8 Crop coefficient curve together with crop water requirements

4.5.3 Estimation of effective rainfall

Crop water requirements may be fully or partly met by precipitation. However, it should be noted that not all rainfall is effective as some may be lost to surface runoff, deep percolation or evaporation. The effective rainfall may be defined as the proportion of the rainfall that is useful for crop production. There are several factors that affect effective rainfall including:

- Rainfall characteristics;
- Soil type;
- Groundwater characteristics;
- Management practices.

There are several empirically based methods available to calculate effective rainfall including:

- Renfro equation;
- US Bureau of Reclamation method;
- US Department of Agriculture Soil Conservation Service method.

The US Department of Agriculture Soil Conservation Service method is often used. Table 4.1 below allows the mean monthly effective rainfall to be estimate provided the crop evapotranspiration and mean monthly rainfall are known (Reference 4.10).

Table 4.1 Mean monthly effective rainfall related to mean monthly ET_{crop} and mean monthly rainfall

	Mean monthly rainfall (mm)	12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	137.5	150
		Mean monthly effective rainfall (mm)											
Mean monthly ET_{crop} (mm)	25	8	16	24									
	50	8	17	25	32	39	46						
	75	9	18	27	34	41	48	56	62	69			
	100	9	19	28	35	43	52	59	66	73	80	87	94
	125	10	20	30	37	46	54	62	70	76	85	92	98
	150	10	21	31	39	49	57	66	74	81	89	97	104
	175	11	23	32	42	52	61	69	78	86	95	103	111
	200	11	24	33	44	54	64	73	82	91	100	109	117
	225	12	25	35	47	57	68	78	87	96	106	115	124
	250	13	25	38	50	61	72	84	92	102	112	121	132

Source: Reference 4.10

An example of an effective rainfall estimation is given below.

Example of an effective rainfall requirement estimation

A tomato crop has a mean monthly evapotranspiration of ET_{crop} = 137 mm/month
The mean monthly rainfall is 95 mm/month

Interpolating using the US Department of Agriculture Soil Conservation Service method outlined in Table 4.1 the mean monthly effective rainfall is approximately 69 mm.

4.5.4 Groundwater contribution

The contribution from groundwater to the crop water requirement is a factor of the following:

- Depth of the groundwater below the root zone;
- Capillary properties of the soil;
- Soil capillary capacities.

For heavy soils the distance of the movement of the groundwater is high and the rate low, and for coarse soils the distance of movement of the groundwater is small and the rate is high. It should be noted that detailed field experiments are usually needed to ascertain the groundwater contribution to the crop water requirement. For most catchment planning purposes it is unlikely that it is necessary to calculate groundwater contributions.

4.5.5 Stored soil water

Stored soil water at the start of the growing season resulting from rain can mean that the soil is close to or at its field capacity. This stored soil water at the start of the growing season can be deducted from the crop water requirement. However, for the purposes of catchment planning it is usually not necessary to take account of stored soil water as it will vary significantly on a seasonal basis.

4.5.6 Estimation of leaching requirements

The leaching requirement is the minimum amount of irrigation water that must be drained through the root zone to control soil salinity (Reference 4.10). For sandy loam to clay loam soils with good drainage, in locations where the rainfall is low, the leaching requirement can be estimated from the following:

For surface irrigation methods including sprinklers the leaching requirement is:

$$\mathrm{LR} = \frac{\mathrm{ECw}}{5\mathrm{ECe} - \mathrm{ECw}} \mathrm{x} \frac{1}{\mathrm{Le}}$$

For drip and high frequency sprinklers $\mathrm{LR} = \frac{\mathrm{ECw}}{2\mathrm{MaxECe}} \mathrm{x} \frac{1}{\mathrm{Le}}$

Where: ECw is the electrical conductivity of the irrigation water (mmhos/cm);
ECe is the electrical conductivity of the soil saturation extract for a given crop appropriate to the tolerable yield reduction;
MaxECe is the maximum tolerable electrical conductivity of the soil extract for a given crop;
Le is the leaching efficiency.

Values of ECe, ECw and MaxECe are tabulated for different crops for a variety of yield potentials in FAO Irrigation and Drainage papers numbers 24 (Reference 4.10) and 29 (Reference 4.23). The leaching efficiency (Le) varies with soil type and can be as low as 30% (0.3) for cracking and swelling clays and as high as 100% (1.0) for sandy soils. The water needed to satisfy both the crop water requirements ($\mathrm{ET}_{\mathrm{crop}}$) and the leaching requirements is:

$$\text{Water to meet crop and leaching requirements} = \frac{\mathrm{ET}_{\mathrm{crop}} - \mathrm{Pe}}{(1 - \mathrm{LR})}$$

Where: Pe is the effective rainfall;
LR is the leaching requirement.

Example of a leaching requirement estimation

The seasonal crop water requirement ET_{crop} for sugarbeet is 850 mm. The effective rainfall during the growing period is 150 mm. A water quality analysis has shown the water to have an electrical conductivity of 6.8 mmohs/cm. The soil is a sandy-loam with a leaching efficiency (Le) of 90% (0.9). For sugarbeet the ECe is 7.0.

Leaching requirement $LR = \frac{ECw}{5ECe - ECw} x \frac{1}{Le} = \frac{6.8}{5x7 - 6.8} x \frac{1}{0.9} = 0.27$

To meet the crop water requirement and leaching requirement to obtain a 100% yield the following quantity of water is required:

Water to meet crop and leaching requirements $= \frac{ET_{crop} - Pe}{(1 - LR)} = \frac{850 - 150}{(1 - 0.27)} = 960$ mm

4.5.7 Irrigation efficiencies

The net irrigation requirements can be calculated from the crop water requirements, effective rainfall, the groundwater contributions and the stored soil water. However, in order to calculate the total irrigation requirements the quantity of water required for leaching together with the irrigation efficiency should be taken into account. The irrigation efficiency is defined as the ratio of water consumed by crops to the water diverted from the source (e.g. a river or reservoir). The irrigation efficiency can be calculated from the equation:

Overall irrigation efficiency $E_i = \frac{V_c}{V_w}$

Where: E_i is the irrigation efficiency;
V_c is the water consumed by the crops;
V_w is the water diverted from the source (e.g. a river or reservoir).

The overall irrigation efficiency (E_i) is made up of the conveyance efficiency (E_c), the field canal efficiency (E_b) and the application efficiency (E_a). These are defined as follows.

The conveyance efficiency is defined as follows:

Conveyance efficiency $E_c = \frac{V_{farm}}{V_W}$

Where: Ec is the application efficiency;
V_{farm} is the quantity of water delivered to the farm or a block of fields;
V_w is the quantity of water diverted from the source (e.g. a river or a reservoir).

The conveyance efficiency is dependent upon on the method of delivery (e.g. piped, lined or unlined canal), the size of the irrigation scheme and the rotation of the water supply. The value of the conveyance efficiency can vary from 0.6 to 0.9 (Reference 4.9).

The field canal efficiency (E_b) is defined as follows:

Field canal efficiency $E_b = \frac{V_{field}}{V_{farm}}$

Where: E_b is the application efficiency;
V_{farm} is the quantity of water delivered to the farm or a block of fields;
V_{field} is the quantity of water delivered to the field.

The field canal efficiency is dependent on the method of delivery and the size of the field. The value of the field canal efficiency can vary from 0.6 to 0.9 (Reference 4.9).

The application efficiency (E_a) is defined as the ratio of the water made available directly to the crop and the water received at the inlet to the field. The application efficiency is defined as follows:

$$\text{Application efficiency } E_a = \frac{V_{crop}}{V_{field}}$$

Where: E_a is the application efficiency;
V_{field} is the quantity of water delivered to the field;
V_{crop} is the quantity of water available to the crop.

Often considerably more water is applied to the soil than it can possibly hold. Irrigation application efficiencies can vary from extremely low values to values approaching 1.0 (100%). In normal irrigation practices, surface irrigation efficiencies are usually around 0.6 (60%), whereas well-designed sprinkler irrigation systems are generally considered to be approximately 0.75 (75%). An example of an irrigation efficiency calculation is given below.

Example of irrigation efficiency calculation

A 2000 ha irrigation scheme is divided into 50 ha blocks fed by unlined canals and utilising furrow irrigation. The scheme has the following irrigation efficiencies:

Conveyance efficiency $E_c = 0.80$
Field canal efficiency $E_b = 0.75$
Application efficiency $E_a = 0.70$

Overall irrigation efficiency $E_i = E_c E_b E_a = 0.80 \times 0.75 \times 0.70 = 0.42$ i.e. 42%

Typical irrigation efficiencies for the SADC region

Irrigation water demand is expected to more than double by 2020, but its share of total water use in the SADC region is expected to decrease from 70% to 63% as urban demand is expected to outpace all other sectors. The agricultural water sector holds even greater potential for savings than the urban sector because it uses three times as much water and is even more inefficient than urban use. Only 40% of water abstracted from water surface and groundwater sources are believed to reach crop root system. Table 4.2 gives indicative values for overall irrigation efficiencies.

Table 4.2 Typical overall irrigation efficiencies

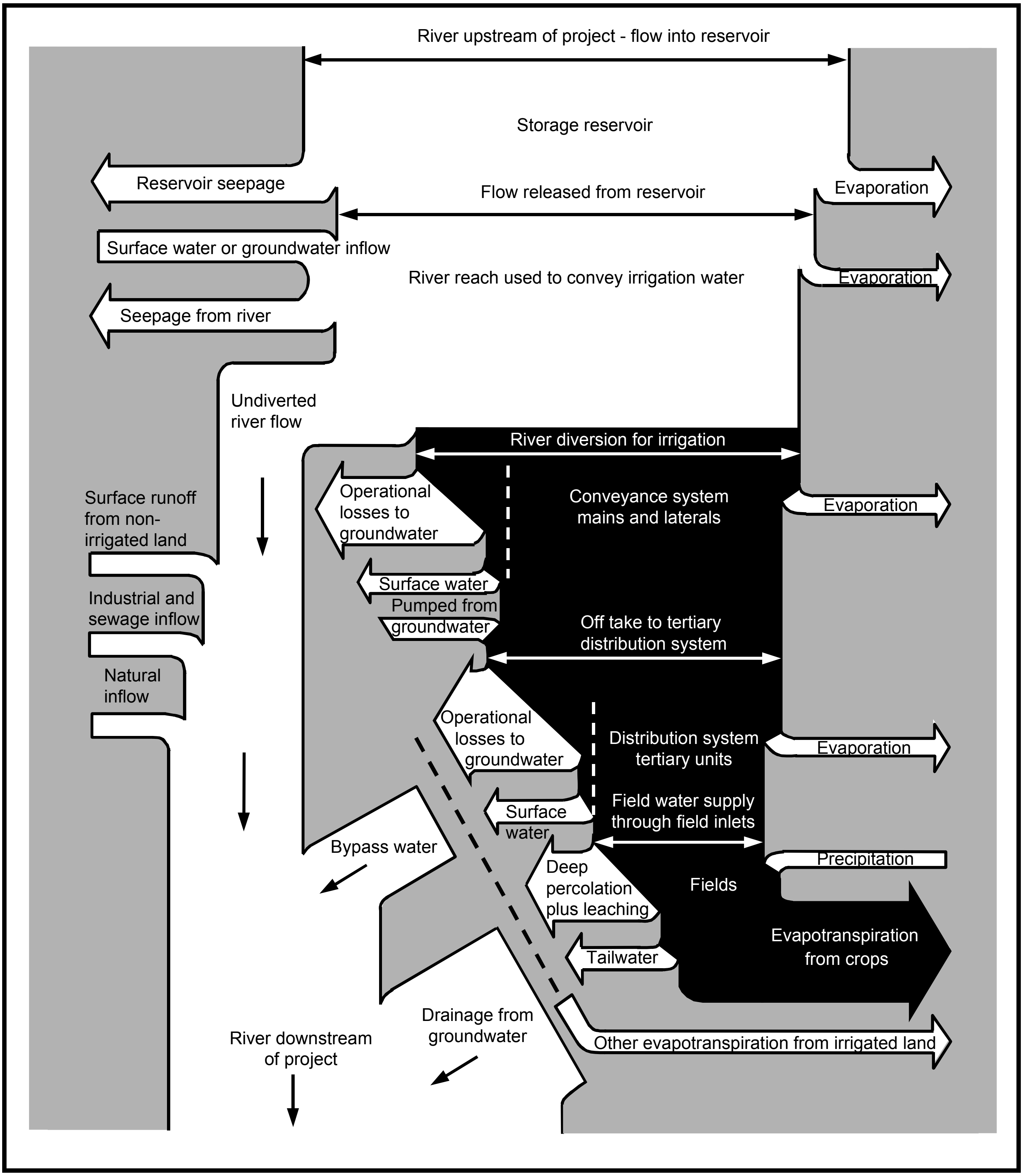
Irrigation system	Typical overall efficiency (%)	Percentage of irrigated area in South Africa in 1990(%)	Percentage of irrigated area in Zimbabwe in 1990 (%)
Surface systems (flood)	55	38	25
Conventional sprinkler	75	22	75
Mechanical (centre pivot)	80	24	-
Micro jet	85	16	-
Drip	90	-	-

Source: Reference 4.1

Table 4.2 shows, the least efficient irrigation method is flood irrigation at 55%, while drip irrigation achieves 90%. In both South Africa and Zimbabwe (the only countries for which data were available for this study), a significant percentage of land is irrigated with flood methods, 38% and 25% respectively. The remainder of Zimbabwe's irrigated land is watered by conventional sprinkler method, while South African agriculture in 1990 had a relatively even distribution of the other methods except drip. Both these methods are inherently inefficient. It is therefore not surprising to see water usage figures of 15,000 m^3/ha in Zimbabwe as opposed to 5,000 m^3/ha for the same crop in a more water efficient Israel (Reference 4.16). Clearly, significant savings in water could be realised by retrofitting inefficient flood and conventional sprinkler irrigation systems with more efficient mechanical, micro jet and drip irrigation methods.

Figure 4.9 shows the irrigation water supply process and the inflows and outflows to a typical irrigation scheme (Reference 4.16). The black part of the figure indicates the quantity of water diverted from the source of water, in this case a river. The width of the arrows downstream of the river diversion illustrates the relative magnitude of water quantities in an "average" irrigation scheme in southern Africa. Figure 4.9 also provides an indication of the relative irrigation efficiencies. This figure also illustrates that water losses resulting from evaporation are relatively small compared with operational losses to groundwater and surface water. These operational losses eventually return to the river. As a result of this the river discharge downstream of the project is higher than would be expected just by looking at the flow that is downstream of the diversion.

The downstream river discharge can be re-used by a downstream irrigation system. Hence the efficiency of irrigation water use at a catchment level can be considerably higher than the overall efficiency of a single project in the catchment. When managing water at a catchment level it has to be appreciated that a significant quantity of water is re-cycled between the sources and sinks. As a consequence water supply can be conceptualised in terms of two distinct components. The primary water supply from precipitation, inter-catchment transfers and desalination. The secondary water supply that derives from re-cycling the primary water supply (Reference 4.16). However, it should be recognised that return flows or re-cycled water can be quite saline and polluted by pesticides and fertilisers. Surface and sub-surface flows of usable water may also drain to salt sinks such as oceans, inland seas or saline aquifers. This will also prevent the re-use of the water. This concept is more fully investigated in Seckler's paper entitled "The new era of water resources management: From "dry" to "wet" water savings" (Reference 4.21).



Source: Reference 4.16

Figure 4.9 The relative magnitude of quantities of water flowing through an "average" irrigation scheme

4.5.8 Detailed estimation of irrigation water demand and use

The irrigation water demands for an irrigation scheme with n different crops being grown on it can be calculated as follows:

$$\text{Irrigation water demand} = \sum_{i=1}^{n}\left[\frac{A(ET_{crop} - Pe - G_e)}{1 - LR}\right]$$

The irrigation water use is estimated by taking the irrigation efficiency into account as follows:

$$\text{Irrigation water use} = \frac{1}{E_i}\sum_{i=1}^{n}\left[\frac{A(ET_{crop} - Pe - G_e)}{1 - LR}\right]$$

Where: E_i is the overall irrigation efficiency.

It should be noted that the groundwater table and stored soil water at the beginning of a growing season can also make a contribution to the agricultural water demand and use. However, these contributions are not easily measured and for the purposes of assessing agricultural water demand and use on a catchment basis it is often usual to ignore them.

In many parts of the world the growing season is long enough that double and some times triple cropping can take place on the same irrigated area. In these cases the irrigated area should reflect the number of crops grown in a year. An example of estimating irrigation water demand and use is given below.

Example of the estimation of irrigation water demand and use

The annual agricultural water demand and use for a 1500 ha irrigation scheme in southern Africa can be calculated as follows. The following crops together with their associated areas, crop water requirements groundwater contribution and leaching fraction are given below. The overall irrigation efficiency of the scheme has been estimated to be 0.55 (55%). The mean annual rainfall for the scheme is 600 mm. A water quality analysis has been carried out that indicates that from the electrical conductivity of the irrigation water ECw is 7 mmhos/cm. The soil is sandy with a leaching efficiency (Le) of 100%.

Crop type	**Crop area (ha)**	**Crop water requirement ET_{crop} (mm/year)**	**Effective rainfall Pe (mm/year)**	**Groundwater contribution Ge (mm/year)**	**Leaching requirement fraction LR**
Maize	500	1140	420	50	0.21
Cotton	250	1210	420	-	0.22
Soybeans	750	870	408	-	0.38

$$\text{Irrigation water demand} = 10\left[500\left(\frac{1140 - 420 - 50}{1 - 0.21}\right) + 250\left(\frac{1210 - 420}{1 - 0.22}\right) + 750\left(\frac{870 - 408}{1 - 0.38}\right)\right]$$

= 12.4 million m^3 per annum

$$\text{Irrigation water use per annum} = \frac{\text{Agricultural water demand}}{\text{Irrigation efficiency } E_i} = \frac{12.4}{0.55} = 22.5 \text{ million } m^3$$

4.6 Measurement of irrigation water use

Measurements of irrigation water use focus on determining the following:

- Withdrawals from surface water resources (e.g. watercourses and reservoirs) and groundwater abstractions;
- Deliveries from surface water delivery systems;
- Conveyance losses owing to evaporation and seepage;
- Return flows from groundwater and surface water.

Consumptive use during application and use of water by the plants are usually estimated. It is important to determine which water use processes are critical to the objectives of the study, particularly where surface water delivery systems are used. Withdrawals may be considered to have occurred when the water leaves a reservoir, with delivery occurring when water is diverted from the canal into the irrigation field. Conveyance losses (evaporation and canal seepage), as opposed to the volume of water applied to the field, can be a major component of the withdrawals, especially in arid areas and areas with low water tables and porous surface material. In other areas, surface water withdrawals may be considered to occur as the water is diverted from the canals adjacent to the fields so that conveyance losses are negligible. Similarly, withdrawals can be from rivers, streams, or wells adjacent to the irrigation field with negligible conveyance loss. To avoid confusion in this section, diversions from natural surface-water bodies and aquifers are considered withdrawals and diversions from canals are considered deliveries to the field.

Surface water irrigation systems rely on water diverted or pumped from a river, stream, lake, or reservoir. Water diverted or pumped from a surface or groundwater sources can be measured using a variety of techniques. For example this can be done by measuring flow in the diversion (the point where water is withdrawn from the stream) or by measuring the flow upstream and downstream from the diversion when the diversion is a significant part of the flow. Similarly, the return flow can be determined by measuring flow at the point of discharge into the stream or measuring the flow upstream and downstream of the discharge. The difference between withdrawals and return flow is consumptive use, which consists of evaporation, deep percolation, and evapotranspiration by and incorporation into the plant. However, to measure consumptive use accurately using this method requires large quantities of data to be collected together and a calibration process to be undertaken.

4.6.1 Measurement of conveyance losses

Conveyance losses (including evaporation and seepage) can be measured after the return flow of one user and before the withdrawal of the next user. Conveyance losses can also be measured by determining the loss attributable to canal seepage and adding an estimate of evaporation. Several methods commonly used to measure canal seepage include:

- Ponding tests;
- Inflow-outflow studies;
- Seepage-meter studies.

4.6.2 Ponding tests

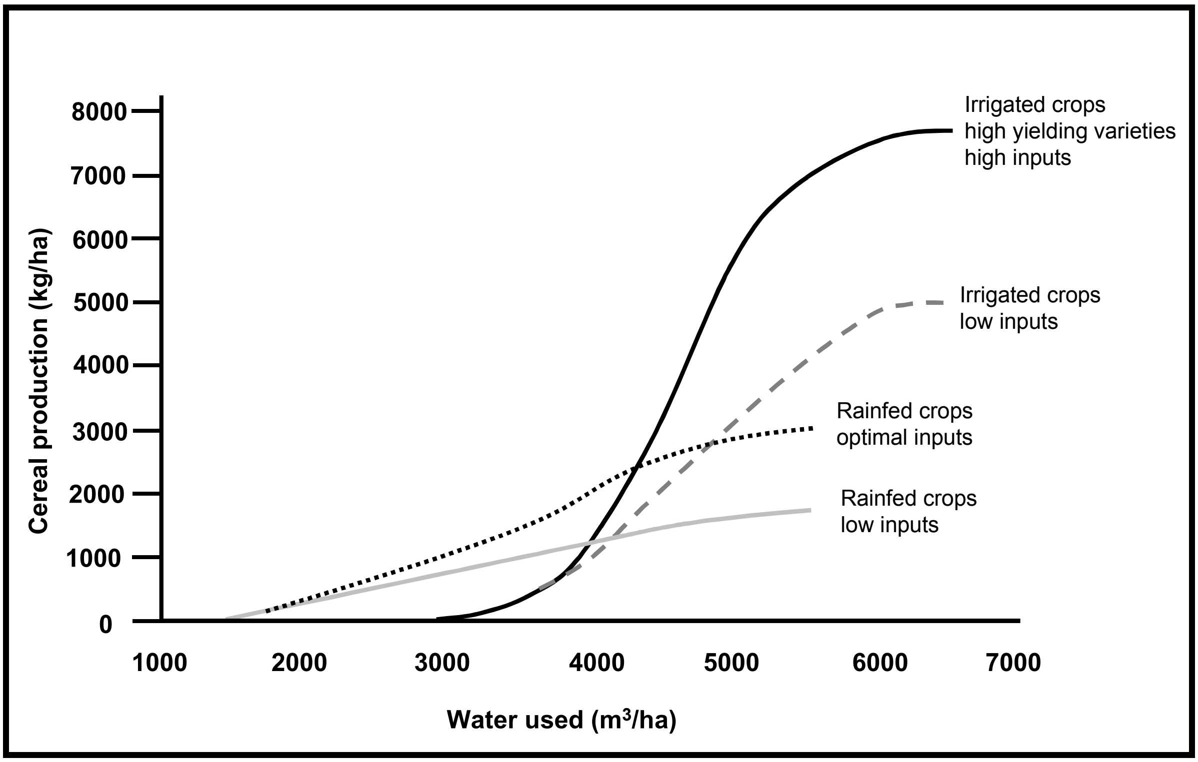
Ponding tests give the most reliable results. To conduct a ponding test, a section of canal is blocked off with dams at each end and filled with water to, or slightly higher than, the level at which it usually flows during the irrigation season. As the water level in the canal section declines, the time is recorded and a seepage rate determined. Corrections should be made for temperature and evaporation and the seepage loss-rate computed. Ponding tests are usually conducted during the non-irrigation season, and are applied in a non-flow situation in which actual flow conditions are not being met. This technique is discussed in more detail in Reference 4.18.

4.6.3 Inflow-outflow studies

Inflow-outflow studies are conducted using long reaches of the canal and require the least extrapolation of the three methods. However, the inaccuracy of an inflow-outflow measurement is proportionate to the total flow in the canal, and can be a much larger value than the amount of seepage that occurs in a reach that has little seepage. Inflow-outflow studies using discharge measurements are described in detail by Rantz et al in 1982 (Reference 4.17). One of the major advantages of using the inflow-outflow method is that it can be applied during the irrigation season.

4.7 Irrigation water use productivity

Over the past 30 years the use of conventional irrigation has grown significantly both throughout the world and in the SADC region. Irrigated agriculture has been an extremely important source of food in the SADC region in recent decades. Figure 4.10 shows that the yields that can be obtained from irrigated agriculture can be more than double the highest yields obtained from rainfed agriculture. Even low-input irrigation is more productive than high-input rainfed agriculture.



Source: Reference 4.27

Figure 4.10 Yields and water requirements of irrigated and rain fed agriculture

However, conventional irrigation cannot continue to grow as quickly as it has over the past 30 years. This is because the environmental costs of conventional irrigation schemes are also high (and are often not reflected in food prices). High-intensity irrigation can lead to waterlogging and/or salinization. About 30% of irrigated land is now severely or moderately

affected by salinization. The salinization of irrigated areas is reducing the existing area under irrigation by 1% to 2% a year. In many countries the real cost of irrigated food production is far from clear since, irrigation is often very heavily subsidised. In spite of these reservations it is likely that not only will irrigation continue to be used but the area under irrigation will also expand. However, what needs to be improved is irrigation water use efficiency or productivity i.e. increasing the crop yield per drop of water applied.
There are basically five types of irrigation:

- Surface irrigation, in which the entire or most of the crop area is flooded;
- Sprinkler irrigation, which imitates rainfall;
- Drip irrigation, in which water is dripped onto the soil above the root zone only;
- Underground irrigation of the root zone by means of porous pots or pipes placed in the soil;
- Sub-irrigation, in which the groundwater level is raised sufficiently to dampen the root zone.

The first two of these, surface and sprinkler irrigation, are together known as conventional irrigation. Surface irrigation is currently by far the most common technique, and is used particularly by small farmers since it does not involve operation and maintenance of sophisticated hydraulic equipment. For the same reason, surface irrigation is still likely to be dominant in 2030, even though it is wasteful of water and is a major cause of waterlogging and salinization (Reference 4.27).

Drip irrigation and underground irrigation are examples of localised irrigation, an increasingly popular form of irrigation in which water efficiency is maximised because water is applied only to the places where it is needed and little is wasted. However, technology is not the only way in which irrigation water productivity can be increased. Small-scale irrigation and the use of urban wastewater promise to increase water productivity as much as changes in irrigation technology.

Drip irrigation has been applied only on a small part of the area for which it is suited. It depends on a pressurised system to force water through perforated pipes running above ground, at rates of 1 litre to 10 litres per hour per emitter. Although the technology is simple, it does require both investment and careful maintenance because emitters can easily become clogged. However, results from many countries show that farmers who switch from furrow systems or sprinkler irrigation to drip systems can cut their water use by 30% to 60% (Reference 4.27). Crop yields often increase at the same time because plants are effectively ‘spoon-fed’ the optimal amount of water (and often fertiliser) when they need it. Drip irrigation has been used in sub-Saharan Africa to significantly increase water use productivity (i.e. the amount of crop per drop) on large irrigation schemes. A case study based in Swaziland is described in Section 4.10.

To produce an optimal yield crops must have adequate water at the right times to increase the productivity of agricultural water, that is, produce more crop per drop of water used. The maximum yield of crops is related to the actual yield by the equation below.

$$\frac{Ya}{Ym} = 1 - ky\left(1 - \frac{ETa}{ETm}\right)$$

Where:
Ya is the actual harvested yield
Ym is the maximum harvested yield
ky is the yield response factor for each stage of the crop development
ETa is the actual evapotranspiration which is related to the quantity of water the crop receives

ETm is the maximum evapotransiration

Further information on the above equation is given in the FAO's Irrigation and drainage paper no. 33 entitled "Yield response to water". Many crops' yields are most susceptible to water shortages during the flowering stage of their development (Reference 4.30). Water shortages that occur in the ripening stage of their development often have significantly less effect on yields. For example water stress at the flowering stage of maize, for example, will reduce yields by 60%, even if the water is adequate for the rest of the year. When and how water is applied to a crop thus has a major effect on the water efficiency of the water use in terms of the yield per unit of water applied. An example of this is given below.

Example water use efficiency for wheat in Zimbabwe

A large agricultural estate in southern Zimbabwe cultivates wheat during the winter season. The wheat crop entirely depends on sprinkler irrigation, as it rarely rains during winter. During five consecutive growing seasons (1995 to 1999), the total amount of water entering five wheat plots was measured, as well as the yields obtained. These data were plotted in a graph Figure 4.11. The research also found that the field application efficiency of sprinkler irrigation on the estate was 80%.

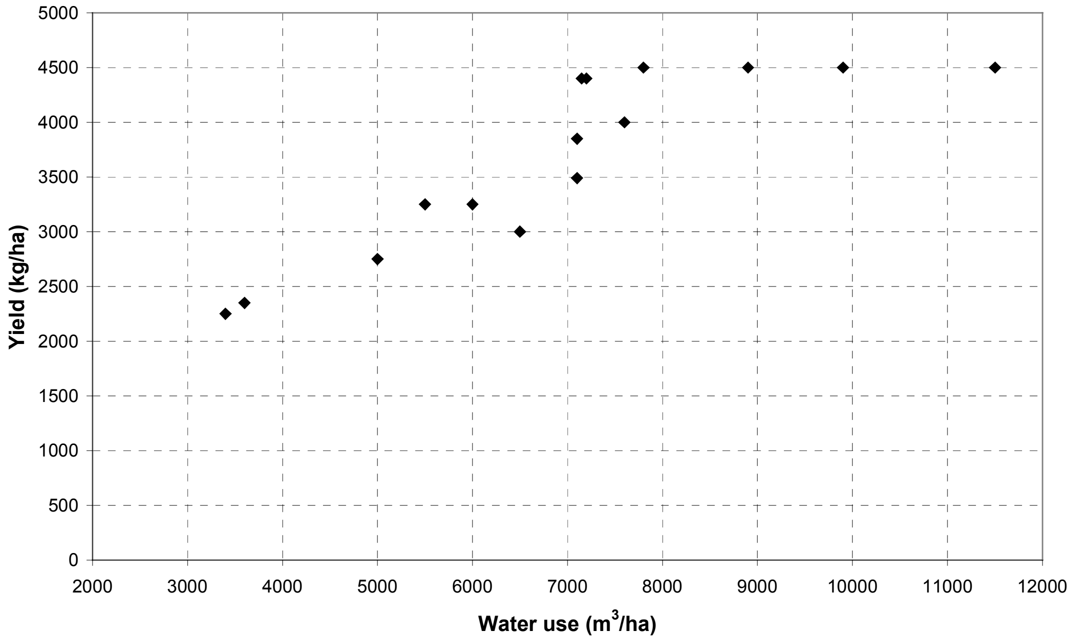


Figure 4.11 **Water use versus yield relationship for irrigated wheat in southern Zimbabwe for 1995 to 1999**

From Figure 4.11 it can be seen that the maximum yield of wheat (Ym) is around 4500 kg/ha. In order to obtain this yield the irrigation requirement is around 8000 m^3 of water has to be applied per hectare of the crop. For the maximum yield of the crop the water use efficiency is:

$$\text{Water use efficiency} = \frac{4500}{8000} = 0.56 \text{ kg/m}^3$$

However, if the scenario is considered where there is insufficient water to obtain the maximum yield. To obtain a yield (Ya) of 3250 kg/ha an irrigation requirement of 5400 m^3 of water has to be applied per hectare of the crop. The water use efficiency is:

$$\text{Water use efficiency} = \frac{3250}{5400} = 0.60 \text{ kg/m}^3$$

Although the maximum yield of the crop has not been obtained the water use efficiency is 10% higher than that which occurs at the maximum yield.

Source: Reference 4.28

An example of the improved water use efficiency that can be gained using drip irrigation in the Cape Verde islands is given below.

Example of the improved water use efficiency using drip irrigation in Cape Verde

In the early 1990s an FAO funded project sought to develop horticulture in Cape Verde. The project was a success but its extension was limited by the availability of water - average precipitation on the islands is about 230 mm/year, providing little more than 700 m^3/person/year. Drip irrigation was then introduced, first in experimental plots and then in farmers' fields. The new system increased production and saved water, allowing for an expansion of the irrigated land and cropping intensity. Convinced by the experiment, many farmers spontaneously adopted drip irrigation on their land. In 1999, six years after the first experiment, 22% of the irrigated area of the country had been converted to drip irrigation, and many farmers had converted their crops from water-consuming sugar cane plantations to high-return horticultural crops such as potatoes, onions, peppers and tomatoes. Total horticultural production increased from 5700 tonnes in 1991 to 17,000 tonnes in 1999. It is estimated that a plot of 0.2 hectares provides farmers with a monthly revenue of US$1000.

Source: Reference 4.27

The relationship between water use and yield can be used to assist in assessing the marginal value of supplementary irrigation. The example below from Zimbabwe illustrates how this value can be estimated.

Example to illustrate the value of water for maize in Zimbabwe

For selected plots in Nyanyadzi irrigation scheme in Zimbabwe research was undertaken that found that one additional m^3 of water (irrigation water plus rainfall) supplied to the maize crop (rainfed with supplementary irrigation) gave an added yield of 1.5 kg of maize per m^{-3} of water (Correlation coefficient $r^2 = 0.81$). Assuming a maize price of US$0.10 per kg, it follows that the marginal value of water (rainfall plus irrigation) is US$0.15 per m^3.

Yields were also correlated with net total irrigation water (Inet in mm). The following mathematical relationship was found:

$$Y = 1450 + 18.67\text{Inet} \qquad (\text{Correlation coefficient } r^2 = 0.71)$$

The constant of 1,450 kg/ha indicates the yields obtainable for a rainfed crop without irrigation. The marginal productivity of net summer supplementary irrigation water was around 19 kg/ha$^{/}$mm, or 1.9 kg/m^3. This means that 1 m^3 of supplementary irrigation water will produce an additional 1.9 kg of maize, which is valued at US$ 0.19. The marginal value of supplementary irrigation for maize in Nyanyadzi is therefore 0.19 US$ per m^3. Figures 4.12 and 4.13 illustrate the discussed relationships.

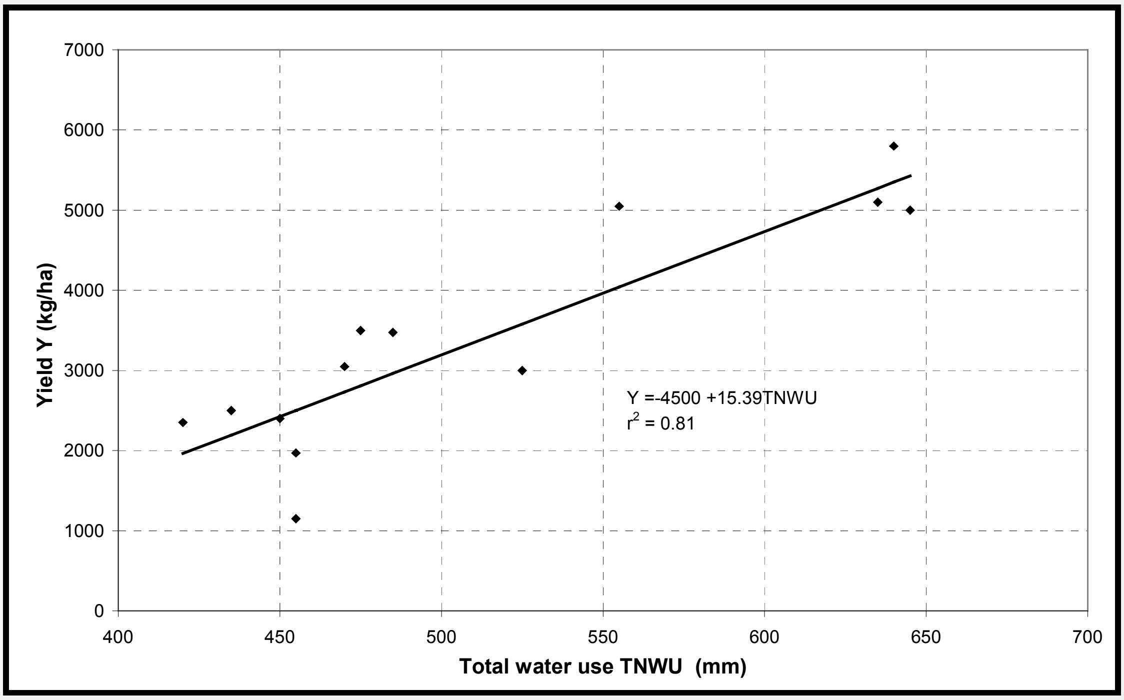


Figure 4.12 **Relationship between net water use and yield for maize for Nyanyadzi in Zimbabwe**

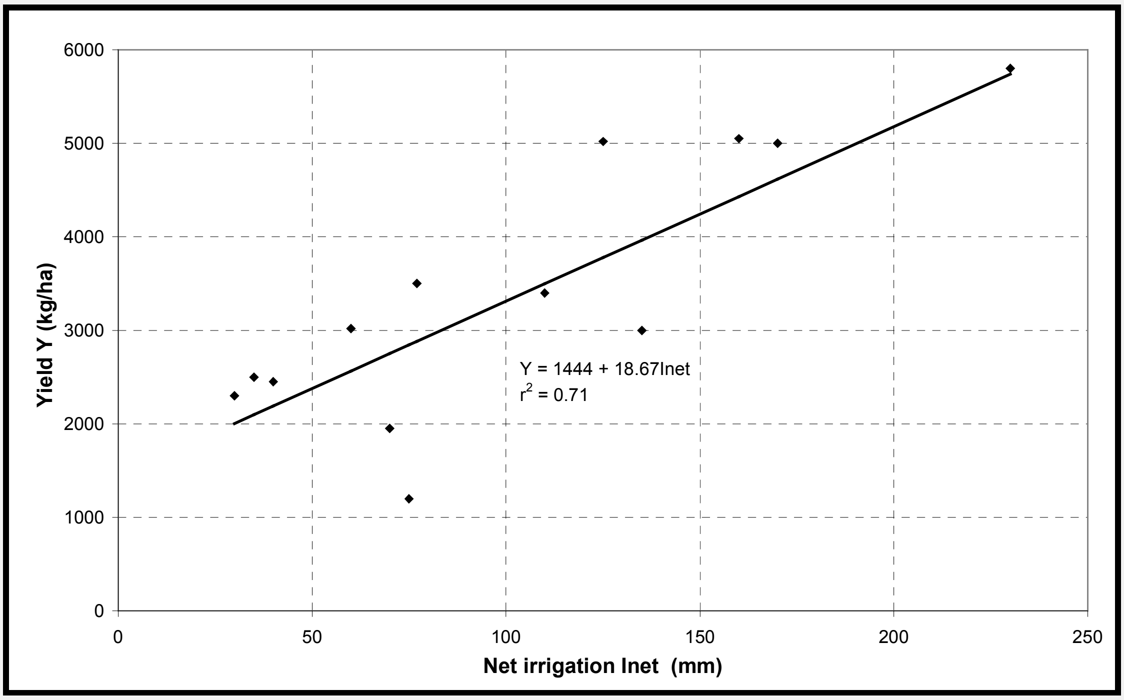


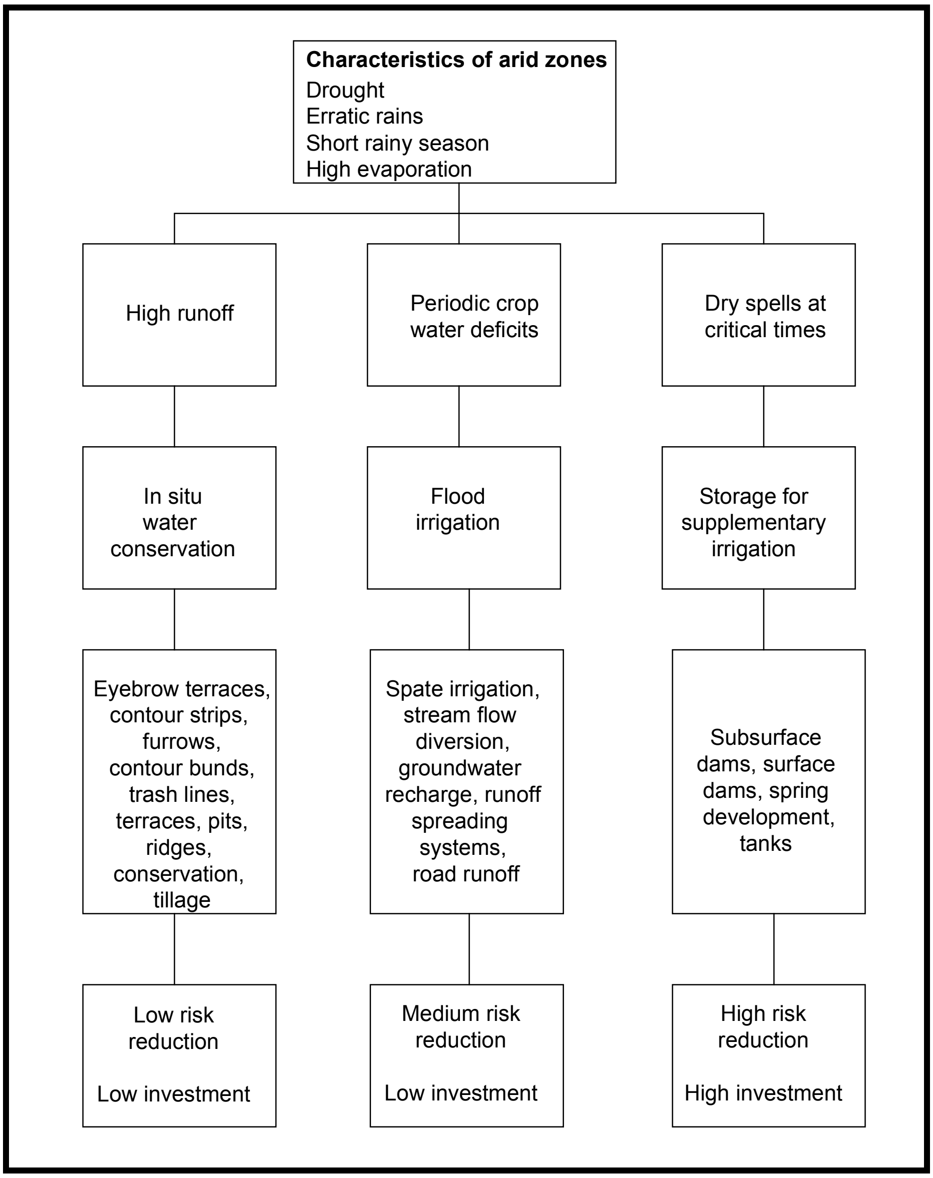
Figure 4.13 **Relationship between net irrigation water and yield for maize for Nyanyadzi in Zimbabwe**

Source: Reference 4.29

4.8 Improving rain fed agricultural production

Increasing the productivity of rainfed agriculture, which still supplies some 60% of the world's food, would make a significant impact on global food production. However, the potential to improve yields depends strongly on rainfall patterns. In arid areas, rainwater harvesting can both reduce risk and increase yields (Reference 4.27). Figure 4.14 shows, there are various forms of rainwater harvesting. These include:

- Using microstructures in the field to direct water at specific plants or plant rows (in situ water conservation);
- Capturing and directing external water from the catchment area to the field in which crops are grown (flood irrigation);
- Collecting external water from the catchment area and storing it in reservoirs, ponds and other structures for use during dry periods (storage for supplementary irrigation).



Source: Reference 4.27

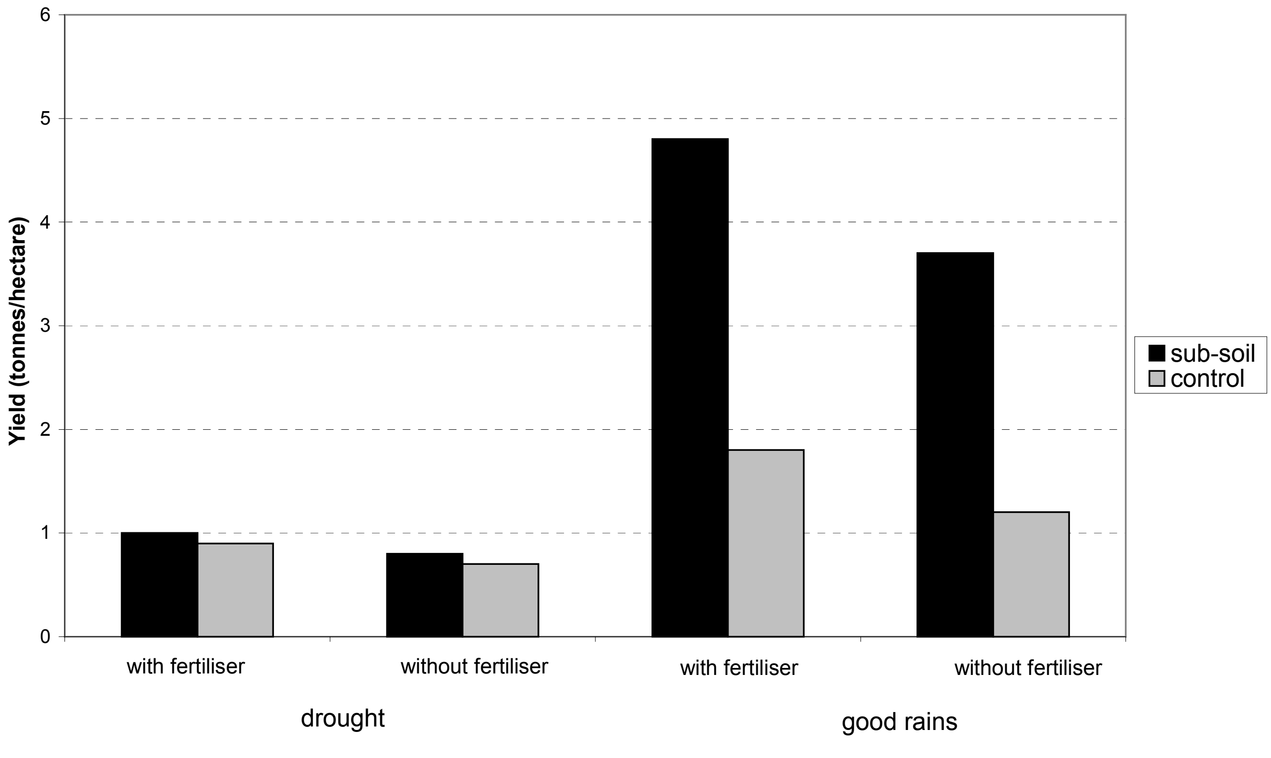
Figure 4.14 Methods of improving rainfed agricultural production

4.8.1 In-situ water conservation

In dry areas, poor land management can greatly reduce crop yields, even to below 1 tonne per hectare. One reason is that land degradation often affects the soil surface, leading to crust formation and other phenomena that prevent infiltration by rainwater. Most rainfall then simply runs off the land surface, collects in silt-laden torrents and produces severe gully erosion. Crops benefit little.

A major cause is turning the soil, by hand, with animal traction or with a tractor, too often. This leaves the soil exposed and prone to both wind and water erosion. While ploughing techniques developed in temperate regions, with their gentle rains and light winds, are harmless enough, they are often poorly suited to tropical climates and soils (Reference 4.27).

Alternative forms of tillage - such as turning the soil only along plant lines, deep ploughing to break up soil crusts, building raised ridges that follow the contour, growing crops in pits, and building eyebrow terraces round trees and shrubs - can improve crop yields and reduce erosion. They lead to a much more efficient use of limited rainfall. Trials in Tanzania have shown, for example, that breaking up the plough-pan increased maize yields from 1.8 tonnes to 4.8 tonnes per hectare in a year with good rains and if manure was applied as fertiliser. The effects of these trials are shown in Figure 4.15. In Damergou in the Niger, 310 hectares were equipped with micro-catchments and contour furrows in less than one month using special ploughs. Costs were only US$90 per hectare. Average yields were 2 tonnes per hectare of sorghum with an annual rainfall of only 360 mm (Reference 4.27).



Source: Reference 4.27

Figure 4.15 Effects of sub-soiling in Tanzania

4.8.2 Supplementary irrigation

Crop yields from rain fed agriculture can be significantly improved via the use of supplementary irrigation. Runoff during spells of rain can be stored using tanks, ponds, cisterns and earth dams. During dry spells this water can be used for supplementary irrigation. Although structures such as tanks and ponds can be costly and require considerable know-how on the part of the farmers who have to build them, they have the advantage of greatly reducing the risk of small or non-existent harvests as a result of drought. Small-scale farming can be productive in marginal rainfed areas if supplementary irrigation is available to overcome short-term droughts which are critical to the crop and reduce yield considerably. If there are cost-effective ways to store water before critical crop stages and apply it when the rain fails in these critical stages, crop production can be considerably increased (Reference 4.27). This results in considerable improvements in water use efficiency.

4.9 Deficit irrigation

In the 2000 the FAO produced a report entitled "Deficit Irrigation Practices". This was published as Water Report No. 22. The studies presented in the report are the latest research concepts and involve various practices for deficit irrigation. Both annual and perennial crops were exposed to different levels of water stress, either during a particular growth phase, throughout the whole growing season or in a combination of growth stages. The overall finding, based on the synthesis of the different contributions, is that deficit or regulated-deficit irrigation can be beneficial where appropriately applied. Substantial savings of water can be achieved with little impact on the quality and quantity of the harvested yield. However, to be successful, an intimate knowledge of crop behaviour is required, as crop response to water stress varies considerably (Reference 4.31).

A study carried out on winter wheat in the North China Plain between 1992 and 2000 showed possible water savings of 25% to 75% by applying deficit irrigation at various growth stages, without significant loss of yield and profits. A dynamic model was used to calculate the net profits of the irrigation treatments. Procedures were developed to schedule irrigation applications according to the number of irrigations required. In deficit studies carried out in India on irrigated groundnuts, it was possible to increase field water use efficiency and dry matter by imposing transient soil moisture-deficit stress during the vegetative phase, i.e. 20 to 45 days after sowing. Water stress applied during vegetative growth may have had a favourable effect on root growth, contributing to more effective water use from deeper layers. While most studies were able to demonstrate the benefits of deficit irrigation, potatoes grown under sprinkler irrigation in the semi-arid environment of eastern Oregon, United States of America, did not show an economic benefit when exposed to stress. Growing four varieties of potatoes under various deficit irrigation treatments resulted in gross revenues declining by more than the production costs, and hence reduced profits. The results of this case study suggest that deficit irrigation of potatoes would not be a viable management option for that region under current economic conditions (Reference 4.31).

Fruit crops such as peach and pear trees and grapevines reacted favourably to deficit irrigation practices, with important water savings and improved fruit quality. In south-eastern Australia, regulated deficit irrigation (RDI) of peach and pear trees increased water use efficiency by 60%, with no loss in yield or reduction in vegetative vigour. In Washington State, United States of America, regulated deficit irrigation of grapevines prior to fruit set (veraison) was effective in controlling shoot growth and pruning weights, with no significant reduction in yield. RDI applied after veraison to vines with large canopies resulted in greater water deficit stress. Wine quality improved with pre-veraison RDI applied as compared to post-veraison RDI. RDI applied at anytime resulted in better early-season lignification of canes and cold hardening of buds (Reference 4.31).

In addition to RDI, partial root zone drying (PRD) is also a promising practice for inducing stress tolerance in fruit trees. PRD is a new irrigation technique that subjects one-half of the root system to a dry or drying phase while the other half is irrigated. The wetted and dried sides of the root system alternate on a 10 to 14 day cycle. Both RDI and PRD systems require high management skills. Close monitoring of soil water content is recommended. Both practices improve the water use efficiency of wine grape production. Micro-irrigation facilitates the application of RDI and PRD. Practical guidelines for using RDI were developed (Reference 4.31).

Subsurface drip irrigation (SDI) also improved the water use efficiency of crops and reduced farming costs. An approach was developed for deficit SDI on cotton grown in arid east Texas, United States of America, to enable farmers with a limited supply of water to decide on the optimal area to plant and the best row width/pattern to apply. By applying deficit SDI, it proved more economical to use the available water resources over the entire farm, rather than to try to maximise water and yield on part of the farm. Moreover, with SDI, it proved possible to apply a large part of the water required as pre-planting irrigation, thus effectively advancing the timing of water application to the beginning of the season when more water is available (Reference 4.31).

4.10 Case study of improved water use efficiency for an irrigation scheme in Swaziland

Irrigation is vital to the production of sugarcane production at the Simunye sugar estate in Swaziland. In an average year the sugarcane crop receives 440 mm of effective rainfall and requires an additional 750 mm of net irrigation for optimum growth conditions to occur. The drought that occurred in southern Africa in the early 1990s led the managers of the estate to investigate methods of improving water use efficiency and sugarcane yield per unit of water in order to release water to grow additional areas of sugarcane (Reference 4.21).

When the full commercial production of sugarcane commenced in 1982 the estate had two main irrigation systems. Overhead sprinklers were used on 77% of the land and surface furrow was used to irrigate the remainder. Although the sprinkler system initially installed worked well and was simple to operate by the mid-1990s it was nearing the end of its serviceable life. Figure 4.16 shows the growth in sugarcane area and the use of drip irrigation between 1982 and 2001 (Reference 4.21).

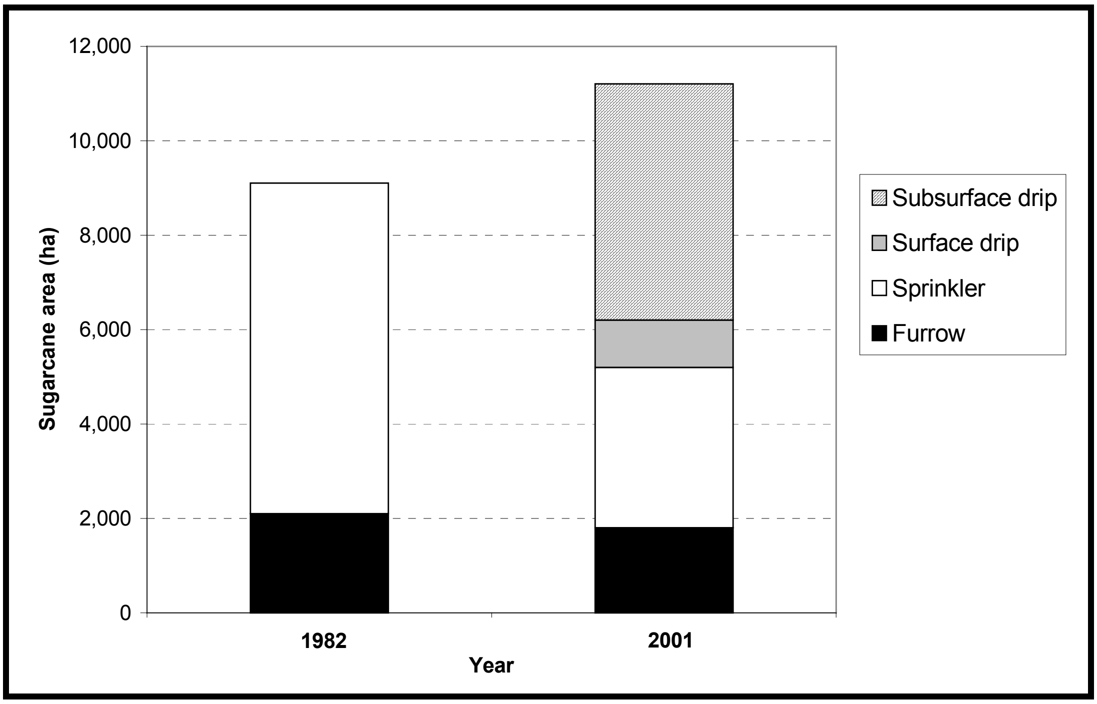
There were several reasons for changing the irrigation system. These included:

- Improving water use efficiency;
- Making water available to increase the area of sugarcane production;
- Increasing the sucrose yield of the sugar cane per unit of water used;
- Improve soil water drainage.

A number of options were considered. On economic grounds the option of converting from sprinkler to drip irrigation was ranked the highest. One of the primary benefits of the drip irrigation option was its sucrose yield per hectare compared to sprinkler irrigation. A performance evaluation carried out on a number of pilot plots showed an average increase of 1.6 tonnes per hectare up to 1997 when the redevelopment decision was made. This is shown in Figure 4.17.

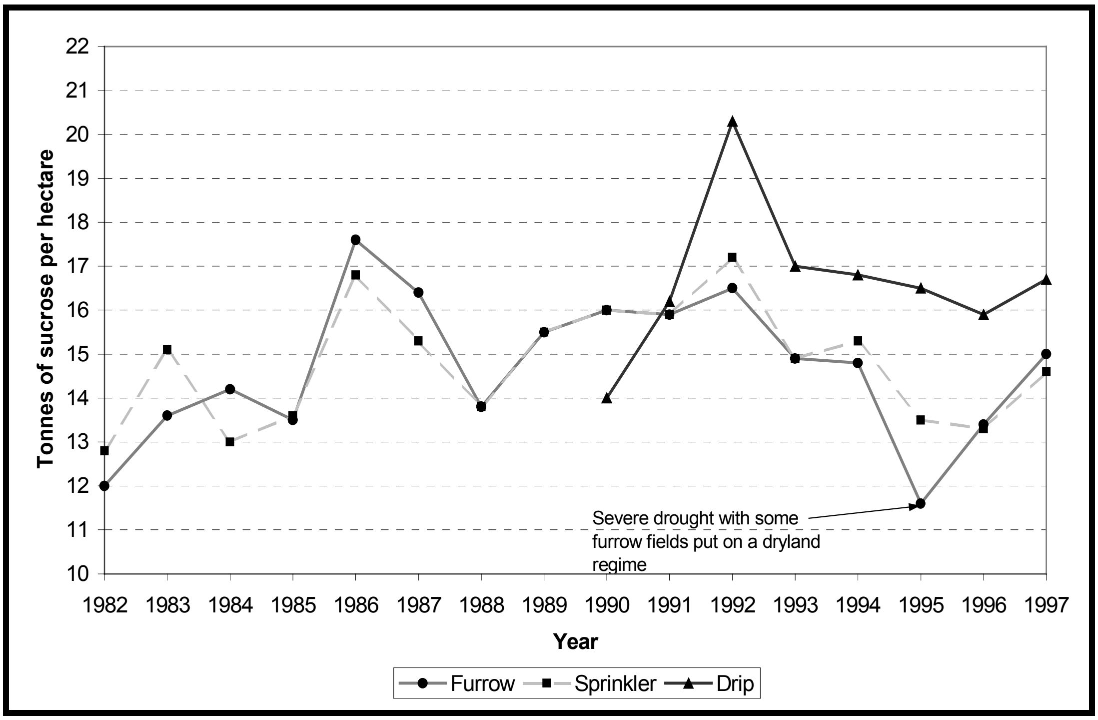
Once the new drip irrigation scheme was installed a post investment audit was carried out to assess whether the benefits accruing from the cost of converting sprinkler to subsurface drip provided an acceptable rate of return. The four major benefits from the redevelopment were:

- **An increase in the yield**. Sucrose yield was found to increase by 1.6 tonnes per hectare;
- **Water saving**. A water saving of 1.5 Ml/ha/year has been made. This has an opportunity cost of some US$160/ha/year
- **Operation and maintenance saving.** Savings in maintenance, power and labour have resulted in a saving of US$140/ha/year;
- **Savings owing to power levelling** The improvement in load factors on the power supply has led to a saving in power of 4.6 kVA/ha/year.



Source: Reference 4.21

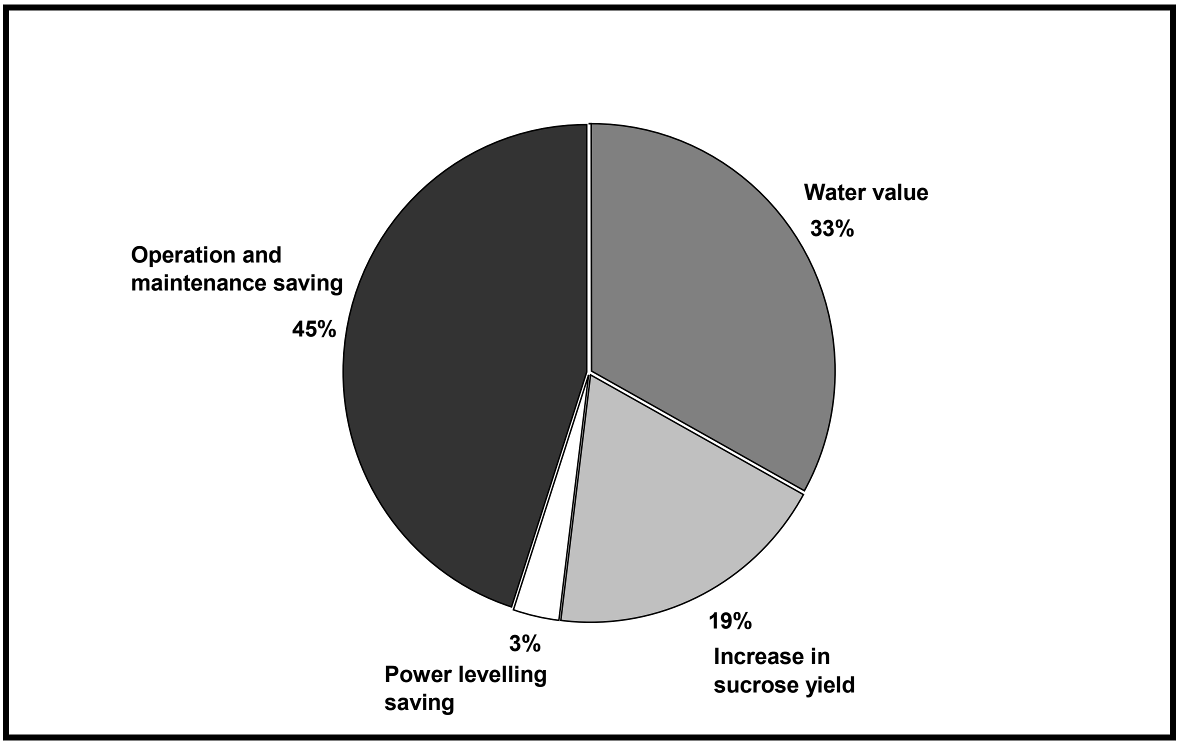
Figure 4.16 Growth in sugarcane area and the use of drip irrigation for the Simunye sugar estate in Swaziland



Source: Reference 4.21

Figure 4.17 Sucrose productivity by irrigation type for the Simunye sugar estate in Swaziland

Figure 4.18 shows the relative benefits as measured at post investment.



Source: Reference 4.21

Figure 4.18 Relative value of the project benefits for the Simunye sugar estate in Swaziland

Further monitoring and analysis was carried out on 46 fields converted to subsurface drip in 1998 and compared to 13 sprinkler fields of equivalent age and ratoon class distributed throughout the scheme. The findings were that the average sucrose increment was 23% for plant cane and 24% for the first ratoon and the water use efficiency was 29% better for plant cane and 18% for the first ratoon (Reference 4.21). These results were superior to the parameters used in the post-investment audit and confirm the gains in water use efficiency and yield per unit of water that can be made by converting to more efficient irrigation methods.

4.11 Livestock water use

The water requirements of livestock are influenced by several factors, including:

- Type of livestock,
- Pregnancy;
- Lactation;
- Type of diet;
- Feed intake;
- Temperature.

Estimating total livestock consumption is relatively simple. The assessment of livestock consumption should be carried out as follows.

- Determine types of livestock;
- Use typical water consumption figures per head for each type of livestock;
- Determine number of each type of livestock in the area being assessed.

Typical water consumption figures for livestock are given in Table 4.2.

Table 4.2 Typical water consumption figures for livestock

Type of livestock	Water consumption
Beef cattle	25 litres to 45 litres per head per day
Dairy cattle	40 litres to 60 litres per head per day
Horses	30 litres to 45 litres per head per day
Pigs	10 litres to 20 litres per head per day
Sheep and goats	4 litres to 10 litres per head per day
Chickens	30 litres to 40 litres per 100 birds per day
Turkeys	40 litres to 55 litres per 100 birds per day

Source: Reference 4.23

Table 4.3 shows estimates of water requirements of beef cattle in different physiological states and in different thermal requirements.

Table 4.3 Water consumption estimates for beef cattle in different thermal environments

Thermal environment	Water requirements
>35°C	8 litres to 15 litres of water per kg of dry matter feed intake
25°C to 35°C	4 litres to 10 litres of water per kg of dry matter feed intake
15°C to 25°C	3 litres to 5 litres of water per kg of dry matter feed intake
-5°C to 15°C	2 litres to 4 litres of water per kg of dry matter feed intake

Note: Young and lactating animals require 10% to 50% more water.

Source: Reference 4.24 and 4.25

Dry matter intake per day can vary between 7 kg per day and 20 kg per day depending on the type of livestock (Reference 4.24 and 4.25). It should be noted that estimates for livestock water use are very variable. However, livestock water use is usually a minor user of water when compared to irrigation water use.

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5. RURAL DOMESTIC WATER DEMAND AND USE

5.1 Background

5.1.1 Definition of water demand, consumption and use

Estimating domestic water demand and use at a catchment level for rural areas in southern Africa is problematic owing to the lack of measured data available. Estimates of rural domestic water demand and use are further complicated by the lack of definitions of the terms used. Hence in the context of assessing rural water demand and use it is important that various terms are clarified. Water demand is different from consumption. Consumption is the actual volume of water consumed, whereas demand is how much water people would use if they had the opportunity. Many of the surveys that have been carried out in rural areas in southern Africa have assessed water consumption, not water demand. Definitions of water consumption, water extracted, water use, water need and water demand are given below.

- **Water consumption** is the volume of water that is actually gathered from water points such as wells, boreholes and communal taps.
- **Water extracted** is the measure of the water actually gathered at a water point and associated wastage i.e. a measure of what is removed from the water point in total.
- **Water use** is the sum of water that is utilised but not always collected. An example of water that is not collected from a water point is washing clothes in a river.
- **Water need** is the required water volume based upon a series of pre-set, often qualitative assumptions and values regarding water use e.g. there are accepted values for the volume of drinking water required by a person per day. An example of such a value is the World Health Organisation’s recommended minimum figure of 50 litres per person per day;
- **Water demand** is the assessment of the perceived need of water by the recipient. It will be affected by a variety of factors including the expectations, wealth, and education of the individual. In many parts of rural Africa water demand can exceed water use.

For water use, consumption and extraction it is physically possible to measure the quantity of water. However, water need and demand are subjective values that require a qualitative assessment in order to be derived.

In some parts of southern Africa the concept of “primary water use” is enshrined in water laws. Primary water use refers to the reasonable use of water for basic domestic needs. As well as including human requirements they may also include requirements such as animal consumption, brick-making, and dip tanks. Primary water uses, together with environmental water requirements are often given priority with regards to water allocation under many recent pieces of water legislation implemented in southern Africa.

5.1.2 Typical rural domestic water sources

In rural areas of southern Africa communities often rely upon a complex system of multiple sources, which are generally used for various activities. These often include non-potable sources of water where water quality is not the prime concern e.g. small dams and rivers are often used for washing of clothes. Typical sources of water in rural areas of southern Africa include:

- **Community tap.** A tap facility with communal access, usually gravity fed by a filtered steam or groundwater supply.
- **Homestead tap (yard).** This is a private water supply from a tap located in the yard of the homestead.

- **Homestead tap (inside).** This is a private water supply by tap located within one of the homestead buildings.
- **Community borehole.** A borehole with a hand driven pump for community access.
- **Private borehole.** This is similar to a community borehole but with the access limited to a select few.
- **Unprotected open well.** A well that is generally open to the environment and generally not very deep (e.g. 2 m to 10 m). The water is prone to contamination by pathogens. Water is collected using a bucket and rope.
- **Protected well**. A well that has been constructed with a cover, windlass/winch and bucket that protects against pathogens entering the water.
- **Protected/unprotected spring.** Similar to a protected/unprotected well, except the water wells up from the surrounding rock.
- **River or stream**. Water is accessed by direct collection from a watercourse.
- **Permanent dam**. Water is collected from the reservoir formed by the dam.
- **Rain water harvesting.** A method of collecting rainwater that runs off the roof of a building.

The seasonality of the regional rainfall in rural areas of southern African countries has a significant impact on the following:

- The type of water source used e.g. in the rainy season rain water harvesting may be the main source of water, whereas in the dry season a deep borehole may be the only reliable source of water;
- The security and reliability of the supply;
- The quality of the supply;
- Access to water.

These sources of water and the seasonality of the rainfall affect how much water is used in rural areas of southern Africa.

5.1.3 Background to rural domestic water supply and sanitation schemes

Rural domestic water supply and sanitation schemes are usually typified by the following:

- Lack of physical infrastructure (i.e. a low level of service). For example:
    - There is often a lack of a piped water system or a water borne sewerage system;
    - Water sources are commonly rivers, hand dug open wells or boreholes;
    - Travel times to water sources can be high;
- Operation and maintenance of rural water supply schemes in sub-Saharan Africa often takes place at a community level;
- The outreach of rural government agencies to rural water and sanitation schemes is often limited.

Figures for rural domestic water coverage in South Africa are shown in Table 5.1.

Table 5.1 Rural domestic water coverage in South Africa

Level of service	Description	Percentage coverage (%)
Minimal	No infrastructure in place	40
Upgradeable	Upgrading required to be classified as basic	25
Basic	25 litre per person per day within 200 m of every resident	20
Intermediate	Households have access to yard taps	10
High	Households have access to in-house connections	5

Source: Reference 5.1

Table 5.1 indicates that even for South Africa, which is a relatively developed country by African standards, the level of service for rural domestic water supply is generally low.

Domestic water demand and use in rural areas of the developing world may be defined as the water required to fulfil basic water supply and sanitation needs. These are defined as follows:

- **Basic water supply** is normally taken to mean all water used for drinking, food preparation, bathing, laundry, dishwashing, and cleaning, but can also include the water needed for watering animals and small gardens;
- **Basic sanitation** is the water used for waste disposal.

Numerous rural water supply studies have shown that the daily level of domestic water use varies considerably in rural areas of Africa. Generally domestic rural water demand will be between the following two figures:

- In Angola rural domestic water use is estimated to be approximately 15 litres per person per day;
- In Madagascar rural domestic water use is estimated to be approximately 270 litres per person per day.

In the majority of rural areas of Africa domestic water use was found to vary from some 20 litres per person per day to 40 litres per person per day. However, the World Bank quotes a figure of 50 litres per person per day. The World Health Organization quotes a figure of 150 litres per household per day in order to provide adequate health and sanitation. It is important to note that both rural domestic water demand and use are affected by a number of complex factors. It is rarely possible to use one simple per capita figure on a catchment basis to assess the demand and use. These factors are discussed in Section 5.3. As a consequence any rural domestic water demand and use assessments should be based on the various factors that influence water demand and use. Section 5.2 gives typical figures for rural domestic water use for a variety of countries in southern Africa.

5.2 Typical rural domestic water use figures for southern Africa

In general there are few measured rural water use figures available for southern Africa. However, details of the figures that are available are given in the Sections below.

5.2.1 Angola

There is very little data available on rural water demand and use for Angola. A feasibility study carried out in 1995 for the Epupa hydropower scheme used a figure of 50 l/person/day for rural water use. However, this figure is about twice what had been previously reported (Reference 5.13).

5.2.2 Botswana

The available data for rural areas in Botswana pertains to "urban villages". These are settlements in rural areas that have populations of several thousand and are supplied by a piped water supply scheme. Table 5.2 gives typical water production for urban villages in Botswana. It should be noted that the figures refer to water production and not consumption. The quantity of water actually consumed will be lower than these figures owing to losses in the water supply networks.

Table 5.2 Water production for urban villages in Botswana in 1995 (l/person/day)

Location	Production (l/person/day)
Kanye	62
Ramotswa	51
Maun	103
Moshopa	48
Molepolole	26
Serowe	96
Palapye	91
Thamaga	54
Mochudi	81
Tlokweng	64
Lethakane	85
Tsabong	113
Mahalapye	99

Source: Reference 5.10

5.2.3 South Africa

In May 2000 a survey of primary water use was carried out in the Mkonmazi River catchment in the province of KwaZulu-Natal South Africa. The primary water demand and use is the water that is required to maintain life and livelihoods. The survey was carried out of some 1,000 settlements. The average water use for the Mkonmazi River catchment was found to be 30.8 l/person/day. The minimum figure supplied was 5 l/person/day. The maximum reported was 122.4 l/person/day (Reference 5.3). These figures incorporated the following uses:

- Drinking;
- Cooking;
- Washing people;
- Washing clothes;
- Drinking water for animals (primarily dogs and chickens);
- Gardening although water may be re-used for gardens after its primary use.

At the time of the 1994 democratic elections, rural South Africa was very poorly served with water supplies. A severe drought in 1991/1992 highlighted the weaknesses in the operation and maintenance of such systems that had been installed. Since then, the Department of Water Affairs and Forestry has embarked on a programme to provide a water supply service to everyone, at a minimum level of 25 litres per person per day within 200 metres walking distance.

5.2.4 Swaziland

In 1999 a survey was carried out in the Mbuluzi catchment in Swaziland. Some 950 homesteads over an area of 200 km^2 were questioned as to their water use. These homesteads house approximately 7,600 people, which is around 10% of the total population of the catchment. The average water use was found to be 15.7 l/person/day (Reference 5.4).

Water use figures used by the Swaziland Government in the planning of rural water supply schemes are given in Table 5.3.

Table 5.3 Estimated rural water demand for Swaziland

Description	Water demand (litres per person/head of livestock per day)
Domestic demand	40
Cattle	35
Sheep and goats	5

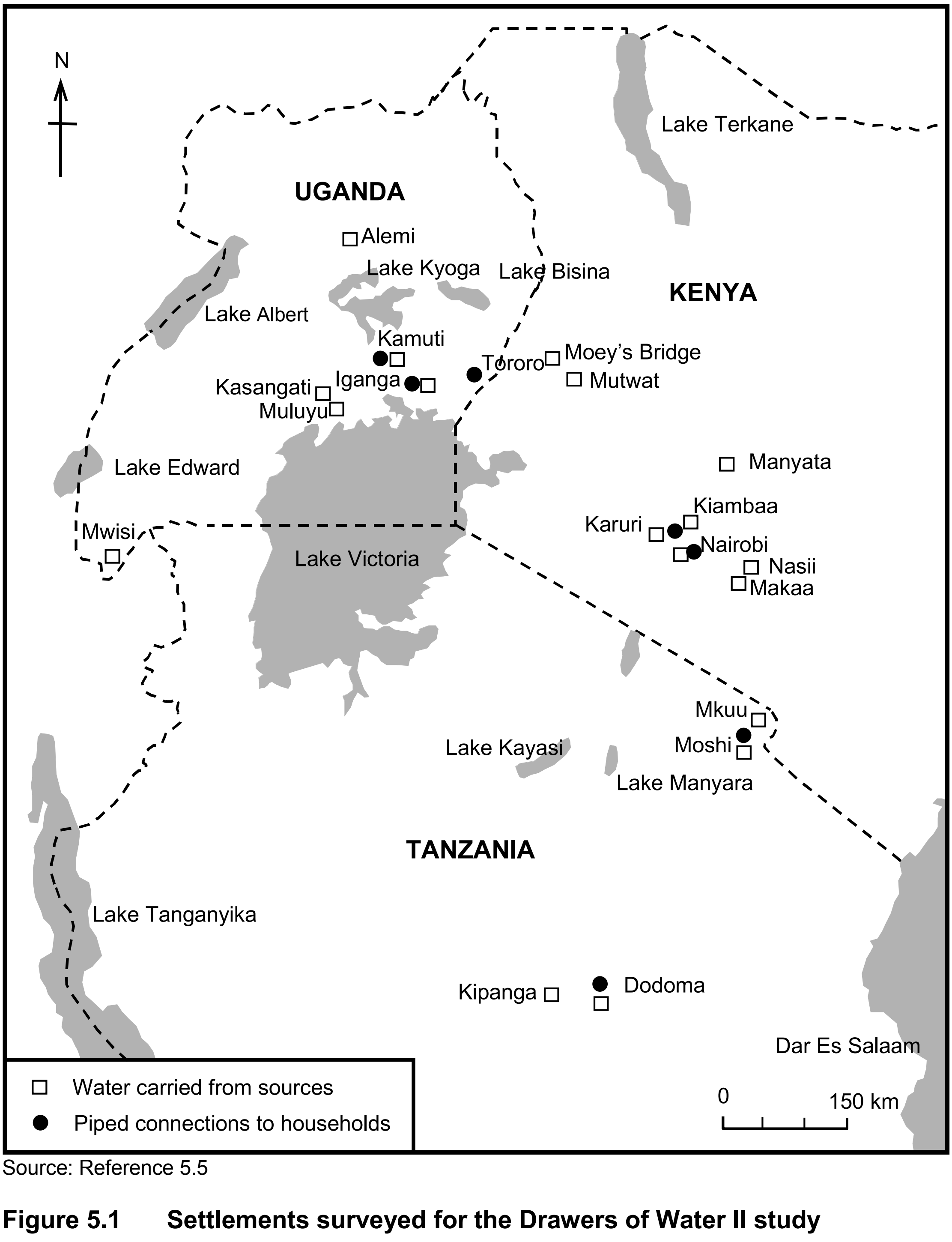
Source: Reference 5.4

5.2.5 Tanzania, Kenya and Uganda

Water use data for the countries of Tanzania, Kenya and Uganda have been collected as part of the Drawers of Water II (DOW II) study. The DOW II study was carried out to assess water use in east Africa. The study collected data during 1997 to 2000 and revisited the sites surveyed in the Drawers of Water I (DOW I) study conducted between 1967 to 1968. The data reported in DOW I were obtained by interviews and observations at 34 study sites in Kenya, Tanzania and Uganda. These sites are shown in Figure 5.1. Research for DOW II sought to carry out a comprehensive, repeat, cross-sectional analysis by replicating the original study closely and adding additional lines of inquiry, where appropriate. As in the original study, information was collected through a household survey in which interviewers spent an entire day with each household, observing water use patterns and gathering other socio-economic and environmental health data. Additional data were collected separately about each site through interviews with key informants, field observations and review of secondary literature. DOW II achieved a considerably higher sample size of 1015 households compared with 713 in DOW I (Reference 5.5).

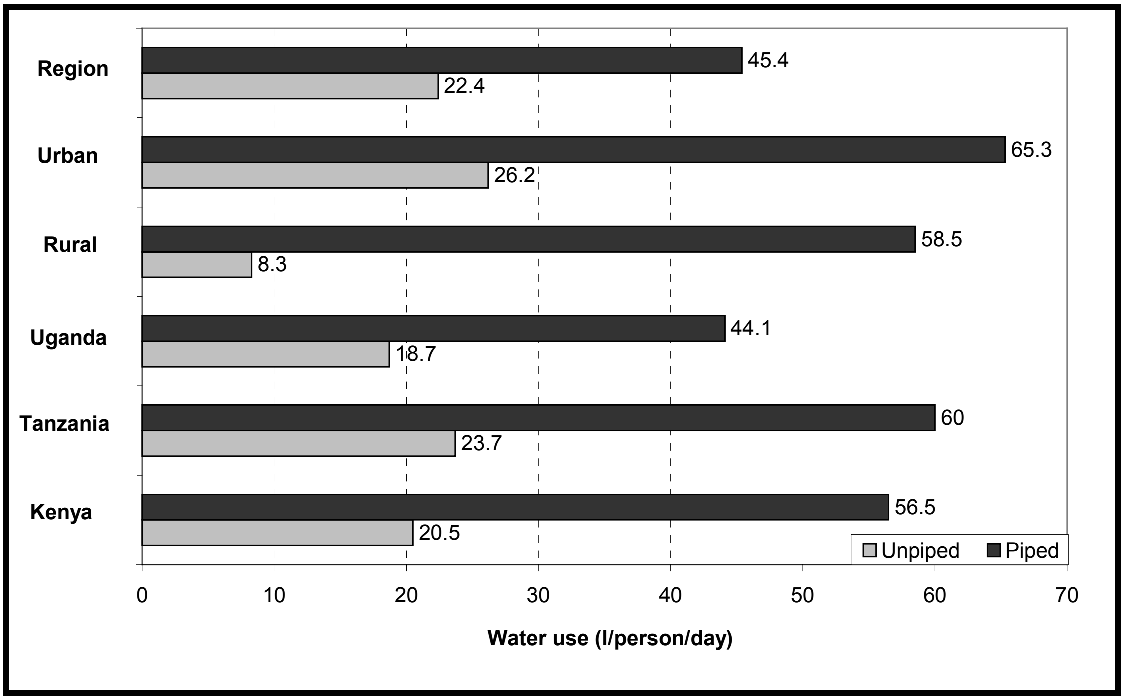
At a regional level, average daily per capita water use has declined by 30 percent over the last thirty years, from 55 to 39 litres. This is a reflection of the almost universal decline in water use by piped households. While water use by unpiped households has almost doubled (rising from 11 to 19.5 litres), use by piped households has decreased by approximately 50 percent. Despite this decline, piped households still use over three times the amount of water consumed by unpiped households (Reference 5.5). The results of the study are illustrated in Figure 5.2.

The average per capita water use was found to be 38 litres per day. However, there were major differences in the quantity of water used by piped and unpiped households. By definition, 'piped' households have piped water supplied to their home, while 'unpiped' households do not, and therefore obtain water from sources outside the home (Reference 5.5). Piped households used on average almost three times more water per capita than unpiped households. Similarly, urban sites had significantly higher levels of per capita water use than rural sites.



Source: Reference 5.5

Figure 5.1 Settlements surveyed for the Drawers of Water II study



Source: Reference 5.5

Figure 5.2 Water use figures for piped and unpiped sources from the Drawers of Water II study

A recent paper on rural water use in the Mwanza region of Tanzania provides figures for rural domestic water use. These figures are shown in Table 5.4.

Table 5.4 Rural domestic water use for Mwanza in Tanzania

Location	Cooking and drinking (l/person/day)	Hygiene (l/person/day)
Minimum for healthy living	2	8
Mwanza rural average	5	14
Typical figure for a developed country	8	192

Source: Reference 5.8

5.2.6 Zimbabwe

In 1999 a survey was carried out of domestic water use in the Mhondoro communal lands in the Mupfure catchment of Zimbabwe. The estimation of per capita water demand was based on the water brought to the homestead only. As a result water used for purposes other than those undertaken within the homestead are not accounted. Approximately 1,470 households were surveyed with a combined population of some 7,300 people. The amount of water used was found to be 16 l/person/day (Reference 5.8). However, as previously stated it should be noted that this is only the quantity of water used for functions undertaken in the homestead e.g. cooking, washing dishes, drinking, bathing. Hence water used for other purposes such as washing clothes, bathing or gardening away from the homestead is not accounted for in this figure. If water used for other purposes undertaken elsewhere, away from the homestead, then the average per capita water use would be much higher than 16 litres.

Tables 5.5 and 5.6 provide water use figures used in a national master plan for rural water supply and sanitation carried out in Zimbabwe in 1985.

Table 5.5 Rural domestic water demand figures for Zimbabwe 1985

Description	Water demand (l/person/day)
Individual connection in a rural area	60
Communal taps within 300 m of homestead	40
Communal taps greater than 300 m from the homestead	25
Boreholes with handpumps less than 300 m from the homestead	30
Wells less than 300 m from the homestead	30

Source: Reference 5.7

Table 5.6 Domestic water demand figures for institutions in rural areas

Description	Water demand
Rural clinics	10 l/outpatient/day 60 l/inpatient/day
Rural hospitals	200 l/patient/day
Rural shops	200 l/shop/day

Source: Reference 5.7

5.3 Indirect and direct methods of estimating rural water demand and use

There are two main methods of assessing rural domestic demand and use. These are:

- Indirect methods, where the quantity of water consumed is calculated from population levels and estimated demand levels in terms of per capita consumption;
- Direct methods where socio-economic surveys and participatory techniques involving the relevant stakeholders are used to estimate the current and future water demand and use.

In general estimation of rural water demand and use is difficult because:

- The majority of rural domestic water supply systems are unmetered;
- Data concerning domestic rural water demand and use is often expensive and time consuming to collect;
- The level of service provided by the water supply system is often unknown.

For catchment management purposes indirect methods are the most appropriate for establishing rural domestic water demand and use. However, in some cases the results of socio-economic surveys and participatory techniques can be extrapolated to a sub-catchment and catchment level. The main methods for estimating rural domestic water demand and use are discussed below. It should be noted that the accuracy of a demand assessment is a trade off between the budget needed for an accurate demand assessment and the predicted usefulness of the results.

5.4 Factors affecting rural domestic water demand and use

Many water supply schemes in rural areas are fairly basic, however, the patterns of use and demand are more complicated and tend to be dependent on many factors. Such factors include:

- Population;
- Household occupancy rate;
- Level of service of the water supply for each household;
- Tariff levels;
- Willingness and ability to pay;
- Local knowledge and indigenous practices;
- Cultural values, traditions and religious beliefs;
- Climate;
- Water quality.

The more important of these factors are discussed briefly below.

5.4.1 Population

Water demand and use is directly related to the population. However, in rural areas it is often difficult to estimate the population levels accurately. This due to the following:

- Lack of accurate, up-to-date census data;
- Lack of up-to-date aerial photography or remote sensing data from which to estimate the numbers of settlements in an area;
- Migratory labour with the male members of households often working in urban areas for long periods of time.

5.4.2 Household occupancy rates

Household occupancy rates affect water use. Studies have shown that low occupancy households generally use more water per head than higher occupancy ones. This trend is shown in Figure 5.1.

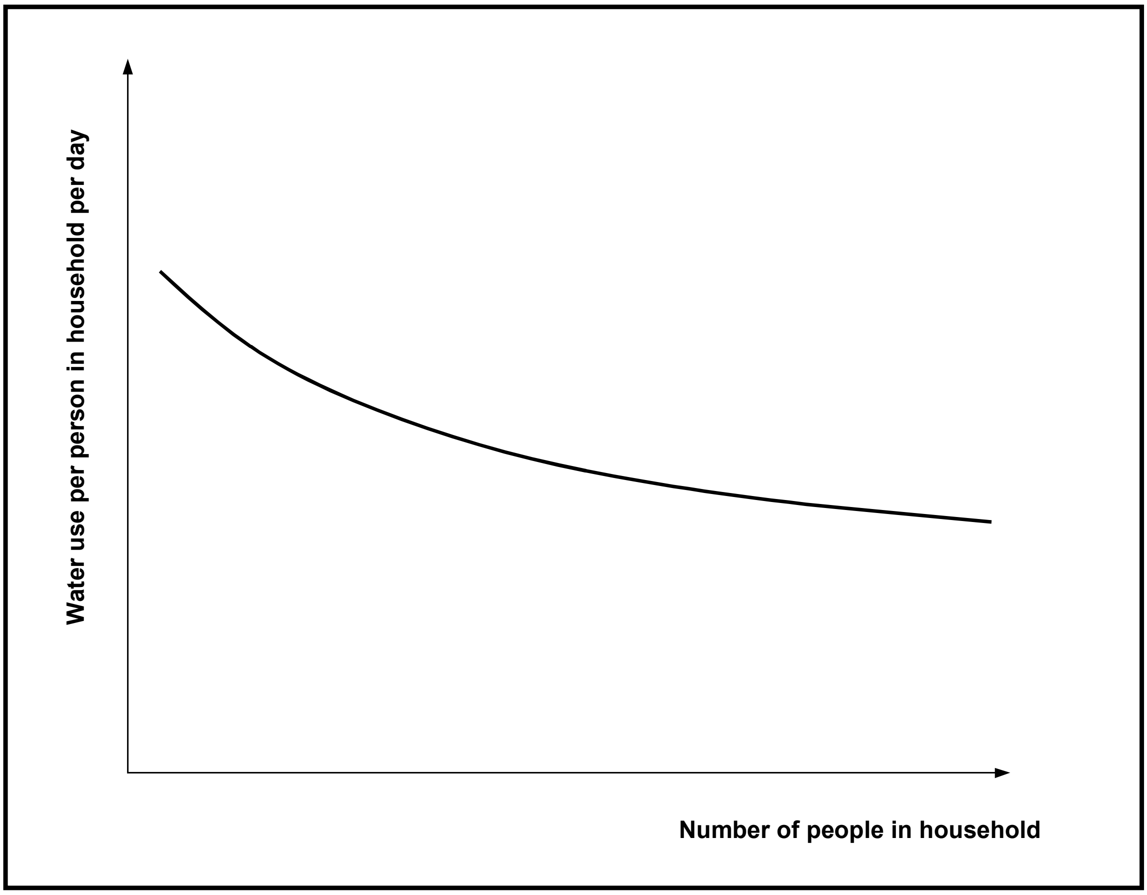


Figure 5.3 Water use per household versus household occupancy

5.4.3 Level of service

The level of service can be defined in the following terms:

- Technical terms as follows:
  - For water supply in terms of the quantity and quality of the water available within a given distance;
  - For sanitation in terms of whether there is a pit latrine, pour-flush latrine or piped sewerage;
- Performance terms e.g. a stipulated measure of reliability.

Typical definitions of levels of service are shown in Table 5.7.

Table 5.7 Typical levels of service providing access to safe water supply and sanitation

Level of service	Water supply	Drainage water disposal	Sanitation
Deficient	Water source unsafe or inadequate or return time travel to source more than 30 minutes	None	Open defecation or dirty communal latrine
Minimum	Communal point source with safe and adequate water and appropriate drainage, return time less than 30 minutes	Soakaway or other drainage at public water point. Some disposal of wastewater at household level on plot or onto field, or in urban areas, gutter or opened or covered drainage channel	Simple pit latrine on householder's plot
Intermediate	Point source (e.g. yard tap) on householder's plot with safe and adequate water supply and appropriate drainage	Soakaway on plot or open or covered drain from plot to safe disposal; connecting channels within plot (made by householder)	Ventilated improved pit latrine or pour-flush toilet on householder's plot
High	Piped connection into house with safe and adequate water under continuous pressure	Open drain to safe disposal or pipe to septic tank or sewerage	Flush toilet with septic tank or sewerage (if water supply is sufficient)

Table 5.8 gives water use for various levels of service. The figures indicate that there is a considerable variation between various studies that have been carried out.

Table 5.8 **Estimated domestic water use for various levels of service**

Level of service	Water use (litres per person per day)					
	Cairncross and Feachem 1993	Hofkes et al 1981	Jinja Uganda	PDG 1996	Van Schelkwyk	Webster 1999
Communal standpipes						
Greater than 200 m walking distance	<16	-	-	15	25	-
Less than 200 m walking distance	16	30	35.5	30	35	25
Yard connection	>16	40	50	70	80	80
House connection						
Single tap		50	155	120	130	130
Multiple tap		150			250	

Source: Reference 5.1

Table 5.9 indicates the effect of different sanitation systems on water use.

Table 5.9 **Effect of the type of sanitation system on water use**

Type of sanitation system	Water required for operation (litres per person per day)
Simple pit latrine	Nil
Pour-flush latrine	5 to 25
Ventilated improved pit latrine	Nil
On-site septic tank	5 to 40
Sewered interception tank	5 to 40
Conventional sewerage	>60

Many studies have been undertaken to try and quantify rural water use and demand in relation to distance from the drinking water source. Most studies have indicated that an inverse relationship exists between travel distance and consumption. As the distance to the drinking water decreases domestic water use increases markedly. However, there is a threshold distance at which the basic water use will not decrease. One study in southern Africa concluded that, although per capita water use drops rapidly once there is not a water connection on the property, water use varies little between households around 100 m from a standpipe and the ones where the water source is several kilometres away. This concept is shown in Figure 5.2.

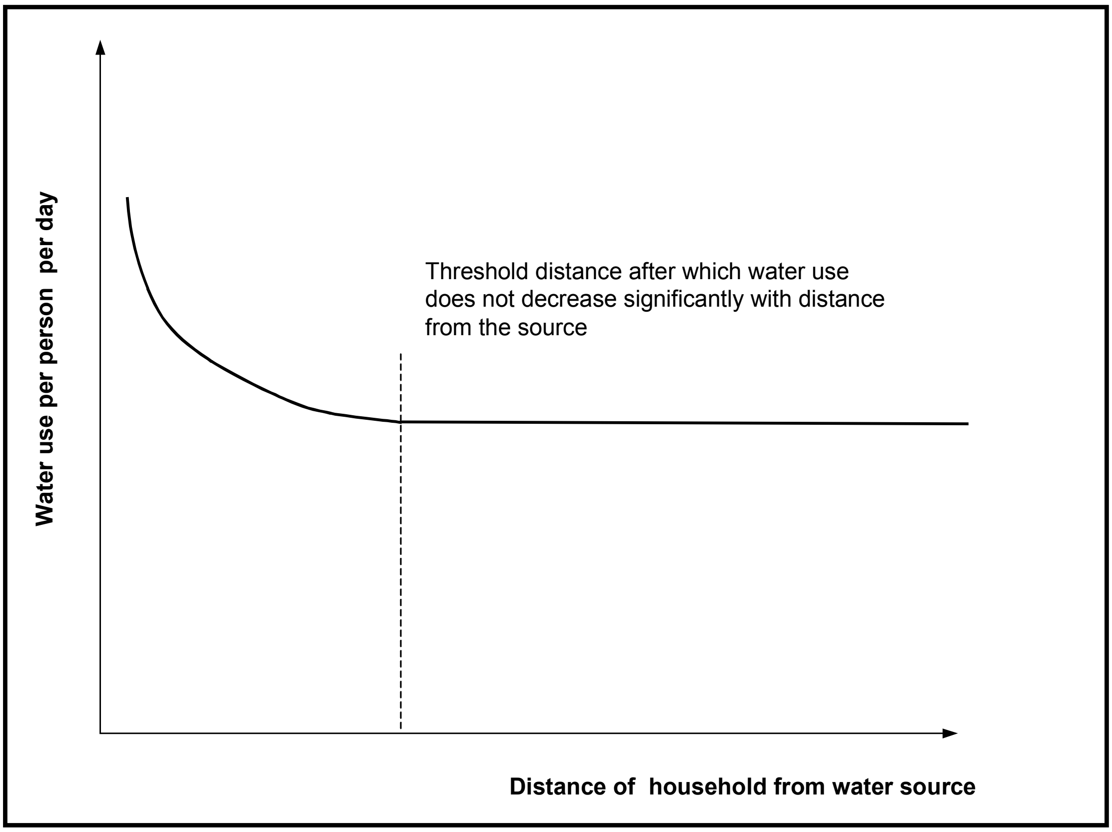


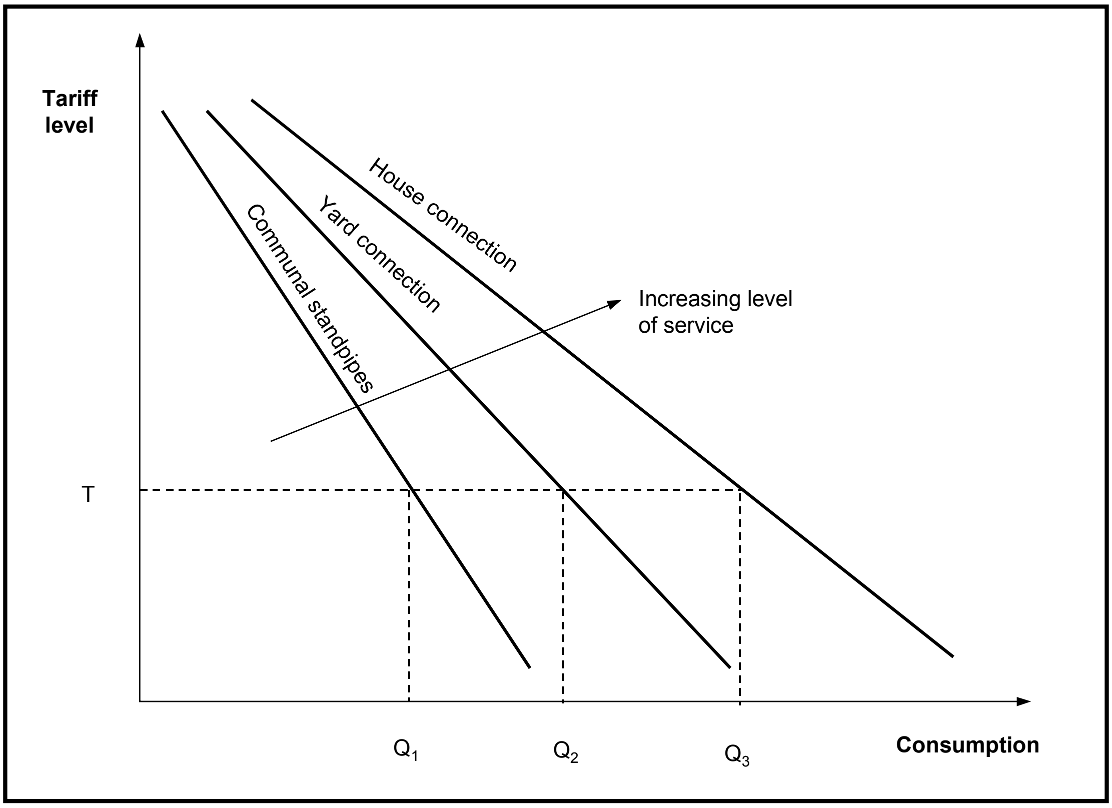
Figure 5.4 Water use versus distance from source

5.4.4 Tariff levels

Water is often viewed as primarily a social good. Many countries' constitutions enshrine the basic right of every citizen to a safe supply of water. However, water can also be viewed as an economic good. In many circumstances rural domestic water users have to pay a tariff towards the cost of their water supply. In some cases consumers are able to choose the level of service for which they are willing to pay. Demand functions and curves can be produced that are related to the following:

- Quantity of water demanded;
- Price or tariff level of the water;
- Price of other related goods or services;
- Household income;
- Other socio-economic factors.

The above variables are often known as determinants of demand. Many researchers agree that different levels of supply and different levels of service will display different functions regarding demand. However, as a rule, water use will generally increase as the level of service increases and decrease as tariff levels increase. This is shown diagrammatically in Figure 5.5.



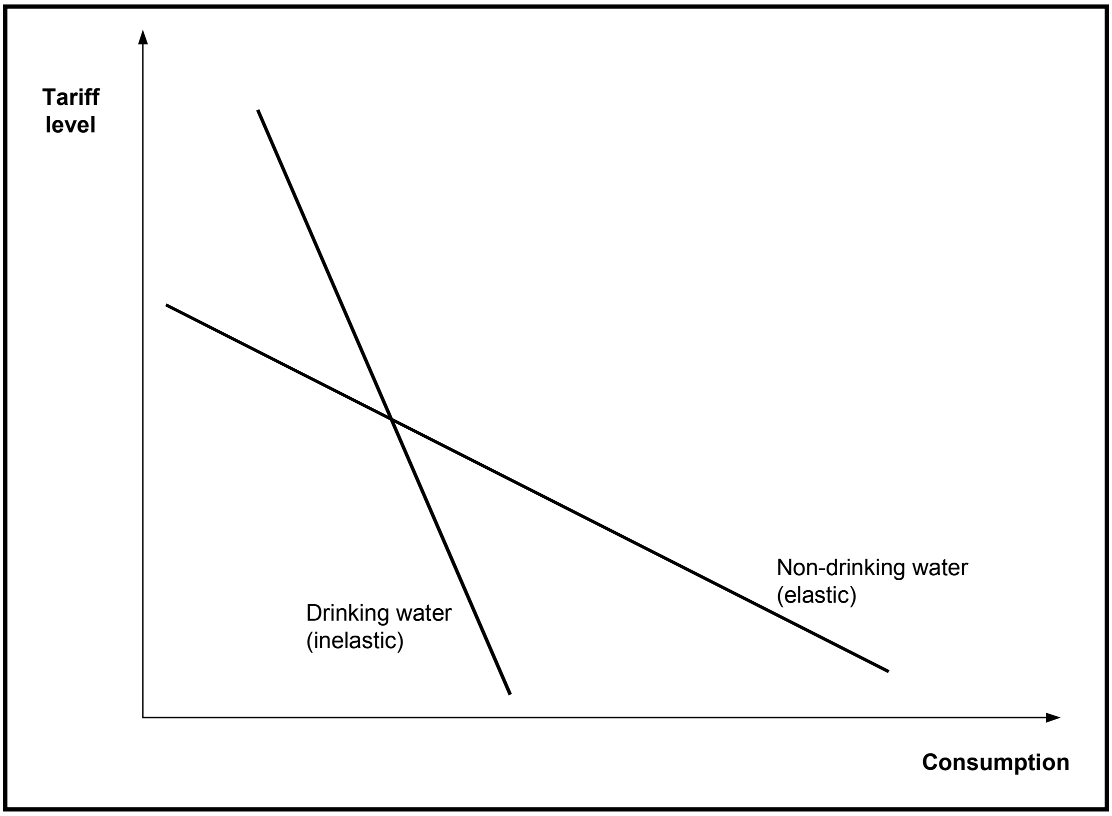
Source: Reference 5.1

Figure 5.5 Effect of tariff levels and levels of service on water use

The determinants of demand influence the "elasticity of demand" i.e. the impact a variable will have on demand. Major factors that influence water supply demand elasticity are:

- Price i.e. tariff levels;
- Income and affordability of the supply;
- Metering of the supply;
- Other factors e.g. distance from the source, level of service.

The demand for drinking water (and water for other basic needs e.g. basic hygiene) is generally considered to be "price inelastic", whereas demand for non-drinking water is "price elastic". This concept is shown in Figure 5.6.



Source: Reference 5.1

Figure 5.6 Elasticity of water demand for different uses

5.5 Indirect methods of estimating rural domestic water demand and use

Indirect methods for estimating rural demand and use are relatively straight forward to use and are the most practical methods for the estimation of water demand and use on a sub-catchment and catchment basis. The following information is required:

- Population data;
- Per capita water demand;
- Unaccounted for water levels i.e. the difference between the total quantity of water abstracted and the quantity of water consumed.

Figure 5.7 shows diagrammatically the process for calculating rural water demand and use.

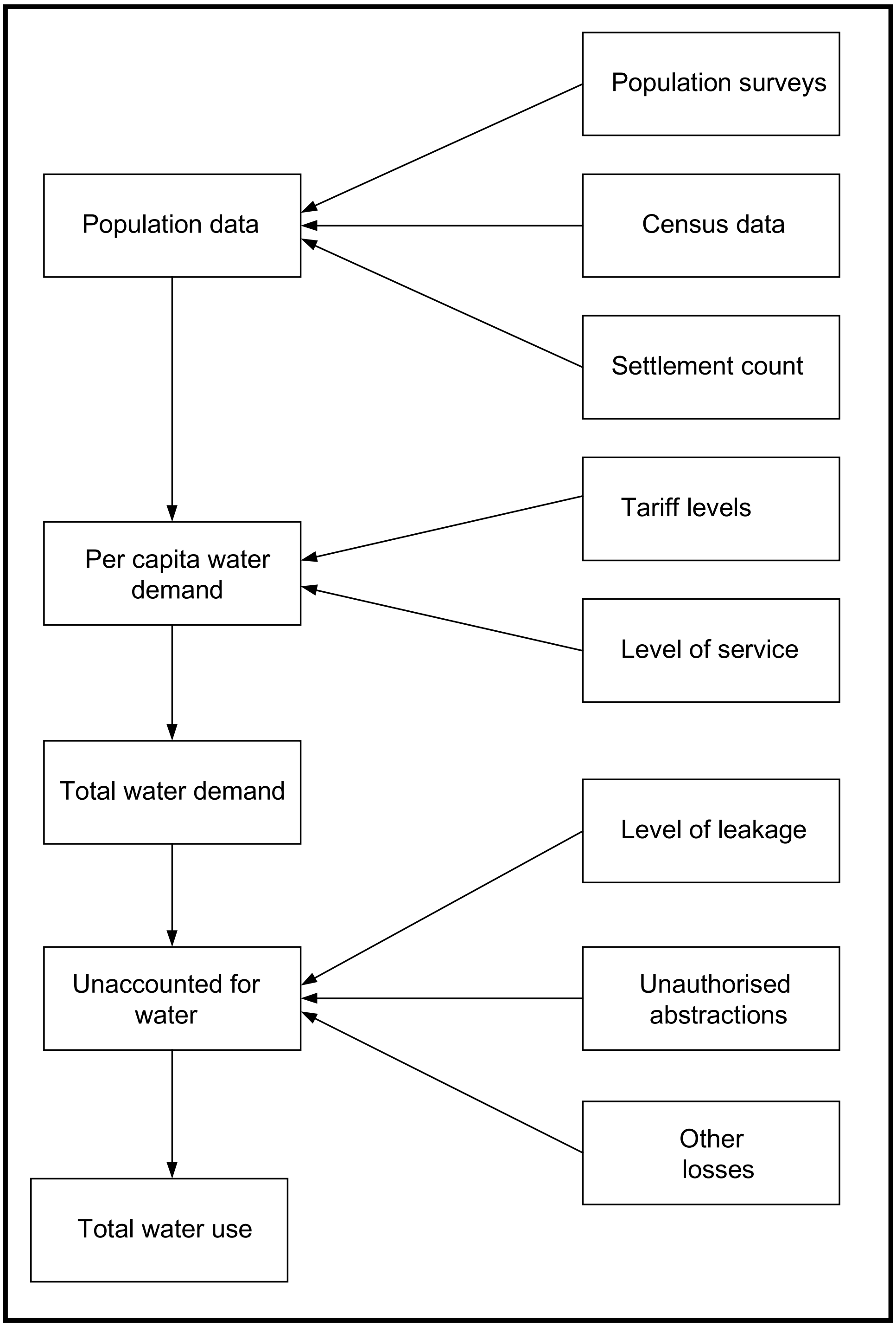


Figure 5.7 Indirect method of calculating total water demand and use

Indirect methods are the simplest, and often the most appropriate method to use when estimating water demand and use on a catchment and sub-catchment basis.

Example of applying an indirect method

Rural domestic water demand and use is to be estimated for the River Kadzi sub-catchment in northern Zimbabwe. The estimate could be carried out as follows:

(i) The number of individual settlements has been calculated from up-to-date aerial photography. There are estimated to be 16400 individual settlements within the Kadzi sub-catchment.
(ii) Local census data, health surveys, economic and engineering studies indicate the following:
  - 35% of settlements have a well or borehole more than 200 m from a water source and use pit latrines for sanitation. These settlements have been estimated to use 20 litres per person per day;
  - 45% of settlements are less than 200 m from a well or borehole and use pit latrines for sanitation. These settlements have been estimated to use 30 litres per person per day;
  - 15% of settlements have a yard tap and use pour-flush latrines. These settlements have been estimated to use 80 litres per person per day and have unaccounted for water of 25% owing to leakage;
  - 5% of settlements have multiple taps in houses and use flush toilets connected to septic tanks. These settlements have been estimated to use 150 litres per person per day and have unaccounted for water owing to leakage of 30%.

(iii) The occupancy rate of settlements in the Kadzi sub-catchment has been found to be approximately 7.3 people per household.

The calculation would be performed as follows:

Water demand = number of settlements x occupancy rate x water demand per capita
Water use = number of settlements x occupancy rate x water use per capita

Water demand for settlements > 200 m from a water source = 0.35x16400x7.3x20 = 0.84 Ml/day
Water demand for settlements < 200 m from a water source = 0.45x16400x7.3x30 = 1.62 Ml/day
Water demand for settlements with yard taps = 0.15x16400x7.3x80 = 1.44 Ml/day
Water demand for settlements with taps in the house = 0.05x16400x7.3x150 = 0.90 Ml/day

Total rural domestic water demand for the Kadzi sub-catchment is 3.92 Megalitres per day

The total rural domestic water demand for settlements supplied by wells and boreholes has been assumed to be equal to water use (i.e. unaccounted for water is negligible).

Water use for settlements > 200 m from a water source = 0.35x16400x7.3x20 = 0.84 Ml/day
Water use for settlements < 200 m from a water source = 0.45x16400x7.3x30 = 1.62 Ml/day
Water use for settlements with yard taps = (0.15x16400x7.3x80)/(1 – 0.25)
= 1.92 Ml/day
Water use for settlements with taps in the house = (0.05x16400x7.3x150)/(1 – 0.3)
= 1.28 Ml/day

Total rural domestic water use for the Kadzi sub-catchment is 5.66 Megalitres per day

5.6 Direct methods of estimating rural domestic water demand and use

Various studies in sub-Saharan Africa have shown that rural domestic water use is related to a “level of living index”. The level of living index is a function of the following:

- Population;
- Income;
- Education;
- Agricultural activity;

- Type of dwelling;
- Household size.

Direct methods of estimating rural domestic water demand encompass responsive approaches. These approaches to domestic water supply development have gained considerable support in the recent years in South Africa and internationally. This approach is being promoted because supply-driven projects, where water is simply delivered to communities with little or no involvement of community members, have largely failed around the world.

It should be noted that direct methods are primarily designed for detailed planning (e.g. feasibility studies and design) of rural water supply schemes. For catchment managers and water resources planners operating at a catchment and sub-catchment level it is recommended that indirect methods are used to estimate water demands and use. Various direct methods are outlined briefly below. Details of demand assessment techniques are also given in Table 5.10.

5.6.1 Direct interviews with individuals

Direct interviews with stakeholders can reveal a lot of information that cannot be obtained from elsewhere. Often personal interviews may reveal more information than group discussions, especially on matters relating to individual households. Sample questions include:

- How many individuals are in the household ?
- What does your household use water for (e.g. cooking, bathing) ?
- How much water does your household use per day (in summer, in winter)?
- Does all the domestic water used by your household come from the same source or from various sources?
- What are the sources (e.g. irrigation canal, well) and how far from your settlement are they?
- Do you think the water supply is adequate?
- If not, how much do you think your household really needs a day for domestic use?
- Who collects the water for domestic use?
- How long in terms of minutes/hours does it take to walk to the nearest water supply point?
- How much water can they carry at one time?
- How many times do they collect water a day?
- Which do you perceive as most important – water for domestic or agricultural use?

These observations and surveys can be used to estimate the level of service and per capita water demand. It should be noted that such direct interview techniques are time consuming to carry out, especially for catchment management purposes. It is also important that a standardised structure is used for any interviews that are undertaken and that training of the interviewers takes place to ensure consistent results.

5.6.2 Community discussions and focus groups

On more general issues, group discussion may provide more information as many different opinions will be put forward and discussed. Sample questions could be:

- Are you satisfied with the current water supply and sanitation services?
- Does everyone have equal access to water for domestic use or are some people disadvantaged? Why?

- Have you been given any incentives to conserve water?
- Would you be willing to pay for water? How much and what services would you expect for your money?
- Do you currently buy water from vendors? If so, how much do you pay?
- Have you received any training on the water and sanitation services available to you?
- Have you got any local traditions and beliefs that affect the take up of water and sanitation services?

5.6.3 Seasonal calendars and diaries

Seasonal calendars can be used like diaries as a record of water used per household over a year for different domestic tasks. It should be noted that incentives may be necessary to encourage people to complete the calendars accurately. Alternatively diaries can be used to record amounts of water used for different uses and from which source.

5.6.4 Transect walks and direct observation

Direct observations can be used to note the following:

- What services already exist;
- What indigenous technologies and appropriate technologies are in use;
- How far people are walking to obtain water;
- How much water is being carried per person on any one journey;
- At what time of day most water is collected;
- What other water sources are available (e.g. irrigation canals, rivers, dams) and whether these are being used.

Table 5.10 Demand assessment techniques: Water supply and sanitation

	Elicit relative demand between different services*	Participatory rapid appraisal (PRA): Internally facilitated*	Participatory rapid appraisal (PRA): Externally facilitated*	Revealed preference surveys (RPS)	Contingent valuation method (CVM)*	'Real' detailed options considered by community or ballot
Description of technique	Improvements to a wide variety of different services such as water, drainage, roads are considered by the communities who express their relative demand for these services. Total funds available for each community area should be reasonably fixed.	Community volunteers are encouraged and trained to undertake a participatory survey in their own community. Preferences and commitments are then agreed in meetings.	A variety of PRA techniques are used by trained researchers or facilitators to confirm the preferences of different community groups who are also involved in the analyses.	RPSs estimate time and financial costs of current household behaviour (e.g. payments to water vendors) and time saved in collecting water.	A questionnaire survey to determine the maximum willingness to pay of individuals for various options for level of service (including improved reliability), payment arrangements, within the context of the current or specified institutional regime	Detailed options and their implications are considered by communities using PRA or ballot
Potential benefits	Simple easy and understood Express 'real' demand if only in real terms Preferences can be refined during micro-planning Inexpensive Compatible with PRA work	Very good community sense of ownership Enhances empowerment Useful if the demand assessment involves ongoing negotiation	Good community sense of ownership Extension staff can assess appropriate time to elicit the demand Can enhance empowerment Can be used in a changing institutional environment	Can provide reasonably accurate estimates of current time and cost expenditure and hence possible willingness to pay for service improvements Data and analysis requirements are modest Good baseline data for impact assessment Compatible with PRA	Provides good data for Project Appraisal Good data on willingness to pay and potential revenues for different service levels assuming a thorough survey is undertaken Can guide tariff subsidy and cost-recovery policy Similarity to public opinion polls means the conceptually easy for non-specialists and politicians to understand	More precise cost estimates lead to less confusion Institutional charging of O&M implications can be thoroughly assessed Can be used in a changing institutional environment
Potential risks and constraints	Possible group or strategic bias Willingness to pay for different service levels not readily known Process can be manipulated by extension workers who do use sufficient technical or financial rigour	Possible group bias Liable to lack technical/financial rigour Reliant on skills being in the community Requires substantial flexibility by external funding agencies and local support institutions	Possible group bias Process can be manipulated by extension workers who may not use sufficient technical/financial rigour if not adequately supervised Extension workers with good facilitation skills are required	Cannot estimate household response to price increases (including for new levels of service options) Poverty may constrain ability of poor people to convert time saving results from service into cash payments for themselves Rarely used for sanitation projects	Risks inhibiting community decision making and ownership for instance by raising expectations about particular options Relatively high cost and requires specialist consultants for reliable results Inaccuracies may occur in a changing institutional environment	Risk of key decisions being based on misleading results from an unrepresentative group unless care is taken to avoid group bias Requires detailed cost information so earlier demand assessment may need to use other methods Detailed work on some options can be redundant
Typical usage	Suitable for village or slum general improvement projects. NGOs often use this technique	More suitable where low-tech, low-cost solutions are definitely viable e.g. handpumps and latrines	Suitable in most situations, possibly complimented by other methods	Suitable where substantial water supply problems exist. To be used in conjunction with PRA	Suitable for informing strategic decision on levels of service in large investment programmes.	Suitable where difficult choices to be made

* Estimated costs of technically viable options are needed for these techniques
Source: Reference 5.2

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6. INDUSTRIAL WATER DEMAND AND USE

6.1 Background

Industrial water use includes water used for the following:

- Industrial processes such as fabrication, processing, washing and cooling;
- Mining;
- Hydropower generation;
- Thermal electric power generation.

This chapter provides specific water consumption for a wide variety of industries and examples of how to carry out water audits for industrial plants.

6.2 Industrial processes water use

Urban industries tend to be metered, usually according to the volume of water used, through an average charge or a variable marginal charge based on block rates. Where larger commercial and industrial users tend to be metered, determining demands can be facilitated through analysing meter records. Alternatively, they may have their own source, especially if they are outside urban centres. Monitoring records may exist or there may be some indication as to the energy consumption of pumps or other references to demand and use.

The factors affecting water demand vary widely between the different industrial operations. The major factors common to the industrial and commercial sectors in determining water demand are:

- Economic activity at a local, national and international level;
- Population;
- Industrial composition;
- Price of water;
- Access to supply and alternative supplies;
- Access to technology;
- Working practices.

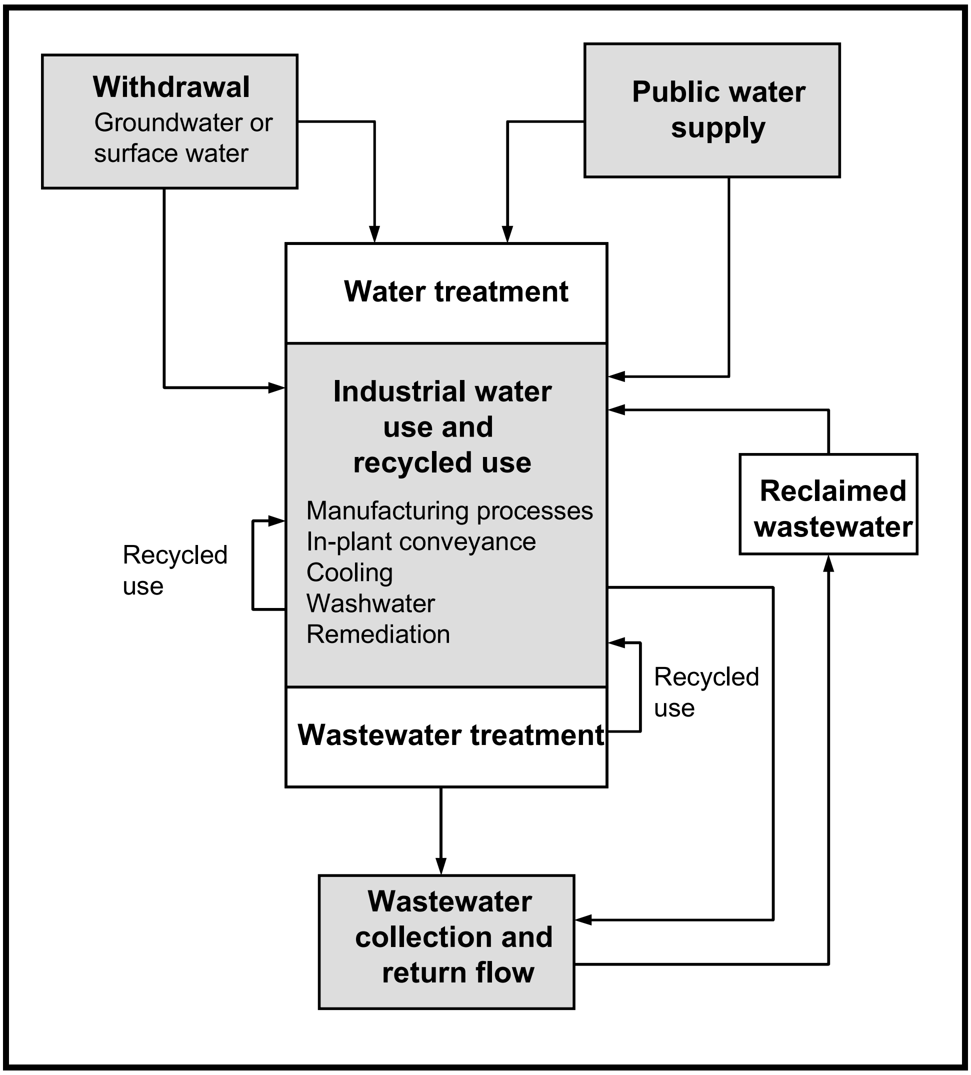
Although information on industrial water use is often available from meter records, additional information may be required to establish industrial water use including:

- Type of industries;
- Expected rates of growth or decline of industrial sector;
- Percentage of industries connected to the public supply;
- Tariff levels for water;
- Extent of the use of water saving technologies;
- Extent of water reuse;
- Effect of conservation measures on demand;
- Government incentives.

Another method for estimating industrial water use is look up tables. Appendix A provides look up tables that detail typical water consumption figures for a variety of industries.

Industrial water use activities include water withdrawals from ground and surface water; deliveries from public water suppliers; consumptive use through evaporation and product incorporation (as in a bottling plant); water and wastewater treatment, recycling, releases to wastewater collection systems, and return flow to ground and surface water. Large industrial water users are more likely to obtain water directly from wells, rivers, lakes, and estuaries, and may supplement this with water purchased from public water suppliers. Small industries, especially in cities, are more likely to obtain water from public water suppliers. Even if water is purchased from a public water supplier, the water may be treated by the industry before use, especially if pure water is required.

Industrial consumptive use occurs either through evaporation during cooling and open-air washing, or through product incorporation, especially in food processing, such as bottling or canning. In recent years, industries have tended to decrease water withdrawals as they began to recycle water within their plants to a greater extent than previously, often due to the high cost of wastewater treatment required to meet the provisions of statutory instruments such as clean water acts. There is an increased consumptive use rate associated with recycled water. More recently, industries have decreased water withdrawals in response to decreasing supply and an emphasis on decreasing use and production of hazardous-waste materials. After use, wastewater may be treated onsite, released to wastewater collection systems, returned directly to surface water or to septic systems, or a combination. Figure 6.1 shows the way in which water supply, use and treatment are related for a typical industrial plant.



Source: Reference 6.1

Figure 6.1 Water supply, use and treatment for a typical industrial plant

6.3 Industrial water consumption statistics

The aim of the look up tables included in Appendix A is to allow staff responsible for water management to assess whether the licensed volumes for an existing or proposed abstraction are reasonable for a given industrial process. There is also some information on the water use steps for each industrial process and potential water saving initiatives that could be employed to reduce consumption levels.

Water consumption figures for industry are often expressed in terms of cubic metres of water used per unit of product produced. For example for steel production water use is measured as m^3/tonne of steel produced, for beer it is measured in m^3/m^3 of beer produced. The method of manufacture used by a particular industry affects its water use. Some industries are relatively consistent in their water use because they use the same processes, the same equipment and produce similar projects. It is these industries that are generally covered by the look up tables. For some industries, e.g. the chemical industry, use different processes, different equipment and produce very different products. For these types of industry the look up table approach is not applicable and each process and site should be assessed on its own merits, not a ‘typical consumption basis’.

The quality of the data in the look up tables varies. There are some industrial sectors where data was available from a wide range of sources, for other industries the data available was limited. In some cases water use figures are based on limited data provided directly by one company. The data in the tables should be treated with care. However, the water consumption figures generally provide at the very least an idea of the order of magnitude of water consumption for various industries.

For industries that consume significant quantities of water, water consumption varies in an approximately linear manner with an increase in production. Hence the planned production capacity of an industrial plant is important in establishing the water consumption. The data in the lookup tables tend to concentrate on industries that use relatively high quantities of water.

There is a clear distinction between the terms industrial water use and industrial water consumption. Industrial water use is defined as the quantity of water that is abstracted from a source (e.g. a river or borehole) for use by an industrial plant. In many industrial processes significant quantities of the water that is abstracted can be re-cycled and re-used. Industrial water consumption is the quantity of water that is “lost” (e.g. by being incorporated in a product such as soft drinks, or through evaporation from cooling towers) during the manufacture of a particular product. The look up tables in Appendix A provide details of specific water consumption in terms of m^3 of water consumed per unit of product produced.

6.4 Participatory methods for obtaining industrial water use consumption data

Water use surveys can be carried out through the use of questionnaires. When such exercises are undertaken it should be stressed to the various participants that the information they provide will remain confidential. One method by which a high level of participation may be achieved is to offer the chance of obtaining a free water minimisation audit. An example of a questionnaire is shown below in Table 6.1.

Table 6.1 Example of an industrial water use questionnaire

Company name:	**Company address:**
Contact name:	
Job title:	
Telephone number:	

Please indicate business sector in which the company operates from the list below

☐ Breweries
☐ Chemicals
☐ Construction
☐ Dairies
☐ Food and drink
☐ Machinery and electronics
☐ Metal processing
☐ Mining
☐ Mineral products
☐ Paper and printing
☐ Retail
☐ Rubber
☐ Textiles and leather
☐ Other (please specify) ______________

Give details of the main company activities/products:

Please provide details of all water sources, annual consumption and purpose of use

Water source	**Annual consumption**	**Units (e.g. m^3)**	**Purpose**
Public supply			
River			
Borehole			
Other			

If water is re-cycled on site, please give details of total annual water use for each source

Water source	**Annual use**	**Water source**	**Annual use**
Public supply		Borehole	
River		Other	

To assess individual water efficiencies it is necessary to have information on annual production, output and the number of employees.

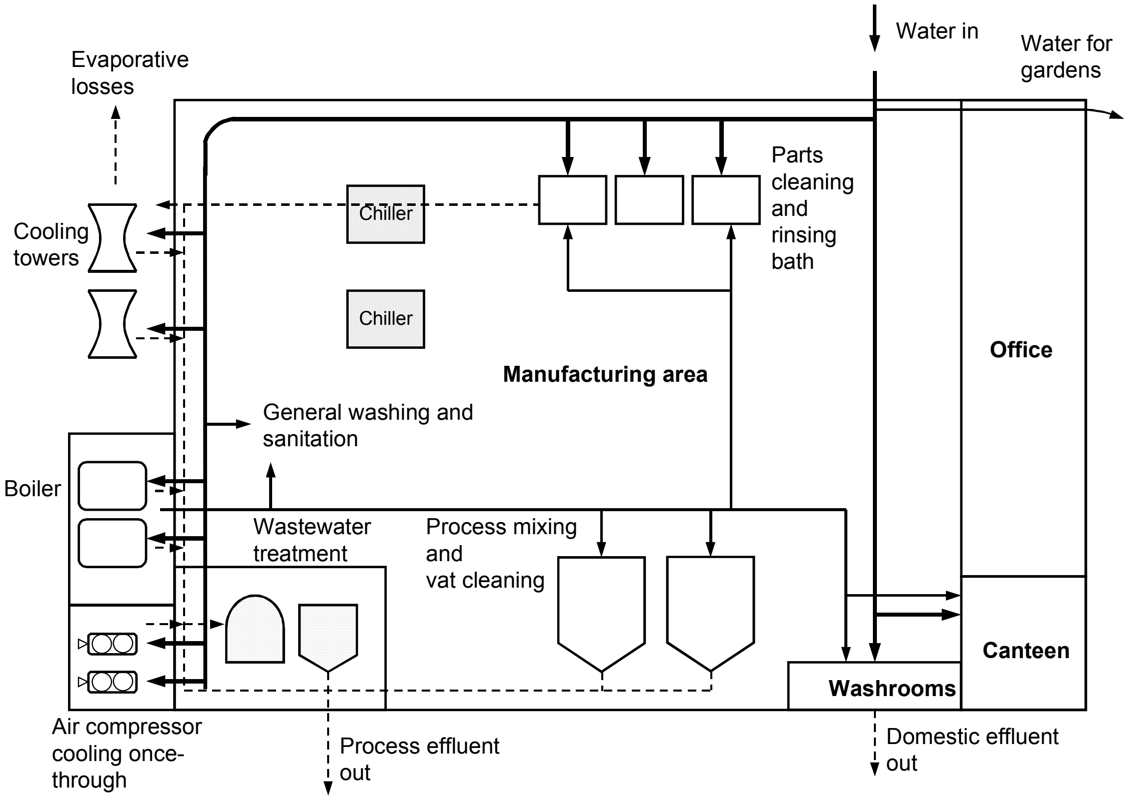
Annual production		Units (e.g. tonnes)	

Number of employees <10 ☐ 10 to 50 ☐ 50 to 100 ☐ 100 to 250 ☐ >250 ☐

Have any water minimisation studies been carried out before ?	Yes/No
Are any water saving devices or water efficient processes installed ?	Yes/No

6.5 Water audits for industry

Carrying out a water audit out of an industrial establishment is one of the key activities that assists in improving the specific water consumption of a site. An example of a simplified water audit for a generic site is shown in Figure 6.2.



Water balance summary

Source of water use	Quantity used per year (litres)	Percentage of total (%)
Cooling: Cooling towers, boiler	7,966,000	38.3
Process use: Parts and mixing vat cleaning	3,848,000	18.5
Domestic: Toilets, taps, showers	3,536,000	17.0
Once-though cooling: air compressors and pumps	2,388,000	11.0
Gardening	832,000	4.0
General washing, sanitation and maintenance	561,600	2.7
Leaks (detected)	416,000	2.0
Food preparation: Canteen	312,000	1.5
Sub-total	**19,859,000**	**95.5**
Total water delivered to site	**20,800,000**	**100.0**
Unaccounted for water	**941,000**	**4.5**

Source: Reference 6.2

Figure 6.2 Simplified water balance for a manufacturing facility

Details of how a water audit should be prepared for and undertaken are detailed in Section 6.5.1.

6.5.1 Preparation for a water audit

Before a water audit of an industrial establishment is carried out the following should be undertaken:

- Establish the size of the facilities including the number of buildings and floor space;

- Obtain plumbing drawings if possible;
- Establish the operating schedule of the facility including the number of employees per shift;
- Estimate or measurement of the total water consumption and specific water consumption per unit of the product produced on a monthly basis;
- Produce an inventory of all water using equipment;
- Collation of all the records and measurements of water coming into the plant including: water meters, tankers, private water sources (e.g. borehole owned by the plant);
- Location and size of all water meters;
- Calibration data for any meters.

The methods that can be employed to measure the in-plant industrial water use are detailed below.

6.5.2 Measuring in-plant industrial water use

There are three main ways in which in-plant industrial water use can be measured. These are:

- Metering;
- Bucket and stopwatch method;
- Micro-weirs.

Metering

For large industrial establishments metering the specific processing equipment used for different operations enables the water consumption for each process to be established. It is possible to obtain temporary strap-on meters that can be used to determine approximate flows. Temporary meters can be used to establish whether it is cost effective to install permanent meters.

Bucket and stopwatch

The use of a bucket and stopwatch is a simple, cost effective and accurate tool for measuring water use. This method involves collecting a specified water in a set amount of time (e.g. if a five litre bucket was taking 10 seconds to fill, the flow rate would be 0.5 l/s).

Micro-weirs

Micro-weirs are hand held weirs that be used to measure low flows in confined spaces.

6.5.3 Conducting a water audit

At the commencement of a water audit of an industrial facility a walk-through survey should be carried out with personnel from the facility who are knowledgeable of how water is used in each part of the site. The following steps should be taken:

- Record the hours of operation of each piece of equipment. Identify water piping layout and areas of older equipment. Note equipment that has multiple uses of water (e.g. a water-cooled ice machine);
- Establish the discharge and quality of the flow for each use. This allows it to be determined if water from one use can be re-used as a potential supply for another application. Parameters that should be measured include:
    - Temperature;
    - pH;

  - Total dissolved solids;
  - Conductivity
  - Biological and chemical oxygen demands;
  - Metals;
  - Oil;
- Measure the actual quantity of water being used. These methods are outlined in Section 6.5.2;
- Check the water quantity and quality specified with the industrial equipment's operating manuals. Equipment is sometimes operated at higher flows than actually required;
- Establish a regular programme of water meter reading. Meters monitoring processes that use large quantities of water should be monitored more frequently than those monitoring processes that do not consume large volume of water;
- Identity the quantity and quality of the wastewater from each process;
- Estimate any water that is generated by the processes. Establish whether it is possible to use this water in another part of the site e.g. as cooling water;
- Prepare a water balance diagram as shown in Figure 6.2;
- If the unaccounted for water is greater than 10% revisit the major areas of water use, talk further with plant operators or take additional measurements.

6.5.4 Measuring leakage

When carrying out a water audit it is important that an estimate of the leakage is made. Leaks often occur at joints and seals. A visual or audio inspection is the best method by which to assess leaks. Employees should be requested to report any leaks that occur. Under floor leaks can be determined using specialised sonic leak detection equipment.

The volume of the leaks has should be established. Small drips can be measured using a bucket. An approximate method for converting the number of drops per second to litres per minute is given in Table 6.2.

Table 6.2 Conversion of drops per second to litres per second

Number of drops per second	Litres per minute
1	0.023
2	0.045
3	0.068
4	0.091
5	0.114

Note: If a pipe is dripping at more than 5 drops per second the leak will be a steady stream of water
Source: Reference 6.2

Rates of water loss for an approximately circular hole can be determined using Greeley's equation (Reference 6.2). This is of the form:

$$Q = 0.215A\sqrt{P}$$

Where: A is the cross-sectional area of the leak in cm^2;
P is the pressure in the pipe in Pascals;
Q is the leakage rate in litres per minute.

Leaks in joints or cracks can be estimated by an equation of the form.

$$Q = 0.0161A\sqrt{P}$$

Where: A is the cross-sectional area of the leak in cm^2;
P is the pressure in the pipe in Pascals;
Q is the leakage rate in litres per minute.

For example in a pipe with a 0.1 cm wide crack that is 3 cm long with a line pressure of 500 kPa, the leakage rate would be about 34 litres per minute.

6.6 The effect of improving water use efficiency on effluent water quality

Often the advantages of improving water efficiency for an industrial plant requires a holistic examination of the facilities operations in terms of not only water use by various components used in the process but also in terms of effluent water quality. A good example of this is the Abakor Abattoir in Johannesburg, South Africa. This abattoir uses single cell protein to manufacture stock feed. Improvements in the treatment of the effluent (through single cell protein recovery) reduced chemical oxygen demand (COD) values from 9,000 mg/l to 200 mg/l, resulting in industrial treatment charges reducing from R5 million to R300,000 per annum. Owing to the improved quality of the effluent, further tertiary treatment was possible to produce water of a high enough quality to be reused in the abattoir. These system improvements reduced the water consumption and effluent discharge by 50%. At full capacity production the cost of reclaimed water is 42% of the cost of the potable supply (Reference 6.3).

6.7 Case studies of industrial water demand management for three industries in Zimbabwe

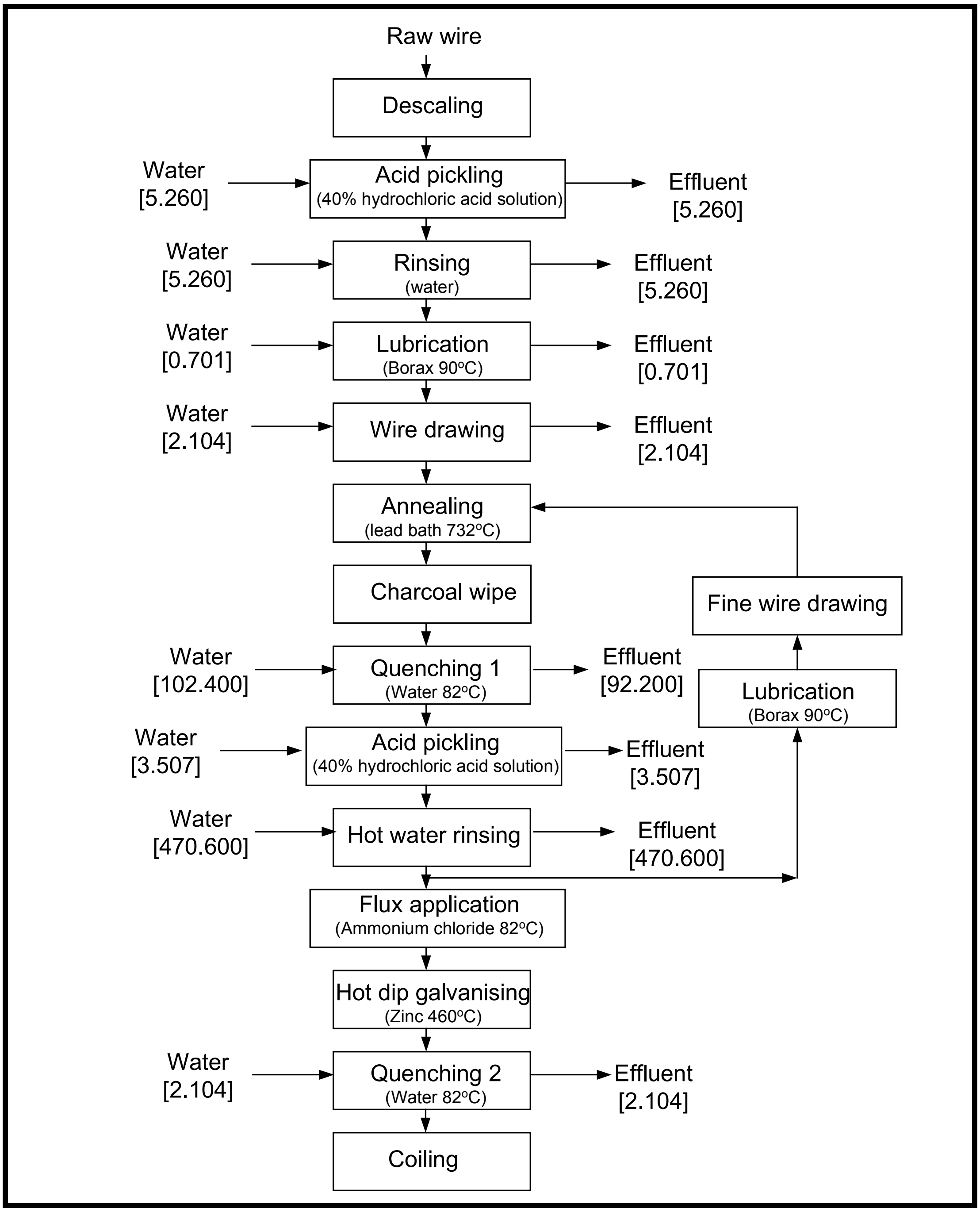
6.7.1 Background to case studies

The city of Bulawayo in Zimbabwe has a population of one million and is faced with extensive deterioration of its sewerage infrastructure. To finance the rehabilitation of the public sewer system there will have to be substantial increases in water and effluent tariffs. Recent studies have indicated that industries are responsible for 25% of Bulawayo's total water consumption (30,000 m^3/day). A number of heavy industries in Bulawayo are a major source of water pollution. Most "wet" industries discharge their effluents untreated to the municipal sewers (Reference 6.4).

Detailed studies of water use and effluent water quality were carried out for three industries in Bulawayo by the University of Zimbabwe. The industrial plants studied included a soft drink manufacturing company, a sugar refining plant and a wire galvanising factory. For each of the three industries an industrial water use survey was carried out. Water quality sampling points were also identified within each process train.

6.7.2 Results from the galvanised wire manufacture

This enterprise about 2.104×10^{-4} m^3/m^2 "galvanised wire surface" municipal water and 0.058 m^3/m^2 "galvanised wire surface" borehole water for the production process. The calculated specific water consumption for the industry is 0.059 m^3/m^2 of wire surface area treated. According to research carried out in South Africa the target specific water consumption for the industry is 0.100 m^3/m^2 for industries for operations treating in excess of 10,000 m^2/month and 0.200 m^3/m^2 and for factories treating less than 10,000 m^2/month (Reference 6.3). A simplified flow diagram for the plant in Bulawayo is shown in Figure 6.3.



Note: Figures in 10^{-4} m^3 of water used per m^2 of galvanised wire surface area
Source: Reference 6.4

Figure 6.3 Simplified flow diagram for the wire galvanising process plant

Although the plant in Bulawayo operates well below the target specific water consumption values there is still the opportunity to save water.

During the process of drawing and galvanising the wire, after the annealing step, the wire is quenched in a water bath. This step is necessary to prevent overheating of the acid bath which is the next step in the process. When the temperature of the water in the bath ahs risen to a level that renders the quenching capacity of the water ineffective, water is discharged to the municipal sewer.

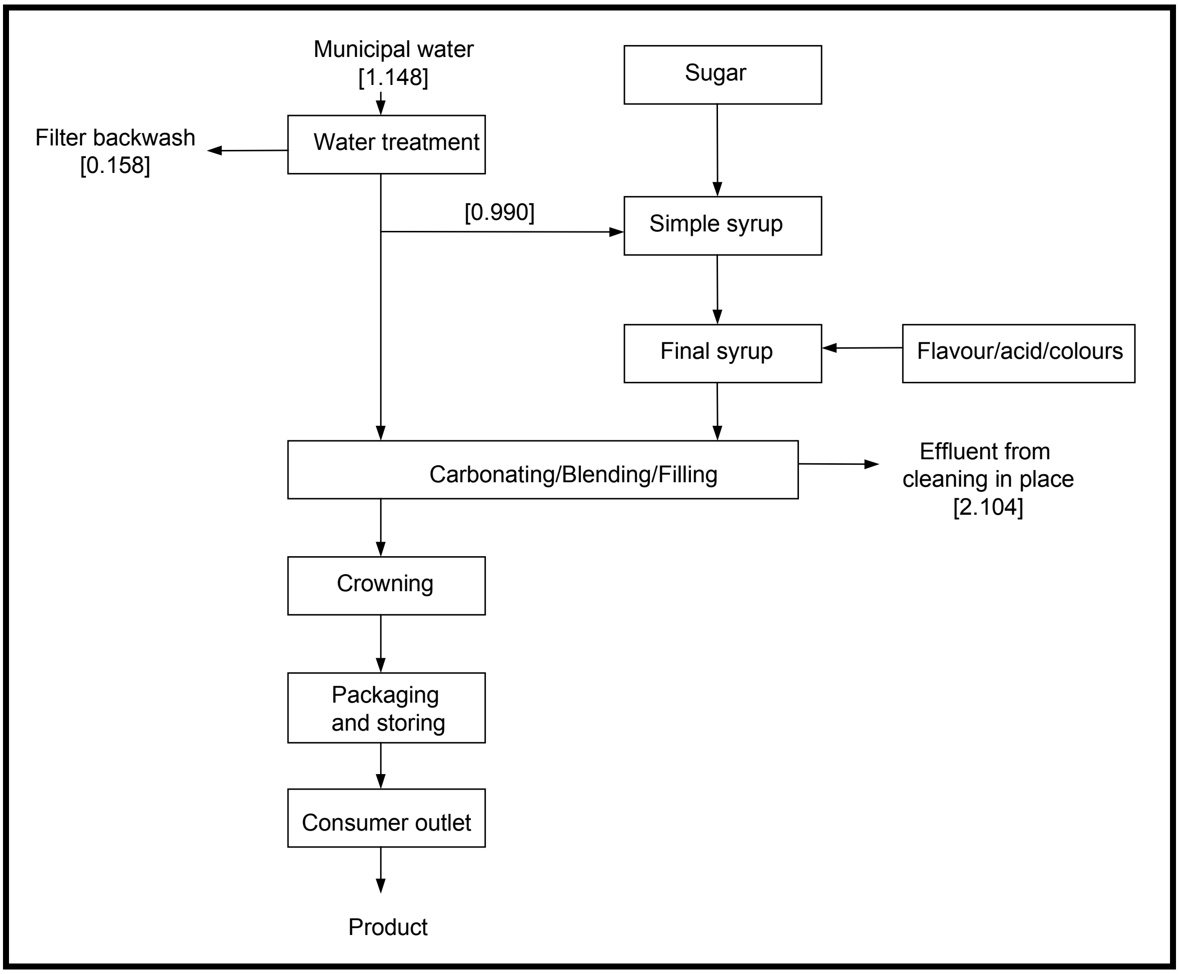
From the water balance carried out for the wire manufacturing industry in Bulawayo the quenching process consumes approximately 0.01 m^3 of water per m^2 of galvanised wire surface produced. This represents 17% of the total water consumption. Instead of discharging the hot quench water as wastewater it can be recycled through a cooling tower and then used as quench water again. The industry would realise about 0.009 m^3 of water per m2 of galvanised wire surface. This would improve the specific water consumption to 0.050 m^3/m^2 (Reference 6.4).

6.7.3 Results from the soft drink manufacturer

The manufacturing of soft drinks requires large volumes of water. In the case of the plant studied the water is pre-treated on the site to meet the product quality requirements before being used in the manufacturing process (Reference 6.4). This process is shown in Figure 6.4.

From research carried out in South Africa the target specific water consumption for a soft drink manufacturing plant is 2.3 m^3 of water for each m^3 of soft drink produced. The soft drink manufacturing process is operated at 3.5 m^3 of water consumed per m^3 of soft drink produced. If a system of recycling the filter backwash water was introduced the specific water consumption could be lowered to 3.3 m^3/m^3. However, the reduction in specific water consumption is not significant because the backwash process only consumes about 5% of the total water used in the plant. Alternatively a large percentage of filter backwash water can be cascaded for use as service water. Once the initial solid content dirty water has gone to drain, the remaining water used in the backwashing process can be reclaimed into a recovery holding tank and then used for services requiring lower quality water e.g. floor washing. An over-capacity water treatment plant can often result in large water wastage due to the backwashing of unnecessary sand and carbon filters. The industry therefore has to optimise on the amount of water for treatment and the backwashing process (Reference 6.4).

Water usage should be included as part of the selection criteria when purchasing major equipment such as bottle washers, sprays and bottling machines. Of particular importance is the water usage efficiency in the bottle-washers as they are responsible for a large percentage of water intake (about 13,300 m^3/month or 54% of the total water used). Older bottle washers should be modified to ensure that bottle spraying is discontinued once the machine is shut off. Automatic shut-off valves and high pressure, low-volume jets for hose pipes could also prove to be effective in helping reduce water intake. Attention should also be paid to future developments such as varying heat transfer systems, e.g. oil as a substitute for steam. At present steam is used for heating up the caustic soda solution in the bottle washing machines. Steam is generated from boilers that use about 0.354m^3/100t “raw sugar” or 10% of total water intake (Reference 6.4).



Note: Figures in m^3 of water used per m^2 of soft drink manufactured
Source: Reference 6.4

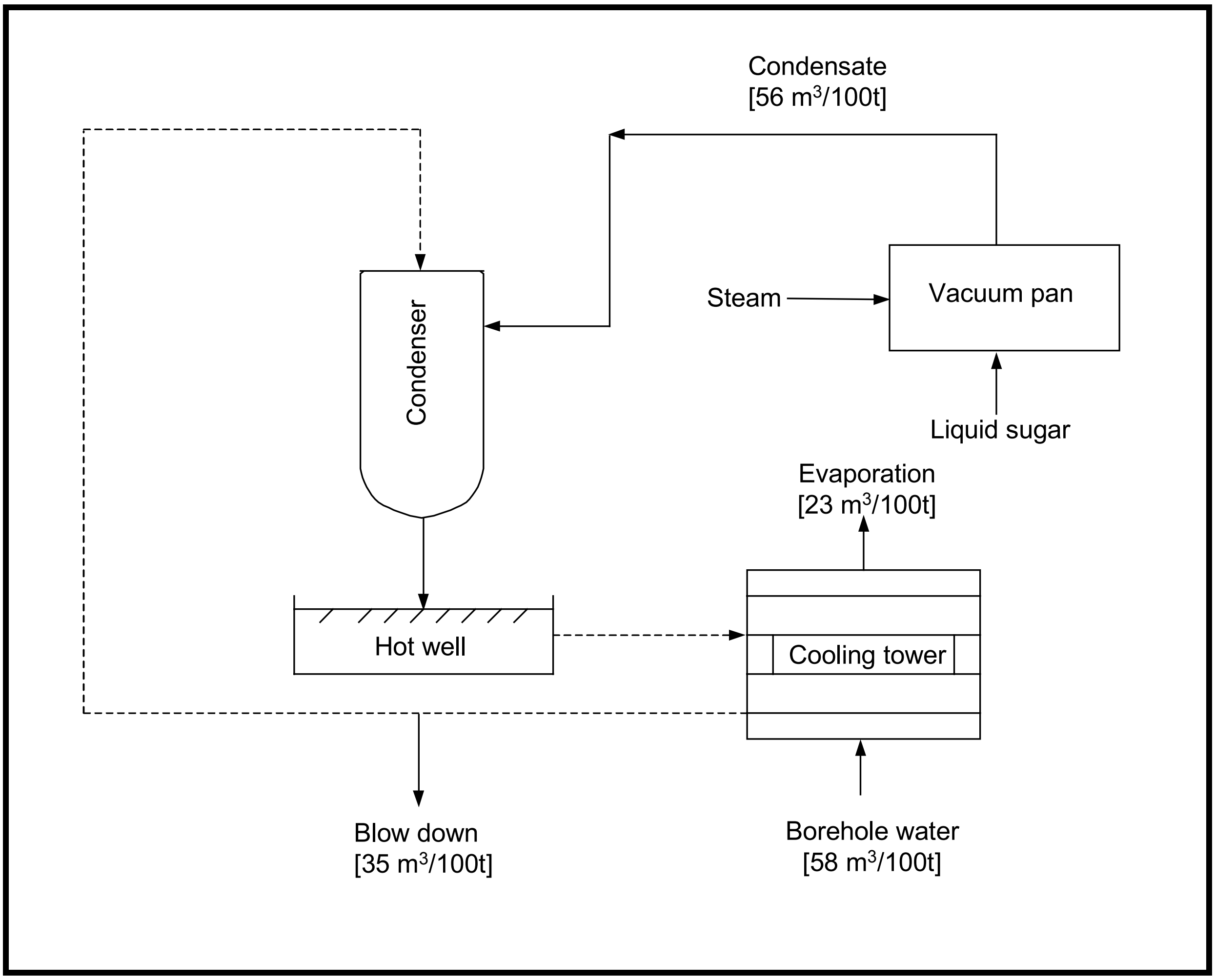
Figure 6.4 Simplified flow diagram for the soft drink manufacturing plant

6.7.4 Results from the sugar refinery

The process of refining sugar consists of four basic steps:

- Washing the raw sugar crystals;
- Adding water to crystals to form a solution;
- Clarifying and decolourising the solution;
- Re-crystallising and finishing the sucrose.

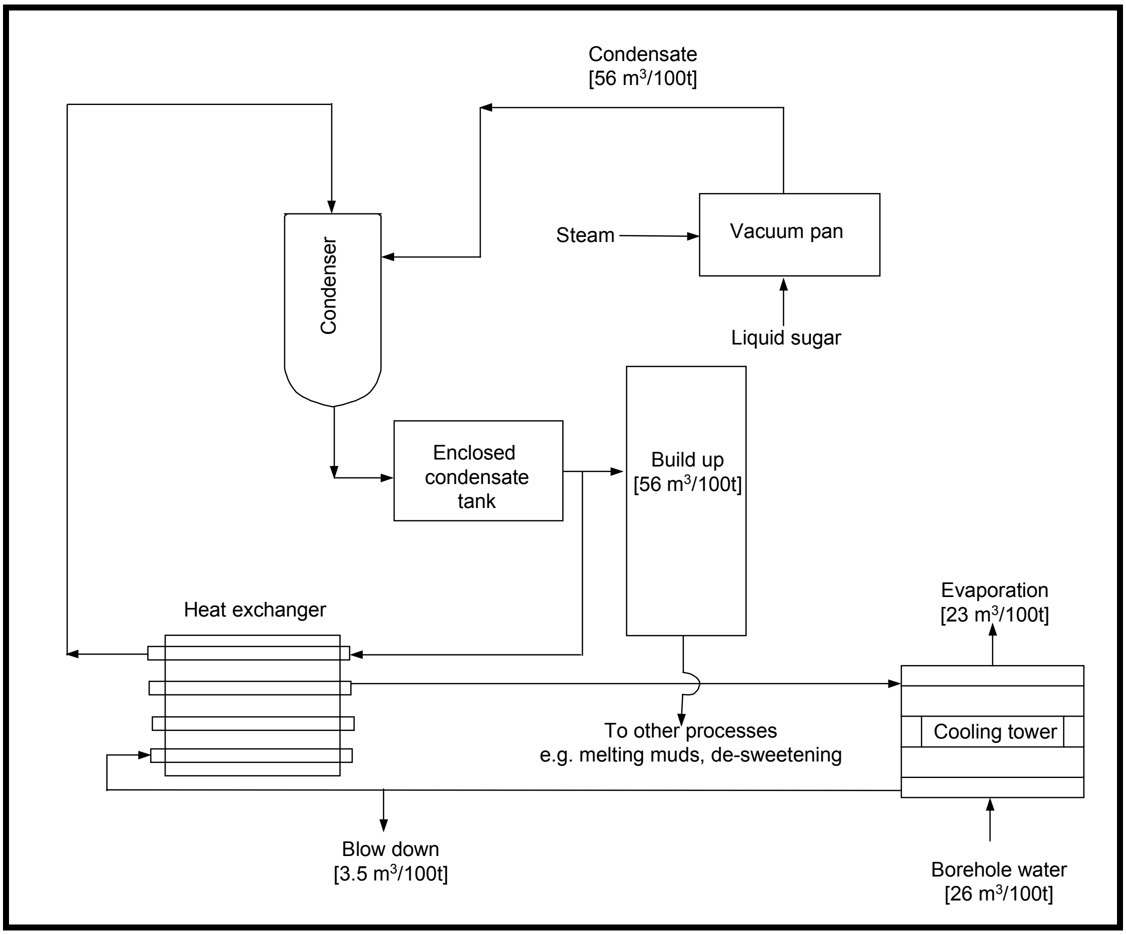
Cooling water from cooling towers water is used to condense the water vapours that boil out of the sugar solution during the re-crystallisation step. This process is shown in Figure 6.5. The condensed vapours, the condensate, that mixes with cooling water is contaminated with sugar (in an amount the refiner desires to minimise for business reasons), which contributes substantially to the chemical oxygen demand (COD) of the wastewater. Owing to this contamination, water from the cooling circuit has to be periodically discharged (cooling tower blow down) as wastewater, otherwise the sucrose content and the COD of the cooling water would become excessive. There are a number of ways that water consumption can be reduced. At present, the refinery is utilising approximately 166 m^3 of water from the municipal supply per 100 tonnes "raw sugar" and 169 m^3 of water from boreholes per 100 tonnes of "raw sugar". About 7400 tonnes of raw sugar is refined per month.



Source: Reference 6.4

Figure 6.5 Existing cooling water and condensate system for the sugar refinery

There are a number of ways in which water can be conserved at the sugar refinery. Cooling water can be separated from the vapour by introducing heat exchangers to separate the condensate from the cooling circuit. The condensate will be contaminated with sugar carried over with the vapour from the vacuum pans, but can be utilised within the process as “sweet water” for dissolving sugar or de-sweetening muds. The cooling water to the heat exchanger would be that from the current cooling water circuit. From the heat exchanger, the now hot cooling water would pass to the cooling towers, after which it would return to the cold water inlet of the heat exchanger. In the condensers, cooling water currently enters at 29°C and after contact with hot vapour, exits at 49°C. The design characteristic of the heat exchanger is to provide a similar temperature for the cooling of the condensate. As occurs in the cooling water system, the volume of condensate would increase at the rate at which the water vapour currently condenses and is entrained (137 m^3 of water per day or 56 m^3 of water per 100 tonnes of “raw sugar”). This system could also help reduce amount of cooling tower blow down because cooling water contamination would be minimised. Figure 6.6 shows the existing and the proposed non-mixing system incorporating a heat exchanger, respectively (Reference 6.4).



Source: Reference 6.4

Figure 6.6 Proposed cooling water and condensate system for the sugar refinery

6.7.5 Conclusions

For the three industries in Bulawayo that were studied, there is no doubt that the identified water demand management measures show potential for savings in water. There is a lot which manufacturers can achieve by firstly carrying out audits to identify areas of improvement within the manufacturing process.

Regular, simple water monitoring surveys of the different water-using areas could be devised to assist in the monitoring of water consumption, as well as to supply information as to the state of equipment e.g. taps, pipes and valves. Initial selection of water using equipment is also crucial. Modifications can also be done although usually costly in the short-term to incorporate recycling and reuse (closed-loop systems). Above all, good house keeping and awareness training for personnel could further help industries practice water demand management and cleaner production.

The initiatives of water demand management can also help reduce the strength and volume of industrial effluents and probably eliminate the use of toxic substances through substitution. The benefits do not accrue only to the industry but to the local authority through reduced costs of conveying and treating industrial effluents. Subsequently, the quality of effluent discharged from municipal sewage treatment works to the environment would improve, thereby limiting environmental damage and social costs leading to sustainable development.

6.8 References

6.1 Hadley, H.K. (1995) *Water use guidelines: Industrial water use*, US Geological Survey

6.2 North Carolina Department of Environment and Natural Resources (1998) Water efficiency manual for commercial, industrial and institutional facilities

6.3 Personal communication (1998) with Muller, J. General Manager of technology development Abakor, Pretoria

6.4 Gumbo, B. Mlilo, S., Broome J., and Lumbroso D. (2002) *Industrial water demand management and cleaner production: A case study of three industries in Bulawayo, Zimbabwe* Third WaterNet Symposium: Integrating Water Supply and Water Demand for Sustainable Use of Water Resources, Tanzania October 2002

7. URBAN WATER DEMAND AND USE

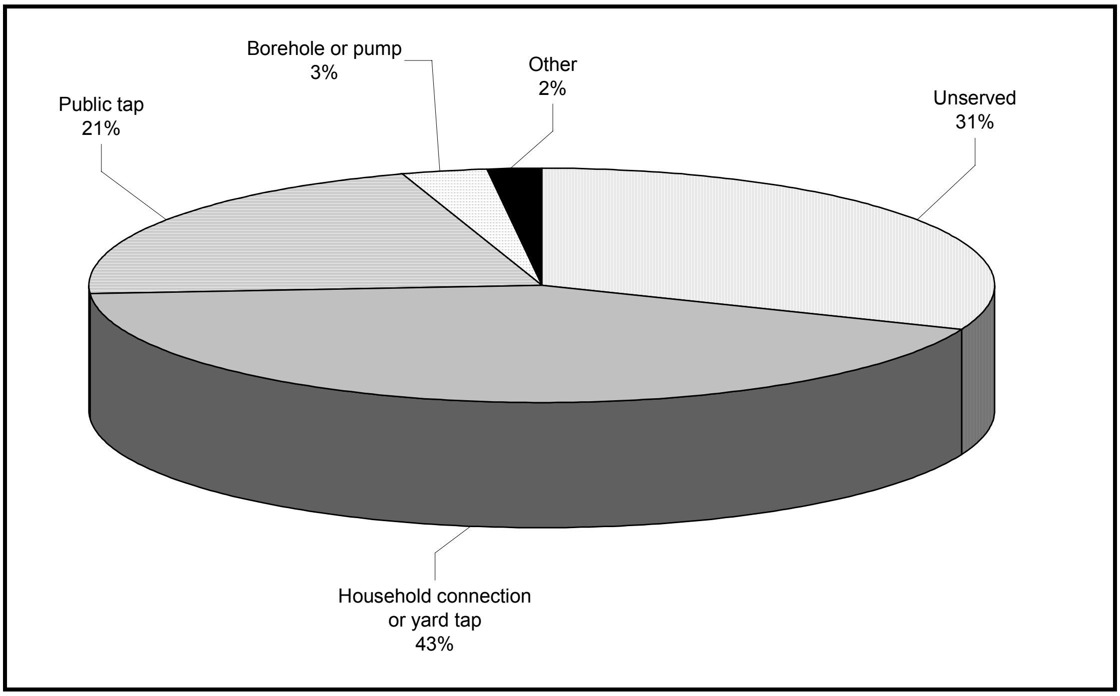
7.1 Background

Urban water demand and use can be divided into the following categories:

- Domestic water use and demands including:
    - In-house use e.g. drinking, cooking, ablution, sanitation, house cleaning, laundry;
    - Out-of-house use (garden watering, swimming pools, livestock, car washing);
- Commercial water use and demands for:
    - Shops;
    - Offices;
    - Restaurants;
    - Hotels;
    - Railway stations;
    - Airports;
- Institutional water use and demands for:
    - Hospitals;
    - Schools;
    - Universities;
    - Government offices;
    - Military establishments;
- Unaccounted for water which takes into account the following:
    - Authorised unmetered water use such as street cleaning, public parks, sewer flushing and fire-fighting;
    - Unauthorised unmetered water use such as leakage, consumer wastage distribution losses, illegal connections and metering errors.

In many African cities urban water demands are often non-homogeneous owing to a range of levels of service occurring within the same urban area. Levels of service can vary from household connections to standpipes or to no service at all. Figure 7.1 shows the percentage of the population in African cities served by various water sources. This figure was produced from data collected from 43 African cities including the following urban areas in southern Africa: Dar Es Salaam, Gaborone, Harare, Luanda, Lusaka, Maseru, Maputo, Port Louis and Windhoek (Reference 7.1).

There are numerous ways in which the level of service can be defined. The South African Government has defined four levels of service for the formally developed areas of the city. These are shown in Table 7.1.



Source: References 7.1 and 7.2

Figure 7.1 Water supply in large African cities: Source of water

Table 7.1 Service level categories used in South Africa for domestic water supply

Level of service	Definition
Inadequate	No access to basic water supply as defined below
Basic	(i) A minimum quantity of 25 litres of potable water per person per day. This should be provided at a minimum flow rate of not less than 10 litres per minute. The source should be within 200 metres of a household. There should not be more than seven days interruption of the supply to any consumer per year i.e. water should be available 98% of the time. (ii) The provision of appropriate education in respect of effective water use should be provided.
Intermediate	Yard tap or yard tank
Full	House connection

Source: Reference 7.3

Section 7.2 provides details of typical urban water demand figures for a number of urban areas in southern Africa. Sections 7.3 and 7.4 discuss the various methods available to establish urban water demand and use.

7.2 Typical urban water demand figures for southern Africa

An overview of urban supply for southern Africa is given in Table 7.2. Urban water demand is often quoted in terms of litres per capita per day (l/c/day) or litres per person per day (l/person/day). It should be noted that the figures in Table 7.2 represent the water production figures. These are the quantity of water produced at a water treatment plant and not the quantity of water used at the point of consumption. In urban water supply schemes there is usual a considerable difference between the water production figures and the water used at the point of consumption. The difference is known as unaccounted for water which is caused by a variety of factors (e.g. leakage, illegal connections, errors in metering readings).

Table 7.2 Overview of urban water supply for southern Africa

Country	Total urban population (million)	Percentage of urban population covered (%)	Largest city	Population of largest city (million)	Water production for the largest city (l/person/day)
Angola	4.40	34	Luanda	4.0	30
Botswana	0.82	100	Gabarone	0.13	286
Democratic Republic of the Congo	15.64	89	Kinshasa	5.7	86
Lesotho	0.60	98	Maseru	0.27	81
Malawi	2.72	95	Blantyre	0.80	-
Mauritius	0.48	100	Port Louis	0.15	200
Mozambique	7.92	86	Maputo	0.97	133
Namibia	0.53	100	Windhoek	0.27	-
Seychelles	0.26	100	Greater Victoria	0.12	140
South Africa	20.33	92	-	-	-
Swaziland	0.27	-	Mbabane	0.94	100
Tanzania	11.02	80	Dar Es Salaam	3.00	150
Zambia	3.63	88	Lusaka	1.21	225
Zimbabwe	4.12	100	Harare	2.38	156

Notes: The urban population is defined as the population living in urban centres according to national criteria.
The percentage of the population covered by the water supply infrastructure is defined in terms of access to water, based upon the type of technology employed, distance from the house and quantity available. Access includes (1) household water connections that can have taps within the house or within a private plot of land, or (2) public water points, including public standpipes, boreholes with handpumps, protected dug wells, protected springs, rainwater collection, or other locally defined technologies. Reasonable access to a public water point is broadly defined as the availability of 20 litres per person per day of safe water from a public water point located within one kilometre of the users' dwelling.

Source: References 7.1 and 7.2

Over the past five years performance indicators for African water utilities have been collected by the Water Utilities Partnership. One of the parameters that was collected was per capita domestic consumption. This indicator represents the average daily water consumption per person per day.

For utilities where most domestic properties are metered, the total domestic consumption can be estimated quite accurately. However, for utilities where the majority of the domestic customers are not metered it can be difficult to determine the spilt between the actual customer consumption and the unaccounted for water. In the UK the per capita domestic water consumption figures range from around 130 l/person/day to 170 l/person/day. The average domestic per capita consumption in the UK is approximately 150 l/person/day. In southern Africa the average urban domestic per capita water consumption ranges from 35 l/person/day to over 370 l/person/day (Reference 7.4).

It should be noted that the accuracy of the various estimates of urban demand will vary significantly and is dependent on the accuracy with which they are recorded. The figures given in the Tables below provide an indication of the range of values that can be expected for domestic urban water consumption in southern Africa.

7.2.1 Angola

In the year 2000 the population of Angola was estimated to be 13.1 million with 34.2% of the population living in urban areas. The majority of Angola's urban population is located in the capital Luanda (Reference 7.2). The existing water supply infrastructure has degraded over the past 20 years owing primarily to the civil war and the lack of capacity and policies in place. There is very little data concerning urban water demand for urban centres in the country. In 1997 it was reported that tankers, low-level tanks and standpipes supplied 70% of Luanda's population with only 30% of the population being supplied by the reticulation network (Reference 7.5).

7.2.2 Botswana

Tables 7.3 and 7.4 provide details on urban water demand estimates for a number of cities in Botswana in 1996. The domestic or residential per capita consumption ranges from about 64 l/person/day to 108 litres/person/day. The total urban water demand that includes institutional and commercial users ranges from 131 l/person/day to 270 l/person/day
.

Table 7.3 **Estimates of water demand for Botswanan cities in 1996 (million litres per year)**

City	Population	Domestic or residential	Institutional or industrial	Commercial	Total use
Gaborone	170,000	6,243	5,287	2,722	14,252
Francistown	89,000	1,664	1,374	1,227	4,265
Selebi-Pilkwe	44,000	1,745	561	2,032	4,338
Lobatse	26,000	607	439	1,061	2,107

Source: Reference 7.6

Table 7.4 **Estimates of water demand for Botswanan cities in 1996 (litres per capita per day)**

City	Domestic or residential	Total use
Gaborone	100.6	229.7
Francistown	51.2	131.3
Selebi-Pilkwe	108.7	270.1
Lobatse	64.0	222.0
Average	89.8	212.0

Source: Reference 7.6

It has been reported that in some urban areas, such as Selebi Phikwe, that are centred around the mining industry, urban domestic water consumption is significantly higher than in other urban areas. A water use and affordability study carried out in Botswana in the early 1990s indicated that in some of the mining towns the mining company pays for the water bills of their employees. This can lead to a culture of wasteful use and relative indifference to water leakage resulting in high overall consumption figures.

7.2.3 Democratic Republic of the Congo

Owing to the continuing civil war in the Democratic Republic of the Congo there is very little reliable information on urban domestic water demand. The figures in Table 7.1 indicate that in 2000 water production for the town of Kinshasa was 86 l/person/day. However, unaccounted for water for Kinshasa was reported to be 47%. Hence at the point of supply only some 40 l/person/day of water is available. This is a low figure for an urban area and indicates that either the reliability and/or the coverage of the water supply system in Kinshasa is low.

7.2.4 Lesotho

The population of Lesotho was estimated at 2.0 million in 2000. About 28% of the population reside in urban areas. In 1995 the urban water demand was estimated to be 109 l/person/day. This figure is relatively low for urban areas. It has been hypothesised that that this is because some urban dwellers are not connected to the reticulation system or that those that are connected use them infrequently. This is because there are water vendors who sell water from community stand pipes at a lower rate than is charged by the water utilities (Reference 7.5). In 2000 the Water and Sewerage Authority in Lesotho reported that their urban per capita domestic water demand was 67 l/person/day (Reference 7.4).

7.2.5 Malawi

There are five water boards that are responsible for urban and peri-urban water supply in Malawi. These are the Lilongwe, Blantyre, Southern, Central and Northern Water Boards. In 1995 the total urban water demand for Malawi was estimated to be 730 million m^3 per year equivalent to a per capita daily water demand of 180 litres.

Table 7.5 provides details of the urban domestic water consumption figures for three water utilities in Malawi. It should be noted that the figures in Table 7.5 only refer to the proportion of the flow that is used by domestic consumers.

Table 7.5 Urban domestic water consumption for water utilities in Malawi in 2000

Water utility	Per capita demand (litres/capita/day)
Central Region Water Board	53.3
Northern Region Water Board	35.4
Lilongwe Water Board	95.0

Source: Reference 7.4

The per capita urban domestic water demand for the Central and Northern Water Boards in Malawi appear to be low indicating that the water supply to domestic consumers is prone to interruptions.

7.2.6 Mauritius

In 2000 the population of Mauritius was some 1.2 million in the year 2000 of which 41.3% reside in urban areas. The urban water consumption for the island has been estimated to be approximately 135 litres/person/day (Reference 7.2).

7.2.7 Mozambique

In recent years there appears to be little readily available data for urban water demand for Mozambican cities. The figures detailed in Table 7.6 are based on data from a study carried out in 1992.

Table 7.6 **Estimates of water demand for Mozambican cities in 1992 (million litres per year)**

City	Population	Domestic	Non-domestic	Losses	Total	Per capita domestic demand (l/person/day)
Maputo	590,324	15,527	10,500	16,920	42,950	199
Beira	83,594	2,850	1,330	3,136	7,317	240
Quelimane	19,986	342	293	254	889	122
Nampula	54,234	895	1,139	1,220	3,255	164
Lichinga	5,811	104	86	48	238	112
Chimoio	11,364	292	267	25	584	141

Source: Reference 7.5

7.2.8 Namibia

Namibia is the most arid country in southern Africa. In recent years the Namibian Government and Namibian water utilities have implemented many water demand management and water conservation measures. As a result domestic water consumption for cities in Namibia is relatively low compared with other urban areas in southern Africa. Table 7.7 provides per capita daily domestic water demand figures for the cities of Walvis Bay and Windhoek.

Table 7.7 **Estimates of domestic water consumption for Namibian water utilities in 2000**

Water utility	Per capita demand (l/c/day)
Municipality of Walvis Bay	108.2
City of Windhoek	120.3

Source: Reference 7.4

7.2.9 South Africa

The population of South Africa was 42.8 million in 2000. Some 55% reside in urban areas. Table 7.8 provides estimates of the domestic water demand for a number of metropolitan areas.

Table 7.8 **Estimates of domestic water demand for South African water utilities and cities in 2000**

Water utility	Per capita demand (l/c/day)
Bloem Water (Bloemfontein)	98.6
Cape Town	219.2
Port Elizabeth	163.9
Durban Metro Water Services	158.0
City of Tygerberg	100.7
Manguang Local Municipality	171.1
Drakenstein Municipality	154.0

Source: Reference 7.4

7.2.10 Swaziland

The main water utility in Swaziland is the Swaziland Water Services Corporation. The 1995 annual urban water demand was estimated to be 25 million m^3 with a corresponding daily urban domestic water demand of 57 litres/person/day (Reference 7.5).

7.2.11 Tanzania

The population of Tanzania was 33.7 million with 27.8% living in urban areas. The 1995 annual urban water demand for the country was estimated to be 1,690 million m^3, equivalent to a demand of 584 litres/person/day. Table 7.9 provides an estimate of domestic water consumption for a variety of water utilities in Tanzania.

Table 7.9 **Estimates of domestic water demand for Tanzanian water utilities and cities in 2000**

Water utility	Per capita demand (l/c/day)
Mwanza Water and Sewerage Company	40.4
Tabora Urban Water and Sewerage Authority	88.5
Dar Es Salaam Water and Sewerage Authority	29.3
Urban Water Supply and Sewerage Authority	105.4
Dodoma Urban Water Supply and Sewerage Authority	194.5
Shinyanga Urban Water and Sewerage Authority	37.4
Tanga Urban Water Supply and Sewerage Authority	59.4
Arusha Urban Water Supply and Sewerage Authority	78.3

Source: Reference 7.4

Table 7.9 indicates that several urban areas in Tanzania have very low per capita domestic demand figures (e.g. the domestic water demand for Dar Es Salaam was stated to be only 29.3 l/person/day according to the local water utility). However, some of the figures are unlikely to reflect the true level of water demand. For example study carried out in 1991 in Dar Es Salaam revealed that the registered house and yard connections in the city accounted for only 30% of the domestic urban water consumption (Reference 7.9). In Dar Es Salaam many domestic water consumers rely on water vendors and other initiatives to fulfil their water demands. In this way private, commercial and community initiatives compensate for the shortcomings of the public water distribution system.

7.2.12 Zambia

The population of Zambia in 2000 was 10.1 million. The percentage of people residing in urban areas is approximately 36%. Table 7.10 provides estimates of domestic water consumption for a variety of water utilities in Zambia.

Table 7.10 Estimates of domestic water consumption for Zambian water utilities in 2000

Water utility	Per capita demand (l/c/day)
Chipata Water and Sewerage Company	115.0
Lusaka Water and Sewerage Company	254.4
Kafubu Water and Sewerage Company	371.2

Source: Reference 7.4

7.2.13 Zimbabwe

The population of Zimbabwe in 2000 was 12.6 million of which 35.3% lived in urban areas. In 1995 the annual urban water demand for the country was approximately 697 million m^3. This is equivalent to a per capita water demand of 169 litres. Estimates of urban domestic water consumption for the cities of Mutare, Masvingo and Gweru are given in Table 7.11.

Table 7.11 Estimates of domestic water consumption for Zimbabwean water utilities in 2000

Water utility	Per capita demand (l/c/day)
City of Masvingo	171.0
City of Mutare	103.2
City of Gweru	137.4

Source: Reference 7.4

7.3 Estimation of water use where records are available

There are number of methods by which urban water demand and use can be estimated. Where demands are metered or records are available the following methods can be used:

- Estimation of water use using meters;
- Estimation of water use from pumping records;
- Estimation of water use using test metering.

Where water demands are not metered there are various other methods that can be employed. These are detailed in Section 7.4.

7.3.1 Estimation of water use using meters

Where the water supply infrastructure is comprehensively metered water use can be calculated from information that is often available through the public water supply utility. Urban water use can be established from the following information:

- Records of total water production from water treatment works;

- Records from individual pumping stations (i.e. hours of pumping, duty flows of pumps, source output meter records);
- Other water meter records (e.g. domestic and commercial properties);
- Estimates of unmetered consumption (alternative sources, government connections, illegal connections).

It is important that water meters are cleaned and serviced regularly. The accuracy of meters can be checked using a temporary weir. The number of broken or unreadable meters should also be estimated.

7.3.2 Estimation of water use from pumping records

Urban water use may also be estimated from pumping records. This can be carried out by collecting the following information:

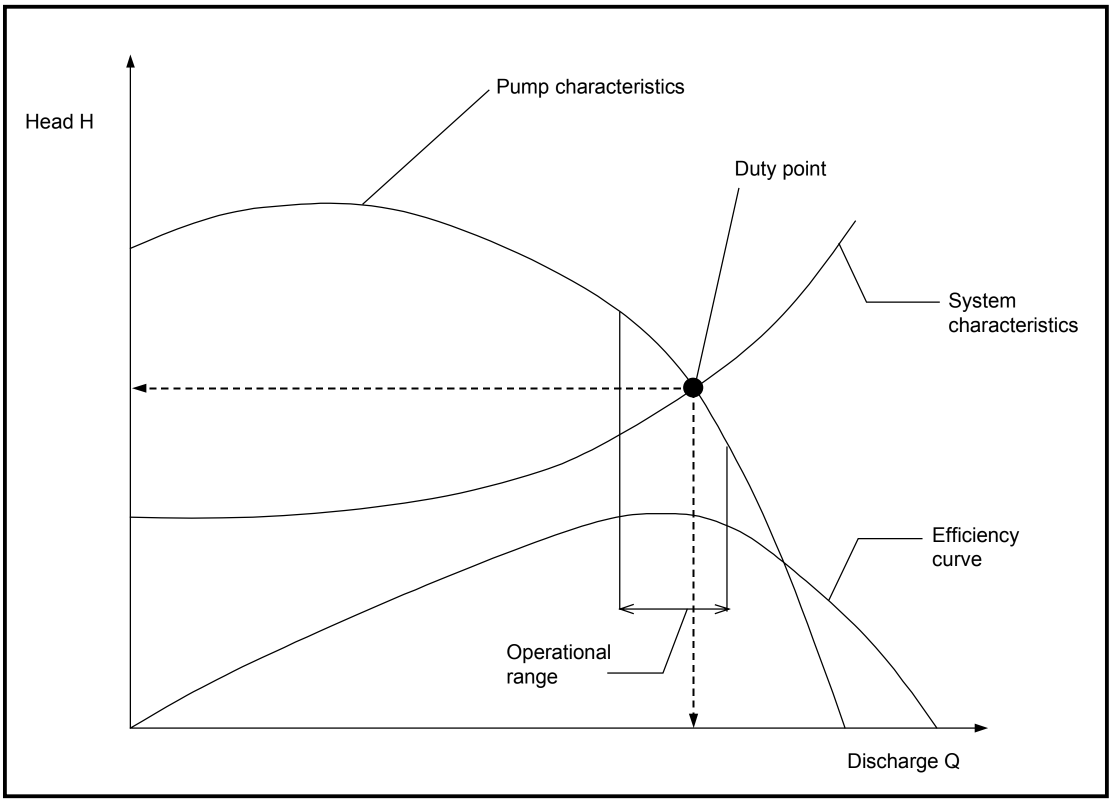
- The pumping regime should be determined;
- It should be established whether water is being pumped to storage (e.g. elevated tanks, service reservoirs) or directly into distribution (e.g. house connections, community tanks, standpipes). It should be noted that water systems that pump to storage would have a constant flow. This is because they are pumping against an approximately constant head. Where water is pumped directly into the distribution system the flow will be determined by the water use that may vary considerably;
- The number of hours per day on average that the pumps are operated, together with the seasonal operating regime;
- The duty point of the pump should be established. The duty point usually coincides with the peak efficiency of the pump. The duty point is shown diagrammatically in Figure 7.2.

Establishing the average number of hours of pumping per day and the normal flow of the pumps (the duty point) will provide an estimate of the average flow per day in the water system, and this can be used as an estimate of total consumption. It should be noted that in old water supply schemes the pump might no longer be operating at its duty point resulting in a different flow to the duty point marked on the pump or in the records.

The duty point can change for the following reasons:

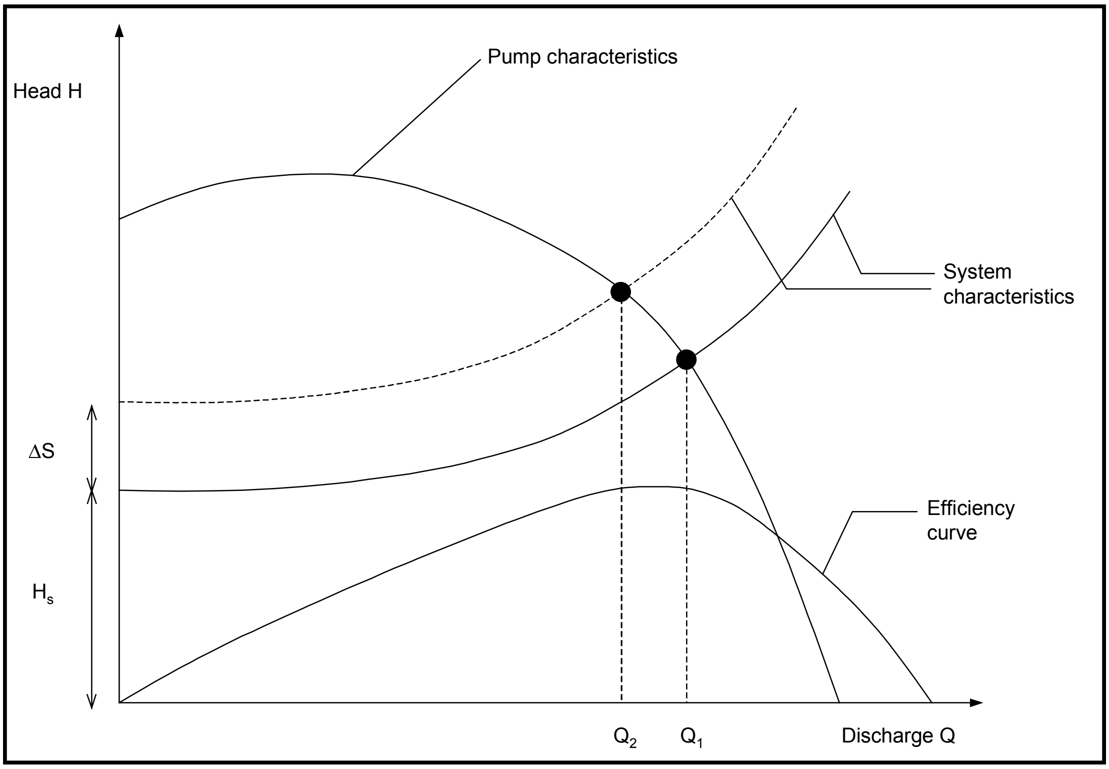
- Water level in the sump may change;
- The roughness of the water distribution system pipeline will change with age;
- Wear and tear on pump impellers;
- Partial clogging of the suction pipe may occur.

An example of how the duty point of a pump can change is shown in Figure 7.3. If the water level in a borehole or well falls by an amount ΔS, the curve for the water distribution system will change and as a consequence the quantity of water pumped into the water distribution system will decrease from Q_1 to Q_2.



Source: Reference 7.8

Figure 7.2 Duty point of a pump



Source: Reference 7.8

Figure 7.3 Effect in the change in static head on discharge

7.3.3 Estimation of water use for unmetered conumers using test metering

Where an urban water supply system is not metered water use can be determined using test metering. This is carried out as follows:

- Classify domestic housing into five or six classes. Examples of domestic housing classifications are given in Table 7.12;
- Select a relatively small sample (i.e. approximately 30 households) from each housing class;
- Check that there is no leakage from these households;
- Carry out test metering (ascertaining the number of persons in each household over the period of the tests). The test period should be between two to four weeks avoiding holiday periods and extreme weather conditions e.g. periods of hot weather when water use is likely to be higher than average. In parts of southern Africa where there is pronounced difference in rainfall throughout the year, test metering should be carried out both in the rainy and dry seasons;
- All standpipes should be test metered and the number of people using them in the test period should be estimated;
- Calculate the mean per capita water use for each class of housing that has been defined;
- Test meter the largest water consuming establishments (e.g. institutions, government buildings).

Table 7.12 Example of domestic housing classifications

Class	Type of housing
1	High and upper middle income groups e.g. villas, detached houses, large flats
2	Average and lower middle income groups e.g. small houses and flats with one or two toilets, one kitchen and one bath/shower
3	Low income groups e.g. tenement blocks with high density occupation (one shower, one pour-flush latrine, one or two taps)
4	Lowest income groups e.g. low grade tenement blocks, one tap dwellings with shared or no latrine, low pressure
5	Standpipe supplies

An alternative to a full test metering programme is to meter the flow through a single main supplying a group of households. However, this masks exceptionally high or low consumption rates and may include undiscovered leakage downstream of the metering point.

The total water use can be calculated as follows from test metered data:

- The total domestic consumption is estimated by marking the supply districts on a map of the water distribution system, and plotting and measuring the amount of each class of housing (including the population densities);
- The aggregate domestic consumption for each district can then be calculated using the mean per capita consumption for each housing class;
- The commercial and institutional water use are apportioned per district from an analysis of the test-metering;
- An allowance for unavoidable distribution leakage should be made for each district, dependent on the age of the system and pressure. It should be noted that the minimum night flow can be test-metered to evaluate system losses during near zero demand periods;

- Deductions should be made for any areas where consumption is below average (e.g. where demand is not satisfied due to low pressure or excessive leakage).

The total urban water use is calculated as follows:

Total urban water use = Domestic water use + Institutional and commercial water use + Unaccounted for water – Unsatisfied demand

Using an approach that utilises metering and information from pumps can provide a reasonably accurate estimate of urban water use. However, in most urban situations, there will be a substantial number of households (especially low-income ones) that do not have access to a piped water supply, and obtain their water from other sources. In these cases an approach based on demand estimation is required.

7.4 Estimates of unmetered urban water demand

Where water use is not metered there are several approaches to estimating urban water demand. The conventional method uses current population and per capita demand for the existing level of service to determine water demand.

There are several sources of data and methods that can be used to estimate the urban population. These are briefly detailed below:

- Recent census figures. These are often the most reliable figures;
- Estimates made by the district or municipal administration;
- Settlement counts. These require access to aerial photographs or remote sensing information. The population can be estimated by counting the number of houses and multiplying this number by the mean household size;
- Self-survey, rapid assessment procedures can be used to estimate population levels. Rapid assessment procedures include:
    - walkabout observations and surveys;
    - mini focus group discussions;
    - informal talks with change agents/key informants living in the relevant areas;
- Population estimates can also often be obtained from community leaders.

7.4.1 Estimates of unmetered urban domestic demand

Urban domestic water demand is directly influenced by the following:

- Level of service;
- Type of housing and its location.

Table 7.13 gives some typical values for different types of housing and levels of service. It should be noted that seasonal variations in demand should also be considered. Table 7.14 provides details of the figures used by the Lusaka Water and Sewerage Company for planning water supply schemes.

Table 7.13 Typical design allowances for in-house water demand

Class	Type of housing	Demand (litres per person per day)
1	High and upper middle income groups: villas, detached houses, large flats	200 to 250
2	Average and lower middle income groups: small houses and flats with one or two toilets, one kitchen and one bath/shower	130 to 180
3	Low income groups: tenement blocks with high density occupation (one shower, one pour-flush latrine, one or two taps)	70 to 130
4	Lowest income groups: low grade tenement blocks, one tap dwellings with shared or no latrine, low pressure	50 to 110
5	Standpipe supplies (including washing) Standpipe supplies (drinking and cooking only)	25 to 70 8 to 10

Source: References 7.9 and 7.10

Table 7.14 Water consumption figures used by the Lusaka Water and Sewerage company for planning

Class of area	Domestic water use (l/c/day)	Garden (l/c/day)	Commercial/ Institutional water use (l/ha/day)	Leakage rate	Wastage rate
Low density	250	80	NA	10%	10%
Medium density	200	40	NA	10%	20%
High density	100	20	NA	10%	30%
Compound	35	0	NA	10%	25%
Commercial	NA	NA	30,000	10%	10%
Institutional	NA	NA	30,000	10%	30%
Industrial	NA	NA	30,000	10%	10%

Source: Reference 7.9

If levels of service are not known there are several methods that can be used to obtain them. These include:

- Conducting a comprehensive survey to collect information on level of service in each household (e.g. house connection or standpipe, number of water-using fittings) and the size of household. It should be noted that this type of survey is expensive, time-consuming and may not give reliable results;
- Rapid assessment procedures can be used to estimate the percentage of each level of service and housing type, and population densities in each zone. However, the confidence limits on the data collected is heavily dependent on the quality and experience of field staff collecting it;
- Conduct participatory assessment of levels of service. Participatory methodologies are not recommended purely for the estimation of water demand and use at a sub-catchment and catchment level. However, if these methods are used as part of a feasibility study for expansion of a water and sanitation system the results can be useful for water resources planning purposes. Common methodologies include:
    - Semi-structured interviewing;
    - Focus group discussions;
    - Preference ranking;

  - Wealth ranking;
  - Mapping;
  - Participatory evaluation and planning.

The urban domestic water demand can then be estimated as follows:

- The supply districts should be marked on a map of the water supply and sanitation system together with the class of housing and the level of service;
- The domestic demand for each district should be aggregated using the average demand for each housing class in each location

Out-of-house demands (e.g. garden watering, filling and livestock watering) are dependent largely on climate and metering. In hot, dry climates where water usage is not metered garden watering can increase the water demand of higher income groups by some 30% to 50%. Similarly, water demand from standpipes can increase substantially where animals are watered at or near the standpipe.

7.4.2 Estimate of the urban domestic demand of the population without access to piped water supply

In many urban areas in Africa there is often a significant minority (or in some cases a majority e.g. in Luanda) of the population who do not have access to a piped water supply. Determining the demand of this proportion of the urban population is difficult. However, in some urban areas it can represent a substantial proportion of total demand.

The following guidelines should be used for determining the demand of the population in urban areas without access to a public water supply:

- Plot the existing supply areas on a map of the urban population;
- Estimate the size of the population without access to public water supply;
- Visit the areas which are not supplied with water and conduct studies (e.g. surveys, rapid assessment procedures and participatory methods) to map the areas and confirm the population (including the number of households, size of households, population density), location of existing water sources, existing water consumption and expenditure on water, existing sanitation, and any unusual local water use practices;
- The water demand can be estimated for the unsupplied areas based on observed or surveyed water consumption. This figure should be compared with a minimum demand of 25 litres per person per day.

7.4.3 Estimating unmetered urban institutional and commercial water use and demand

Water use and demand information for commercial and institutional establishments may be available from metered records. If commercial and institutional estimates of water use and demand are not available they must be calculated. One estimation method is to apply a demand allowance on a per capita basis for various institutions and commercial buildings. Table 7.15 gives typical allowances for commercial and institutional establishments. These allowances assume piped water connections and waterborne sanitation, and should be adjusted down where the establishments have a lower level of service (e.g. standpipes, handpumps or pit latrines at schools).

Table 7.15 Typical demand figures for commercial and institutional establishments in urban areas

Usage	Demand allowance
Small businesses, shops and offices	Up to 25 litres per capita per day (applied as per capita allowance to the whole urban population)
Offices	65 litres per day per employee*
Department stores	100 litres to 135 litres per day per employee*
Hospitals	350 to 500 litres per day per bed
Hotels	250 litres per day per bed
Schools	25 to 75 litres per day per pupil*

*Note: These figures should only be applied when the above are operating or open

Another method for calculating the institutional and commercial water use and demand is to subtract the distribution system loss and domestic use and other uses (e.g. industrial and public use) from the public supply figures.

7.4.4 Estimating unmetered public water demand and use

Water for parks, fountains, ornamental ponds, public gardens, and government buildings is often supplied free of charge. Some studies carried out suggest that a figure as high as 45 litres per person per day may be appropriate for watering ‘green areas of town’ in hot dry climates (provided there is sufficient water to meet the demand). Firefighting, hydrant-testing and sewer flushing generally consumes an insignificant quantity, when expressed as an average daily demand.

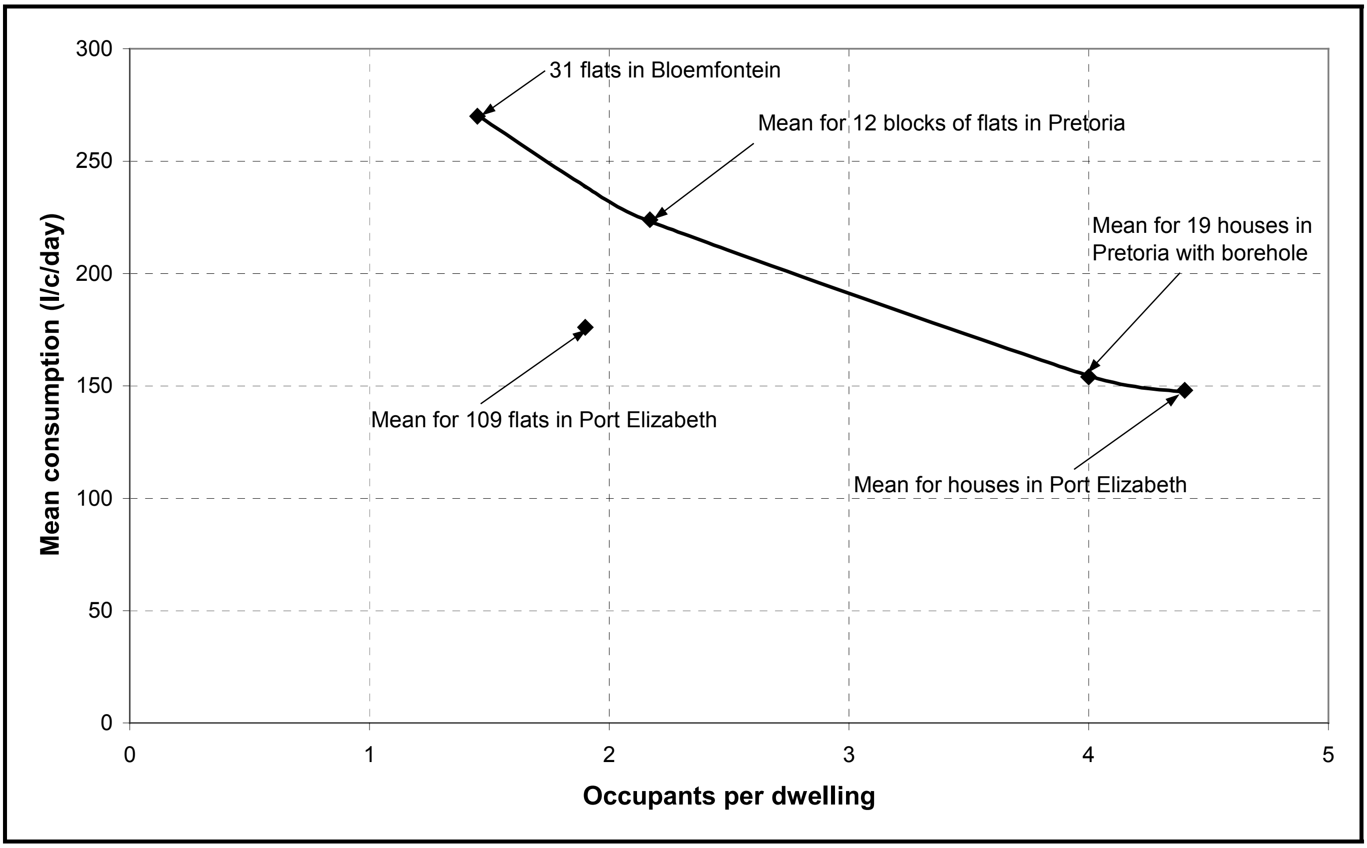
7.4.5 The effect of the number of occupants in a household on water use

The number of occupants in a household can have a significant effect on water use. In 1987 the Water Research Commission in South Africa carried out a study to assess the difference in per capita water consumption between houses and flats for middle income groups in the late 1980s. Table 7.16 indicates that the per capita indoor water consumption for houses is lower than for flats. However, the occupancy rates of houses is higher than that of flats. This is because there are certain common uses of water that are spread amongst people in the same dwelling (e.g. laundry, kitchen use, floor washing). This leads to a drop in per capita water consumption the more occupants there are per dwelling. Figure 7.4 illustrates this phenomenon.

Table 7.16 Comparison of water use and occupancy rates for middle-income flats and house in South Africa

City	Indoor water use (litres per person per day)		Occupants per dwelling	
	House	Flat	Houses	Flat
Port Elizabeth	148	176	4.4	1.9
Pretoria	154	224	4.0	2.2
Bloemfontein	145	270	4.1	1.4
Kiowa (Bulk metered)	-	170	-	2.4
Kiowa (Individual meters)	-	130	-	2.4

Source: Reference 7.12



Source: Reference 7.12

Figure 7.4 Average internal water consumption for middle income group dwellings in South Africa in 1987

There is no other data available for other countries in southern Africa relating occupancy rates of households to water consumption. However, water consumption data for urban areas in other parts of the world indicates that per capita water consumption generally decreases with an increase in the number of occupants of a household.

7.5 Unaccounted for water

7.5.1 Background

Unaccounted for water can be defined as the difference between the volume of water put into the supply and the authorised volume used by the consumers. In some respects unaccounted for water is a misleading term. This is because unaccounted for water includes unmeasured water put to beneficial use (e.g. firefighting) as well as water losses form the system. Unaccounted for water is made up of the following:

- Authorised unmetered uses include fire fighting, main flushing, process water at for water treatment plants and landscaping of public areas;
- Unauthorised water losses from the water supply system e.g. caused by leakage or illegal connections;
- Meter reading and billing errors;
- Accounting procedure errors;
- Malfunctioning distribution system controls e.g. meter error at various levels in the supply system.

Table 7.17 and 7.18 give unaccounted for water figures for a number of southern African water utilities and countries. Unaccounted for water figures vary from 16% for Walvis Bay in Namibia up to 65% for Mwanza in Tanzania. As a comparison, for many countries in Europe an unaccounted for water level of 10% is the recommended value. According to data collected by the World Bank the mean level of unaccounted for water for water utilities in developed countries is 16%.

Table 7.17 Unaccounted for water for large southern African cities

City	Percentage of connections that are metered (%)	Unaccounted for water (%)
Luanda, Angola	40	60
Gaborone, Botswana	100	20
Kinshasa, Democratic Republic of the Congo	76	47
Maseru, Lesotho	97	32
Port Louis, Mauritius	100	45
Maputo, Mozambique	100	34
Windhoek, Namibia	100	11
Greater Victoria, Seychelles	100	26
Mbabane, Swaziland	100	32
Dar Es Salaam, Tanzania	10	60
Lusaka, Zambia	44	56
Harare, Zimbabwe	85	30

Source: Reference 7.5

It should be noted that the figures for unaccounted for water in Tables 7.17 are crude. Water utilities often overstate their performance indicators or manipulate data so that they appear favourable. In some cases unaccounted for water figures may not be credible when water production and consumption are not well metered. As Table 7.17 shows there are some cities in southern Africa were the percentage of connections that are metered is extremely low. Even taking into account that the figures for unaccounted for water in Table 7.18 may be an underestimate it is still the case that many water utilities in southern Africa are failing to meet standards achieved by their peer utilities.

The Global Water Supply and Sanitation Assessment 2000 Report also stated that:

- Many water utilities have difficulty in collecting and maintaining records related to the performance indicators;
- The quality of the data need to be cross-checked, as many of the water utilities are not happy with the quality of their own data;
- There is a need to address concerns among utilities that they are providing confidential information that may be made public;
- There is a slow response to questionnaires and evidence of lack of commitment on the part of some utilities.

Table 7.18 Unaccounted for water figures for water utilities in southern Africa

Water utility	Country	Year of data collection	Unaccounted for water (%)
Water Utilities Corporation	Botswana	2000	20.8
Water and Sewerage Authority	Lesotho	2000	22.5
Central Water Authority	Malawi	2000	43.2
Blantyre Water Board	Malawi	2000	37.8
Northern Region Water Board	Malawi	2000	28.6
Lilongwe Water Board	Malawi	1999	34.3
Central Water Authority	Mauritius	2000	43.2
Walvis Bay Municipality	Namibia	2001	16.0
City of Windhoek	Namibia	2000	19.8
Bloem Water (Bloemfontein)	South Africa	2000	50.0
Durban Metro Water Services	South Africa	2001	20.0
City of Tygerberg	South Africa	2001	18.2
Manguang Local Municipality	South Africa	2001	26.6
Drakenstein Municipality	South Africa	2000	25.9
Arusha Urban Water Supply and Sewerage Authority	Tanzania	2001	38.9
Mwanza Water and Sewerage Authority	Tanzania	1999	65.2
Dar Es Salaam Water and Sewerage Authority	Tanzania	2000	34.8
Iringa Urban Water Supply and Sewerage Authority	Tanzania	2000	45.0
Shinyanga Urban Water and Sewerage Authority	Tanzania	2000	44.0
Dodoma Urban Water and Sewerage Authority	Tanzania	2000	42.2
Urban Water Supply and Sewerage Authority	Tanzania	2000	30.0
Tabora Urban Water and Sewerage Authority	Tanzania	2000	36.9
Department of Water Development	Tanzania	2000	30.0
Tanga Urban Water Supply and Sewerage Authority	Tanzania	2000	34.3
Chipata Water and Sewerage Company	Zambia	1999	40.1
Mulonga Water and Sewerage Company	Zambia	2000	37.0
Lusaka Water and Sewerage Company	Zambia	2000	50.0
AHC Mining Municipal Services Limited	Zambia	2001	59.5
Kafubu Water and Sewerage Company	Zambia	2001	50.0
City of Mutare	Zimbabwe	2000	57.6
City of Gweru	Zimbabwe	1999	35.0

Source: Reference 7.4

7.5.2 Methods for reducing unaccounted for water

In order to reduce the level of unaccounted for water it is important that the factors causing the unaccounted for water are well understood. Estimation and detection of the loss in a water supply system can be applied only if the following basic requirements are in place:

- A thorough understanding of the structure and functioning of the system;
- Availability of adequate measuring devices for flow volumes/flow rates;
- Availability of engineering drawings, instruction and operation manuals.

Metering of water volumes supplied is an essential part of a demand orientated management strategy and any programme to reduce the unaccounted for water and increase the financial revenue should be based on it. Some publications on demand management strategies stress the need for financial and institutional changes as water pricing, institutional reforms and policy changes. However, it should be well understood, that good intentions and policy changes towards reduction of unaccounted for water could not succeed if the above-mentioned requirements are not in place. Methods by which unaccounted for water can be reduced are shown in Table 7.19.

Table 7.19 Methods by which unaccounted for water can be reduced

Area	**Issues**	Actions
Metering	Unmetered connections	Meter installation
	Faulty meters	Meter replacement/repair
	Under registration of meters	Bulk metering
	Lack of confidence on billings	Bulk metering
	Lack of confidence in number of customers	Bulk metering
Leakage	Leakage in reservoirs and mains Poor quality pipe material and installation	Systematic maintenance, detection, monitoring and maintenance of old pipes
	Lack of information on pipe network	Information programmes to public and others Standardisation of installation, material and control
	Lack of maintenance	Pipe database Replacement connection policy Adequate pressure regulation
Operational control	Deficient operational control	Monitoring indicators Water distribution system automation Designing operations control units
Commercial systems	Inefficient billing system Poor connection and/or disconnection procedures High level of accounts receivable	Database of users Design/implementation of better commercial systems
	Low income consumers not billed	Improved users/demand data
	Illegal/unregistered connections	Disconnect policies
	Water pricing policies	Control of high volume users

Source: Reference 7.13

The major sources of unaccounted for water in the majority of African cities are leakage and illegal abstractions. The factors that affect the proportion of unaccounted for water that occurs through leakage are:

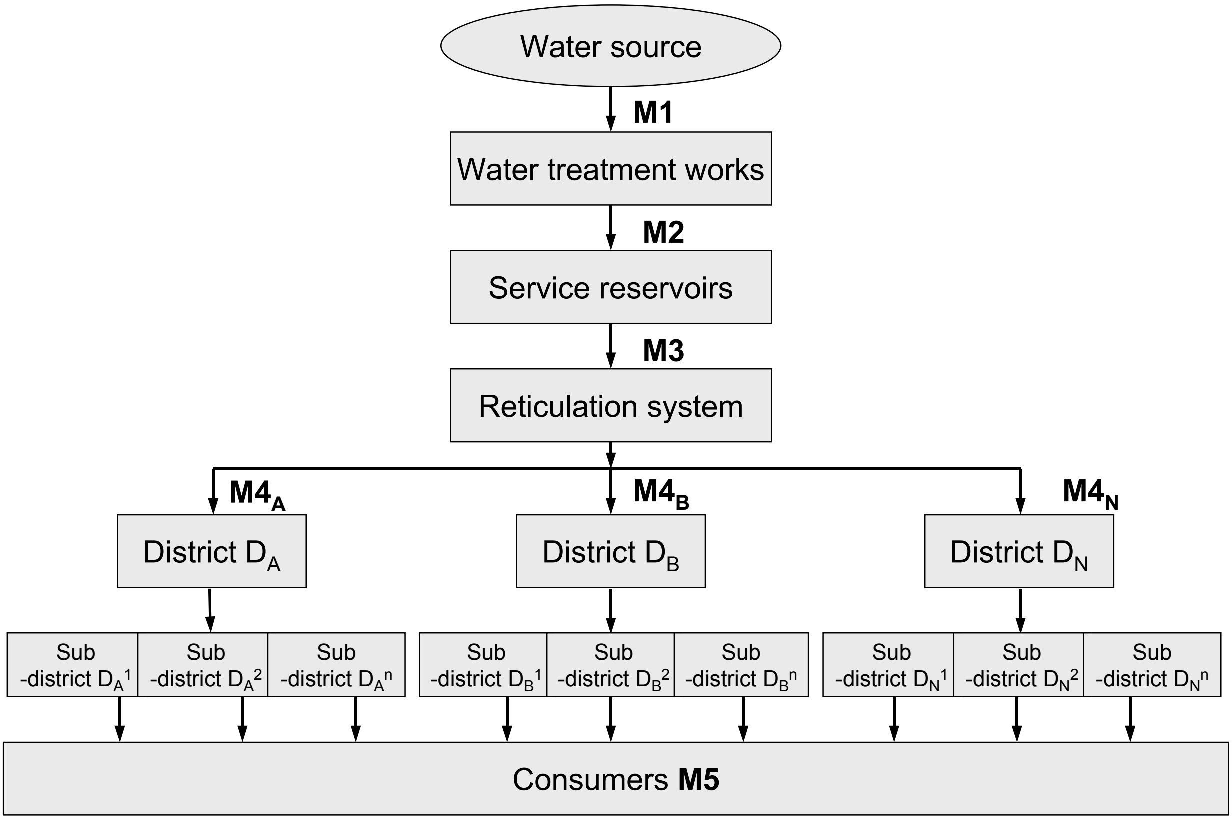
- **Pressure.** This has the following effects:
    - The higher the pressures the higher the rate of leakage through broken pipes or faulty fittings. An example of this is given below.
    - The higher the pressure the greater the frequency of bursts in pipes.
    - Pressure surges can cause pipes to fracture and fittings to move out of place.
    - Cycling the pressure between high and low value within the design pressure causes fatigue.
- **Movement of the soil.** This can cause pipes to break, joints to move, or may result in local stress concentrations within pipe or fitting which eventually leads to its failure.
- **Soil characteristics.** Soil characteristics can affect the running time of individual leaks. For example, in some soils water from underground leaks may show on the surface fairly quickly whilst in others leaks can run indefinitely without showing.
- **Deterioration of water mains and pipes.** The common forms of failure of pipes owing to deterioration of their quality are hole formation and transverse or longitudinal fracture of the pipe. Concrete or asbestos cement pipes can also corrode owing to the presence of high levels of sulphates in the water or soil. Soft water also leaches calcite from asbestos-cement pipes weakening them and introducing internal stresses that lead to failure through longitudinal splitting. Poor quality pipes, fittings and workmanship can promote leakage. Age also comes into play as older pipelines tend to deteriorate more than pipelines that have just been laid.

7.5.3 Estimation of water losses in an urban water supply system

The estimation and detection of the loss in a water supply system can be applied only if the following basic requirements are in place:

- A thorough understanding of the structure and functioning of the system;
- Availability of adequate measuring devices for flow volumes/ flow rates;
- Availability of engineering drawings, instruction and operation manuals and/or a Geographical Information System (GIS).

Metering of water volumes (rates) supplied is an essential part of a demand orientated management strategy and any programme to reduce the unaccounted for water and increase the financial revenue should be based on it. The configuration of a water supply system may vary in wide limits, depending on water source, topography and the engineering solutions adopted. The discussion on this topic is based on a generalised scheme, shown on Figure 7.5 that assumes that water is abstracted from a surface impoundment.



Note: M1 to M5 represent points at which water flow or volume measurement should be metered

Source: Reference 7.13

Figure 7.5 General scheme of a water supply system

7.5.4 Location of water losses in an urban water supply scheme

The main water losses in a water reticulation scheme are:

- Water losses along trunk mains;
- Water losses within the treatment plant;
- Water losses within the distribution system;
- Water losses within the consumers' premises.

Water losses along trunk mains. These losses are due to leakage from trunk mains, including the main from the source to the treatment plant, from the plant to the reservoir(s) and from the reservoir to the junction within the reticulation system. Owing to the bulk amounts transported, and in most cases high pressures, the volumes of water losses might be considerable, but they are relatively easy to detect by visual inspection and lower in numbers. Trunk mains are usually designed and constructed at high standards of reliability, because of their importance, and leakage along them is an indication of ageing and the need of replacement. In cases where they are very long and also complex hydraulic structures are involved, leaks can reach a significant value, amounting to 60% of that from trunk distribution mains, expressed as m^3/km/day.

Water losses within the treatment plant. These are losses due to the treatment process itself, their amount can be decreased by improving the operation of the plant or introducing treatment methods for reclamation of the sludge generated. To estimate these losses and to include them into the water balance of the system water flow measurements are imperative. The quantity of water entering the treatment plant (point M1 on Figure 7.5) and leaving the treatment plant (M2 on Figure 7.5) should be measured.

Water losses within the distribution system. These losses are usually smaller in volumes but numerous in numbers. Their identification and location is difficult, because of the large area covered by the reticulation system. Measures for leakage control and detection are usually dedicated to the reduction of this type of water losses. This need is also supported by the fact, that water supply projects executed in conditions of financial restrictions are resulting in less reliable solutions, correspondingly the expected number of breakdowns is higher, especially in high pressure zones.

Water losses within consumer's premises. These might be relatively small in volume but their large numbers can lead to a considerable percentage of the total water loss of the system. If a measurement device (M5) is installed within each household, the amount of water consumed, including losses will be recorded. Therefore, the losses within consumer premises, usually associated with leaks from plumbing and fixtures, and illegal irrigation of loans and home gardens, are difficult to measure and estimate. It is interesting to note that in the case of Johannesburg that has unaccounted for water of 42% it has been estimated that the majority of this results from leakage on private property (Reference 7.26).

Tariff regulations are aiming at the reduction of this type of loss through financial punishment. However, it should be noted that all other types of leaks, described above lead to financial loss of the municipality (managing institution), but the water lost in consumer premises leads to a financial revenue, provided that it is correctly metered and billed (Reference 7.13).

Provided that water consumed is paid on the basis of metered volumes, water losses within the system, but excluding consumer premises, form part of the unaccounted for water. Under this context, it is the responsibility of local authorities to reduce as much as possible of the water loss within the system, excluding consumer's premises, while consumers are responsible for the reduction of water loss within their premises.

7.5.5 The level of metering required within an urban water supply reticulation scheme

A major objective of the management of water supply systems is to account for water volumes within the system. Thus monitoring of the system's water balance is very important in order to estimate demand trends, expenditure, as well as, to account for water losses. This can be done only on the basis of adequate number and adequate accuracy of water discharge measurement devices, located at characteristic points in the system. Preferably, these points should be identified during the design stage, but experience gained during the exploitation period can indicate the need of additional measurement points. Regular data collection, recording and leakage history is essential for good management of the scheme. The various ways in which water can be metered effectively in an urban reticulation scheme are discussed below.

District metering

In district metering separately defined areas, typically containing 2000 to 5000 properties, are metered continuously, and the total quantity of water entering the district is recorded. The meters are read regularly and if supply is inexplicably high, inspectors are sent into that district to locate leaks. Metering at a district level is shown as M4 on Figure 7.5.

This method has the advantage that water utility personnel can concentrate their efforts in those districts where the highest levels of leakage occur. It also has the added advantage that information regarding flows and use of water within the network is obtained that can be useful for the day-to-day running of the network and for the planning and design of future extensions. However, the method is not sensitive to changes in leakage and does not determine the position of leaks. Although district metering allows the detection and estimation of water losses within the district it is highly dependent on the range of measurement, accuracy and sensitivity of the water meter (Reference 7.13).

Waste metering

The urban water distribution system are often sub divided into sub-districts containing 200 to 3000 properties. These are shown as D_a^1 to D_a^n on Figure 7.5. These areas are isolated and fed through a single meter, capable of measuring and recording the low rate of flow that occur during the early hours of the morning, also known as *minimum night flows*. It is assumed that the night flows closely represent the water loss. This is because little legitimate consumption is expected to take place during the period of measurement. The flows are recorded at regular intervals. This allows water utility personnel to establish the districts with higher flow records, indicating leakage (Reference 7.13).

The flow meter, which is used, is one that is capable of measuring low rates of flow and is normally, referred to as a *waste meter*. The waste meter may be permanently installed on a by-pass or carried on a mobile trailer and connected temporarily into the system via hydrants. There is a type of waste metering technique that is referred to as *step testing* or *valve inspection*. This technique involves closing the valves within the district, so that the metered area is successively reduced. The resultant reduction in flow rate following the closure of a particular valve indicates the total leakage plus legitimate night consumption in that section of the distribution system. There are a number of ways in which the step test can be undertaken. These include:

- **Isolation method.** Starting furthest from the waste meter, valves are successively closed so that the different subdistricts are isolated sequentially and less and less of the district is supplied via the meter. The sequence of closing valves is followed right up to the last valve whereupon the flow should drop to zero.
- **Close and open method.** This entails closing valves on each step, noting the resultant drop on the flow meter and then re-opening again.

The success of both waste metering and step testing depends to a large extent upon the ability to isolate completely the waste meter district from the rest of the system and this depends on valves shutting down tight. The method is sensitive to small leaks and also establishes the position of that leak between valves within the sub-district. However, this leads to time being spent in monitoring districts where no leakage has occurred and hence no benefits would be obtained.

Waste metering is more accurate than district metering and locates water losses within sub-districts. However, it requires the application of waste meters, with higher level of accuracy, in addition to the already installed district meters. These could be installed permanently in identified sub-districts where the incidents of leaks occurring is high or could be installed temporarily for specified periods to identify zones of high leaks.

Combined district and waste metering

This method consists of both district metering and waste metering. When increases in supply are indicated on the district meter, the waste meters downstream of it are read in order to sub-divide the district into more manageable units and therefore guide inspectors to the areas containing most leaks. The need to use waste meters in addition to district meters might be overcome if the range of measurement of the district meter is chosen so that it can detect the night flows in the sub-districts. A combination of two meters, one of them installed on a bypass, is also a possible solution

7.5.6 Methods for locating leaks

There are three main methods for locating leaks. These are:

- Visual inspection;
- Regular soundings (proactive leak detection);
- Pressure control;
- Visual inspection.

Visual inspection

In this method only those leaks that become self-evident are located and repaired. A leak may be self-evident because water shows on the surface or may become so upon investigation following consumer complaints such as poor pressure or noise in the plumbing system. Leakage is identified by visual inspection or based on consumer complaints. This method is widely applied and requires regular inspection by the managing authority. No special professional skills are needed. It is a low cost measure and is effective in areas where pipelines are laid at lower depth and soil conditions are such that leaks quickly come to the surface (Reference 7.13).

Regular sounding (proactive leak detection*)*

This method involves teams of inspectors seeking to locate leaks by systematic direct sounding on all stopcocks, hydrants and valves through the distribution system and listening for the characteristic noise of leaking water.

As water under pressure exits a crack or a small hole, the pipe wall and the surrounding soil emit sound waves in the audible range. Water impacting the soil and circulating in a cavity creates lower frequency waves that have limited transmission through the ground. Through the use of surface microphones, leaks can be located with greater precision. The leak noise detected will depend upon the position at which a sounding is made.

Proactive leak detection requires special sounding equipment, specifically trained personnel and considerable practical experience in order to be applied successfully. Regular proactive leak detection could be recommended to areas where leaks could cause severe damage of surrounding structures or along parts of the system of highest importance (Reference 7.13).

Pressure control

Pressure control does not directly involve leakage detection, but sudden drops in pressure may indicate to a possible leak. In general, reduction in pressure leads to reduced rate of escape through each leak and may also affect the number of leaks occurring. Pressure reduction is relatively cheap and can be quickly effected, but lower pressure may also increase the leak population by making them less detectable. Pressure reduction can be achieved in a number of ways such as reducing pumping heads, installing break pressure tanks and using pressure-reducing valves. The control of pressure surges and cycling is likely to reduce the numbers of bursts and leaks that occur, especially in plastic pipes. Pressure control is a necessary tool for the technical management of the system and combined with any other method of water loss estimation could give very useful information in order to identify the causes of water lost through leakage (Reference 7.13). Pressure control does not directly involve leakage detection, but sudden drops in pressure may indicate to a possible leak. In general, reduction in pressure leads to reduced rate of

7.6 Water demand management measures

The provision of adequate water supply and sanitation to rapidly growing urban populations is increasingly becoming a problem for governments in the SADC region. The continuing expansion of the numbers of people in cities who need water and sanitation services and who cannot readily get these services by self provision, form a continuous pressure to either invest in additional production capacity or to stretch the available supplies to serve more people. At the same time, industrial activity also demands the expansion of urban water supply services.

The predominant approach towards meeting these increasing water demands has been towards supply augmentation schemes. However, the cost of developing new sources or expanding existing sources is getting higher and higher as the most accessible water resources have already been tapped. The real costs of water per cubic metre in second and third generation projects in some cities have doubled between a first and the second project and then doubled again between the second and third. At the same time, governments are becoming reluctant to pay the rising investment costs as long as utilities are unable to meet these cost from user charges.

It has been demonstrated in many countries that saving water rather than the development of new sources is often the best ‘next’ source of water, both from an economic and from an environmental point of view. Water demand management therefore is seen as the preferred alternative to meet increasing water demand and can be defined as a strategy to improve efficiency and sustainable use of water resources taking into account economic, social and environmental considerations.

The main objective of water demand management is to contribute to more efficient and equitable provision of water and sanitation services and to reach this objective a number of instruments have been developed. These instruments are interdependent and mutually reinforcing and the most optimal way they are applied will depend on the prevailing local conditions and are the topic of a number of presentations in this symposium. With regards to the domestic consumer, water demand management measures can be divided into:

- Water conservation measures including:
    - Leakage detection;
    - Reduction of illegal connections;
    - In-house retrofitting;
    - Out-of-house water saving measures;
- Water pricing measures including:
    - Water metering;
    - Tariff structures;
- Information and educational measures including:
    - Awareness raising;
    - Public involvement;
    - In-school education;
- Legal measures including:
    - Rules and regulations that form the basis of water demand management policy;
    - Regulations on resale of water.

This section focuses on the most main and most promising water demand management measures including:

- Reduction of the pressure in a water distribution system;
- Physical measures to reduce water consumption such as reducing toilet cistern capacity;
- The use of tariff structures.

7.6.1 Pressure reduction as a demand management measure

Pressure reduction in a water distribution system can be one of the simplest methods to reduce water demand. The control of pressures can save water in a number of ways. High pressures increase losses of water through leaks, and increase use when the amount of water used is based on time rather than the volume of water discharged. The leakage from water distribution systems has been shown to be directly proportional to the square root of the distribution system pressure as indicated by the relationship below.

Leakage α (distribution system pressure)$^{0.5}$

The objective of any pressure control strategy should be to minimise excessive pressure as far as possible, while ensuring that sufficient pressures are maintained throughout the network to make sure that consumer demands are satisfied at all times. The idealised objective of such a strategy would be to always maintain a head profile in the network such that the pressure at each connection is just sufficient to provide the corresponding demand. This is referred to as an optimal head profile or the target pressure level. However, owing to the head-flow relationships in the network, target pressure levels can only be achieved by few points of the system while in the others the operational pressure remains higher. As the complexity of a distribution system grows, the task of achieving the target pressure level becomes more difficult and the average overpressure tends to increase.

Historically many water utilities have not managed pressures to optimum limits to reduce leakage for a number of reasons including:

- Lack of awareness or understanding of the leakage problem;
- Lack of awareness or understanding of the pressure leakage relationship;
- Concerns over fire fighting regulations;
- Concern of customer complaints;
- Concerns of storage not filling properly at night;
- Lack of financial incentive if water was cheap and plentiful.

However, pressure management is becoming recognised as an effective tool for reduction of real losses (in most cases leakage) and also in the reduction of unwanted demand. The South African Code of Practice SABS 0306 “Code of Practice for the Management of Potable Water in Distribution Systems” recommends that for water distribution networks that the static pressure should be limited to between 30 m and 60 m. An example of the effect of pressure reduction on leakage for the city of Bulawayo in Zimbabwe is given below.

Example of the effect of pressure reduction on leakage for Bulawayo in Zimbabwe

Example for a low density suburb

Queens Park East is a low density (high income), residential area in the city of Bulawayo that was included as part of a pilot water conservation study in 2001. The total population of the suburb was calculated to be 3,101 and the number of connections was 460. The total length of the water distribution system is 12,640 m and the estimated length of connection pipes 9,500 m.

Total water consumption during a 24 hour period was recorded as 614 m^3/day. The minimum night flow was recorded at 4.4 l/s. Minimum night flow consists of legal night consumption and leakage. The legal night consumption was estimated to be 0.8 l/s. The losses in the area at night is therefore 4.4 l/s - 0.8 l/s = 3.6 l/s. Adjusted for pressure changes during the daytime this corresponds to a per connection loss of 580 l/day.

Pressure was reduced from an average of 4.3 bar to 3.7 bar, resulting in an average consumption reduction of 0.7 l/s. The flow is reduced by a factor of 1.09. This clearly verifies pressure reduction as an effective method for reduction of losses.

Example for a high density suburb

Emganwini is a high-density (low cost) housing development in the city of Bulawayo. In December 1999 a study revealed that the pressure in Emganwini's water distribution system was up to 10.6 bar at night time with an average of 9.5 bar. This is an extremely high pressure for a water distribution system. The minimum night flow was recorded at 7.9 l/s. The legal night consumption was calculated to be 1.5 l/s. Adjusting for the legal night consumption the leakage at night was estimated to be 6.4 l/s, this is equivalent to a daily leakage of 495 m^3/day or 215 l/day/connection. Using 1.5 l/s/connection as an average waste/loss figure at private premises, adjusted for the existing pressure the losses in the distribution system can be calculated to be 338 m^3/day.

In April 2000 a new pressure reducing valve was installed for Emganwini and the pressure was reduced to 5.5 bar. A total consumption of 916 m^3/day and a minimum night flow of 1.7 l/s was recorded. Adjusting for the legal night time consumption, the leakage in the area at night was only 0.5 l/s. The reduction in the leakage resulting from reducing the pressure was considerable. Part of this may have resulted from repairs carried out to the distribution system between December 1999 and April 2000. As the pressure is constant the net night flow can be converted into a daily leakage of 43 m^3/day, corresponding to a per connection loss of only 38 l/day.

Pressure was reduced further to an average of 4.3 bar. The corresponding minimum night flow was measured at only 1.12 l/s. This is almost identical to the calculated legitimate night consumption. This example clearly illustrates the effect that reductions in pressure can have on water saving.

Source: Reference 7.12

7.6.2 Physical measures to reduce water demand

At a domestic level there are many physical measures that can be introduced to reduce water demand. These measures include:

- Reducing the cistern capacity of toilets;
- Use of low pressure shower heads;
- Garden timer taps to limit the time spent irrigating domestic gardens;.
- Flow restrictors at kitchen tap.

It has been shown that retrofitting plumbing fittings, such as installing low volume water closets and low volume shower roses, reduce overall water use by at least 25% of domestic water consumption (Reference 7.27). One immediate and cheap measure that can be implemented is to reduce the cistern capacity of toilets. It has been estimated that water used for flushing constitutes about 30% of total domestic water use (Reference 7.28). Adjusting floats in existing installations, or simply putting one or two standard bricks in the cistern would reduce cistern capacity by 10% or more. This means that each household would reduce its consumption by approximately 3%, without requiring any significant investment, thus saving money through a reduced water bill, while not compromising the quality of the service enjoyed.

In New York 1.33 million inefficient toilets were replaced by efficient ones during 1994 to 1997, reducing the city's consumption by 0.3 million m^3/day. Other demand management measures were also implemented. As a result, per capita water use dropped from 738 l/day in 1991 to 640 l/day in 1999 (Reference 7.27).

7.6.3 The effect of tariff levels on water demand

With ordinary economic goods there is a relation between price and demand following a demand curve. The dimensionless slope of this demand curve is called the price elasticity of demand. It is defined as the percentage of increase in demand resulting from a percentage of increase in price. This elasticity is a negative number since demand is expected to decrease as price increases, and normally ranges between -1 and 0. The problem is that the elasticity is not a constant. It depends on the price, it depends on the water use and it varies over time. So it is an equation with limited applicability.

Primary uses of water have a special characteristic in that the elasticity (E) becomes rigid (inelastic; E close to zero) when we approach the more essential needs of the user. This is illustrated in Figure 7.6. People need water, whatever the price and for the most essential use of water (drinking) few alternative sources of water are available. For sectors such as industry and agriculture demand for water is generally more elastic (i.e. E closer to -1) which is more in agreement with the general economic theory. This is because alternatives for water use exist in these sectors (e.g. introducing water saving production technologies, shifting to less water demanding products/crops). For basic needs, however, demand is relatively inelastic or rigid.

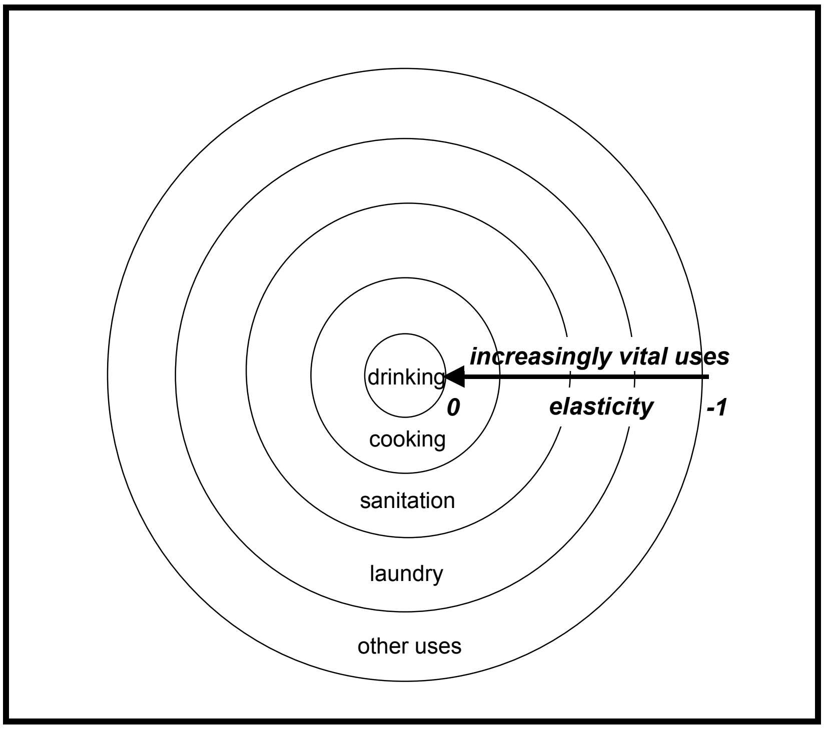
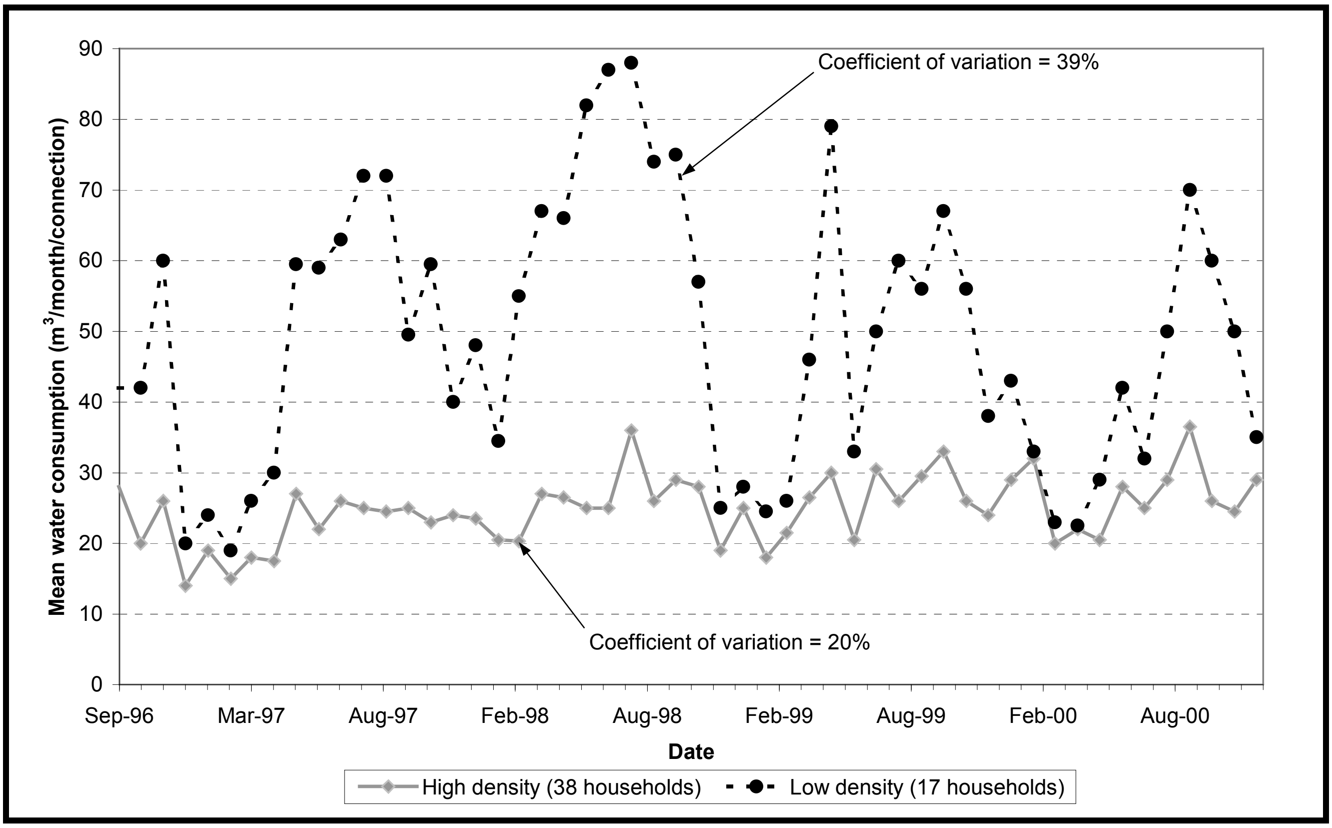


Figure 7.6 Diagram of different uses of domestic water and their elasticities of demand

In urban water supply, elasticities are therefore generally close to 0, unless additional (non-financial) measures are taken. Poor consumers often only can afford to use small amounts of water (the basics), and any increase in tariffs will have little effect because they cannot do with less water. For large consumers (e.g. the ones that irrigate their gardens and own cars that need to be washed) the ability to pay is such that the need to save money on water is limited. In the latter case, awareness campaigns, regulation, policing, leak detection and renewal of appliances are often more effective than the price mechanism per se.

Figure 7.7 shows the different patterns of water use during the year for high-density (poor) and low-density (rich) consumers for Ruwa, a town in Zimbabwe. The figure shows that for high-density consumers seasonal fluctuation of water demand is low, indicating that most uses are confined to essential purposes. Water consumption of low-density consumers is much higher during the dry season than during the rainy season, probably related to non-vital uses of water, such as watering gardens and filling pools when it is dry. One could hypothesise that part of the additional water use during the dry season for these consumers is relatively elastic, and could be influenced by tariffs, whereas this may not be the case for the other types of water uses. Similar findings to these were found for the city of Masvingo in Zimbabwe. This example is given below.



Source: Reference 7.29

Figure 7.7 Water consumption for high and low density suburbs for the town of Ruwa in Zimbabwe

Water use by affluent and less affluent households in Masvingo, Zimbabwe

Trends in domestic water use in the city of Masvingo, Zimbabwe, were studied by considering affluent and non-affluent residential areas. The residential areas of Rhodene and Clipsham, comprising 1,050 households were considered affluent. The residential areas of Rujeko and Mucheke, represented by a sample size of 3,350 households, were considered less affluent. The total sample size represents some 34% of all domestic users of Masvingo. Monthly water consumption was derived from billing data of 1999 to 2001. The results of average consumption patterns in different residential areas are presented in the Figure 7.8.

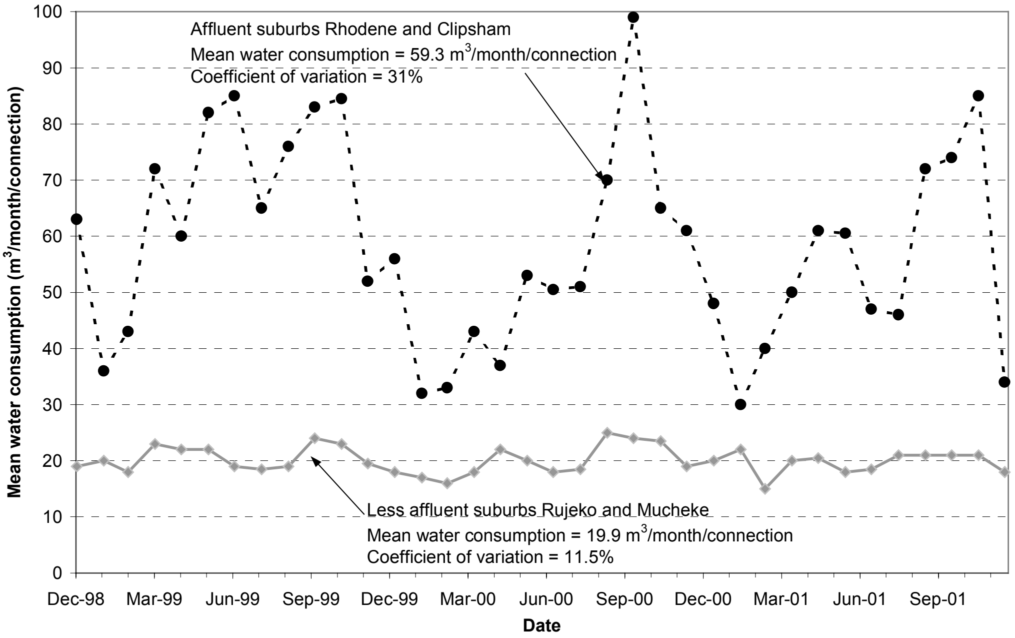


Figure 7.8 Monthly billed water consumption for affluent and less affluent households in Masvingo

Figure 7.8 shows that there is a large difference in water consumption between affluent households that consume 59 m^3/month on average and less affluent households that consume on average 20 m^3/month. Water consumption fluctuates much more in affluent households that have coefficient of variation CV of 31% than that of less affluent households that have a CV of 11.5%. This fluctuation is related to rainfall, as water use tends to be higher in the hot dry months, especially for non-essential purposes such as the use of treated water for watering gardens. In the hot dry month of October, for instance, affluent households may consume as much as 80 m^3/month or more, whereas the less affluent counterparts consume at most 25 m^3/month i.e. less than a third. In the poorest section of the city (500 households within Mucheke residential area) average household consumption was only 12 m^3/month. This amount may therefore be considered the basic minimum or "lifeline" quantity, and is, with an average household size of 8 people equivalent to 50 l/person/day, the minimum quantity recommended by the World Health Organisation.

The explanation for the observed trend in Figure 7.8 is clear: poor households cannot afford to use a lot of water because of their inability to pay. In addition, they have relatively small plot sizes (200 m^2 to 300 m^2). This puts an upper limit to the use of water for gardening even if they did have the ability to pay. As a result, the seasonal variation in their water use is relatively small, since water is mainly used for the most essential purposes. For the affluent household the opposite is true: their ability and willingness to pay is large, and water use is seemingly restricted by the size of their gardens (4,000 m^2 on average), the presence of a swimming pool as well as the number of cars they wish to wash. A large part of water is thus applied to uses that are considered non-essential. It may therefore be hypothesised that the CV of monthly consumption data is an indicator for the elasticity of demand. This hypothesis would suggest that the elasticity of demand for water in affluent households in Masvingo may be 2.7 times higher than that for poor households (31/11.5=2.7). Detailed economic research would be required to falsify or accept this hypothesis. This preliminary finding suggests that water pricing influences water use by affluent households to a much larger extent than that of non-affluent households.

Source: Reference 7.30

With regards to the effect of tariff levels on water consumption the following can be concluded:

- The elasticity of water consumption is generally low;
- The price elasticity is greater when the price is higher;
- In the household sector, the price elasticity varies between -0.15 and -0.70;
- With respect to drinking water the demand-price relation will never be elastic (E < -1);
- In the industrial sector, the majority of estimates are in the range of -0.45 to -1.37

Increasing block tariff system

It should further be noted that any pricing policy aimed at influencing demand should consider the basic right of people to access of safe drinking water. Thus demand management through economic means should consider financial (full cost recovery) and equity criteria. The increasing block tariff pricing structure implies a cross-subsidy from rich to poor users. It is a good example of a satisfactory compromise between both criteria and is becoming increasingly adopted, especially in water scarce regions.

The increasing block tariff system charges the water for the most vital human needs such as drinking at the lowest levels and the uses for less vital needs highest. This tariff system therefore makes a mockery of conventional economic theory, which would price the most valued uses highest.

In order to find a satisfying compromise between *full cost recovery* and *equity*, each block should have a clearly defined purpose, from which block size and tariff can be derived. Below is an example of how the functions of four blocks could be defined:

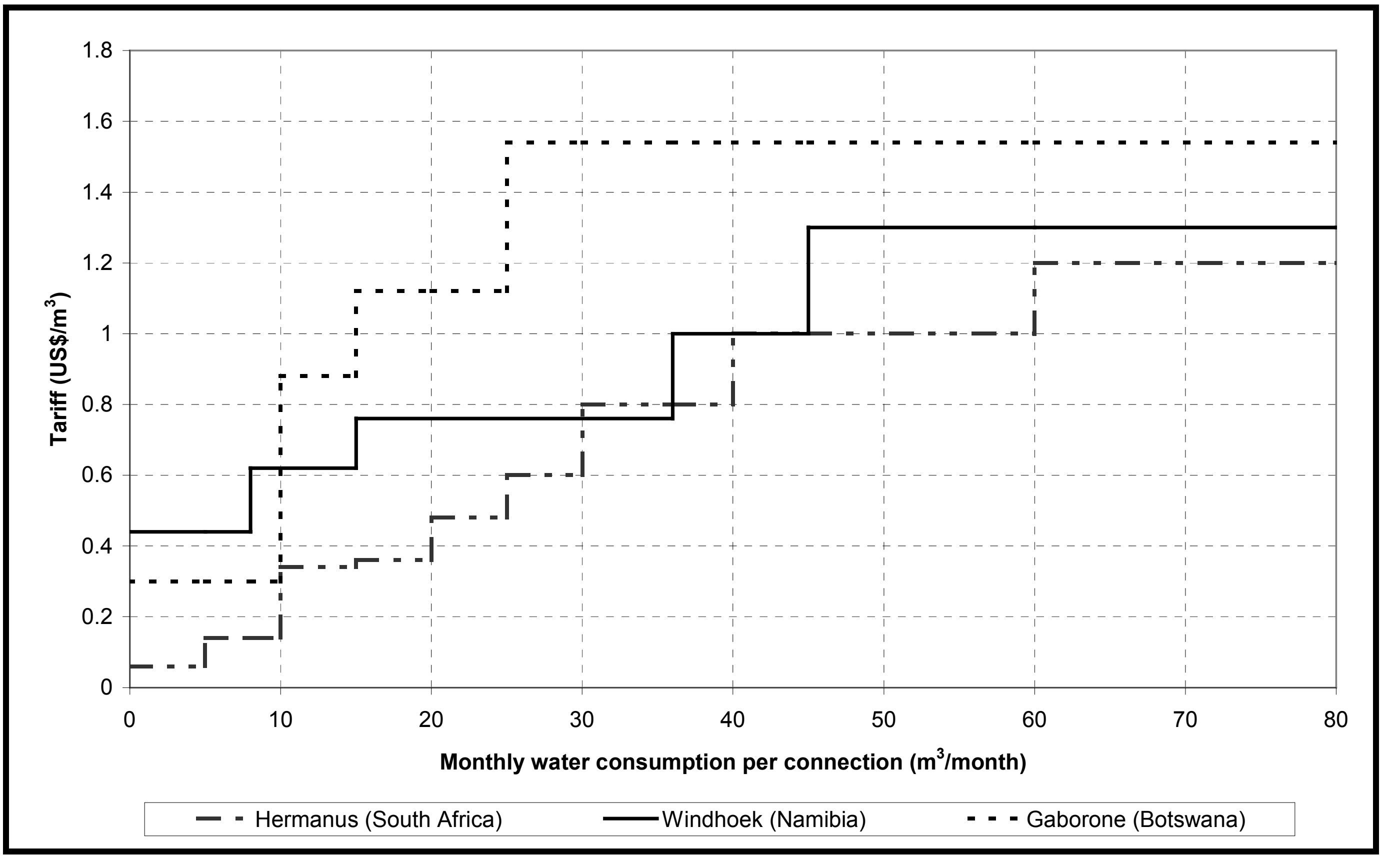
(1) The poorest households have access to a lifeline amount of water and do not spend more than a certain percentage of their income on water.

(2) The ‘ideal’ per capita water consumption level is defined, which will ensure “well-being”. This “well-being” amount is, for example twice the lifeline amount. All water consumed over and above the lifeline amount, but less than the well-being amount, is charged at the Full Cost of Water Supply (FCWS expressed in e.g. US$/m^3); meaning that the average price of water is still less than FCWS, so these households still receive a subsidy.

(3) Those households that use water over and above the well-being amount, but less than a certain upper limit (e.g. four times the lifeline amount) will pay the full cost of water over their entire use. This means that the tariff of the third block should off-set the implicit subsidy that these users receive in the first block;

(4) Water use over and above the amount specified in the third block will be charged at a rate that will off-set the subsidy received by households falling within blocks 1 and 2.

The above functions of the tariff blocks would ensure full cost recovery *and* equity.



Source: Reference 7.9

Figure 7.9 Block tariff structures for Windhoek, Gaborone and Hermanus

Case study of Masvingo's tariff structure

The city of Masvingo in Zimbabwe derives its largest income from the water account, which contributed between 25% to 40% of the council's revenue since 1995. The City Council made, on average, about 80% profit on each cubic metre of water sold during 1999 to 2001. The water account is able to meet the present operation and maintenance needs of the water supply utility.

Since 1999 Masvingo has adopted an increasing block tariff, with the first block covering consumption up to 18 m^3/month per connection and the second anything in excess, in conjunction with a fixed monthly charge. The fixed charge is differentiated between households in affluent neighbourhoods and those in other areas. Owing to the unstable economic climate, since 2001, the tariffs are reviewed every six months. Table 7.20 shows that the tariffs were increased significantly during 2001 and 2002. Table 7.21 shows that low water consumers pay a relatively high price per cubic metre of water. This is due to the relatively high fixed charge, which, for a household consuming only 12 m^3/month, contributes 43% to its water bill. The largest water users, the affluent, pay on average about the same unit water price of water as the non-affluent users.

Table 7.20 Domestic water tariffs for Masvingo 2001 and 2002

Year	Fixed charge		Consumption	
	Poor	Rich	Less than or equal to 18 m^3/month	More than 18 m^3/month
	(Zim$/connection/month)		(Zim$/$m^3$)	
January 2001	80	287.30	8.98	12.82
July 2001	100	359.13	11.23	16.03
January 2002	155	556.45	17.41	24.85
July 2002	186	667.74	20.89	29.80

Source: Reference 7.30

Table 7.21 Average water price at different consumption levels in Masvingo January 2002

Household	Monthly consumption (m^3/connection /month)	Total water bill (Zim$/month)	Average water price (Zim$/$m^3$)	Fixed charge (%)
Less affluent	12	364	30	43
Less affluent	18	468	26	33
Less affluent	30	767	26	20
Affluent	60	1,914	32	29
Affluent	120	3,405	28	16

Note: In January 2002, 1 US$ was equivalent to Zim$ 55 (official rate) and Zim$ 300 (parallel market rate)

Source: Reference 7.30

Income levels of the majority of residents in Masvingo are not high. An oral opinion survey was carried out which found that Zim$3,500/month was the average cash income per household for the low-income bracket (the minimum set by government is Z$ 8,900 per month). Using tariffs applicable from January 2002, and 12 m^3/househehold/month as the average water consumption per household in the poorest neighbourhoods, a household would pay Zim$364 per month, or 10% of their estimated cash income. World Bank studies have recommended that not more than 5% of income should be spent on water for basic requirements. The high-income consumers, however, spend less than 5% of their income on water. Assuming an average income of an affluent household of Zim$60,000 per month, and average water consumption of 60 m^3/month, its monthly water bill would amount to Zim$1,914, or only 3% of household income.

It therefore appears that Masvingo's water tariffs could be improved: the fixed charge must go down since it compromises equity; whereas the tariff of the second block should be increased relative to the first block, since that would give a clear signal to high water users to reduce their consumption. Such a change in the tariff structure is likely to have little effect on water consumption by poor households, since these have a relative inelastic demand for water. However, the tariff change would influence consumption levels of the affluent households, which have a much higher elasticity of demand.

In 2002 a study carried out by the University of Zimbabwe proposed an alternative tariff structure. This structure abolishes the fixed charge and introduces a four-stepped rising block tariff structure that is based on the same principles developed by for the city of Windhoek. The first block considers the lifeline amount (12 m^3/household/month), and its tariff recognises the limited ability to pay by the poor, assuming that the low income bracket may not spend more than 3.5 % of cash income on water. The tariff for the second block, the well being quantity (24 m^3/household/month), is set at the real cost of water supply. The third block has a tariff that meets the full cost of water supply. The tariff of the highest block compensates for the subsidies enjoyed by the lowest two blocks, and caters for the financial requirements of future extensions of the water supply utility that is shown in Table 7.22.

Table 7.22 An alternative tarrif structure for domestic water users for Masvingo January 2002

Block (m^3/connection/month)	Tarrif (Zim$/$m^3$)
0 to 12	10
13 to 24	20
25 to 36	35
>37	55

Source: Reference 7.30

The alternative tariff would result in the following:

- Yields the same revenue as present (including an estimated 50% of income over and above operation and maintenance costs, meant to cover infrastructure development);
- Considers the poor's limited ability to pay in that the water bills of the poorest households would be reduced by over a third.

Such a block tariff structure can assist with water demand management in that as consumption increases the average charge per unit of water also increases.

7.7 Urban water demand case study for the city of Windhoek in Namibia

In 1995 in the city of Windhoek, water demand was 242 litre per day per person in 1995, with unaccounted for water being only 11%. Windhoek adopted an integrated policy on water demand management in 1994, which is financed by a 0.5% levy. Efforts that started in the 1950s have primarily focused on re-use of water. Currently Windhoek can re-use all its wastewater for the watering of parks, sport fields and cemeteries through a two-pipe system and the reclamation of wastewater to a potable standard. Of all domestic water use, 13% is treated for reuse. About 60% of all water used in the more affluent households is for gardens. The infiltration of this water into lawns and gardens makes it unavailable for reuse. Water for gardening still represents a large sector for water savings (Reference 7.9).

An important part of the water demand management programme involves appropriate tariffs. When tariffs are sufficiently high, they tend to keep exterior irrigation demands to within reasonable levels. Water tariffs were recently raised by 30% and any water demand exceeding 45 m^3 per month per household or enterprise was billed at US$ 1.30 per m^3.

Other water demand measures that have been implemented include:

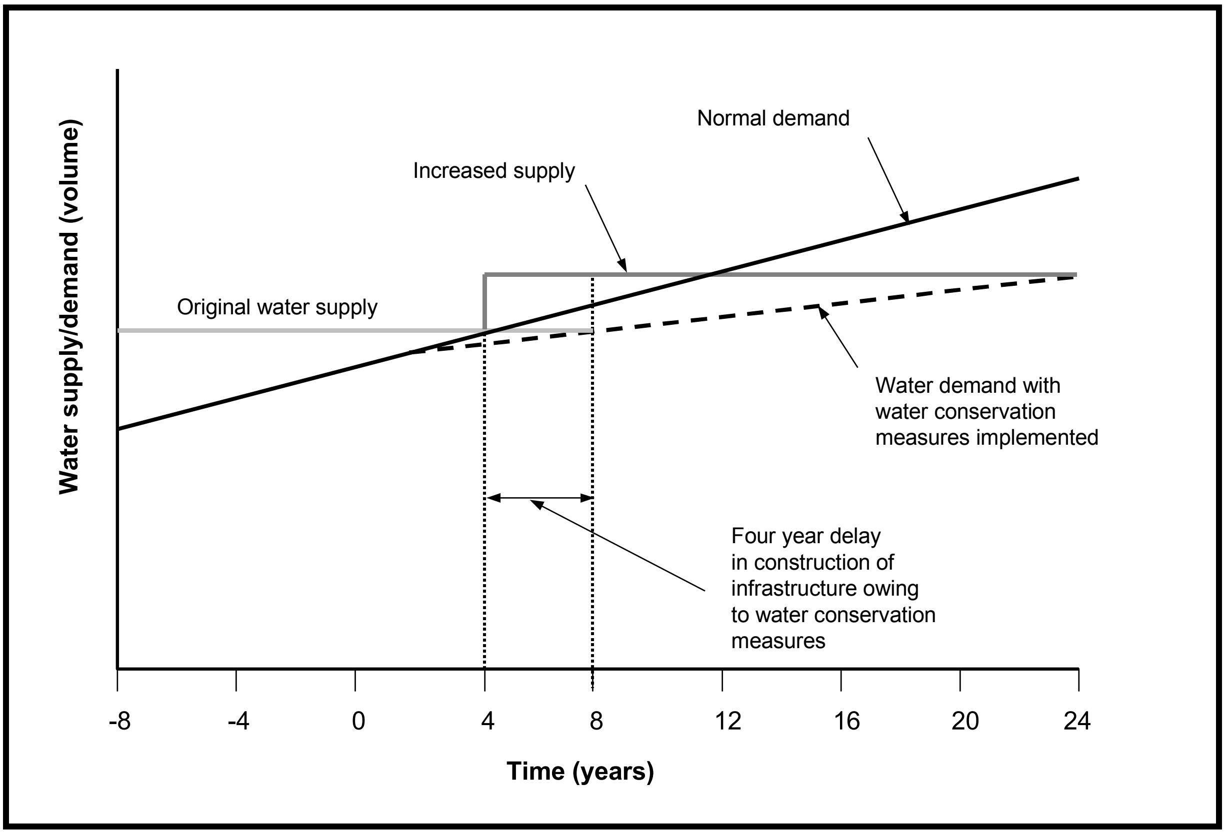
- Public awareness and education;
- A ban on the irrigation of gardens between the hours of 10:00 and 16:00;
- The mandatory use of swimming pool covers;

- Use of low-flush toilets. This has been a mandatory requirement for all new buildings since the beginning of 1997;
- The use of low flow showers (i.e. showers with a flow of less than 10 litres/minute);
- On-site reuse of grey water
- Metering of all connections;
- Reuse of purified effluent for irrigation and reclamation to potable standard;
- Water conservation guidelines for wet industries.

The combined effect of all these measures was a decrease in the per capita water consumption. In 1996 per capita water use decreased from 242 litre per day per person to 196 litres per day. Whereas the residential population grew 5%, total residential water consumption decreased from 10 million m^3/year to 7.8 million m^3/year.

The benefits from water conservation include:

- Long-term water demand reductions of up to 30% can be achieved using the measures adopted by Windhoek. It should be noted that larger, short-term reductions of up to 60% reduction in water demand can be achieved through the implementation of a drought management programme;
- Less waste water has to be treated, and less energy is used;
- The environment will benefit from reduced alteration of flow patterns and from fewer dams and other infrastructure having to be constructed;
- Financial savings from reduced capital as well as operating costs. Figure 7.10 illustrates savings due to delay in construction of "the next dam".



Source: Reference 7.9

Figure 7.10 The effect of water conservation measures on the construction of infrastructure

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8. FORECASTING WATER DEMAND AND USE

8.1 Background

Predicting future water demand and use is increasingly important in sub-catchment and catchment management. It is generally easier to forecast water demand and use for the short-term rather than for the long-term. For short-term forecasts it is possible to make assumptions that some factors will not have changed significantly from the present. However, for long-term forecasts there is a greater degree of uncertainty as to how the water demand and use will change. It is important that uncertainties resulting from a lack of information are explicitly reflected in the demand forecasts. At a catchment level demand forecasting should be carried out for each of the major demand sectors. These are:

- Environment;
- Urban and rural domestic;
- Industry;
- Agriculture.

There is no absolute level of accuracy that is appropriate in all demand forecasting circumstances. As a consequence the level of accuracy of the forecast should be sensitive to its purpose. The cost of improving the demand forecast should be balanced against the additional benefits that are derived from the greater accuracy. The demand forecast method that is used will be dependent upon the purpose of the forecast and the cost of assembling the data. For example a more accurate and costly forecast would be required to justify the construction of a major new piece of infrastructure (e.g. a dam or a large pumping station) than for general internal monitoring purposes of a catchment management agency.

8.2 Influences on water demand and use

There are many influences that affect water demand and water use. Some of the most commonly cited factors relate to:

- Population;
- Level of service;
- Tariff levels;
- Demand management measures and increased efficiency in water use;
- Climatic conditions.

To predict demand accurately all of the above factors should be taken into account. There is a number of forecasting methodologies that can be used. These are discussed in Section 8.5.

8.3 Criteria for assessing forecasting methods

There are numerous methods available to forecast water demand. To assess alternative forecasting methods it is necessary to establish criteria by which the methods can be judged. Suggested criteria are as follows:

- Consistency and transparency of the method;
- Logical/theoretical appeal of the method;
- Method incorporates and explains historical trends;
- The way in which factors that have not been taken into account in the past are treated;
- Empirical validation of the method;

- The acceptance of the method by regulatory bodies and other relevant organisations;
- The cost and feasibility of the method.

These criteria are discussed below.

8.3.1 Consistency and transparency of method

These are basic requirements of any systematic forecasting method. If other organisations cannot understand or reproduce the results there is no way of them assessing the reliability of the method. If the method has not been documented systematically it will be difficult in the future to determine the reason for forecasting errors. Demand forecasts carried out by organisations should be consistent. This aids revision of forecasts that are made in future years. Aspects that contribute to consistency include:

- Geographical consistency. This is required at a number of levels ranging from small areas (e.g. sub-catchment or district, local authority) to a catchment or regional level;
- Population forecasts should be carried out in the same manner at all geographical levels;
- Water demand and consumption figures available should be consistent with previously published data unless anomalies can be explained.

8.3.2 Logical/theoretical appeal

Even if a particular forecasting method has produced good results it is unlikely to inspire confidence among practitioners unless it has a logical appeal to practitioners. Forecasting method without a sound theoretical basis are also unlikely to be acceptable to regulatory bodies.

8.3.3 Incorporates and explains historical trends

Simple extrapolation of historical trends are often likely to be unsatisfactory for a variety of reasons. In some cases what has happened in the past with regards to water demand and use is mostly irrelevant to future forecasts. However, there are lessons that can be learned from historical trends and if a forecasting method is unsuccessful in explaining past trends this casts doubts on its usefulness in predicting future demands.

8.3.4 The treatment of factors not taken into account in the past

There may be several factors that have not been taken into account in past water demand forecasts (e.g. metering, price, regulatory changes, reductions in unaccounted for water, climatic changes). It is important that these influences are incorporated explicitly into demand forecasts.

8.3.5 Empirical validation

This addresses how well the forecasting method has performed in the past i.e. how well has the method predicted actual measured water demand and use.

8.3.6 Acceptance by the regulatory body

This is an important criterion, if a forecasting methodology is not accepted or recognised by the regulatory body it would be unwise to rely on a method that is not widely recognised or accepted.

8.3.7 Cost and feasibility

Some methods may have a strong theoretical basis and have performed well in the past. However, the demands of the method on resources may make it impractical to implement. These demands may take the form of unrealistic demands on data (e.g. with respect to quality, availability or financial cost) or excessive demands on the skills and time required to operate and maintain the method.

8.4 Choice of forecasting method

The are no simple rules that can be used to establish which water demand forecasting method should be used and the scale of the resources that should be invested in demand forecasting. In deciding which method to use in predicting future water demands, a balance needs to be made between:

- The level of accuracy of the forecast required;
- The cost of obtaining the required level of accuracy;
- The benefits accrued from having a higher level of accuracy.

The advantages of producing as accurate forecasts as possible are as follows:

- Reduces the mis-allocation of resources and allows investment decisions to be delayed;
- Enables the effects of water resources policies to be examined with confidence;
- Identifies areas and sectors to be targeted for conservation programmes.

There are some principles that can be applied. These are as follows:

- The accuracy of the forecast should be in relation to the cost of the errors that may result from an inaccurate forecast e.g. such as construction of a large piece of infrastructure that is not needed because demand has been overestimated;
- The forecast of a demand component that represents a small proportion of the total demand can be relatively inaccurate without causing too much concern. For example if unmetered households only made up 5% of the total urban domestic demand of a city a forecast of this component that was in error by 50% would not cause a major inaccuracy in the overall forecast of urban domestic water demand.
- The most important water demand sectors and sectors and components should receive the most attention. This does not mean that the sector or component with the largest water demand should have the most resources allocated to it.

The question often arises of whether to use a simple or sophisticated forecasting technique. This is often viewed as a trade off between cost and accuracy.

The methods used for long-term water demand forecasts (i.e. forecasts with a horizon of more than ten years) are often unsuitable for forecasts over shorter periods of time (i.e. for the next two years). In the short term demand is likely to be influenced by the weather or the precise timing of the economic cycle. Often data available for the explanatory variables required by a long-term forecasting model are not available at the necessary level of frequency making the model difficult to apply. Checklists for determining and applying forecasting methods are given below.

8.4.1 Checklist for determining the forecasting method

Before deciding which forecasting method to implement, the following questions should be considered:

- What was the previous forecast and are the results available?
- What are the previous forecasts errors and why did they occur?
- What is the objective of the new forecasts? (e.g. long term or short term planning, sub-catchment or catchment level);
- What data are available and over what period and at what level of detail? (e.g. water demand data, data on population growth, demand management measures to be implemented);
- What are the possible forecasting methods available?
- Which of these are feasible given the various constraints on data, budget and skills available to implement the method?
- Is the method used previously still satisfactory for the purpose? (e.g. is a sophisticated method still preferable to a simpler method);
- Do additional data need to be collected in the future?

8.4.2 Checklist for applying the chosen forecasting method

Once the forecasting method to be used has been decided upon the following issues need to be considered:

- What specification is to be used?
- How well would the forecasting method have performed in the recent past? (e.g. can any large discrepancies be understood);
- What assumptions need to be made for the forecast? (e.g. implementation of water demand management measures, changes in tariff structures);
- Is there any information available to help form the assumptions? (e.g. are details of future tariff levels available, are demand management measures to be implemented);
- Is the last year a “normal” year to predict from? (e.g. were water demand figures affected by water rationing brought about by a drought);
- Are the forecasts plausible? (i.e. how do the forecast changes in demand compare with the historical changes in demand).

8.5 Incorporating uncertainty into forecasts

Uncertainty is an integral part of water demand and use forecasting. All forecasting methods for water demand and use are subject to uncertainty. It would be desirable to be able to present a forecast with statistically based confidence limits around it. However, in practice most forecasting methods do not yield purely objective confidence limits, and in some cases the data are inadequate to permit statistical analysis to yield precise estimates. Uncertainty is therefore better considered through the construction of a various scenarios. Incorporating scenario modelling into forecasts allows the sensitivity of long-term forecasts to various factors can be established. For example water demand and use forecasts are often carried out based on high, medium and low population growth rates or a variety of demand levels, or levels of reduction of unaccounted for water. A typical sensitivity analysis is shown in Figure 8.1.

There can be expected to be different degrees of uncertainty surrounding different components of the demand. For example when forecasting urban domestic demand it is likely that uncertainty over unmeasured household demand would be high. This is due to the limited information about the impact of charges and prices on the demand.

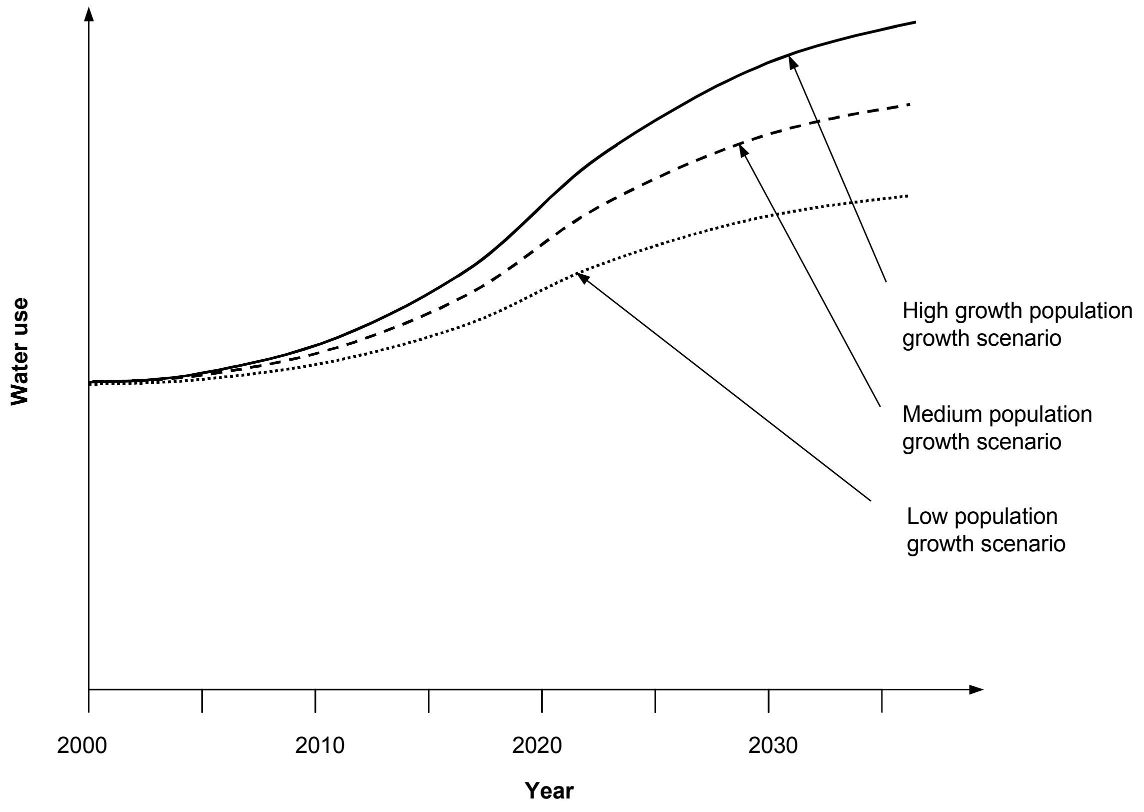


Figure 8.1 Forecasting water use for three population growth scenarios

8.6 Details of forecasting methods

There are a number of forecasting methods that are commonly used to predict future water demands and use. These include:

- Judgemental forecasts;
- Extrapolation of historical data;
- Forecasts based on population growth and per capita consumption;
- Trend analysis;
- Component analysis;
- Multiple linear regression analysis;
- Multiple non-linear regression analysis.

These are discussed below.

8.6.1 Judgmental forecasts

Judgmental forecasts are based on personal or group knowledge. They may be purely subjective or merely an adjustment of a more formal forecast. Judgmental forecasts have a number of disadvantages in that they are subject to a number of biases that may add to or filter existing knowledge and thus effect the overall forecast. These biases can be classified as follows:

- **Professional biases** – the profession of a person may influence their judgement e.g. professionals who are used to supply oriented solutions may produce forecasts greatly in excess of professionals who look at demand management issues. Different professions may also use different methods and data;
- **Spatial and project biases** – The forecasts may be based on areas that have common factors (e.g. accessibility) and these areas may not be representative;
- **Person biases** – The stakeholders interviewed and assessed to determine demand forecasts may in some cases overestimate their needs to ensure supplies under extreme conditions;
- **Seasonal and climatic biases** – Judgements may have been made during untypical dry or wet periods.

Although judgmental methods may prove useful in conjunction with other methods it is not recommended that such techniques are used solely for demand forecasting of future water use.

8.6.2 Extrapolation of historical data and trend analysis

A wide range of methodologies is used for forecasting water demand and use at a national, regional and local level. Extrapolative techniques have been used frequently in the past but there is a need to improve forecasts in line with more comprehensive planning approaches and changing priorities (such as demand management techniques). Extrapolative techniques suffer from a number of major drawbacks including:

- Very different predictions can be gained from trends which fit past data equally well;
- The methods assume past trends will continue into the longer-term future;
- Any errors that occur in the forecast do not provide a sound basis for future learning. This is because the errors occur owing to changes in trends;
- Extrapolation techniques tend to use aggregate demands rather than components of demand.

Forecasts based on a trend analysis use time as the independent variable and utilise mathematically fitted functions to historical water demand and use to forecast future demands and use. The function used to fit the data depends on the user and can have a significant effect on future predictions. The method has the following advantages:

- It is relatively cheap to implement and takes account of past uses;
- It is generally not very demanding in terms of the data that is required
- It can be related to separate water demand and use sectors if the information is available.

The method has the following disadvantages:

- It assumes the historical water use and demand is representative of future water demand and use;
- It can produce inaccurate results because the forecast is dependent on the fitting function;
- The method cannot account for the effects of a reduction in unaccounted for water.

An example of a forecast using trend analysis is given below.

Example of forecasts using trend analysis

The Mupfure sub-catchment in Zimbabwe has 20 years of recorded and reliable water use figures for the catchment. Three different curves have been fitted to the available historical water use data to forecast the future water use in the Mupfure catchment in Zimbabwe. Three methods have been used to forecast future demand. These are:

- Exponential fit;
- Second degree polynomial fit;
- Linear regression.

The results of the analysis are shown in Figure 8.2.

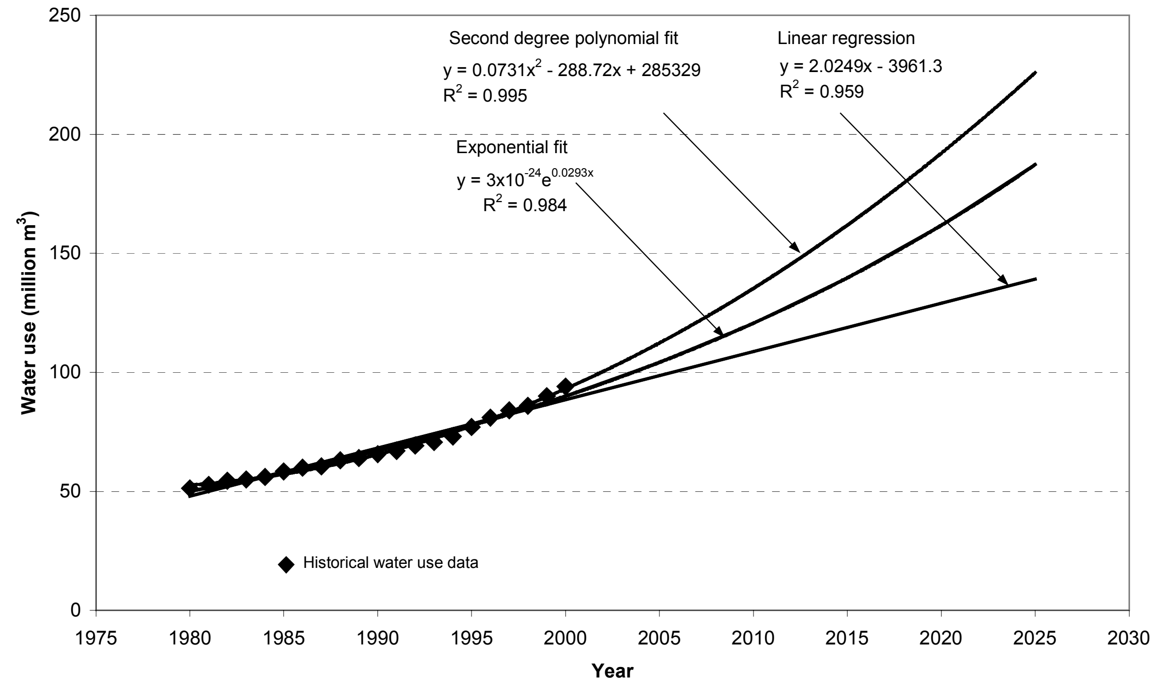


Figure 8.2 Results of trend analyses using different fitting techniques

Figure 8.2 illustrates that even though each of the fitting techniques chosen to forecast future water use has a high correlation coefficient (R^2) the choice of technique can have a significant effect on the estimate of the future water use in the year 2025.

Another example of some of the problems that can occur with the extrapolation of historical data is shown in Figure 8.3. Figure 8.3 shows the total water produced to supply the city of Masvingo in Zimbabwe. Between 1991 and 1992 there was a serious drought in Zimbabwe that had a significant impact on water demand for most urban areas. If a forecast of future water demand had been made in 1991 by fitting an exponential curve to the available data between 1977 and 1991 the forecast water demand for the year 2001 would have been almost 10 million m^3/year. However, in 1992 a series of demand management, economic and water rationing measures lead to in the rate of growth of water demand decreasing significantly. In 2001 the actual quantity of water produced for the city of Masvingo was some

6.8 million m^3/year. The figure forecast for 2001 using a simple exponential curve fitting technique for the recorded data between 1977 and 2001 is over 47% higher than the figure actually recorded. This clearly illustrates the dangers of using simple curve fitting techniques to forecast future water demand.

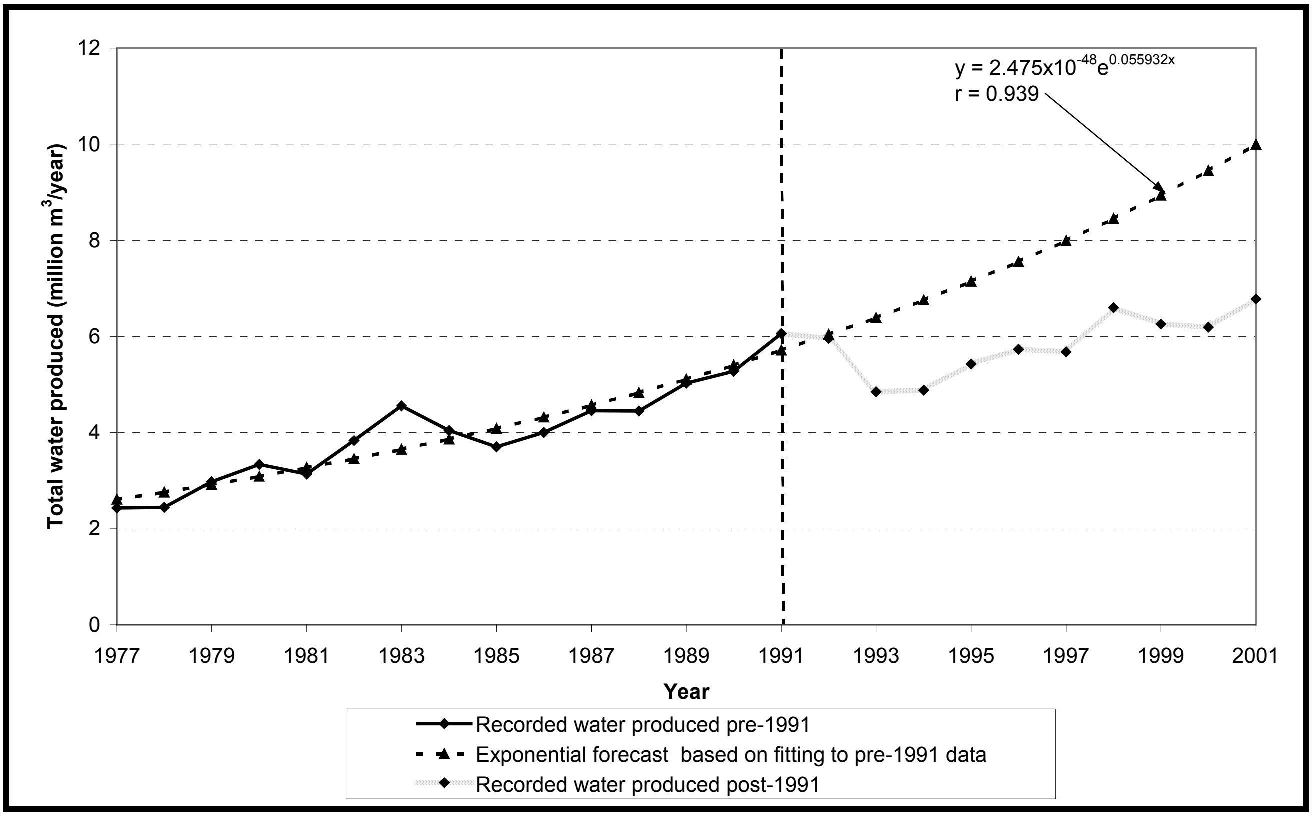


Figure 8.3 The dangers of using extrapolation techniques for forecasting water demand for Masvingo in Zimbabwe

8.6.3 Forecasts based on population growth rate

The estimated demand is derived from projected population growth figures multiplied by an estimated per capita water use or demand. The per capita figure may be derived either directly where water use is divided by the population (normally for a year in which a census has been undertaken) or from international estimates for average water use, minimum standards or from selective surveys.

The method has the following advantages:

- It is relatively inexpensive to carry out;
- It requires a limited amount of data.

The method has the following weaknesses:

- The accuracy can be poor for long term forecasts;
- In the light of the AIDS/HIV pandemic in southern Africa long term predictions of future population growth are hard to make accurately;
- The method does not take into account variation in water use between sectors or even within sectors.
- Past trends of total water demand are projected into the future;

- Estimates of population and per capita consumption are made for future dates without reference to past trends in water consumption;

This latter technique is the most commonly used because it does not require a large quantity of data. There are three main disadvantages with this technique. These are:

- It assumes that the factors influencing demand in the past will remain the same in the future;
- It makes no attempt to understand why water consumption fluctuates over time;
- It relies on data about past water demand that may be poor or non-existent and which may well under-estimate the actual water requirements of the population.

Data to carry out the forecast can be acquired as follows:

- **Primary data sources.** Water usage is based on amounts delivered by public supply and licensing authorities for private abstractions. Population data is taken from national or regional census.
- **Secondary data sources.** Water use data is taken from records of municipal authorities of water delivered, or from surveys or direct measurement. Population data is taken from local estimates.
- **Derived data.** Data can be derived from restricted surveys to obtain per capita demand or use. Population figures can be extrapolated using statistical methods. Water usage may also be estimated from levels of service.

An example of a forecast based on population growth rates is given below.

Example of a forecast based on the population growth rate

The population of the Mazowe catchment in Zimbabwe was estimated to be 1,671,000 in 1999. The per capita water use was estimated to be 140 litres per head per day. The population growth rate has been estimated to currently be 3.2% reducing to 2.5% from the year 2015. An estimate of the annual water use per year up to the year 2025 is required.
In 1999 annual water use = 140 x 365 x 1,671,000 = 85.4 million m^3
The water use is calculations are tabulated below.

Year	**Water use (million m^3)**
1999	85.4
2005	$85.4(1+0.032)^6 = 103.2$
2010	$85.4(1+0.032)^{11} = 120.8$
2015	$85.4(1+0.032)^{16} = 141.4$
2020	$141.4(1+0.025)^5 = 159.9$
2025	$141.4(1+0.025)^{10} = 181.0$

A graph of the above forecast is shown in Figure 8.4

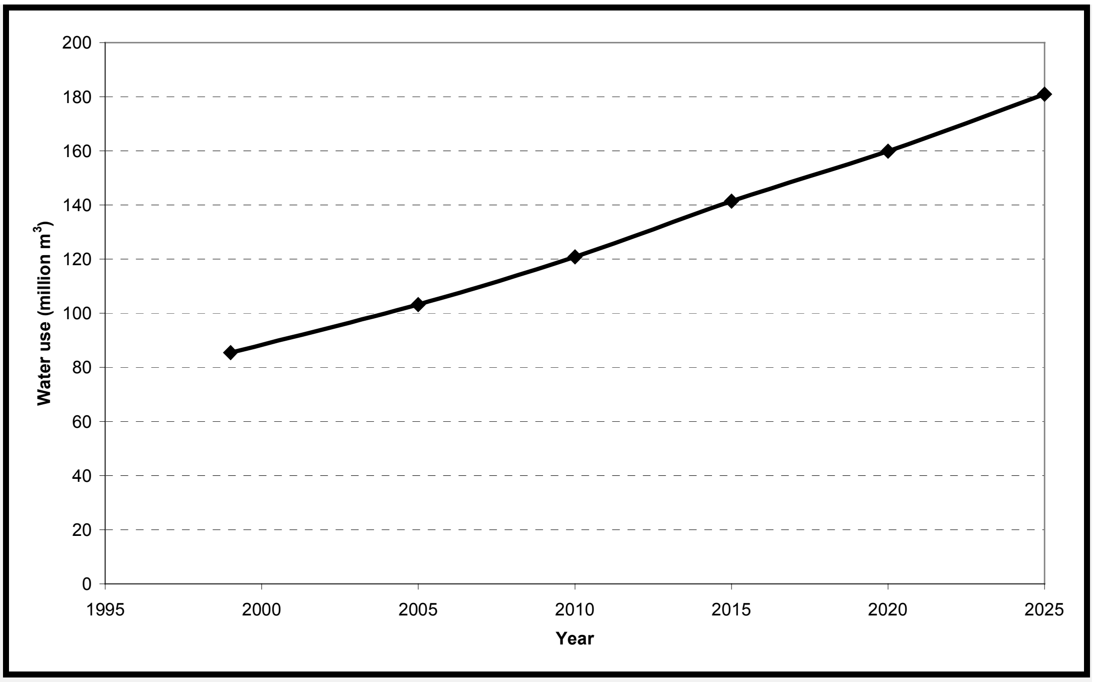


Figure 8.4 Water use forecast based on population growth

8.6.3 Forecasts based on component analysis

The component analysis technique allows estimates of water use to be based upon an individual component, e.g. household appliances, industrial machinery, crop and the extent of usage or production of that individual component.

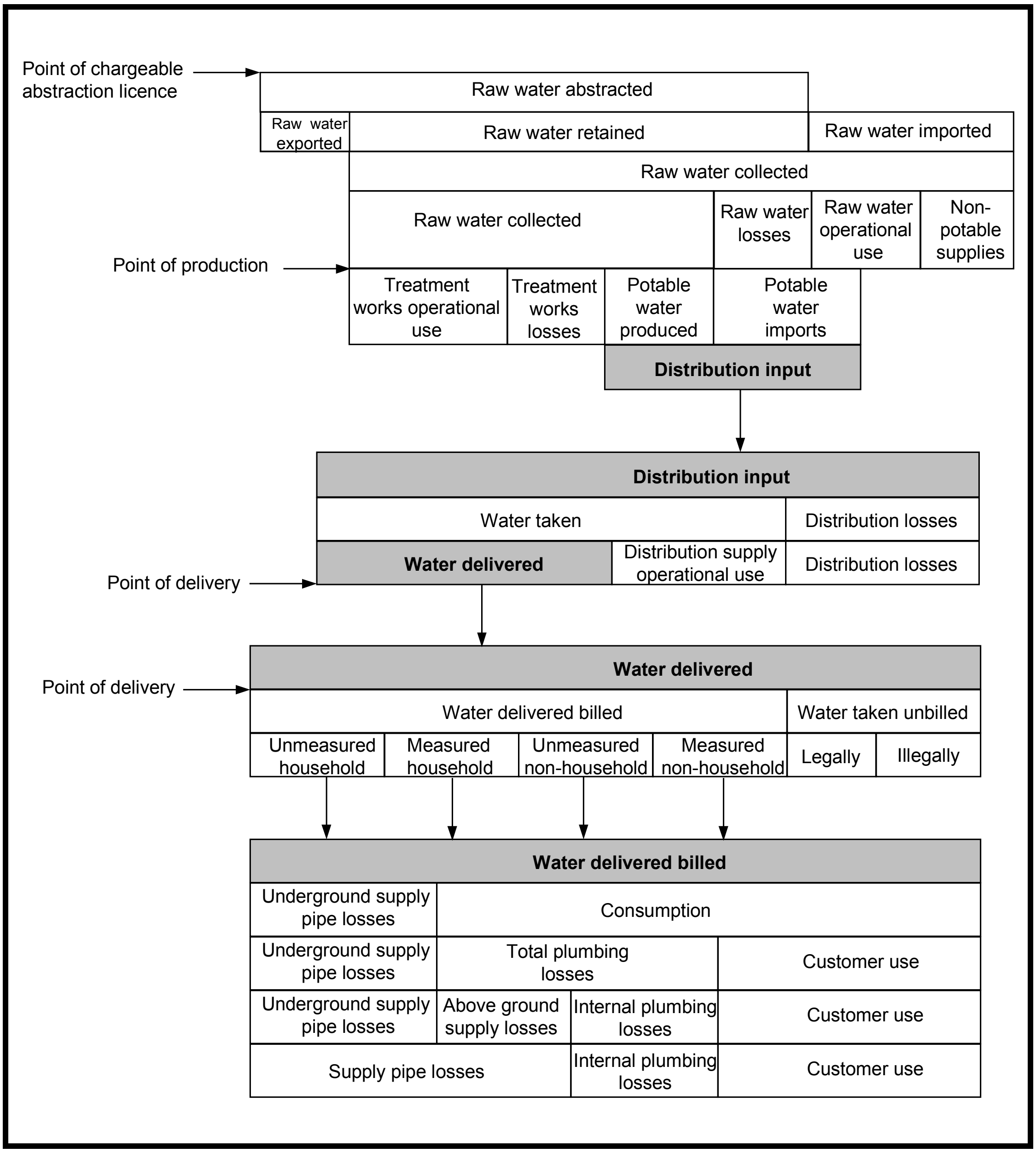
The component method of water use forecasting has the following advantages:

- It can be useful in determining the effect of changing uses and production technologies on overall water use;
- It can be used to identify key areas of use, predict areas of use which may increase or decrease and how these may effect the total water use.

The component method of water use forecasting has the following disadvantages:

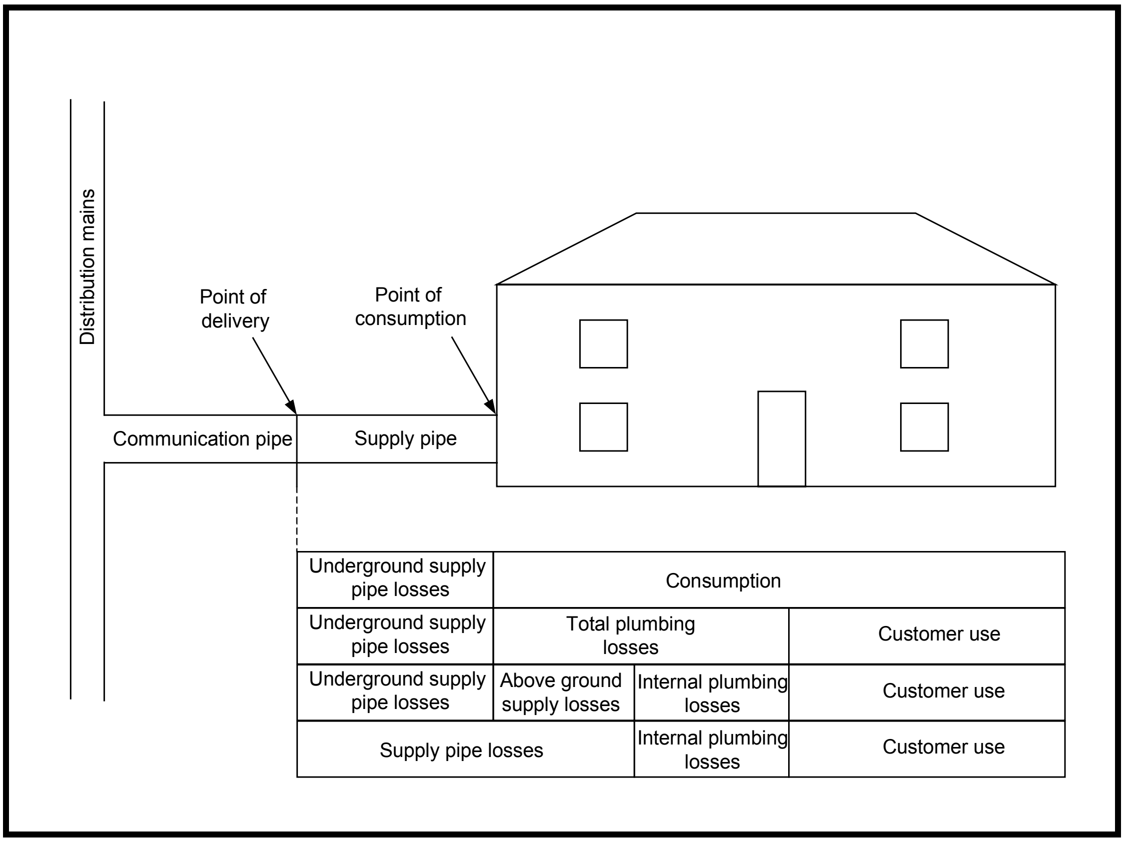
- It requires a large amount of data;
- The analysis required is detailed;
- Representative surveys to collect the relevant information needed to carry out the analysis can be costly;
- The method may not produce reliable results.

Component methods attempt to relate the water demand and use to demand determinants. Component methods are more complex and rely on greater data and information needs. However, if improved demand forecasts are required, these techniques are likely to be of greater value to the users. Water demands and use are disaggregated into major components e.g. the water demand of an individual component, be it household appliance or crop, is estimated or measured. Examples of the components of an urban water supply are shown in Figures 8.5 and 8.6.



Source: Reference 8.6

Figure 8.5 Components of an urban water supply system



Source: Reference 8.6

Figure 8.6 Household level components

Future changes in each component are predicted separately and then aggregated. For water demand and use forecasting carried out at a sub-catchment and catchment level, the following should be taken into account:

- Population levels and growth;
- Socio-economic factors;
- Changes in unaccounted for water;
- Policy decisions affecting water resources management.

The first two components in the list are relatively easy to incorporate as data is usually available. The population component tends to be based on information about demographic characteristics such as age, sex, fertility rates, death and birth rates and migration. The socio-economic situation component includes information on personal incomes, employment and industrial production. Components such as changes in unaccounted for water and policies affecting water resources management such as water pricing, metering, subsidies and water quality standards, are harder to forecast, although they will have a significant impact on water demand.

This technique requires more input and therefore cannot be implemented unless the requisite data is available. Where data is available on other uses of water that are likely to affect future demand, then they too should be incorporated into the forecast.

8.6.4 Multiple linear and non-linear regression analysis

Multiple linear or non-linear regression analysis can be used to relate water use to the various parameters such as Gross Domestic Product (GDP), tariff levels or population levels. The main disadvantage of this method is that it is time consuming to set up multi-variable relationships and it requires large data sets to produce a reliable relationship. It is not recommended that such techniques are used at a catchment or sub-catchment level to forecast water use.

8.7 Forecasting agricultural water demand and use

Agricultural water demands are primarily a function of the following:

- Meteorological conditions;
- Crop type;
- Cropped area for each type of crop;
- Type of irrigation method and irrigation efficiencies;
- Water charges.

In assessing future agricultural demands the changes in one or more of the above must be predicted. Owing to the potential for changes in the future and the relatively few variables, component analysis is the forecasting methodology likely to yield the best results. Component analysis is a forecasting method based upon the usage of water by an individual component. The expected trends in each of the components (e.g. changes in irrigation technology, climatic changes, crop type and irrigation area) should be analysed separately and the overall result assessed.

Meteorological conditions are changing due to the effects of global warming. For agriculture, the main considerations are rainfall and evaporation rates. As rainfall decreases and/or evaporation rates increase, the irrigation needs are increased. Changes in crop type can have a significant impact on water demands, which may or may not be positive. High value crops such as garden vegetables generally have higher water requirements than, for example, grain crops. Changes in cropped area can be a change in total area, as new land is developed or existing land taken out of production, or it can be a result of changes in crop type, as the area of one type is changed to accommodate changes in another type. Losses and inefficiencies usually account for a significant proportion of total irrigation requirements. Their impact can be improved through various means and the analyst will have to determine the likelihood and magnitude of improvement programmes.

Instituting water user associations can also affect water demand and use. The main purpose behind water user associations is to improve water security and equity in access to water. Hence, while the water user association is beneficial in many ways, its formation may increase water demands. Water charges have a significant impact on water demands because of the incentive to reduce waste in water application, though consideration must be given to willingness to pay and ability to pay on the part of the water users.

Changes in irrigation technology can also affect water demand. Modern technologies that deliver water to the plant more efficiently reduce overall demand through reducing field losses and non-beneficial evapotranspiration. Improvements in field level water management and irrigation system operation also reduce irrigation water use through improving efficiency and reducing losses. Other means of managing agricultural water use is practising new techniques in application of water through precision irrigation and deficit irrigation, though the ability of farmers to adopt such techniques must be assessed. Figure 8.5 shows how switching from sprinkler irrigation to drip irrigation can reduce losses (i.e. increase irrigation efficiency) and have a significant effect on agricultural water demand forecasting.

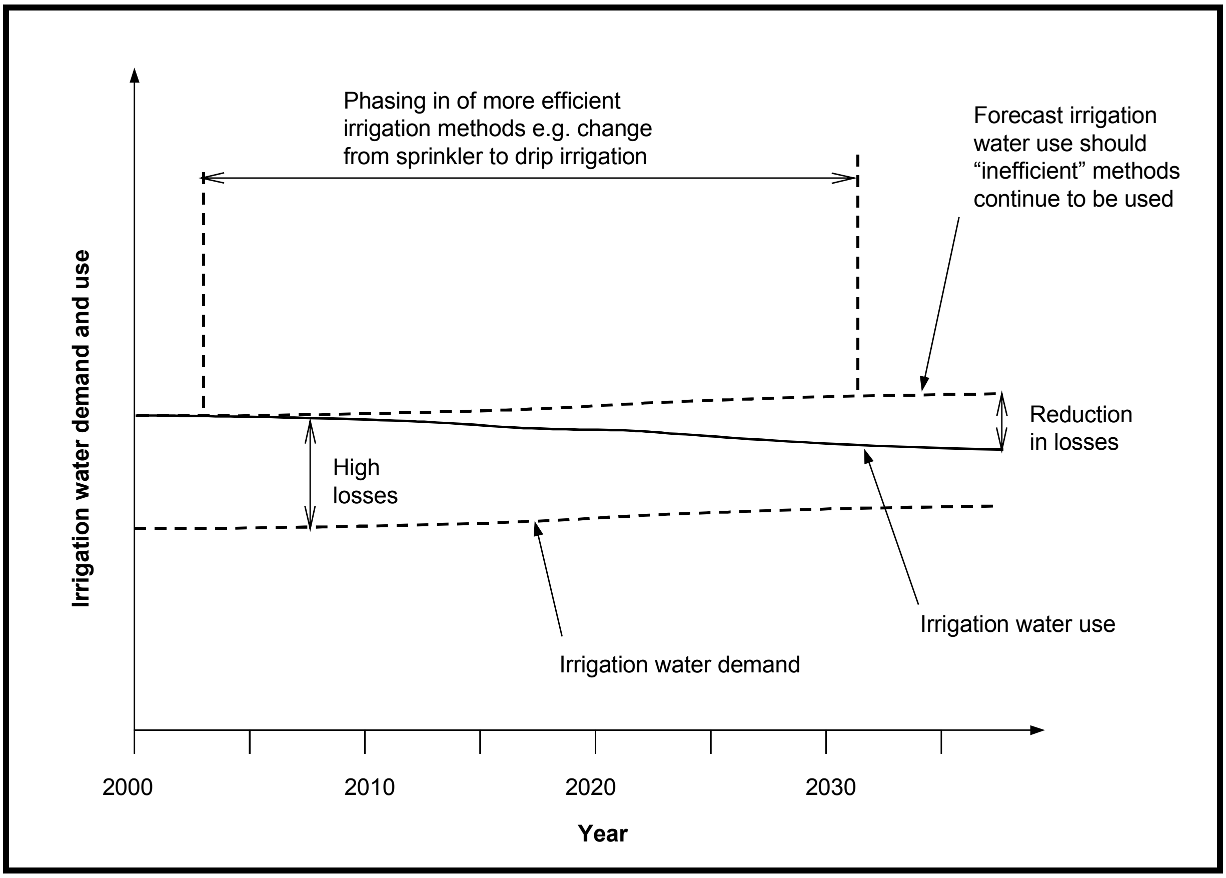


Figure 8.7 The effect of a change in irrigation technique on water demand and use

Change in population is critical in the local sense and in the national sense. Nationally, a change in population affects the nation's food needs. The impact of rural-to-urban migration, a feature in most countries in the last few decades, also changes food needs and also changes the labour force available for agriculture, which affects water use. Changing economic conditions, especially increasing affluence also has an effect on what crops are grown and consumed.

8.8 Demand forecasting for rural domestic water supply

Historical information for rural domestic water demand and use are often not available. This means that it is often not possible to assess future rural domestic water demand and use through trend analysis. The two most important factors that affect future rural domestic water demand and use are:

- Population growth;
- Change in the level of service owing to upgrading of the water supply system.

Population growth can be estimated from national, regional or local trends. It should however be noted that improvements to infrastructure, such as water supply systems, could increase the population growth above the average. Upgrading of water supply schemes and the consequential changes in the level of service are difficult to predict. It has been postulated that the upgrading of rural water supply schemes is related to:

- Economic conditions such as the Gross Geographic Product (GGP) the regional equivalent of the Gross National Product (GNP);
- Tariff levels.

For simplicity, catchment managers and water resources planners will have to make assumptions concerning upgrading (e.g. from a communal borehole to a yard connection to a house connection). The increase in water demand may be estimated from other areas where similar upgrading of the water and sanitation infrastructure has occurred. There are significant discrepancies in the literature on rural water supply schemes as to what water demand level can be expected from different levels of service. An example of rural water demand forecasting is given below.

Example of rural water demand forecasting

The village of Manoti in Zimbabwe has a total of 500 settlements. These have the following levels of service:

- 350 settlements are supplied by community boreholes within 100 m of the properties. These have a water demand of 30 litres per person per day;
- 100 settlements are supplied by yard connections and have a water demand of 70 litres per person per day;
- 50 settlements are supplied by a household connection and have a water demand of 130 litres per person per day.

The household occupancy rate is estimated to be six people per settlement. The water demand over the next ten years is required. Demographic studies have indicated that the number of settlements reliant on community boreholes will decrease by 1% a year over the next decade, with the number of settlements using yard connections and supplied by household connections will increase by 15% and 11% respectively over the next decade. The calculations and water demand projections are shown below. The forecast is shown in Figure 8.8.

Year	**Growth rate for different settlements**			**Water demand (Ml/day)**
	Number supplied by boreholes (-1% growth p.a.)	**Number supplied by yard connections (+15% growth p.a.)**	**Number supplied by household connection (+11% growth p.a.)**	
2000	350	100	50	24.00
2001	347	115	56	25.74
2002	343	132	62	27.59
2003	340	152	68	29.68
2004	336	175	76	32.21
2005	333	201	84	34.98
2006	330	231	94	38.29
2007	326	266	104	41.92
2008	323	306	115	46.06
2009	320	352	128	50.88
2010	317	405	142	56.32

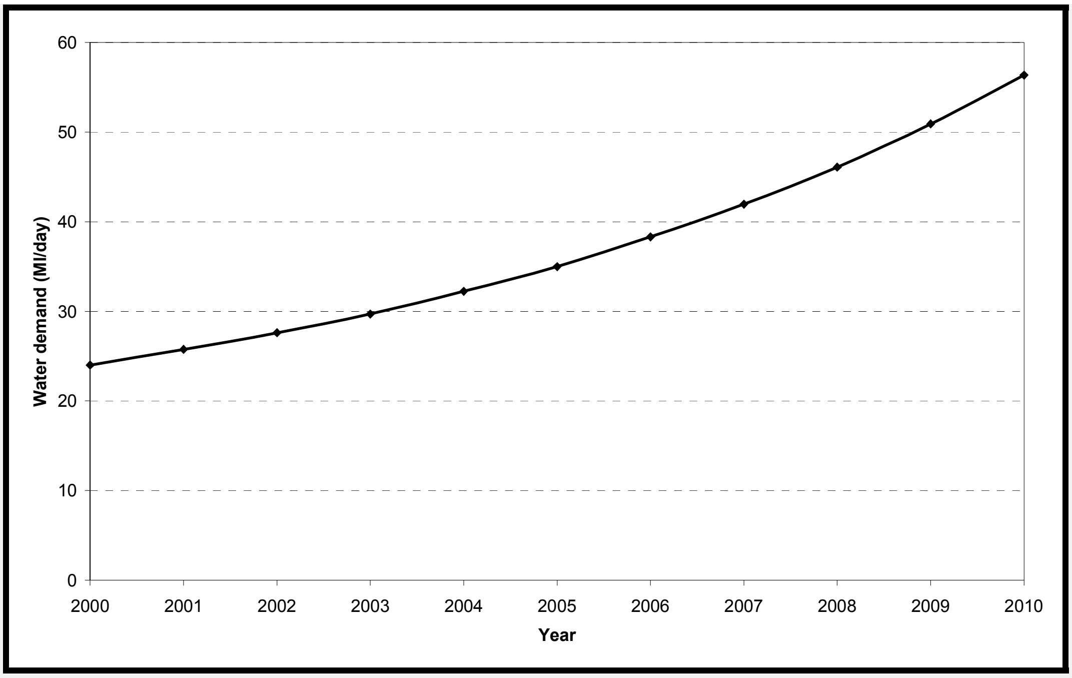


Figure 8.8 Example of a rural domestic demand forecast

8.9 Forecasting industrial water demand and use

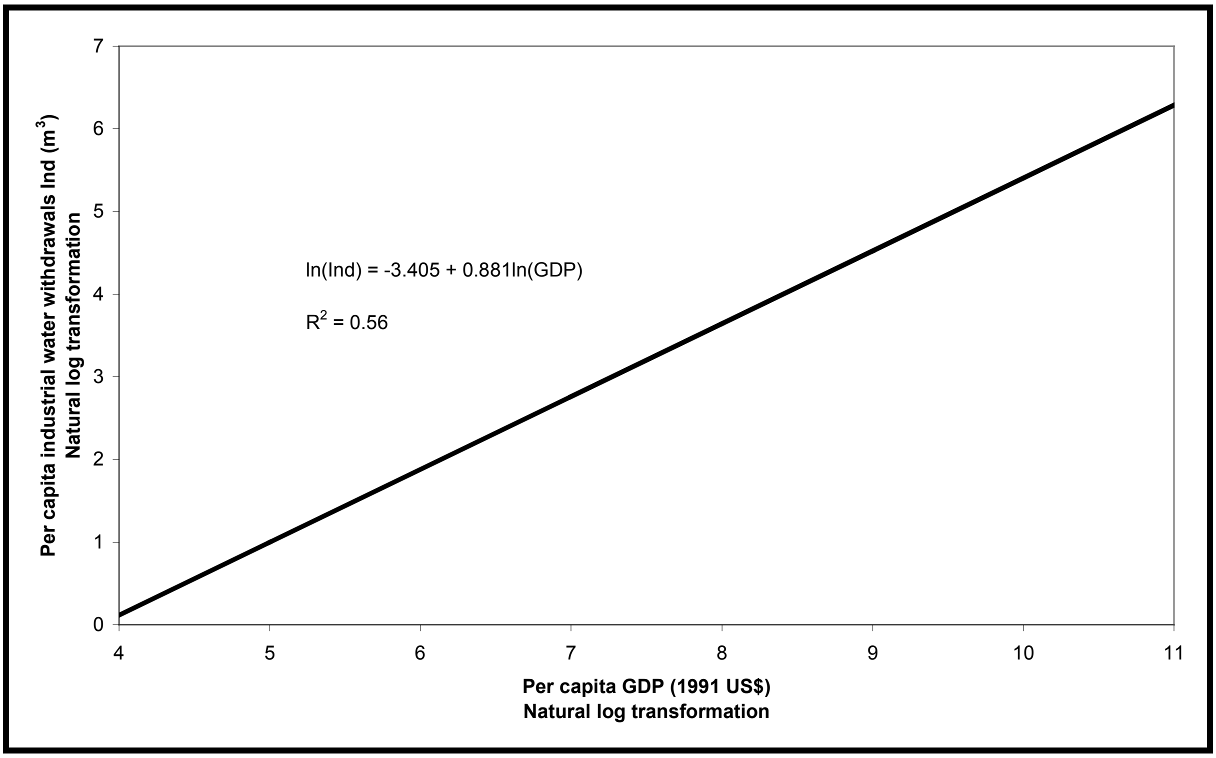
The simplest approach to forecasting industrial water demand and use is to carry out a trend analysis as follows:

- Establish the relationship between industrial production and water use for various sectors;
- Assess the trends in industrial production;
- Project trends in industrial production into the future to establish the future water use.

Where industries are metered the relationship between water use and productivity should be relatively simple to establish. However, the above approach will be more difficult for non-metered industries. For non-metered industries a well-planned programme of surveys and spot measurements will provide enough data to achieve an assessment to a reasonable level of accuracy.

Gross Domestic Product (GDP) has become a common variable used in demand forecasting models. Past studies in a number of countries have shown that there is a reasonable correlation between GDP and industrial water use. However, no account is taken of the changing nature of industrial production and the effect on water demand and use. For example, in many industrialised countries production has moved away from manufacturing and towards the commercial service sector and this provides different patterns of water use. Technological improvements in industrial production can also lead to significant water savings. For example, in Israel, industrial production increased by 250% whilst water consumption rose by only 30% owing to regulation and licensing encouraging the use of water saving and re-use technologies.

A study carried out by the International Water Management Institute in 1998 produced a relationship between per capita water withdrawals and GDP in the year 2025 for countries with a per capita industrial water demand of 10 m^3 or above in 1990. This relationship, shown in Figure 8.9, was based on GDP estimates for various countries provided by the International Food Policy Unit and forecast industrial water withdrawals in 2025. It should be noted that the correlation coefficient of 0.56 is relatively low indicating that there was a relatively high degree of scatter in the data.



Source: Reference 8.1

Figure 8.9 Example of a relationship between GDP and industrial water demand

Component analysis is also applicable to the industrial sector because each industry uses water differently. A component analysis looks at the use of water by an individual component e.g. type of industrial machinery or application of water saving technology, and the extent of usage or production of that individual component. Additional usage outside of the aggregated components (depending on the coverage of the components) can be assigned to miscellaneous uses and system losses. The relationship between the component and water use is established using such tools as linear regression analysis. However, to use such a method to forecast industrial water demand and use on a catchment or even sub-catchment basis would be costly and time consuming.

8.9.1 Checklist of data for forecasting industrial water use

Before a forecast of industrial water demand and use is made the following checklist should be consulted:

- For which industries are data currently available?
- Are there groups of industries with similar intensities of water use?
- Which are the major water using industries?
- Are there industrial sectors where past water use is not expected to provide a good guide to future levels of water use?
- What is the present and likely future quality and reliability of the water supply?
- What are the current and likely future costs of the disposal and treatment of wastewater?
- What water demand management measures are likely to be implemented in the future?

8.10 Forecasting urban water demand

There are a number of factors that affect urban water demand and that should be taken into account when forecasting urban water demand and use. These include:

- Demographic factors (e.g. population growth, migration, urbanisation)
- Socio-economic factors (e.g. standard of housing and living , employment opportunities);
- Climate;
- Type of sanitation;
- Extent of distribution leakage which is dependent upon the age of and pressure of the system;
- Consumer wastage;
- Ratio of institutional and business demand and use to domestic consumption
- Availability of non-piped supplies;
- Tariff levels.

The main factors in estimating water use will be urban population growth and the level of unaccounted for water. In many urban areas in Africa unaccounted for water levels can be as high as 50%. Demand management measures including leakage reduction programmes and other water conservation measures can often significantly reduce the level of unaccounted for water. In some European countries unaccounted for water levels are of the order of 10%. In any demand forecasting that is carried out for urban areas it is important that estimates are made concerning the reduction in unaccounted for water levels in the future. Figure 8.10 shows an example of urban water demand and use forecasting. The forecasting method has taken into account that the level of unaccounted for water will drop significantly over the next 35 years.

There are several methods available to forecast unmeasured household consumption. These include:

- Micro-component analysis;
- Use of a constant annual per capita demand;
- Changes in consumption owing to assumed changes in household size.

Micro-component analysis involves forecasting the future demand for water by assessing the future trends in the underlying elements of water use. It requires forecasts of the following:

- Water appliance ownership (e.g. washing machines, showers, baths);
- Frequency of the use of the various water appliances;
- The volume of water that is used each time the appliance is used;

The accuracy of a micro-component analysis is dependent on the quality of the baseline data. This method requires large quantities of data and is relatively expensive to implement even for a small sample size.

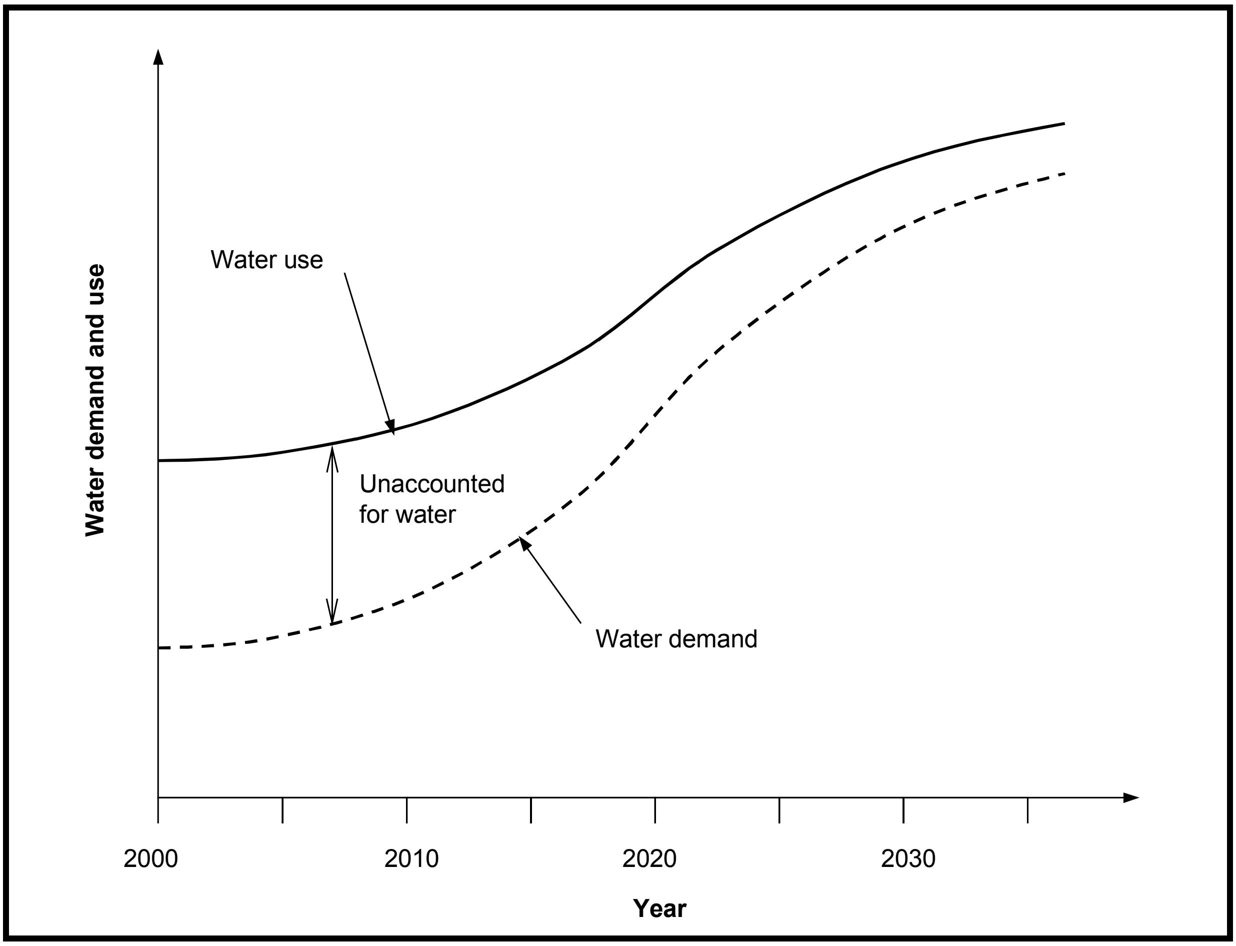


Figure 8.10 Forecasting urban water demand

8.11 The effect of the HIV/AIDS virus on future water demand in southern Africa

The spread of the HIV/AIDS virus in southern Africa has increased the difficulty in accurately projecting possible population numbers over a long time frame. Population projections that extend beyond a five to seven year time frame contain increasingly larger inaccuracies and hence should be treated with caution. This is largely due to uncertainties around probable behavioural changes in response to the anticipated massive number of deaths that can be expected as the AIDS pandemic proceeds. Population projections are also affected by uncertainties around the numbers of new immigrants that arrive in urban areas each year, either from rural areas or from neighbouring countries. Therefore, due caution must be exercised when population projections are made for periods beyond the next five years. In addition, it is essential to remember that the limited availability of accurate, widespread surveillance in southern Africa suggests that any estimates made are likely to underestimate the true prevalence of HIV/AIDS.

Predictions of mortality rates owing to HIV/AIDS are based almost exclusively on the realisation that no effective cure for HIV has yet been discovered. Currently it is believed that every person recorded as HIV-positive appears certain to die within a period of between seven to ten years from the date of first infection, unless antiretroviral therapy is administered to halt the progression of the disease. In children, the situation is far worse and life expectancy can drop to as low as two years for babies. Informed medical opinion considers that the prevalence of HIV/AIDS appears to reach a plateau at between 32% and 35%, when approximately 1 in every 3 individuals is infected. Prevalence survey data demonstrate that somewhat fewer men than women are infected with HIV/AIDS (Reference 8.2).

Given the range of uncertainty around predictions of the possible numbers of people infected with HIV/AIDS and the resultant mortalities, it is clear that estimates of population numbers will also likely be inaccurate. Together, these uncertainties will reduce the accuracy and reliability of future water demand estimates for specific geographical areas and countries.

If water demand estimates do not take HIV/AIDS-related mortality into account, demands for water could be over-estimated by between 10% and 30%. This would pose several possible unanticipated consequences for the construction and operation of large-scale water supply schemes. In particular, if anticipated number of deaths from HIV/AIDS do reach the very high levels suggested above, this would delay the demand for water by between 10 and 20 years. In addition, if this scenario were to hold true, construction of large water supply schemes within current planning time frames would result in unnecessary expenditure of capital. The converse situation is also important: if mortality rates are over-estimated, the growth in water demand profiles of an area or country will not be anticipated correctly. Given the relatively long lead-in times for water supply projects, a population would face undue hardship if adequate water supplies cannot be provided in time (Reference 8.2).

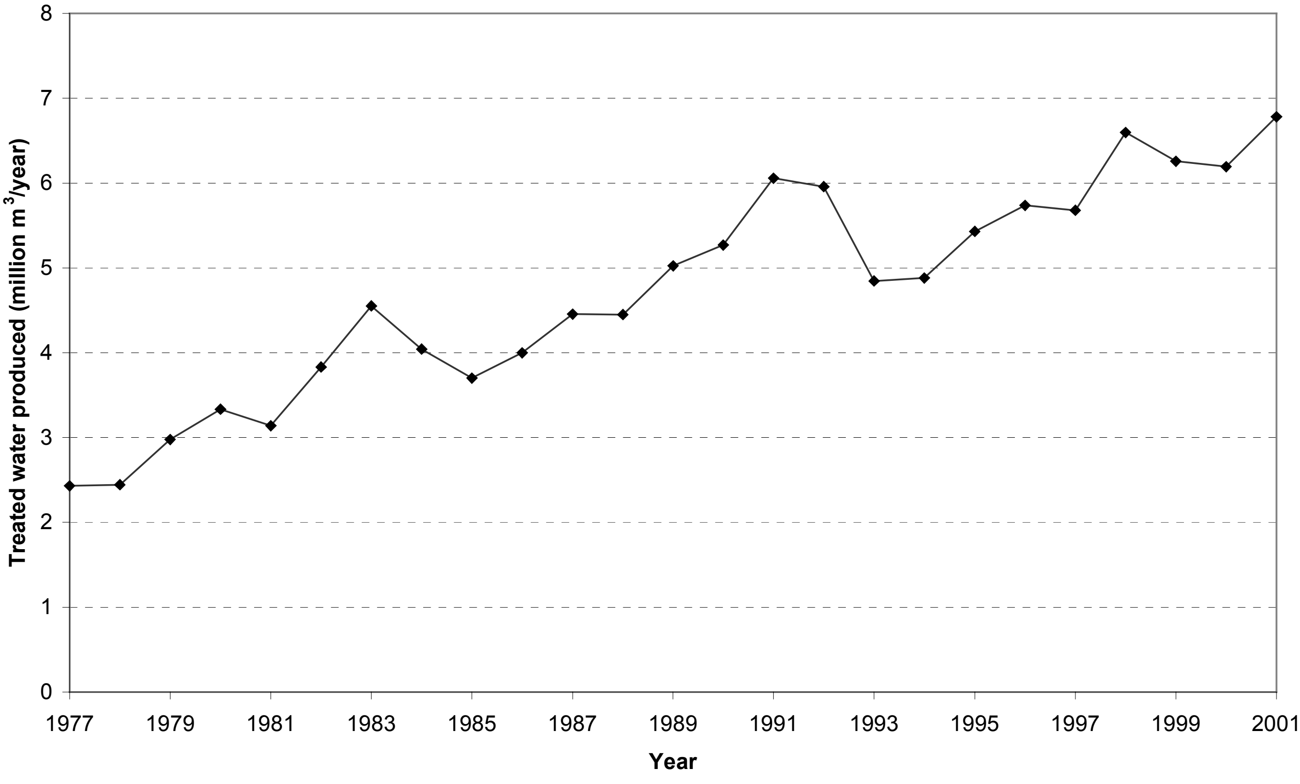
8.12 Case study for demand forecasting for city of Masvingo in Zimbabwe

8.12.1 Background

In 2002 the University of Zimbabwe carried out a case study of water demand for the city of Masvingo in Zimbabwe (Reference 8.3). This section details the findings of the study.

The city of Masvingo is located approximately 300 km south of Zimbabwe’s capital Harare and has an estimated population of around 70,000. Between 1977 and 2001 water use in Masvingo increased from 2.4 million m^3 per year to 6.8 million m^3 per year. Lake Mutiriki, which has a storage capacity of some 1,400 million m^3 acts as a reliable source of water for Masvingo. However, the main purpose of Lake Mutiriki is to support several thousand of hectares of irrigated sugar cane. The water treatment works in Masvingo has a capacity of 24,000 m^3/day. In the hotter months of September and October this is insufficient to meet demand that can reach 28,000 m^3/day (Reference 8.3).

Figure 8.11 shows the treated water production for Masvingo between 1977 and 2001. There has been a general increase in water production. However, the effects of droughts in 1983/84 and 1991/92 on water consumption can clearly be seen. During droughts demand for water is suppressed through rationing measures, decreased economic activity and public awareness campaigns. Studies carried out between 1999 and 2001 indicate that unaccounted for water is around 15% (Reference 8.3).



Source: Reference 8.3

Figure 8.11 Treated water production for the city of Masvingo 1977 to 2001

In order to model past and to forecast future water consumption for Masvingo a multiple linear regression model was developed. This is discussed below.

8.12.2 Use of a multiple linear regression equation to forecast demand

A multiple linear regression analysis was carried out correlating water consumption for Masvingo with the following factors:

- Population based on annual data;
- Rainfall based on annual rainfall data;
- Economic development based on figures for Gross Domestic Product;
- Rationing. This was represented using a dummy factor with a "memory" of five years. This factor is 1.0 for a drought year and decreases by a factor of 0.2 for each year subsequent to a drought.

The multiple linear regression equation yield an equation of the form:

$$Q = 1{,}496 + 90.2N - 1.5P + 26.8GDP - 837R$$

$$R^2 = 0.965$$

Where:

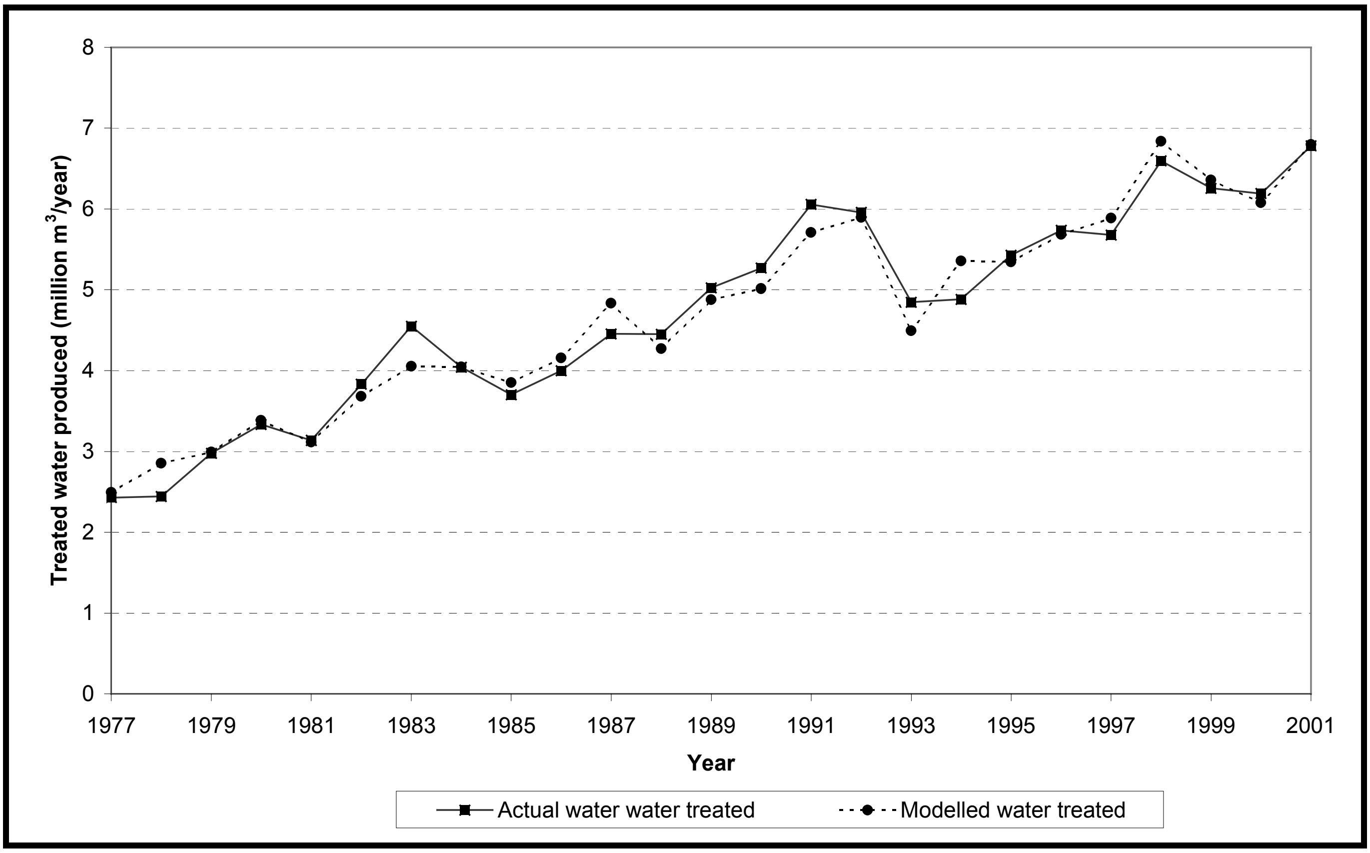
Q is the annual quantity of water treated in 1000 m^3/year;
N is the population of Masvingo in thousands;

P is the annual precipitation in mm/year;
GDP is the annual change in Gross Domestic Product in percent;
R is the rationing factor with a "memory" of five years starting a value of 1.0 and decreasing by 0.2 in each year subsequent to a drought.

The formula implies the following:

- The constant 1,496 represents water uses that are more or less fixed and independent of population, rainfall, GDP and rationing in 1000 m^3/year. These uses include water losses (950 x 10^3 m^3/year, see above), to some extent institutional water uses, and to a lesser extent industrial and commercial uses.
- The constant 90.2 is in m^3/person/annum and is equivalent to 247 l/person/day. This represents the "crude" per capita water consumption, and includes some industrial and commercial uses. Population alone explains 88% of total water supply.
- The constant 1.5 is in 1000 m^3/mm means that if rainfall is 100 mm above the average of 600 mm/year, water consumption decreases by 150,000 m^3/year, if rainfall is 100 mm below average, consumption increases with the same amount. Including rainfall improves the correlation with 5%.
- The constant 26.8 is in 1000 m^3/year and implies that change in GDP has relatively little effect on water consumption: a 1% increase in GDP leads to an increase in water consumption of 27,000 m^3/year. Including this factor increases the correlation by only 0.4%.
- The constant 837 is in 1000 m^3/year. This figure indicates that rationing has a significant impact on water consumption. In a drought consumption drops by 837,000 m^3/year. If this factor is included the correlation is improved by 3%, yielding a total correlation of 96.5%.

A comparison between the multiple regression equation and the actual observed data is shown in Figure 8.12.



Source: Reference 8.3

Figure 8.12 Actual and modelled water use for Masvingo 1977 to 2001

The projections in future water demand were made assuming that the factors that influenced past water consumption, as given in the multiple linear regression, will remain dominant in the future. The following assumptions were also made:

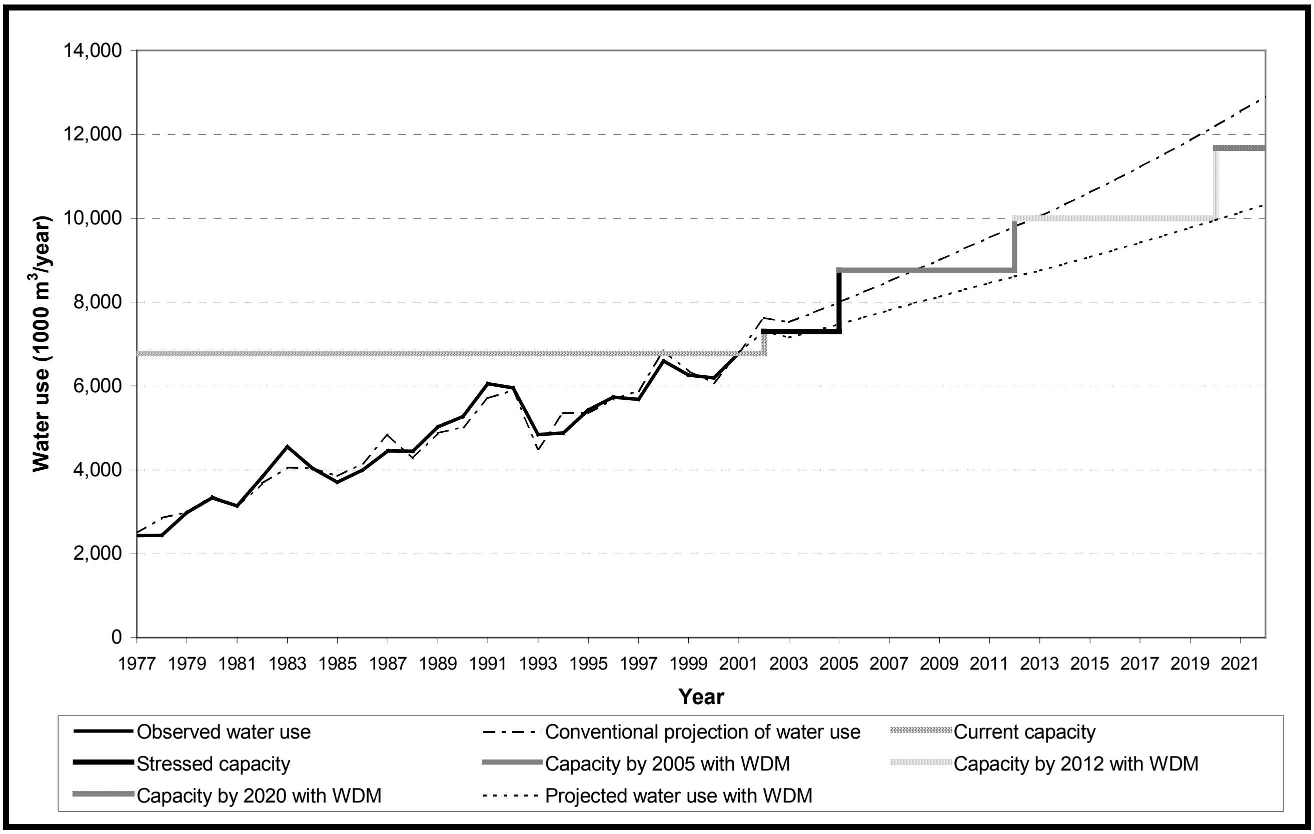
- The gross domestic product will be positive;
- Normal rainfall will occur and there will be no water rationing as a result;
- The population growth of 3% per year over the past four years will continue.

Table 8.1 below provides details of the unrestricted demand forecasts. The predicted water use is shown in Figure 8.13.

Table 8.1 Forecast of unrestricted water production for Masvingo using a multiple linear regression

Year	Population (thousands)	Annual rainfall (mm)	Annual change in GDP (%)	Forecast unrestricted water demand (million m^3/year)
2001	71	676	-4	6.8
2002	74	356	-1	7.6
2003	76	600	1	7.5
2004	79	600	2	7.8
2005	81	600	3	8.0
2006	83	600	4	8.2
2007	86	600	5	8.5
2008	89	600	6	8.8
2009	91	600	6	9.0
2010	94	600	7	9.3
2011	97	600	7	9.5
2012	100	600	7	9.8

Source: Reference 8.3



Source: Reference 8.3

Figure 8.13 Predicted water use for Masvingo up to 2021

8.12.3 The effect of water demand management measures on future water demand

The multiple linear regression equation was used to estimate unrestricted water demand. However, per capita water use in Masvingo is high especially in the more affluent parts of the city. After forecasting the unrestricted water demand a forecast was carried out assuming that demand management measures were implemented. The demand management measures that were considered were:

- Reduction of water losses;
- Changes in the tariff structure;
- Retrofitting of water saving devices.

(i) Reduction of water losses

Unaccounted water for the city of Masvingo is about 15% equivalent to 2,600 m^3/day. Some of the losses are caused by the high static pressure (in many places between 80 m and 90 m) that leads to a high number of pipe bursts. Reducing the pressure to between 30 m and 60 m could lead to a reduction in water losses of some 7% equivalent to 180 m^3/day. There is also leakage of some 100 m^3/day on one of the major reservoirs on the system (Reference 8.3).

Currently there are no passive leakage surveys being carried out in Masvingo. The introduction of leakage surveys and quick responses to leaks coupled with a public awareness campaign to encourage members of the public to report leaks could lead to a saving of 600 m^3/day.

(ii) Changes in the tariff structure

There are currently 1,200 households in Masvingo that can be classified as affluent. These are households with relatively large disposable incomes, large gardens and some times swimming pools. The average water use of these households is 78 m^3/month compared with non-affluent households that consume around 20 m^3/month. A change in the tariff structure could result in reduction in water use of 480 m^3/day. The proposed tariff structure would comprise a rising block tariff. The effect of the new tariff on water consumption would have to be carefully monitored to quantify the saving derived from this measure (Reference 8.3).

(iii) Retrofitting of water saving devices

The retrofitting of devices such as low volume toilets and shower heads have been shown to reduce overall domestic water use. The expected savings that can accrue from these measures have been shown to be at least 25% of domestic consumption. For Masvingo if this were to be effectively applied to cover 50% of all the households there would be a water saving of 1,540 m^3/day. An immediate and cheap measure that can be implemented is to reduce the cistern capacity of toilets. The flushing of toilets has been estimated to constitute 30% of total domestic water use. Adjusting floats in existing installations, or simply putting a standard brick in the cistern would reduce its capacity by at least 10%. This means that each household would save 3% of its consumption equivalent to 370 m^3/day for the whole of Masvingo (Reference 8.3).

8.12.4 Potential and short-term reduction of water demand for Masvingo

Table 8.2 shows the potential short and long term reductions in water demand for Masvingo.

Table 8.2 Potential long and short term reductions in water demand for Masvingo

Water demand management measure	Long term reduction of water demand (m^3/day)	Short term reduction of water demand (m^3/day)
Reducing losses		
Pressure reduction	180	180
Repair of reservoir	100	100
Passive leakage control	600	300
Reducing demand		
Block tariff structure	480	240
Retrofitting	1,540	370
Total reduction	2,900	1,190
Current water use	18,600	18,600
Percentage reduction of demand	15.6%	6.4%

Source: Reference 8.3

The decrease in water demand of 1,190 m^3/day or 0.44 million m^3/year can be achieved in the short term. This reduction in demand is equivalent to the expected growth in water use during a period of two years. This would provide a window to implement the next supply option. In the longer term with sustained campaigns coupled with political and technical support, the reduction in demand may reach 1.0 million m^3/year or 15.6% of current water use. Table 8.3 provides details of the forecast water production with demand management measures in place.

Table 8.3 Forecast water production with demand management measures in place

Year	Unrestricted forecast water production (million m^3/year)			Water demand management measures		Forecast water production with demand management measures in place (million m^3/year)
	Domestic	Industrial	Losses	Domestic demand reduction factor	Reduction factor for losses	
2001	4.76	1.22	0.82	1.00	1.00	6.8
2002	5.34	1.37	0.91	0.95	0.95	7.3
2003	5.26	1.35	0.90	0.94	0.94	7.1
2004	5.43	1.40	0.93	0.93	0.93	7.31
2005	5.56	1.44	0.96	0.92	0.92	7.5
2006	5.77	1.48	0.99	0.91	0.91	7.6
2007	5.95	1.53	1.02	0.90	0.90	7.8
2008	6.13	1.58	1.05	0.89	0.89	7.9
2009	6.30	1.62	1.08	0.88	0.88	8.12
2010	6.49	1.67	1.11	0.87	0.87	8.3
2011	6.67	1.72	1.14	0.86	0.86	8.4
2012	6.86	1.76	1.18	0.85	0.85	8.59

Source: Reference 8.3

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9. RIVER TRANSMISSION LOSSES

9.1 Background

In many parts of southern Africa there is considerable temporal and spatial variation in the rainfall patterns. In general river flows show even more variation than rainfall. To make the optimum use of these limited and varying water resources river flows are often regulated, often via reservoirs, not only between seasons but also often over periods of more than one year.

There are numerous storage reservoirs in southern Africa that are used to store and control water resources. Ideally these reservoirs are located close to the point of use. However, in many cases this is not possible owing to physical and economic reasons. Water often has to be conveyed over long distances. To avoid the costs of pumping and constructing pipelines or canals, water is often transmitted via natural watercourses. Although this method of conveyance avoids constructing expensive infrastructure it can result in significant losses particularly in sandy rivers that do not have a perennial flow. This chapter details the nature of river transmission losses and methods that can be used to estimate them. The information in this chapter is based on work carried out in 1998 by D. Kammer of the Department for Water Development in Zimbabwe (Reference 9.1).

9.2 Nature of river transmission losses

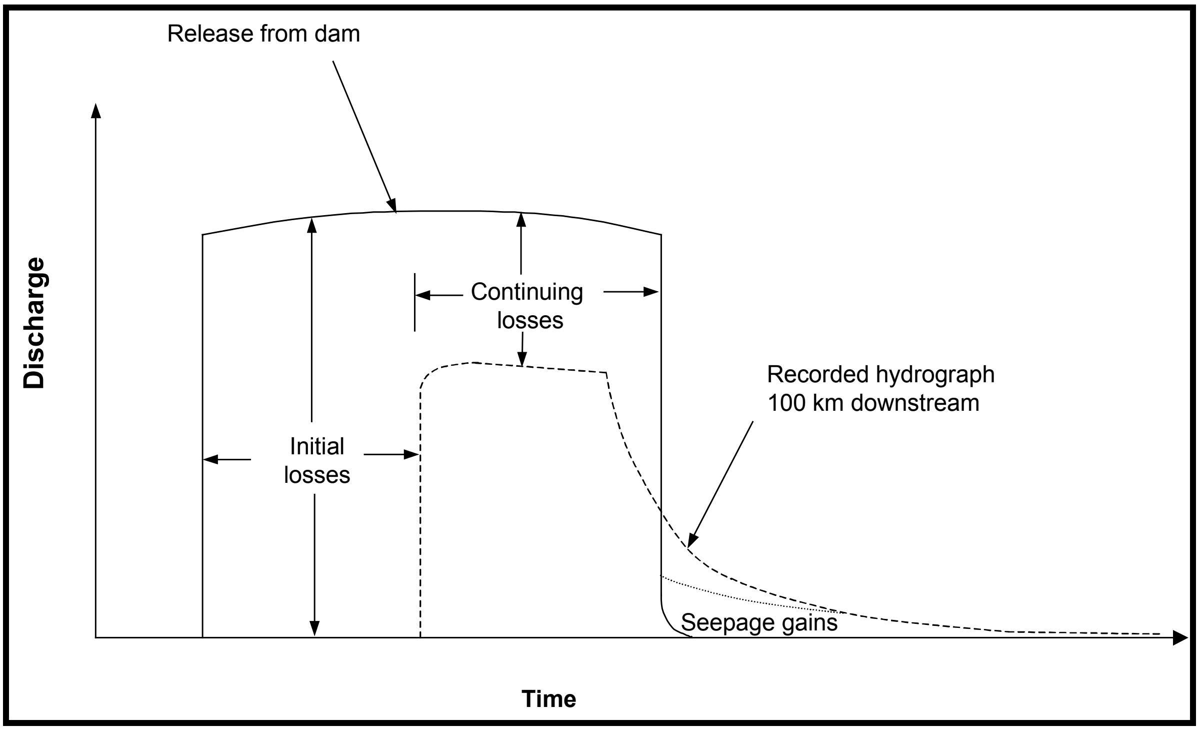
When allocating water at a catchment level and carrying out catchment management plans it is important that these losses are taken into account. The losses in rivers can be categorised as follows:

- Natural losses. These are:
    - Evaporation and transpiration;
    - Bed and bank storage seepage;
- Artificial losses e.g. abstractions for domestic, industrial and agricultural uses.

This section concentrates on natural losses that occur from artificial releases from dams. Losses caused by evaporation from open water surfaces and by transpiration from riverine vegetation are often relatively small. The majority of transmission losses consist of two components:

• Initial losses	These are losses that occur at the front end of the release wave and that are used to fill up pools and saturate the river bed.
• Continuing losses	These losses occur after the initial wetting of the bed has taken place and a steady flow has been established. They are caused by evaporation and bed and bank seepage.

The river losses are to some extent offset by influent “seepage gains”. These gains are the results of water stored in the river banks seeping back into the stream after the release wave has passed and the channel storage has been depleted. These losses are illustrated in Figure 9.1.



Source: Reference 9.1

Figure 9.1 Illustration of transmission losses

The main parameters that affect these losses are:

- The discharge rate of release;
- The physical nature of the river channel (e.g. gradient, bed material);
- The degree of saturation of the river bed and banks;
- The duration and total volume of the release.

The loss process is complex and it is difficult to quantify the effects that differences in the physical and release conditions have on the loss process. This is because they can influence each other in a positive or negative way depending on the conditions. It is therefore necessary to assess the effects on a case by case basis.

9.3 Example of transmission losses from southern Africa

9.3.1 Zimbabwe

In 1998 research was carried out into transmission losses on 13 rivers in Zimbabwe which are used to convey water released from dams. The rivers that were investigated were grouped into three broad categories (Reference 9.1). These are:

Category 1	Relatively steep rivers with gradients varying in the range of 1 in 150 to 1 in 400. The bed of such rivers consists mainly of rock and varies in total width from 30 m to 300 m. Rivers in this category often contain small pools created by rock, sandbars or small weirs. The riverine vegetation and individual stream channels within the main bed are limited.
Category 2	These are less steep with gradients in the range 1 in 500 to 1 in 800. They often range in width between 100 m to 800 m and contain more sand beds

and vegetation than Category 1 rivers. Pools are common and are often connected by relatively narrow stream channels.

Category 3 These are usually very flat rivers with gradients shallower than 1 in 900. They are often wide, (up to 1000 m) and have extensive, deep sand beds. Large pools occur and vegetation can be abundant in wide braided rivers.

The other important factor that affects losses is the degree of saturation of the river bed and the degree to which a natural flow is present. The degree of saturation is hard to quantify and is subjective. In Zimbabwe a broad classification was devised to help categorise how wet or dry a river is. This classification is as follows:

- "Very wet" The bed of the river was totally saturated, pools are full and there is a substantial base flow (at least 5% of the release rate).
- "Partly wet or dry" There is relatively little base flow, the bed is only partly saturated and the pools are partly dry.
- "Very dry" There is no base flow and the pools and bed are dry.

Tables 9.1 to 9.4 provide generic data gathered from 13 rivers in Zimbabwe on the initial losses, continuing losses, the velocity of release waves, provisional guidance for seepage gains. It should be noted that the rates in the tables often overlap. This is the result of that the tables accommodate a wide range of results

Table 9.1 Guideline rates for "initial losses" from rivers in Zimbabwe ($x10^3$ m^3/km or Megalitres/km)

Degree of saturation	Release rates in m^3/s					
	< 1	1 to 3	3 to 5	5 to 7	7 to 10	10 to 15
Category 1						
Very wet	0	0 to 1	1 to 3	3 to 6	5 to 9	8 to 13
Partly wet or dry	1 to 4	3 to 6	5 to 9	7 to 12	10 to 16	13 to 22
Dry	3 to 8	6 to 12	9 to 16	12 to 20	15 to 25	19 to 35
Category 2						
Very wet	0 to 2	1 to 4	3 to 8	7 to 12	10 to 17	14 to 24
Partly wet or dry	3 to 8	6 to 13	10 to 17	15 to 26	20 to 35	27 to 44
Dry	6 to 14	12 to 23	19 to 33	27 to 42	35 to 53	47 to 67
Category 3						
Very wet	0 to 4	2 to 7	6 to 12	10 to 19	15 to 25	21 to 35
Partly wet or dry	5 to 11	10 to 20	16 to 30	23 to 40	31 to 55	40 to 66
Dry	10 to 20	19 to 35	30 to 50	43 to 63	56 to 80	75 to 100

Source: Reference 9.1

Table 9.2 Guideline rates for “continuing losses” from rivers in Zimbabwe (x10^3 m^3/km or Megalitres/km)

Degree of saturation	Release rates in m^3/s					
	< 1	1 to 3	3 to 5	5 to 7	7 to 10	10 to 15
Category 1						
Very wet	1 to 4	3 to 7	5 to 9	8 to 12	10 to 14	12 to 17
Partly wet or dry	3 to 7	6 to 11	9 to 14	12 to 17	15 to19	17 to 22
Dry	4 to 10	8 to 14	12 to 18	15 to 21	18 to 24	21 to 27
Category 2						
Very wet	2 to 5	4 to 8	7 to 12	10 to 16	14 to 20	17 to 24
Partly wet or dry	5 to 9	9 to 15	13 to 22	19 to 28	24 to 33	29 to 38
Dry	7 to 14	13 to 23	20 to 32	27 to 39	34 to 36	41 to 53
Category 3						
Very wet	2 to 5	4 to 9	8 to 15	12 to 20	17 to 25	21 to 30
Partly wet or dry	6 to 12	11 to 20	18 to 30	26 to 40	33 to 47	40 to 55
Dry	10 to 19	18 to 34	28 to 45	40 to 60	50 to 70	60 to 80

Source: Reference 9.1

Table 9.3 Guideline rates for the velocity of release waves from dams for rivers in Zimbabwe (km/day)

Degree of saturation	Release rates in m^3/s		
	<1 to 3	3 to 7	7 to 12
Category 1			
Very wet	10 to 30	20 to 38	30 to 45
Partly wet or dry	6 to 19	14 to 28	22 to 36
Dry	1 to 8	8 to 18	16 to 27
Category 2			
Very wet	8 to 22	16 to 31	25 to 40
Partly wet or dry	4 to 14	11 to 22	18 to 30
Dry	1 to 6	5 to 13	12 to 20
Category 3			
Very wet	6 to 14	12 to 23	20 to 35
Partly wet or dry	3 to 9	7 to 16	13 to 24
Dry	>1 to 4	2 to 8	7 to13

Source: Reference 9.1

There is little information available concerning the rates of seepage gain from rivers in Zimbabwe. Provisional guidance on seepage gains for rivers in Zimbabwe are given in Table 9.4.

Table 9.4 Provisional guidance for "seepage gains" for rivers in Zimbabwe

Release rate (m^3/s)	Seepage gains (x 10^3 m^3/km or Megalitres/km)
1 to 3	1 to 3
3 to 7	3 to 5
7 to 10	5 to 7

Source: Reference 9.1

The initial and continuing loss rates vary considerable. In the case of initial losses they vary from 0 m^3/km to 100,000 m^3/km for relatively large releases in very dry, flat and sandy rivers. To determine which rate to use for a particular river it is important to know not only the physical conditions but the also the conditions under which the release occurred.

An example of how a calculation could be used for estimating the losses from an artificial release in Zimbabwe is given below.

Example of estimating transmission loses in Zimbabwe

Some 20 million m^3 of water is to be released from a dam in Zimbabwe. This water has to be conveyed 100 km via a natural watercourse to its point of use. The river has a gradient of between 1 in 500 and 1 in 800 and a total width between 400 m and 500 m. The bed consists party of rock but there are also significant sandy patches. Pools are fairly common. Prior to the release the river bed is only partly saturated, there is little base flow and some pools are partly dry. The release rate is to be kept at 4 m^3/s this means that the entire duration of the release is 58 days

Interpolating from Tables 9.1 to 9.3 gives the following figures:

• Initial losses:	14,000 m^3/km
• Continuing losses:	17 litres per second per kilometre
• Seepage gains:	4,000 m^3/km
• Speed of release wave	14 km/day

The initial losses = 14,000 m^3/km x 100 km = 1.4 million m^3

The duration of the initial losses = 1.4 x 10^6 m^3/4 m^3/s = 4 days

The duration of the continuing losses = 58 days – 4 days = 54 days

The continuing losses = 17 l/s x 100 km x 54 days x 86400 seconds = 7.9 million m^3

The seepage gains = 4000 m^3/km x 100 km = 0.4 million m^3

The total losses = 1.4 + 7.9 – 0.4 = 8.9 million m^3

The losses equate to approximately 45% of the water that has been released from the dam.

Source: Reference 9.1

It should be noted that the use of Tables 9.1 to 9.4 only provides guideline rates for Zimbabwe.

9.3.2 Kenya

In Kenya the following equation has been developed for estimating transmission losses:

$$Q_l = 57.73KA^{0.5}$$

Where: Q_l is the loss rate in l/s/km
K is a constant varying with the nature of the bed and the bank material e.g.:
K = 0.44 for sandy and gravelly channels;
K= 0.13 for sandy loam beds;
K = 0.08 for heavy clay
A is the cross sectional area in m^2

Example of estimating transmission loses in Kenya

For a river in Kenya with a sandy bed (e.g. K = 0.3) that has a flow of 5 m^3/s at a mean velocity of 0.5 m/s (i.e. a cross sectional area of 10 m^2) the equation will give a continuing loss of 55 l/s/km. If the bed were rocky (e.g. K = 0.1) the loss rate would be of the order of 18 l/s/km.

9.4 References

9.1 Kammer, D. (1998) *River transmission losses in Zimbabwe*, Department of Water Development Zimbabwe (unpublished)

APPENDIX A

INDUSTRIAL WATER CONSUMPTION LOOK UP TABLES

A1.1 Background to look up tables

The aim of the look up tables is to allow staff responsible for water management to assess whether the licensed volumes for an existing or proposed abstraction are reasonable for a given industrial process. There is also some information on the water use steps for each industrial process and potential water saving initiatives that could be employed to reduce consumption levels.

The quality of the data in the look up tables varies. There are some industrial sectors where data was available from a wide range of sources, for other industries the data available was limited. In some cases water use figures are based on limited data provided directly by one company. The data in the tables should be treated with care. However, the water consumption figures generally provide at the very least an idea of the order of magnitude of water consumption for various industries.

For industries that consume significant quantities of water, water consumption varies in an approximately linear manner with an increase in production. Hence the planned production capacity of an industrial plant is important in establishing the water consumption. The data in the look up tables tend to concentrate on industries that use relatively high quantities of water.

A1.2 Examples of how to use the industrial water consumption look up tables

The look up tables presented in Section A1.3 provide water resources managers with indicative industrial water consumption figures. The look up tables aid decisions on water abstraction licences, forecasting and demand management. Examples of how the look up tables can be used are given below.

Example of water consumption for a new brewery

A proposed new brewery requires 780,000 m^3 of water per year when fully operational

Information required

How many litres of beer are to be produced ?	10 million litres per month when fully operational

Calculations

The quantity of beer produced per year = 10 x 12 = 120 million litres per year
= 120,000 m^3 per year

The quantity of water consumed per m^3 of beer produced = 780,000/120,000 = 6.5 m^3/m^3

Conclusions

The look up tables indicate that the typical range of water consumption for medium to large breweries is 5 m^3 to 15 m^3 per m^3 of beer produced. Hence the water consumption of the proposed new brewery of 6.5 m^3 per m^3 of beer produced would appear to be reasonable.

Example of water consumption for a new beef processing factory

A new beef processing factory has been proposed. The new factory will to process 7,000 tonnes of beef per year. The plans indicate that the factory will consume 40 m^3 of water per hour.

Information required

What is the product to be produced ?	Beef
What is the production capacity ?	7,000 tonnes of beef per year
How much water is required ?	40 m^3 of water per hour
How many hours is the plant in operation ?	7,500 hours per year

Calculations

The quantity of water consumed	= 40 x 7500 = 300,000 m^3 per year
Water consumed per tonne of beef produced	= 300,000/7,000
	= 42.9 m^3 of water per tonne of beef produced

Conclusions

The look up tables indicate that the best available figure for water consumption for a beef processing factory is 4.3 m^3 and an average figure is 5.8 m^3 of water per m^3 of beef produced.

The site's request for 42.9 m^3 of water per tonne of beef produced appears unreasonable when compared with the average figure from the look up tables of 5.8 m^3 of water per m^3 of beef produced. There would seem to be considerable scope for recycling water and reducing the consumption of the site.

A1.3 Industrial water consumption look up tables

A1.3.1 Beverages (soft drinks)

A soft drink can be defined as a non-alcoholic carbonated or non-carbonated beverage. The production involves the blending of concentrates and additives with water. In terms of water consumption in some cases the washing of returnable bottles can use up to 50% of a plant's total water consumption.

Orange juice concentrates are made by extracting the juice from oranges and concentrating it in an evaporator. Fruit juice is manufactured by the blending of juice concentrates with water. Table A1.1 below gives water consumption figures based on a survey of 26 soft drink factories in South Africa. Table A1.2 below gives water consumption figures for a range of beverages based on information collected in Europe.

Table A1.1 Water consumption for soft drink factories in South Africa (m^3/m^3)

Average	2.6
Typical range	1.3 to 3.8

Note: The above figures are for all types of soft drink manufacture including carbonated and non-carbonated drinks.
The degree of bottle washing has a significant effect on water consumption. The figure of 1.3 m^3 of water per m^3 of soft drinks produced is for a factory where no bottle washing takes place.
Source: Reference A1.1

A study carried out of a bottling plant in Zambia indicated that the specific water consumption for a soft drink bottling plant in Lusaka was 6.4 m^3/m^3. This figure includes the water used for bottle washing (Reference A1.39).

Table A1.2 Water consumption for beverages

	Carbonated soft drinks (m^3/m^3)	Orange juice concentrate (m^3/tonne of oranges)	Fruit juices (m^3/m^3)
Average	4.0	0.55	14.5
Best available	3.0	Not available	3.0*

Note: *This figure assumes re-circulation of the cooling water
Source: References A1.2 and A1.3

In many plants that produce bottled beverages it is bottle washing that is often the major consumer of water. It has been estimated that for a relatively old beverage plant in Bulawayo in Zimbabwe some 54% of the water consumed was used in the washing of bottles. However, it should be noted for more modern plants this figure may be significantly lower (Reference A1.4).

Methods by which water use efficiency can be improved include:

- Replacement of flow through systems with recirculation, recycling and re-use systems;
- Improvement of plant washing procedures;
- Controlling flow rates for spray, sealing and cooling water supplies especially in bottle washing processes;
- Modifications to wastewater treatment systems to allow an increase in re-use and recycling.

A1.3.2 Breweries

Modern larger breweries tend to be more efficient than small breweries. One of the most efficient breweries in the world is located in Windhoek in Namibia. The brewery was constructed with water efficiency in mind. The short lines in the beer production process used in the brewery reduce the quantity of water needed for washing and reduces consumption by around 10% (Reference A1.5). Table A1.3 provides typical water consumption figures for breweries taken from a survey of eight breweries in South Africa.

Table A1.3 Water consumption for breweries in South Africa

	Large breweries producing greater than 10,000 m^3 of beer per month (m^3/m^3 of beer)	Medium breweries producing between 2,000 m^3 and 10,000 m^3 of beer per month (m^3/m^3 of beer)
Typical range	5.5 to 7.1	6.7 to 8.8
Mean	6.3	7.7

Source: Reference A1.6

South African Breweries recently estimated that the water consumption for their breweries worldwide was 6 m^3 of water per m^3 of beer produced. South African Breweries most efficient clear beer brewery is Alrode in South Africa. This uses 4.19 m^3 of water per m^3 of beer produced (Reference A1.7). The target water consumption for this brewery is 4.0 m^3 of water per m^3 of beer produced. Table A1.4 provides water consumption figures collected for breweries in Europe and compare them with the best available figure for southern Africa.

Table A1.4 Water consumption for breweries

	Medium to large breweries (m^3/m^3 of beer)	Small breweries (m^3/m^3 of beer)
Typical range	5 to 15	Up to 22
Mean value	10	Not available
Best available	4*	Not available

Note: *Figure is for the Windhoek Brewery, Namibia
Source: References A1.3 and A1.5

Various measures that can be implemented to make water use in breweries more efficient include:

- Utilising ammonia as a refrigerant for the main refrigeration system, as well as the air conditioning. This reduces water cooling requirements;
- Recycling of caustic soda solutions reduces the water consumption of bottle washing machines;
- Use of stainless steel product handling vessels and pipe work provide a self-sterilising effect that reduces the water needed for cleaning;
- A separate effluent discharge system allows separate treatment of all wastewater thus optimising water recovery;
- An incoming water filter backwash recovery filter system can allow re-use of water for gardening thus avoiding the need for irrigation water.

A1.3.3 Sorghum beer and sorghum malting

Sorghum beer is often referred to as “traditional” or “African” beer. The process of converting sorghum grain into sorghum beer involves two distinct processes. These are:

- The malting of the sorghum grain;
- The brewing of the beer.

Typical water consumption figures for these processes taken from a survey in South Africa are given in Tables A1.5 and A1.6.

Table A1.5 Water consumption for sorghum malting for South Africa

	Medium to large maltsters (m^3/tonne)	Small maltsters (m^3/tonne)
Typical range	2.5 to 10.0	Up to 12.3
Weighted average	3.3	Not available
Target	3.0	7.0
Best available	2.5	Not available

Source: References A1.6 and A1.7

The water consumption for malting is related to the size of the plant as well. There are certain operations that require the same amount of water regardless of the level of production

Table A1.6 Water consumption for brewing sorghum beer in South Africa (m^3/m^3)

Typical range	2.3 to 4.8
Target	2.0
Mean	2.5

Source: References A1.6 and A1.7

The results of the survey in South Africa indicated that large sorghum breweries are not necessarily more efficient than smaller ones. South African Breweries recently estimated that typical water consumption figures for their sorghum breweries are between 2 m^3 and 3 m^3 of water per m^3 of sorghum beer produced (Reference A1.8).

Water efficiency can be improved as follows:

- Improvements in the efficiency of use of washdown water. This is used to wash tanks, floors and vehicles. The use of pistol grips on hoses can reduce water use;
- The use of compressed air for cleaning can reduce water use;
- A high pressure low volume system can reduce water consumption by 35%;
- In maltings mechanised water control systems reduce water use;
- In sorghum brewing the following measures can be undertaken to improve water use efficiency:
- Install boiler condensate returns to reduce evaporation losses;
- Pressurised cooking reduces evaporation.

A1.3.4 Brick production

Bricks are manufactured by grinding natural clays and mixing them into a marl by the addition of water. The exact composition of the marl determines the type of the brick. The figures for water consumption given in Table A1.7 are taken from information collected from a large brick factory in the UK.

Table A1.7 Water consumption for brick production (m^3 per tonne of bricks produced)

Typical range	15 to 30

Source: Reference A1.3

Water use efficiency can be improved by monitoring the actual use versus the theoretical usage (with respect to the marl-water content specification) and maintaining the water use as close to the theoretical usage as possible.

A1.3.5 Cement and concrete products

Typical water consumption figures for various cement and concrete products are given in Table A1.8. The figures are based on information taken from a variety of sources worldwide.

Table A1.8 Water consumption for various cement and concrete products

Type of product	Water consumption
Cement manufacture	Cooling water 0.41 kg/kg clinker Product water 0.325 kg/kg raw materials
Cement production	3.8 m^3 per tonne of product
Concrete products	1.0 m^3 per tonne of product
Concrete blocks	1.0 m^3 per 200 blocks
Reinforced concrete	0.63 m^3/m^3

Source: Reference A1.3

A1.3.6 Ceramics manufacture

The main steps in the production of ceramic products are cooling of equipment, finishing of the products, preparation of glazes and the washing of equipment. Typical water consumption values for a range of ceramic products are given in Table A1.9.

Table A1.9 Water consumption for ceramics manufacture (m^3/tonne of product)

	Ceramic whiteware	Sanitary ware	Stone ware	Glazed tile (m^3/m^2)	Fine porcelain
Typical range (without closed cooling water)	15 to 20	6 to 15	2 to 10	0.5 to 8.0	5.5 to 14.0
Typical figures with closed cooling water cycle*	1.6	2.4	2	0.04	Not available

*Note: These figures assume that water use for auxiliary needs is met by the water reclaimed from the purified industrial wastes

Source: Reference A1.3

There are a number of methods by which the water consumption of ceramics manufacture can be improved. The re-circulation of water in a fully closed system and the reuse of reclaimed water from industrial wastes can significantly reduce water consumption as illustrated by Table A1.9.

A1.3.7 Manufacture of various specialist chemical products

There is a wide range of specialist chemical products for which typical specific water consumption figures are given in Table A1.10. The main steps that use water include: cooling, steam production, product washing, effluent dilution, plant and product washing.

Measures for water reduction can be split into three distinct areas: water management techniques, good house keeping measures and plant/process modifications.

Table A1.10 Water consumption for various chemical products

Type of product	Water consumption (m^3/tonne)
Resins, adhesives, disinfectants, photographic solutions	Less than 1
Sulphonic acids, detergents, rubbers, pigments, salts	1 to 2
Silicones, polyacrylics, water treatment chemicals, chelating agents, surfants, amine products, synthetic organic polymers, esters, imides, anhydrides, quaternaries, alkyl ethers, salts, soaps	2 to 5
Brightening agents, dyes, biocides, herbicides, insecticides, phosphates, pharmaceutical, intermediates, polyacrylics, amine products, esters, soaps	5 to 10
Esters biocides, fungicide intermediates, mercaptan gas, odorants, carbonates, thioglycollates, thioureas	10 to 50
Pharmaceutical intermediates, acrylates, amine products	50 to 100
Liquid crystals, buffer solutions, pigments, chlorine and bromine products	Greater than 100

Source: Reference A1.3

Water reduction measures for the production of specialist chemicals can be spilt into:

- Water management techniques;
- Good housekeeping measures;
- Plant and process modifications.

Table A1.11 gives an indication of the percentage reductions in water use that can be achieved.

Table A1.11 Water reduction measures for the chemical industry

Measure	Reduction in water use (%)
Water management techniques	
Metering individual product areas and setting reduction targets	30
Production scheduling, improvements in plant washdown, use of trigger hoses	50
Good housekeeping measures	
Improved pipe work to reduce leaks	10
Good housekeeping (e.g. taps on hoses)	8
Better housekeeping to avoid cleaning	3
Storm water prevented from entering effluent system	7
Leak detection and reduction	30
Flow restrictors on vessel cooling lines	5
Plant and process modification	
Cooling water re-use	21
Installation of cooling tower	50
Improved cooling tower	50
Re-use of water for batch dilution	25
Installation of pressure washers for cleaning blending tanks	5
Re-circulation of water in liquid ring vacuum pumps	50
Replacement of water seal vacuum pumps with dry versions	24
Installation of air chillers	5
Reduction in process water wastage	5
Water minimisation project	20
Modernisation of manufacturing facilities	38
Improvements in process efficiency	5

Source: Reference A1.3

A1.3.8 Chipboard and medium density fibreboard (MDF) production

Chipboard and medium density fibreboard are manufactured from waste wood that is shredded, mixed with resin and pressed into boards. Typical consumption figures are given in Table A1.12.

Table A1.12 Water consumption for chipboard and MDF

	Chipboard (m^3/tonne of board produced)	Medium density fibreboard (m^3/tonne of board produced)
Typical range	0.23 to 7.2	0.31 to 7.2
Best available	0.23	0.31

Source: Reference A1.3

The higher figure of 7.2 m^3 of water used per tonne of board produced is for a ‘once-through’ manufacturing plant where there is minimal re-use of water. The lower values of 0.23 m^3 and 0.31 m^3 of water used per tonne of board produced are for plants with the latest manufacturing techniques and water re-use technology and procedures.

It should be noted that the water re-use is inherent in the process. Environmentally there is often a balance between decreasing water use and increasing energy consumption.

A1.3.9 Cosmetics manufacture

Typical water use figures for cosmetic products are given in Table A1.13. The quantity of water use is dependent upon whether the cosmetics are packed on the site of production. Water use efficiency can be improved by the efficient use of water for cleaning and re-cycling of steam.

Table A1.13 Water consumption for cosmetics manufacture (m^3 per tonne)

Typical consumption	4.18

Source: Reference A1.3

A1.3.10 Electronic goods assembly

The data in Table A1.14 has been collected for the production of electronic goods worldwide. It should be noted that the water consumption figures are given in terms of m^3 per m^2 of production space.

Table A1.14 Water consumption for electronic goods (m^3 per m^2 of production space)

Low consumption	Medium consumption	High consumption
0.02	Not available	30.0
Photocopiers, domestic appliances, computers, data storage devices	Digital test equipment instruments	Clean room operations e.g. manufacturing of laser devices

Source: Reference A1.3

A1.3.11 Fibreglass production

Fibreglass is produced by extruding glass fibres from a furnace. This fibre is wound to form the final product. The quantity of water used is dependent on the type of binding agents used and the final form of the product. Typical water use figures are given in Table A1.15.

Table A1.15 Water consumption for fibreglass production (m^3/tonne of produced)

Average range	10 to 20
Best available	2.5

Source: Reference A1.3

Water efficiency can be improved by:

- Improving the efficiency with which vessels are cleaned;
- Introducing closed loop cooling systems;
- Using a water consumption monitoring and management system.

A1.4.12 Fish processing

There are a number of steps involved in the processing of fish. The main water use step can be the use of holding and thawing tanks. These can account for 30% to 40% of the water used. Water is also used for butchering, chilling, glazing, cleaning, cooking and cooling fish. The quantity of water used is dependent upon the final product i.e. fresh or frozen. Table A1.16 gives typical ranges of water use for a variety of fish.

Table A1.16 Water consumption for fish processing (m^3/tonne of product)

	Tuna	Other fish	Filleting	Herring	Shrimp	Fish meal
Average	10 to 20	17	9 to 25	4 to 8	30 to 60	1 to 3
Best available	Less than 10	4	9	4	30	1

Source: Reference A1.3

Table A1.17 provides specific water consumption figures collected in the 1980s for fish processing plants in South Africa.

Table A1.17 Water consumption for fish processing for South Africa (m^3/tonne of product)

	Freezing of white fish	Perlemoen (abalone) shellfish	Fish meal (South Africa)	Fish meal (Walvis Bay Namibia)
Range	3.1 to 8.5	2.5	0.37 to 2.30	0.40 to 2.15
Average	6.5	-	0.84	0.84

Source: Reference A1.9

Water use can be reduced by:

- Replacing water cooling systems with air cooling ones;
- Improving the efficiency of cleaning by using more efficient high pressure hose systems.

A1.4.13 Food processing – dairy produce

Pasteurised milk

There are a number of steps in the production of pasteurised milk. These include:

- Raw milk reception including chilling and storage;
- Pasteurisation to destroy harmful bacteria;
- Standardisation to remove excess cream;
- De-aeration to expel unwanted gases;
- Homogenisation to ensure the milk has a uniform fat distribution;
- Cooling and packing

Specific water consumption figures for pasteurised milk dairies in South Africa are given in Table A1.18.

Table A1.18 Water consumption for pasteurised milk dairies in South Africa

Production capacity (m^3 of pasteurised milk produced per month)	Water consumption (m^3/m^3 product)
1000 or less	3.25
1000 to 2000	0.98
More than 3000	1.04

Notes: The maximum specific water consumption was found 5.5 m^3 of water per m^3 of pasteurised milk produced, the minimum specific water consumption was found 0.75 m^3 of water per m^3 of pasteurised milk produced
The water usage figures presented in the above table are for milk production until the end of processing including reception and vehicle washing but not including packaging
The volume of milk produced is not necessarily sold, as part may be utilised as raw material for further processes
Source: Reference A1.10

Figures from Europe for specific water consumption for liquid milk processing plants range from 0.5 m^3/m^3 to 12.9 m^3/m^3 (Reference A1.3). Table A1.19 gives details of water consumption figures for dairies producing milk in Zimbabwe. The figures are based on a survey of Zimbabwean dairies carried out in 1999.

Table A1.19 Water consumption for milk dairies in Zimbabwe

Production capacity (m^3 of pasteurised milk produced per month)	Range of water consumption (m^3/m^3 product)
More than 3000	1.15 to 6.00

Source: Reference A1.11

The effect of packaging of milk on water consumption

The effect of different types of packaging of milk products on specific water consumption is shown in Table A1.20. Inefficiencies in bottle washing operations can lead to a two fold increase in the specific water consumption for pasteurised fresh milk.

Table A1.20 Water consumption for milk in different packages in South Africa (m^3/tonne of product)

	Unpackaged	Bottled	Sachets	Cartons
Mean	1.6	3.0	1.7	2.2
Maximum	5.5	5.4	3.2	2.6
Minimum	0.75	2.0	1.1	1.5

Note: Produced from raw milk, the reception stage is included
Source: Reference A1.10

Other dairy products

Specific water consumption figures for other dairy products collected in South Africa are given in Tables A1.21 and A1.22. It should be noted that in the case of cheese and milk powder significant quantities of milk are required to produce a relatively small mass of the final product.

Table A1.21 **Water and steam consumption for dairy produce in South Africa (m^3/tonne of product)**

	Cultured products (m^3/m^3)	Fruit juices and mixes (m^3/m^3)	Sterilised /UHT products (m^3/m^3)	Butter (m^3/tonne)	Ice cream (m^3/tonne)
Mean	10.2	2.7	3.7	1.5	2.5
Maximum	13.8	5.5	6.2	6.9	3.1
Minimum	6.3	0.75	2.0	1.3	1.9

Source: Reference A1.10

Table A1.22 **Water and steam consumption for dairy produce in South Africa (m^3/tonne of product)**

	Skimmed milk (m^3/tonne)	Milk powder (m^3/tonne)	Cheese (m^3/tonne)	Condensed milk (m^3/tonne)
Mean	3.6	11.8	23.0	4.4
Maximum	5.0	16.6	29.0	5.3
Minimum	2.1	8.7	16.4	3.5

Source: Reference A1.10

Other water consumption figures that have been collected from around the world are given in Table A1.23.

Table A1.23 **Water and steam consumption for dairy produce (m^3/tonne of product)**

	Bottled pasteurised milk	Cheese	Ice cream	Yoghurt	Powdered milk
Water	5.8	8.5	0.9 m^3/m^3	4.2	0.03
Steam	0.19	0.25		0.14	0.09

Note: Includes water used at the reception stage
Source: Reference A1.3

Ways in which the specific water consumption can be reduced include:

- The use automatic shut-off nozzles on all water hoses;
- The use of high-pressure, low-volume cleaning systems;
- Minimising spills of ingredients and of raw and finished product on the floor.

A1.3.14 Food processing – flour products

Table A1.24 gives figures for a variety of flour products.

Table A1.24 Water and steam consumption for flour products

	Bread	Bakers yeast	Corn starch	Corn snacks	Pasta
Water (m^3/tonne)	2* to 6	25	6.3	0.03	0.3
Steam (tonne/tonne)	0.06	0.4	-	-	-

Note: *The lower value is based on an audit of a multi-product bakery in North Carolina, USA
Source: Reference A1.3

The water consumption figures in Table A1.4.24 are based on the actual requirement with no water recycling. As a consequence the figures should be treated as a worst case value. Methods by which specific water consumption can be reduced include:

- The use of nozzles on all water sprays;
- Installation of automatic shutoff valves on all water hoses;
- The use of a high-pressure, low-volume cleaning system;
- Installation of pressure regulators on supply lines for hoses and pan washers;
- Reuse of water where permitted, such as in pan or tray washer;
- If flour, product, or debris collect and it requires excessive amounts of water to flush them away, a redesign of the equipment should be considered to prevent the materials from collecting.

A1.3.14 Food processing – fruits

Tables A1.25 and A1.26 provide specific water consumption figures for the canning and juicing of a variety of fruit products. The figures are based on a survey of South African fruit processing plants carried out in the late 1980s.

Table A1.25 Water consumption for the canning of fruit produce in South Africa (m^3/tonne of product)

	Typical range	Average	Target
Apples	4.3 to 11.3	6.6	3.6
Apricots	2.5 to 14.5	5.5	5.5
Citrus fruit	1.1 to 2.6	2.1	1.5
Guavas	4.0 to 10.0	6.4	6.0
Peaches	2.5 to 11.5	5.5	5.1
Pears	4.5 to 12.9	12.7	8.0
Pineapples	2.1 to 4.5	2.9	2.8
Strawberries	6.8 to 27.0	17.0	-
Tomatoes	2.0 to 3.0	2.4	2.2

Source: Reference A1.12

Table A1.26 **Water consumption for the juicing of fruit produce in South Africa (m^3/tonne of product)**

	Typical range	Average	Target
Apples	-	1.8	0.5
Citrus fruit	1.1 to 2.6	2.1	1.5
Pears	1.4 to 1.9	1.5	0.6

Source: Reference A1.12

Table A1.27 provides water consumption figures based on data collected worldwide.

Table A1.27 **Water and steam consumption for fruit products (m^3/tonne of product)**

	Frozen apples	Fruit puree	Fruit jam/preserve
Average water consumption	2.0	0.4	8.0
Average steam consumption	-	0.18	0.28*

Note: This steam figure is included with the average water consumption figure shown in the top row of the table.
Source: Reference A1.3

The main ways in which specific water consumption can be reduced include:

- Optimising the layout of the plant in order to minimise spillage;
- Recycling of wash water;
- The use of air cooling systems rather than water cooled ones;
- The recycling of steam;
- The implementation of good housekeeping techniques.

A1.3.15 Food processing – miscellaneous

Table A1.28 provides data for a variety of miscellaneous food products. The information is based on figures collected in Europe.

Table A1.28 **Water consumption (m^3/tonne of product)**

	Refined sugar beet	Baby food	Canned pet food
Average	9.0	0.2	2.8

Source: Reference A1.3

A1.3.16 Food processing – multi-product confectionary plant

The figures in Table A1.29 are based on a water audit that was carried out for a Cadbury Schweppes plant in Australia that produces chocolate confectionery products. The table indicates the reduction in water consumption after the audit was completed. These reductions were achieved by using specially designed wash bays, automatic hoses on nozzles, automatic taps and utensil washers.

Table A1.29	Water consumption (m^3/tonne of product)
Before audit	6.0
After audit	1.5

Source: Reference A1.3

A1.3.17 Food processing – vegetable products

Frozen vegetables

Table A1.30 provides figures for the water consumption for frozen vegetables based on data collected in South Africa.

Table A1.30 Water consumption for the freezing of vegetable produce in South Africa (m^3/tonne of product)

	Typical range	Average	Target
Broccoli	-	8.1	-
Cauliflower	-	25.0	12.5
Carrots	6 to 26	6.1	5.8
Corn	-	4.6	-
Green beans	10 to 25	25.0	16.0
Peas	-	30.0	20.0
Potatoes	-	25.7	1.3

Source: Reference A1.12

The target water consumption figures in Table A1.30 were set after audits of several factories in South Africa. The main ways in which water consumption can be reduced is as follows:

- Optimisation of the factory's layout. Many old plants have been steadily extended leading to long distances between process areas. This leads to long inter-stage transportation systems with inherent spillage and excessive water use if wet systems are employed;
- Improvements in the standards of house keeping;
- Use of water monitoring equipment;
- Hose pipe management;
- Efficient operation of boiler and steam plants.

Canned vegetables

Table A1.31 provides typical water consumption figures for the canning of vegetable products based on data collected in South Africa. The main ways in which water consumption can be reduced are detailed above.

Table A1.31 **Water consumption for the canning of vegetable produce in South Africa (m^3/tonne of product)**

	Typical range	Average	Target
Beans in tomato sauce	20 to 70	20	15
Corn	6 to 11	9.8	5.0
Green beans	-	7.4	5.1
Peas	19 to 25	22	10

Source: Reference A1.12

Edible oil

Figures in Table A1.32 detail typical water consumption ranges for the two main stages of edible oil production based on data collected in South Africa. It should be noted that most plants that produce edible oil also produce secondary products such as margarine, peanut butter and mayonnaise. An average water consumption of 1.4 m^3/tonne was found for margarine manufacture.

Table A1.32 **Water consumption for edible oil in South Africa (m^3/tonne of product)**

	Typical range	Average
Milling	2.1 to 3.1	2.6
Refining	3.2 to 4.6	3.8

Source: Reference A1.13

The survey of edible oil industry was carried out in 1989. At this time only some 65% of the capacity was being utilised. It should be noted that many plant operations require the same amount of water regardless of the amount of oil produced. This leads to higher specific water consumption figures when a plant is operating below its design capacity.

Table A1.32 implies that the water consumption for a combined mill and refinery should be 6.4 m^3/tonne. This agreed well with figures collected in South Africa, although there are some economies of scale that tend to reduce this figure for an efficiently designed combined plant. Table A1.33 illustrates the breakdown of water use at a typical edible oil processing plant.

Table A1.33 **Breakdown of water use at an edible oil processing plant in South Africa**

	Mill	Refinery	Total
Process	2%	13%	15%
Boilers	10%	30%	40%
Cooling	25%	10%	35%
Washdown	1%	7%	8%
Domestic	1%	1%	2%
Total	39%	61%	100%

Source: Reference A1.13

Specific water consumption can be reduced as follows:

- Maximising the condensate return to the boiler house;
- Ensure cooling towers are working efficiently;
- Use of high pressure, low volume equipment for floor washing;
- Installation of water meters.

Miscellaneous vegetable properties

Table A1.34 illustrates various other specific water consumption figures collected worldwide for a variety of vegetable products.

Table A1.34 Water consumption for vegetable products (m^3/tonne of product)

	Frozen vegetables	Tomato paste	Margarine
Average	25.2	0.3	1.4

Source: Reference A1.3

Table A1.35 gives typical water consumption figures for a mushroom farm. These figures include the water used to prepare compost and the steam that is used to kill any bacteria in the compost. The figures are based on a mushroom farm in Europe.

Table A1.35 Water consumption for mushroom farm (m^3/tonne of product)

	Compost production	Including steam
Average	2.1	25.0

Source: Reference A1.3

A1.3.18 Fresh meat production

In the late 1980s a survey was carried out of abattoirs in South Africa. To enable comparisons to be made between abattoirs where more than one species of animal is slaughtered, the non-bovine species are counted in terms of cattle unit (cu) equivalents (e.g. one cow is equivalent to 15 sheep). To allow a comparison of water consumption to be made a water-related cattle unit (wrcu) was developed e.g. the quantity water used to process one cow is equivalent to the water required to process six sheep. Details of these units are given in Table A1.36.

Table A1.36 Comparison of cattle units and water related cattle units

Species	Cattle units/head	Water related cattle unit/head
Cattle	1	1
Calves	3	2
Sheep	15	6
Goats	15	6
Pigs	5	2.5

Source: References A1.14 and A1.15

Water consumption figures for fresh red meat consumption for different grades of abattoir are given in Table A1.37.

Table A1.37 Water consumption for fresh red meat production in South Africa

Grade of abattoir	Maximum daily slaughter allowed (cattle unit/day)	Minimum (m^3/wcru)	Maximum (m^3/wrcu)	Median (m^3/wrcu)	Mean (m^3/wrcu)
A	>100 or for export purposes	0.71	2.88	1.12	1.42
B	99	1.25	3.15	1.73	2.04
C	50	1.01	4.64	2.36	2.33
D	15	0.70	4.71	2.45	2.38
E	5	1.31	4.19	2.35	2.28

Source: References A1.14 and A1.15
Note: wrcu is a water related cattle unit see Table A1.36

The main water use steps and the breakdown of water use for these processes are given in Table A1.38.

Table A1.38 Breakdown of water use in red meat abattoirs in South Africa

Activity	Operations	Percentage of total		Typical water use (m^3/wrcu)
		Range (%)	Mean (%)	
Processing	Lairage	5 to 12	10	0.142
	Slaughtering	8 to 20	12	0.170
	Carcass dressing	5 to 13	8	0.114
	Offal processing	11 to 60	25	0.355
Utilities	Hot water generation	14 to 36	25	0.355
	Cooling and refrigeration	5 to 11	8	0.114
	Steam raising	2 to 9	5	0.071
Services	Vehicle and yard washing	1 to 5	2	0.028
	General washing	1 to 5	2	0.028
	Laundry and ablutions	1 to 3	3	0.043
Overall			**100**	**1.420**

Source: References A1.14 and A1.15

Water use in red meat abattoirs can be minimised through:

- Use of water metering;
- Use of high pressure, low volume jets for cleaning;
- Elimination of steam losses from steam lines;
- Minimisation of windage and drift losses from evaporative cooling towers and condensers by the fitting of demisters;
- The fitting of self closing nozzles to hoses;
- Recovery and re-use wastewater where possible.

Table A1.39 below provides water consumption figures collected for abattoirs in the UK.

Table A1.39 Water consumption for fresh red meat production (m^3/tonne of product)

	Lamb only	Beef and lamb only	Beef only	Pig meat only
Average	2.2	3.3	5.8	8.9
Best available	1.6	2.4	4.3	3.3

Source: Reference A1.3
Note: No significant difference in the specific water consumption were noted due to the production level.

Data for beef from the USA indicate that specific water consumption ranges from 568 litres/animal to 1703 litres/animal.

A1.3.19 Commercial laundries

The processes used in commercial laundries are similar to those used in the domestic situation. A survey carried out of South African commercial laundries yielded the information shown in Table A1.40.

Table A1.40 Water consumption for laundries (m^3/tonne of product)

	Range	Typical value	Target consumption
Rinse water recycled	8.0 to 16.7	9.0	8
Rinse water not recycled	23.0 to 58.4	30.0	20

Source: Reference A1.16

The survey detailed in Table A1.40 did not indicate that the size of the laundry or the type of articles to be washed had an influence on the water consumption. Water efficiency can be improved by recycling the rinse water. Table A1.41 gives water consumption figures for laundries in the UK and USA.

Table A1.41 Water consumption for laundries (m^3/tonne of product)

	UK	USA	Domestic washing machinery
Average	27	38	20 to 15
Best available	21	10	15

Source: Reference A1.3

A1.3.19 Lead acid battery production

Table A1.42 gives figures for water consumption for the production of lead acid batteries based on data collected in the UK. It should be noted that automotive and standby batteries tend not to be charged hence the water requirement for cooling is eliminated.

Table A1.42 **Water consumption for lead acid batteries (m^3/tonne of lead processed)**

	Industrial	Automotive and standby
Average	16 to 20	5 to 10
Best available	15	5

Source: Reference A1.3

The main ways in which water use efficiency can be increased includes:

- Implementation of water monitoring and management systems;
- Re-use of water from slurry preparation;
- Re-use of cooling water from the charging operation;
- Re-use of plate washing water;
- The use of dry fume abatement systems.

A1.3.20 Leather tanning

Tanning is the process by which animal hides and skins are converted to leather. There are three clearly defined stages in leather tanning. These are:

- The ‘wet-blue’ stage;
- Re-tanning;
- Dyeing.

In the last ten years in South Africa there has been a trend for animal hides to only be processed to the wet-blue stage and then to be transported elsewhere for further processing. Water consumption results from a survey of 11 tanneries in South Africa are shown in Table A1.43 below.

Table A1.43 **Water consumption for leather tanning (litres/hide)**

	Range	Average
Full tanneries	320 to 744	432
Wet blue plant	-	339
Re-tanning, dyeing and finishing plant	-	389

Source: Reference A1.17

There was some indication from the results of the survey that large tanneries have a better water use efficiency than smaller tanneries. The water consumption for full tanneries producing more than 900 hides per day was 356 litres per hide while for tanneries producing less than 900 hides per day the water consumption was found to be 546 litres per hide. Table A1.44 gives figures for leather tanning based on figures collected in the UK and USA.

Table A1.44 **Water consumption for leather tanning (m^3/tonne)**

Average for chrome tanning	40 to 67
Average for vegetable tanning	16 to 27

Source: Reference A1.3

Water efficiency can be improved by:

- The re-cycling of effluent from the secondary treatment to the pre-tanning stage;
- The re-use of effluent from liming wash.

A1.3.21 Light industrial estate water consumption

Table A1.45 provides information on water consumption for light industrial estates. The figures for light industrial consumption are based on typical figures collected for a variety of light industrial estates worldwide.

Table A1.45 Water consumption (m^3/worker/day)

Usage	Consumption
Basic factory requirements for cleaning and sanitation	0.05
Average consumption in light industrial estates with no large water consuming factories	0.25 to 0.50
Average consumption in light industrial estates that include a proportion of factories engaged in food processing, ice making and soft drink manufacture	0.90 to 1.10

Source: Reference A1.3

A1.3.22 Metal finishing

Metal finishing is used to give a product a service that makes it suitable for its intended service conditions as well as providing an attractive appearance. The term “metal finishing” covers a wide range of techniques for the treatment of metallic articles. These techniques include chemical and mechanical surface pre-treatments, electroplating, post-treatments, stripping, and anodising and protective coatings. The electroplating, anodising and chemical surface treatment processes are the processes that consume the most water.

Electroplating is the process by which a thin coating of metal possessing certain desirable properties (e.g. corrosion resistance, appearance) is deposited onto a cheaper base metal via an electric current. Anodising is the process by which aluminium components are treated to provide them with a protective oxide layer against atmospheric corrosion. Phosphating is a common form of chemical surface treatment. It is used to improve corrosion resistance under paint. Typical water use figures for these type of metal finishes taken from a survey carried out in South Africa are given in Table A1.46.

Table A1.46 Water consumption for metal finishing for South Africa

	Electroplating (m^3/m^2)	Anodising (m^3/m^2)	Phosphating (m^3/m^2)
Range	0.03 to 1.25	0.03 to 0.96	0.03 to 0.42
Average	0.31	0.10	0.13

Source: Reference A1.18

Target water consumption figures for the three processes in Table A1.46 should be 0.1 m^3/m^2 for operations treating in excess of 10,000 m^2/month and 0.2 m^3/m^2 for operations treating less than 10,000 m^2/month (Reference A1.18). Table A1.47 presents typical water consumption figures for metal finishing based on data from the UK, USA and Australia.

Table A1.47 Water consumption for metal finishing

	Metal finishing (m^3/m^2)	Metal finishing (m^3/tonne)	US electroplating (m^3/m^2)	Galvanisers (m^3/tonne)
Average	0.2 to 0.5	2.5 to 11.7	0.045	0.025
Best available	0.07	0.5	0.0008	-

Note: Water use will be product, material and finish specific.
Water consumption is normalised against tonne of product or treated surface depending on the form of the product e.g. plate material or door furniture.
Source: References A1.3 and A1.19

Water efficiency can be improved by:

- The re-use of rinse water, this can reduce water consumption by up to two-thirds;
- Counter-current rinsing. This can reduce water use by 90% to 97%;
- Correct design of the rinse tank to ensure that the rinse water is well mixed;
- Treatment and re-cycling of water;
- Vacuum devices to remove dragout liquid.

A1.3.22 Metal processing

After mining metal ores require processing. The main steps in the processing are as follows:

- Concentrating based on physical and chemical methods;
- Smelting where the metal is melted and oxidised to separate it from the ore;
- Refinement of the smelted metal into commercially useful grades.

Tables A1.48, A1.49 and A1.50 give water consumption figures for the processing of lead, nickel and copper respectively.

Table A1.48 Water consumption for nickel processing (m^3/tonne)

	Smelting	Refining	Iron castings
Average	0.6	5.0	0.4

Source: Reference A1.3

Table A1.49 Water consumption for lead processing (m^3/tonne)

	Refining
Average	0.4

Source: Reference A1.3

Table A1.50 Water consumption for copper processing (m^3/tonne)

Typical range	6 to 8

Source: Reference A1.20

Table A1.51 gives figures for water consumption for metallurgical plants processing gold and uranium ore based on data collected in South Africa.

Table A1.51 Water consumption for gold and uranium processing (m^3/tonne)

	Gold recovery only	Gold and uranium recovery	Gold, uranium and pyrite recovery	Gold, uranium, pyrite recovery and production of sulphuric acid
Typical range	0.9 to 1.4	2.5	3.0	4.0 to 4.5

Source: Reference A1.21

The main ways in which water efficiency can be improved are:

- Improvements in the efficiency of cleaning methods and coating make-up procedures;
- Re-cycling of cooling water;
- Adopting an efficient steam system, including a condensate return to minimise leaks.

A1.3.23 Mining

Water is used by the mining industry for the extraction of minerals (e.g. solids such as coal and ore), liquids (e.g. crude petroleum) and gas (e.g. natural gas). The mining industry also uses water for quarrying, crushing, screening and washing.

It is recommended that the water used in the mining industry is divided into four categories. These are:

- Metal mining;
- Coal mining;
- Oil and gas extraction;
- Mining and extraction of non-metallic materials.

The quantity of water used by a mining facility is dependent on the size and the type of the operation. It may be possible to develop a relationship between the water used per tonne of material produced. In many cases mines will be self-supplied from surface or groundwater sources. It is recommended where possible that mine water use is taken from metered records. It should be noted that mines often have to be dewatered. Hence a mine may actual be a net producer of water (Reference A1.22).

Coal mining

Typical figures for coal mining from data collected in the UK are given in Table A1.52 below

Table A1.52 Water consumption for coal mining (m^3/tonne)

	Mining	Open cast
Typical range	0.33 to 0.45	0.11

Source: Reference A1.3

The factors that determine water use are specific to the type of mine. The water use efficiency is highly dependent on the type of processes and the amount of water re-use that occurs at each mine.

Diamond mining

Typical figures for diamond mining are given in Table A1.53 below. These figures are based on data collected from the Orapa diamond mine in Botswana. The figures are based on the quantity of water consumed per tonne of ore produced.

Table A1.53 Water consumption for diamond mining (m^3/tonne)

Typical range	0.3 to 0.5

Source: Reference A1.5

The Orapa diamond mine has significantly increased its water efficiency in the past decade by improving the efficiency of its wastewater re-use.

A1.3.24 Plastic manufacturing

The basic processing steps in the manufacture of plastics include:

- Preparation of reactants;
- Polymerisation;
- Polymer recovery;
- Polymer extrusion;
- Supporting operations e.g. equipment cleaning.

Table A1.54 gives figures for the water consumption of a number of products based on data collected in the USA.

Table A1.54 Water consumption for various plastic products

Type of product	Water consumption (m^3/tonne)
Polyethylene	2.5 to 10.0
Polypropylene	1.7 to 2.8
Elastomer	9.2 to 37.5
Polyvinylchloride (PVC)	9.2
Monomers	66.6
Resin	5.8

Source: Reference A1.3

Water reduction steps that can be implemented are similar to those outlined for the speciality chemicals sectors in Section A1.4.7.

A1.3.25 Power generation

There are two main methods by which power is generated in southern Africa. These are:

- Thermal power stations;
- Hydropower stations.

The water use for these two methods is discussed below.

Thermal power station water use

Thermal power station water use can be defined as the amount of water used in the production of electricity generated by heat. The source of the heat may be fossil fuels (e.g. coal, oil or natural gas), nuclear fission or a geothermal source. In order to estimate the quantity of water used by thermal power stations the following information is required:

- Self-supplied surface and groundwater withdrawals;
- Deliveries from public suppliers;
- Consumptive use;
- Power generation;
- Number and type of facilities.

Information on water use for generating electricity in thermal power stations is best obtained from each individual utility. The quantity of water used at both fossil fuel and nuclear power stations depends primarily on whether or not the cooling water is re-circulated. Power stations that use a “once through cooling system” withdraw the largest quantity of water because the water is not re-circulated within the facility. This technology is commonly used in older thermal power stations (Reference A1.23).

The more water efficient alternatives to once-through cooling include cooling ponds and cooling towers. In some cases where it is not possible to get the quantity of water used directly from a power plant facility it may be possible to use data from other similar plants to estimate the quantity of water used per kilowatt or mega-watt hour of electricity generated.

Eskom, the electricity utility in South Africa, estimates that approximately 1208 m^3 of water is used to produce 1 GWh of electricity (Reference A1.24). Water consumption figures for coal and oil fired power stations in South Africa are given in Table A1.55.

Table A1.55 Water consumption for power stations in South Africa

Fuel type	Direct cooled (m^3/GWh)	Indirect cooled (m^3/GWh)
Coal	220 to 330	1280 to 2550
Oil	320 to 4600	-

Source: Reference A1.24

Dry cooling technology in power stations significantly reduces the water use. Eskom has implemented dry-cooling technologies at their Kendal, Matimba and Majuba power stations. Approximately 80% of the water consumed at wet-cooled power stations is lost due to evaporation from the cooling towers (Reference A1.24). Dry-cooled technology reduces these losses and hence the total amount of water consumed at power stations.

According to design specification, the total station water consumption of a dry-cooled system will not exceed 800 m^3 of water consumed per GWh of electricity produced. The Morupule Power Station in Palapye Botswana is a coal fired power station that utilises dry-cooled modern technology. In 1997 it was estimated that this power station consumes 1140 m^3 of water per GWh of electricity produced. These figures compare to 2500 m^3 of water consumed by wet-cooled systems to produce one GWh of electricity (Reference A1.25). These numbers vary depending on the technology employed at the various power stations.

However, the dry-cooled system may result in a loss of overall efficiency, thus impacting on emissions produced.

Hydropower water use

Hydropower water use can be defined as the quantity of water used by a power plant where the turbines are driven by falling water. In most cases the hydropower facility will be located in the channel of the watercourse, often in the form of a dam (e.g. Kariba Dam in Zimbabwe). The water used by these types of facilities is considered to be an instream water use. It should be noted that in some cases water is diverted away from the watercourse to generate electricity (e.g. the hydropower plant that forms part of Lesotho Highlands Water Project). These types of facilities are considered to be an offstream water use. Instream and offstream hydropower facilities are shown schematically in Figure A1.1 below.

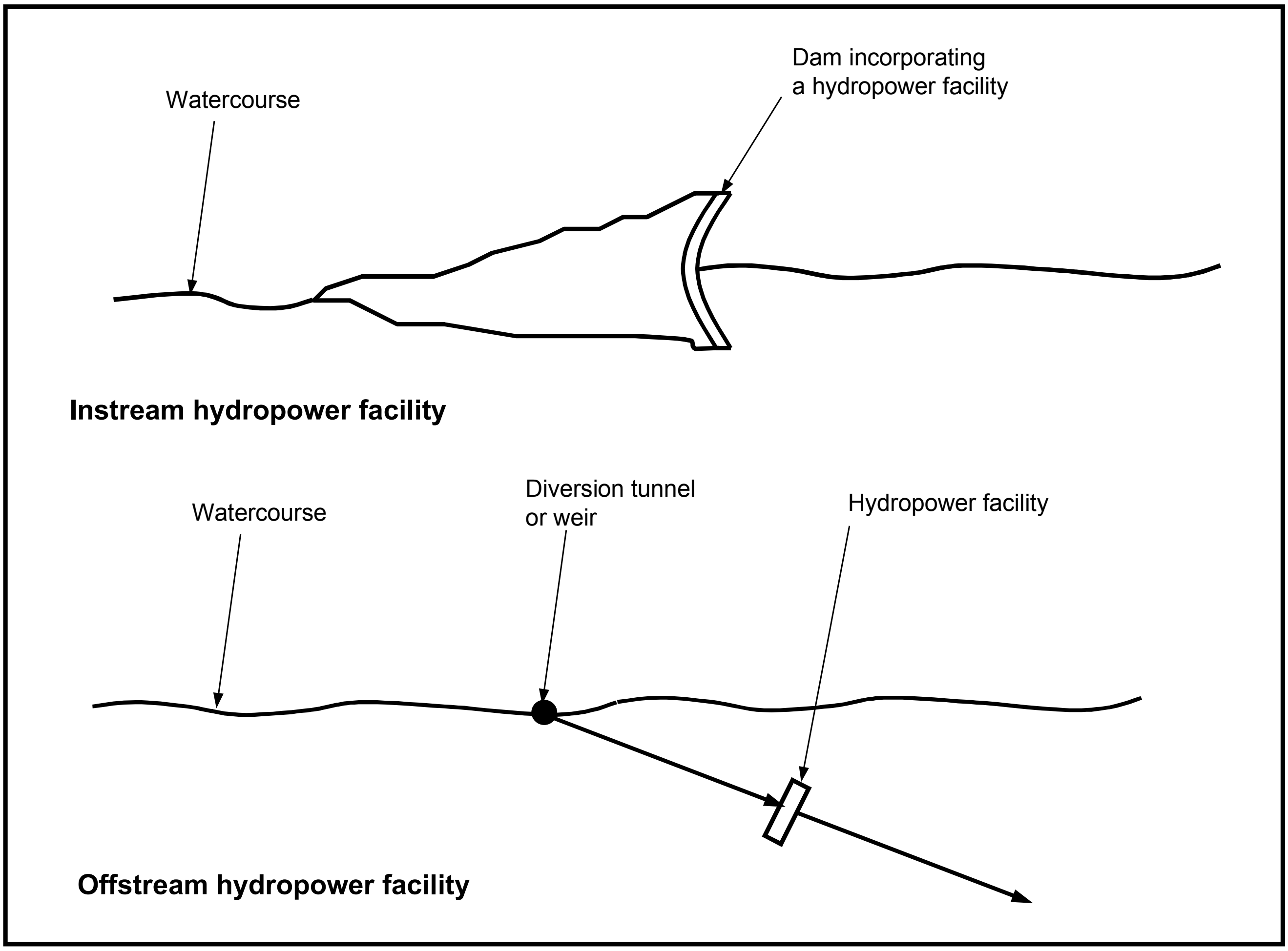


Figure A1.1 Instream and offstream hydropower facilities

In order to estimate the water used by hydropower facilities the following data is required:

- Instream water use;
- Withdrawals from surface water sources;
- Power generation;
- Number of facilities.

There are two main techniques for establishing the quantity of water required by hydropower facilities. These are:

- Direct method;
- Indirect estimation method.

In the majority of cases the instream and offstream water used by a hydropower plant will be available directly from each individual facility. However, in some cases where information is not directly available, water use estimates can be made using the effective head for the hydropower plant, the generated electricity and the efficiency of the turbines (Reference A1.25). The following equation can be used:

$$P = \eta \rho g Q H$$

Where: P is the power generated in watts;
η is the overall efficiency of the station expressed as a percentage;
ρ is the density of water in m^3/kg;
g is the acceleration due to gravity in m^2/s;
Q is the quantity of water flowing through the turbines in m^3/s;
H is the effective head difference in metres.

Rearranging the above equation gives:

$$Q = \frac{P}{\eta \rho g H}$$

Using this equation the water use for both instream and offstream hydropower requirements can be calculated. It should be noted that wherever possible the quantity of water used by a hydropower plant should be taken from direct method figures. Overall efficiencies for hydropower stations are given in Table A1.56.

Table A1.56 Overall efficiency of hydropower stations

Type	Efficiency
Head losses	85% to 95%
Turbine	80% to 90%
Electrical generation	90%
Total	60% to 77%

Source: Reference A1.26

Example of estimating the minimum instream flow requirement for a hydropower facility

Kafue hydropower plant in Zambia has six 150 MW turbines each with an efficiency of 90%. Head losses are estimated to be 95% and electrical generation efficiency is 90%. To produce sufficient electricity to meet the base load requirements a minimum of three of these turbines are required to be in operation. The effective head difference for the plant is 400 m.

The minimum instream flow requirement can be calculated as follows:

Overall efficiency of the hydropower station = 90% x 90% x 95% = 77%

Minimum power requirement $P = 3 \times 150 \times 10^6 = 450 \times 10^6$ W

Minimum instream flow requirement $Q = \frac{P}{\eta \rho g H} = \frac{450 \times 10^6}{0.77 \times 1000 \times 9.81 \times 400} = 149\ m^3/s$

A1.3.26 Poultry processing

Table A1.57 includes water consumption figures based on a survey of 17 poultry abattoirs in South Africa. The surveys indicated that the abattoirs processing over 10,000 birds per day tended to have a lower specific water consumption than those processing less than 10,000 per day.

Table A1.57 Water consumption for poultry processing in South Africa (litres/bird)

	More than 10,000 birds per day	Less than 10,000 birds per day
Average	18.4	23.9
Typical range	15 to 20	15 to 30
Best available	15	15

Source: Reference A1.27

Figures available from the USA indicate that for broiler chickens the specific water consumption varies from 13 litres/bird to 38 litres/bird. The American data for the processing of turkeys indicates that specific water consumption varies from 42 litres/bird to 87 litres/bird (Reference A1.3).

Water use can be reduced using the following measures:

- Using dry clean up practices i.e. removing all dry wastes from the floor before cleaning with water;
- Introducing a water monitoring and management system;
- Maximising condensate return to the boiler house;
- Using of trigger gun attachments on hoses.

A1.3.27 Pulp and papermaking

The pulp and paper mills in southern Africa can generally be categorised as integrated, non-integrated and secondary fibre mills. An integrated mill is one where pulping and paper making take place on a single site. Mills that manufacture paper but not pulp are termed non-integrated mills. Mills that use waste paper as their main product are referred to as secondary fibre mills. The processes involved in paper making are briefly described below.

Pulping is the process by which cellulose fibres are recovered from the raw material (e.g. wood). This includes:

- Debarking;
- Mechanical pulping;
- Chemical pulping.

The processed pulp is then made in paper via the following stages:

- Bleaching;
- De-inking (wastepaper only);
- Steam raising;
- Cooling;
- Process.

Typical water consumption figures for various mills and processes are given in Tables A1.58 to A1.59.

Table A1.58 Water consumption from a survey of paper mills in South Africa

Mill	Production (tonnes/day)	Water intake (m^3/day)	Water consumption (m^3/tonne)
1	650	44,840	70
2	1,200	39,320	33
3	290	20,000	69
4	900	122,400	136
5	145	2,700	19
6	120	1,000	8
7	900	32,600	36
8	22	230	11
9	185	145	0.8
10	15	740	49
11	148	2,800	19

Source: Reference A1.28
Note: Mills 1 to 5 are integrated mills with pulp and paper making
Mills 6 to 11 are non-integrated i.e. paper making only

Table A1.59 Water consumption for pulp and paper making in Europe

	Comments	Water consumption (m^3/tonne)
UK average	Average over whole industry	35.0
UK well designed	Production of paper from waste paper	3.7
Netherlands average	Average of 18 paper mills	8.5
Newsprint	Modern system with closed white water system	13.6

Source: Reference A1.3 and A1.29

Table A1.60 provides typical water consumption figures for a number of different paper types based on data collected worldwide.

Table A1.60 Typical water consumption figures for various paper types (m^3/tonne)

	Minimum	Maximum	Mean
Packing board	1	50	14
Corrugated casing	2	46	23
Newsprint	-	-	29
Printings/Writings	2	68	32
Tissue paper	44	75	60

Note: Water consumption is directly linked to paper quality and starting material (e.g. wood pulp or wastepaper)
Source: Reference A1.3

A1.3.28 Quarries

There are two major types of quarry. These are:

- Hard rock e.g. basalt, graphite, limestone;
- Sand and gravel.

Depending on the geology, depth and location of the quarry, dewatering is often required to prevent flooding of the operation. Similar to mines quarries may be a net producer of water. The type of quarry, the quality and quantity of the deposit, together with the local hydrogeology will all effect the water requirements. As a consequence it is not possible to determine water use figures for a particular type of quarry. Each quarry should be assessed on its own merits. The process efficiency of water usage will be dependent upon the efficiency of collection treatment (usually settling lagoons) and re-use of water.

A1.3.29 Semiconductor wafer fabrication

In order to produce semiconductors ultra pure water is required. This can mean that the actual demand on the water supply system is 25% higher than the quantity of ultra pure water used. This is due to the fact that there are losses in the water purification steps. The water consumption figures given in Table A1.61 are based on data collected in the USA.

Table A1.61 Ultra pure water consumption for semiconductor wafer (m^3/m^2)

Range	56 to 345

Source: Reference A1.3

The main ways in which water use can be reduced are:

- Re-use of water in cooling towers and air scrubbers;
- Re-cycling of rinse water;
- Using more efficient rinse techniques.

A1.3.30 Steel manufacturing

Table A1.62 presents data for water consumption for steel manufacture. The data was collected for a number of steel manufacturing operations in the UK. The wide range of figures is due to a number of factors including the age, size and location of the plants together with the grade and the final form of the steel product.

Table A1.62 Water consumption for steel manufacture (m^3/tonne)

Range	3 to 62

Source: Reference A1.3

Water use efficiency can be improved by:

- Recycling cooling water;
- Cascade use of water.

A1.3.31 Sugar cane refining

The processing of sugar cane takes place in two stages, milling and refining. Sugar cane contains approximately 70% water by mass. The main process in both a mill and a refinery is to extract sugar crystals from the solution. Theoretically utilising the water in the cane can satisfy all the water requirements of a sugar processing plant. However, for practical reasons sugar plants usually take their water from other surface or groundwater sources. Water from these sources is usually used for cooling or domestic consumption. Table A1.63 below gives water consumption figures for sugar mills in South Africa.

Table A1.63 Water consumption for sugar mills in South Africa

	Sugar cane processed (tonnes/hour)	Water consumption (m^3/tonne)
Range	100 to 600	0.3 to 1.0
Mean	250	0.6

Source: Reference A1.30

Figures for sugar mills in the USA indicated water consumption range of 0.4 to 1.3 m^3 per tonne of cane crushed (Reference A1.3).

A1.3.32 Textile manufacturing

The textile industry is extremely diversified, producing a wide variety of end-products ranging from processed fibres to woven materials to finished garments. In terms of water consumption extremes in the industry are represented by factories that employ a large number of people but carry out mainly “dry” operations and factories operating as commission dyers using large volumes of water for these “wet” processes. This section provides water consumption figures for the wet processes. Many of the steps that use water in the textile industry are common to a number of different fibre types. The main water using steps in textile manufacture are described briefly below.

- Sizing – The coating of yarns with a film of agents to provide protection during weaving;
- Singeing – The protruding fibres are burnt to give a smooth finish;

- Desizing – The size solution is removed;
- Scouring – The fabric is cleaned using alkali solution to remove inherent or added impurities in raw fibre or fabrics;
- Bleaching – The fabric is decolourised before printing;
- Mercerising – This process improves the dyeability of cotton goods;
- Dyeing – The addition of colour to the textile;
- Printing – There are a variety of techniques used including rotary screen, direct, discharge, resist, ink-jet and heat transfer;
- Finishing – Chemical and mechanical treatments performed on the yarn or fabric to improve appearance, texture or performance.

Typical water consumption for the various processes gathered from a survey carried out in South Africa are given in Table A1.64.

Table A1.64 Water consumption for textile manufacturing (m^3/tonne)

Process step	Low value	High value
Singeing	1	2
Sizing – woven goods	1	2
Desizing	5	15
Scouring	4	25
Mercerising	6	17
Bleaching	10	100
Dyeing	9	330
Printing	3	33
Washing-off prints	29	505
Finishing	13	134
Overall (typical)*	100	300

Source: Reference A1.31

*Note: For some types of fibres or product, one or more of the processing steps indicated may not be carried out at all, in which case the lower case would be zero. The “overall (typical)” water consumption values given are thus not obtained by summing the individual values in the above table.

Table A1.65 gives typical water consumption figures for a range of fabrics based on data collected world-wide.

Table A1.65 Water consumption for textile manufacturing (m^3/tonne)

Fibre	Process	Consumption
Cotton	De-sizing	3 to 9
	Scouring or kiering	26 to 43
	Bleaching	3 to 124
	Mercerising	232 to 308
	Dyeing	8 to 300
Wool	Scouring	46 to 100
	Dyeing	16 to 22
	Washing	334 to 835
	Neutralisation	104 to 131
	Bleaching	3 to 22
Nylon	Scouring	50 to 67
	Dyeing	17 to 33
Acrylic	Scouring	50 to 67
	Dyeing	17 to 33
	Final scour	67 to 83
Polyester	Scouring	25 to 42
	Dyeing	17 to 33
	Final scour	17 to 33
Viscose	Scouring and dyeing	17 to 33
	Salt bath	4 to 13
Acetate	Scouring and dyeing	33 to 50

Source: Reference A1.3

Table A1.66 provides typical water consumption figures for various textile processes in the USA.

Table A1.66 Water consumption for textile manufacturing in the USA (m^3/tonne)

Processing sub-category	Minimum	Median	Maximum
Wool	111.0	284.6	658.4
Woven	5.0	113.5	508.2
Knit	20.0	83.5	377.2
Carpet	8.3	46.7	162.7
Stock/Yarn	3.3	100.1	558.3
Non-woven	2.5	40.1	82.6
Felted fabrics	33.4	212.8	933.0

Source: Reference A1.3

A1.3.33 Vehicle manufacturing

The water consumption figures for vehicle manufacture given in Table A1.67 are based on a variety of data collected world-wide. The main water uses during the construction of motor vehicles is for engine test bed cooling and during production. Water re-use options are to re-cycle cooling water and to utilise cascade rinsing in metal finishing operations.

Table A1.67	Water consumption for vehicle manufacture (m^3/vehicle or engine)		
	Passenger vehicles (i.e. cars)	**Commercial vehicles (i.e. lorries, buses)**	**Engine manufacture**
Typical range	2.6 to 8.0	12.0 to 16.0	0.04

Source: Reference A1.3

A1.3.34 Wallpaper manufacturing

Table A1.68 provides information on water consumption for wallpaper. The figures are based on data collected for the UK. The figures in Table 6.68 do not include the water used in manufacturing the paper.

Table A1.68	Water consumption for wallpaper manufacturing (litres per roll of product)
Typical range	1 to 5

Source: Reference A1.3

Water use efficiency can be improved via:

- Re-cycling of cooling water;
- Introduction of cleaning methods and coating make-up procedures;
- The use of an efficient steam system including the return of condensate and reducing leaks.

A1.3.35 Wine production

Tables A1.69, A1.70 and A1.71 give details of water consumption for wine making, distilling and bottle washing. The information is based on a survey of South African wineries carried out in the early 1990s. The variations in water consumption shown in the tables are to a certain extent affected by factors such as the scale of the operation and the types of packaging and bottling employed. However, there is no evidence to suggest that larger wineries or distilleries are more water efficient than smaller ones.

Table A1.69	Water consumption for wine making in South Africa		
	Production (tonnes/year)	**Water intake (m^3/day)**	**Water consumption (m^3/tonne)**
Range	8,000 to 22,000	12,000 to 33,000	0.7 to 3.8
Average	14,000	25,200	1.8

Source: Reference A1.33

Table A1.70 Water consumption for distilling in South Africa

	Production (tonnes/year)	Water intake (m^3/day)	Water consumption (m^3 per litre of absolute alcohol)
Range	1,250 to 35,000	1,000 to 11,500	18 to 62
Average	14,000	1,400	35

Source: Reference A1.33

Table A1.71 Water consumption for wine bottle washing in South Africa

	Water consumption (litre per bottle)
Range	0.3 to 2.1
Average	1.5

Source: Reference A1.33

Water use can be reduced by:

- Use high pressure low volume cleaning equipment;
- Sweeping up loose dirt before floors are hosed down;
- Clean cooling towers regularly.

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