WATER DEMAND MANAGEMENT

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Table of contents

Lecture note

Reader

Prepared by WATERNET for the
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WaterNet, in collaboration with: University of Zimbabwe (Harare), University of the Western Cape (Cape Town) and ZimConsult (Harare)

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1. Target audience

The Post-graduate course module on Water Demand Management targets professionals involved in different aspects of water resources management, and at various levels, including:

- *water managers* in charge of a water network (such as catchment managers, operations managers of industrial plants, chief engineers of public water utilities, irrigation managers etc.), who supervise and provide guidance to professionals; **Water managers**
- professionals working in a water network; who supervise technicians. **Professionals**

2. Objective

Long-term objective

The long term objective of the course is to ensure that Water Demand Management analysis and measures are implemented on the ground, so that water is used more wisely, i.e. more equitably, more efficiently and in a more sustainable manner. **Wise water use**

The course objectives are informed by our understanding of why WDM is rarely implemented on the ground. We believe that WDM is often not implemented on the ground because of two reasons:

- Most persons involved in water management lack: (a) an appreciation of the merits of WDM; (b) an understanding of systems' approach, and (c) the required WDM skills.
- Managers lack political will to motivate and guide their staff towards implementing WDM.

Although the second reason is very important, it falls outside the scope of the course.

Learning objectives

At the end of the course, participants:

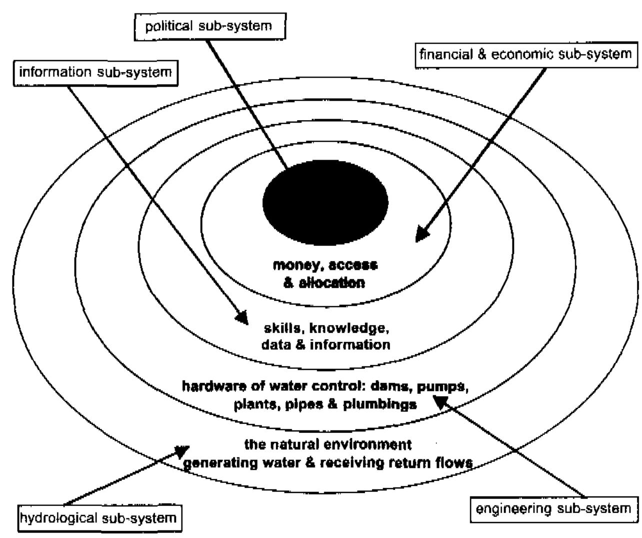
1. have gained a good appreciation of the merits and limitations of water demand management in IWRM **Merits & limitations**
2. have gained a good understanding of a holistic system's approach to water networks, which they can apply to real-world networks **System's approach**
3. have acquired analytical and practical skills in at least 50% of the subsystems identified, and all *major* linkages between sub-systems **Skills**
4. have acquired teamwork skills so as to combine insights from the different sub-systems into a comprehensive water demand management strategy and to identify implementation priorities. **Teamwork**
5. are able to apply the newly acquired skills to a real-life situation.

3. Rationale of the course

The course has been designed on the premise that effective water demand management requires a holistic understanding of the water network under consideration. This means that not only the physical aspects need to be understood, but also other aspects, such as finance, information management and politics. This is depicted by the "onion" with the different layers of a water network (see figure below). **Water network**

The different layers interact and are interdependent. Water demand management measures will be effective when this is well understood, and an appropriate strategy is adopted.

The "onion" with different layers of a water network



4. Course content

The course consist of the following teaching elements:

1 Water demand management in the context of IWRM; merits and limitations
2. Systems approach to water demand management
3. The hydrological system in the context of water demand management
4. The engineering sub-system
5. The economic/financial sub-system
6. Political and institutional aspects of water demand management
7. The information and communication sub-system
8. Linkages: water networks as a holistic system
9. Field study exercise

All teaching elements contain many practical examples and exercises. The aim of the field study is to apply acquired skills to a real-world situation, and serves as an integrating device.

Teaching elements 2-7 have adequate examples of different types of water networks, including:

1. Catchment area / river basin; **Cases:** **– catchment**
2. Bulk water supplier and public water utility (both urban and rural), and **– bulk water**
3. Community level / end users (e.g. poor and rich **– end-users**

neighbourhoods in an urban environment, industrial users and irrigation systems).

5. Course materials

The materials pertaining to this course include the following:

1. Lecture note (main text), with a chapter dedicated to each teaching element. These include brief examples, exercises, and a bibliography
2. Reader with case studies and essential readings
3. Spreadsheet exercise

Note that the Reader does not contain:
- the DFID Handbook;
- reports produced under the IUCN Water Demand Management Programme.

These will be made available separately.

6. Course programme and time allocation

Since skills-training has a strong emphasis in this course module, sufficient time should be allocated to practical work.

For the post-graduate course module on WDM to fit within the WaterNet format, it should have a total duration of 15 days, of which one day dedicated to revision and swot and one day for the exam. The remaining 13 days are available for teaching/ training/ exercises/self-study/fieldwork. These could be filled as follows:

- 55% for conventional classroom teaching situations, including exercises etc.
- 45% practical field study, including report writing and presentation.

Moreover, at least 50% of the conventional classroom time should be dedicated to exercises, group assignments, etc.

The lectures and exercises before the field study exercise should provide all the tools and skills required, including methodology, to carry out a comprehensive systems analysis during the field study.
The following time allocation is therefore proposed:

Day	Teaching element
1	1. Water demand management in the context of IWRM; merits and limitations
	2. Systems approach to water demand management
2	3. The hydrological sub-system
	4. The engineering sub-system
3	4. The engineering sub-system
	5. The economic/financial sub-system
4	5. The economic/financial system
5	6. The political system.
	7. The information and communication sub-system
6	7. The information and communication sub-system
	8. Linkages: water networks as a holistic system
7	8. Linkages: water networks as a holistic system
8	9. Field study exercise: preparation
9	9. Field study exercise: data collection
10	9 Field study exercise: data collection; interpretation of data
11	9 Field study exercise: interpretation of data; sharing of data
12	9 Field study exercise: strategy document
13	9 Field study exercise: implementation priorities; presentation
14	Revision
15	Exam

The table below provides a suggestion how the total available notional study hours (3 weeks @ 40 hrs per week) can be assigned to the various types of study hours for this module:

Type of study hour	hours
Lecture hours	21
Supervised exercises	28
Groupwork (Practical field study)	48
Self study	20
Exam	3
Total notional study hours	120

7. Assessment

The following suggestion is made with regard to the assessment of the participants:

Type of assessment	weight
Assignments during coursework	20%
Groupwork (Practical field study)	15% (individual contribution) 15% (overall quality of group report & defence)
Written exam	(3 hours) 50%

NB The relatively large weight assigned to the overall quality of the group result and defence (15%) is because of the interdisciplinary nature of the exercise and the need for the individual participants to work as a team.

8. References

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Access: measures the performance of a system against constitutionally defined rights of citizens to water. An indicator may be the coverage of the water service over the population.

Allocative efficiency: the allocation of resources between competing uses so as to maximise the attainment of some social goal or goals. These goals could be defined in any way, to include for example equal access to a resource such as water. In conventional neo-classical economics, however, allocative efficiency is conceived of in a way that abstracts from equity. In the neoclassical approach, the goal is limited to the maximisation of **utility** (the degree to which human wants are satisfied). The criterion of efficiency is **Pareto optimality**, which states that an allocation is efficient if there is no possible improvement that could raise the utility of one consumer without reducing the utility of another (irrespective of the distribution of assets and resources amongst different consumers).

Asset database: A computerised database for network information comprising data to describe the networks geographical position, construction and condition.

Audit: Determining whether, and to what extent, the measures, processes, directives, and organisational procedures conform to norms and criteria set out in advance.

Benchmark: Reference point or standard against which progress or achievements may be com pared, e.g., what has been achieved in the past, what other comparable organisations or development partners are achieving, what was targeted or budgeted for, what reasonably could have been achieved under the circumstances.

Billing volume: The total volume of water actually recorded as having passed through a consumer meter during a specific time interval for which payment would normally be made.

Blue water: is water involved in the runoff (sub-)cycle, consisting of surface water and groundwater (below the unsaturated zone).

Capabilities of individuals are their abilities to do things that will enable them to lead fulfilled human lives. This is a term introduced by Amartya Sen, who conceives of economic development as a process of expanding the capabilities of people. Sen's ideas (see also definition of 'entitlements') have been widely adopted, for example by the United Nations Development Programme, which has promoted the idea of human development over the establishment fixation on economic growth and reliance on trickle down for the resolution of problems of inequality and poverty. Hence the establishment of the Human Development Index [HDI], which is published every year for almost all countries. It should be noted, however, that the construction of the HDI is limited by the availability of internationally comparable data and is thus a rather poor and inadequate measure of human development itself.

Conservation: Increasing the efficiency of energy use, water use, production, or distribution.

Conveyance loss: Loss of water from a channel or pipe during conveyance, including losses due to seepage, leakage, evaporation and transpiration by plants growing in or near the channel (also known as distribution loss).

Cost recovery: refers to the revenues generated by the tariff structure in aggregate covering operation and maintenance costs and perhaps also capital costs; see discussion under **Rising block tariff structure.**

Cross-subsidisation: see discussion under **Rising block tariff structure.**

Crop irrigation requirement: Quantity of water, exclusive of effective precipitation, that is needed for crop production.

Discounting: is a technique for systematically including time preference in the assessment of decisions which have consequences over a long time period. See also **Time preference.**

Economic approach: see **Service provision management as applied to water.**

Efficiency: is used in two different senses: Usage efficiency and Allocative efficiency.

Entitlements: are commodity bundles a person is able to command. The concept of entitlements (due to Amartya Sen) is a useful reference point when analysing why people fail to have access to basic requirements (such as food or water) despite plenty of these commodities being available overall. See also **capabilities.**

Equity: this principle measures the performance of a system in terms of allocation of the resource or the service over its population, and the volumes involved. An indicator may include the ability to pay. See also: **Access.** See also **Rising block tariff,** where equity refers rather narrowly to providing basic needs quantities of household water at a very low tariff that can be afforded by almost all households.

Feedback: The process of presenting the findings of an assessment, monitoring, review or evaluation exercise to any of the people involved in the work, so that the findings are incorporated into discussions, plans and policy relating to the work being evaluated.

Food security: the ability of a household or a country to provide its family members or its citizens with adequate levels of food.

Food self-sufficiency: the ability of a household or a country to produce its own basic foodstuffs. It is only in agrarian societies that it would make sense for all households to strive to be food self-sufficient.

The same logic applies to countries, yet it is very common for nations to confuse the two concepts and to place food self-sufficiency ahead of food security in its hierarchy of objectives.

Geographic Information System (GIS): A computerised decision support system that integrates geographical data, attribute data, and other spatially referenced data. A GIS is used to capture, store, retrieve, analyse and display spatial data.

Governance: Governance comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences (UNDP, cited in Rogers and Hall, 2003).

Green water: is soil moisture in the unsaturated soil layer, stemming directly from rainfall, that is transpired by vegetation

Inflation: the rate of change of prices in an economy. The first step in measuring inflation is to establish a price index. This is done by tracking the prices of a particular basket of commodities, putting each of these onto an index basis and calculating a weighted average index for the entire basket. Inflation is then the change in the index relative to say the previous month, corresponding month of the previous year or some average over a specified period. Like HDI as a measure of human development, measures of inflation have both practical and theoretical problems associated with them.

Information System (IS) for WDM: A computer system or related group system which collects and presents water management information relating to a water business within a local authority or utility in order to facilitate effective implementation and monitoring of water demand management measures.

Integrated Water Resources Management (IWRM): a process that "promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". (Source: GWP, 1999.)

Irrigation efficiency: The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage.

Leakage: The part of the water that escapes from the system, other than for normal outlets.

Long-run average incremental cost [LRAIC]: the strict 'marginal' or 'last unit' cost is often difficult to calculate and instead the average cost which would be incurred to meet a specified increment in demand is calculated. This is the average incremental cost and becomes the long-run average incremental cost when successive investments to meet demand increments are considered over an extended time horizon.

Long-run marginal cost [LRMC]: the marginal cost of supply taking into account future investment costs as well as operation and maintenance costs.

Management meter: A water meter installed in the water supply system, either at the point of ingress or at any other point, to measure the amount of water that passes through that point. Management meters are installed in each metering zones to measure the import and export of water in the zone.

Marginal cost: the cost incurred to supply the last unit demanded. This will typically be higher than the average cost incurred to supply the entire number of units demanded. One of the theorems of neoclassical economics is that allocative efficiency is achieved when the price of a commodity is set equal to the marginal cost of its supply. This rule is subject to all the limitations of neo-classical economics (see definition of **Efficiency**), but is often a useful starting point when deriving prices. A further refinement that is required is to distinguish between **short-run marginal cost (SRMC)**, **long-run marginal cost (LRMC)** and **long-run average incremental cost (LRAIC)**. In the context of infrastructural development, with large 'lumpy' investments being made at discrete intervals, both LRMC and LRAIC involve deriving the least cost supply augmentation and WDM investment sequence, and averaging over the resulting unstable SRMC curve by using a discounting approach (see Chapter 5, graph in Section 5.2.3, as well as definition of discounting).

Metering zone: A separately isolated section of a district or sub district, usually not exceeding 2000 – 4000 residential properties or their equivalent, and in which quantities of water entering and leaving can be measured.

Monitoring: A process of tracking or measuring what is happening. This includes: measuring progress in relation to an implementation plan for an intervention – programmes / projects / activities, strategies, policies and specific objectives; measuring change in a condition or a set of conditions or lack thereof.

Nominal values: monetary values which are subject to the effects of inflation. Nominal values, which reflect on-going price increases, are said to be in terms of 'money of the day'. See also **Inflation** and **Real values**.

Pareto optimality: see definition of **efficiency**.

Pressure zone: An area that is supplied from a single pressure control device or reservoir.

Price elasticity of demand: is a measure of the degree to which consumers react to prices changes. In more formal terms, the price elasticity of demand is defined as the percentage change in demand resulting from a percentage increase in price. Mathematically, if the demand curve as a function of price is Q(p), the elasticity at any particular point on the demand curve is $E = (dQ/Q)/(dP/P)$. The elasticity is a negative number since demand normally decreases as price increases, and typically the value ranges between –1 and 0.

Real values: monetary values which have been put onto a basis whereby they can be directly compared. This is achieved by removing the effects of inflation so as to produce values which reflect the same purchasing power or ability to acquire real goods and services. See also **Inflation** and **Nominal values**.

Rising block tariff structure: a tariff structure for water supplied within urban areas which simultaneously seeks to achieve **efficiency** of use of water, **equitable access** to water and **cost recovery** for the utility. These objectives are simultaneously achieved by having a basic volume of water available at a very low tariff, and subsequent tranches of demand at ever higher tariffs which progressively increase the incentive for efficient use of water. The essence of the structure is crosssubsidisation, with affluent customers with high levels of consumption charged at the highest tariffs providing the resources to subsidise poor customers who can only afford to consume minimal quantities of water.

Service provision management as applied to water: the deployment of water resources to meet the demand of consumers. Two broad approaches to the management of service provision can be distinguished: the *Supply-oriented approach* and the *Economic approach*. The latter approach values water as an economic good and seeks, through effective tariff mechanisms and other water demand management strategies, to ensure that water is used efficiently (in both the usage and allocative sense of efficiency). The economic approach is progressively supplanting the supply oriented approach.

Short-run marginal cost [SRMC]: the marginal cost incurred in the short-run, where adequate capacity is assumed to be available (the costs therefore are largely operation and maintenance costs).

Specific Water Intake: the volume of water consumed per unit of product produced; unit: e.g. m^3 water / tonne of produce. (Specific Water Intake is the quotient of Water productivity.)

Sustainability: The sustainability principle looks at the long-term survival of the system, and how it impacts on the wider environment and on the general issue of allocating a scarce resource among competing users. Here the focus is on long-term maintenance, the (economic) productivity of water (more jobs per drop) etc.

Sustainable system: A sustainable system is active and able to maintain its structure (organisation), function (vigour) and autonomy over time and is resilient in stress". (Source: after Costanza, 1994.)

System: A system is an entity that maintains its existence through the mutual interaction of its parts. (Source: Betalanffy, 1975)

Systems approach: A systems approach accounts for (1) the technical aspects, (2) the human relations, (3) the operating environment and (4) the effective utilisation of feedback.

Time preference: is preference for resources (such as water) now or in the near future over having the same resources at some later time. When the value of the resources are specified in monetary terms, it is important that real rather than nominal values are used before discounting, that is, before bringing time preference into the analysis. See also **Discounting, Inflation, Nominal values** and **Real values**.

Unaccounted-for water (UAW): the difference between the volume of water diverted from source and the authorised volume used by the consumers. The components of UAW are leakage in the transmission and distribution net work, water abstracted through illegal connections and water used for legitimate purposes which is not metered (e.g. fire-fighting). In cases where authorised yet unbilled water use is relatively small, unaccounted-for water may be equated with "un-billed water".

Usage efficiency: the avoidance of waste so that the minimum amount of a commodity is used to meet a particular need. It can be measured for instance by calculating how much water is used for a specific purpose.

Utility: is used in this training module in two very different senses.
- With reference to the neo-classical economics definition of efficiency, **utility** may be defined as the degree to which human wants are satisfied.
- **Utility** is also used to refer to a structure which is responsible for the supply of water to customers. This may be a public entity (such as a water and sanitation department within a municipality) or a stand-alone company (with public or private ownership or some form of publicprivate partnership).

Virtual water: the amount of water which would have been needed to produce a certain product (often crops), but which arrives in the country more efficiently and at a much lower cost than the importation of water itself.

Water budget: An analytical tool whereby the sum of the system inflows equals the sum of the system outflows.

Water consumption (or consumptive use): the flux (volume per time unit) of water use minus return flows; i.e. the net volume of water (a) incorporated in the product, and (b) lost through evaporation and/or transpiration; unit: e.g. m³/day.

Water demand management: the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource. (Modified from Savenije & Van der Zaag, 2002.)

Water demand: the flux (volume per time unit) and quality of water desired by one or more water users; unit: e.g. m³/day.

Water network: A system, be it natural or human-made that is a (potential) source of water that can be gainfully used by any form of life is a water network. Examples of water networks include: any natural system of watersheds, rivers etc.; any well equipped with a bucket and a winch; any network of pipes to supply water to customers; or any system of canals used to supply water to crops.

Water productivity: the amount of produce per unit of water consumed; unit: e.g. tonne of produce / m³ water. (Water productivity is the quotient of Specific Water Intake.)

Water use: the flux (volume per time unit) of water diverted for a specific use; unit: e.g. m³/day

Lecture note

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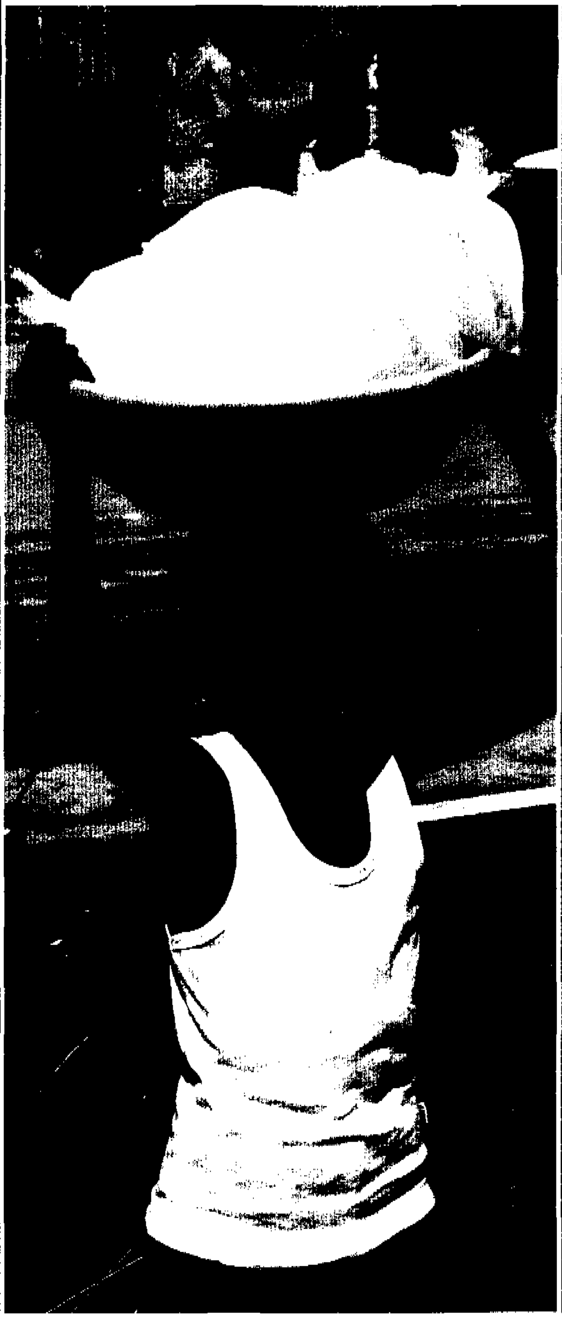
1. Water Demand Management in the context of Integrated Water Resources Management: merits and limitations

Lewis Jonker



1.1 Introduction

Water resources management can be defined as matching the supply of water with the demand for it. Water resources management is ideally the simultaneous management of supply and demand (Van der Zaag & Sa venije, 2000). Historically, water resources were managed under the "water resources development" paradigm. This "predict and provide" approach emphasised the supply-side of the water resources management equation. In areas with abundant water, a supply-side approach to water management might still be justified. However, due to increased water use during the last 20 years, the increasing cost of infrastructure, as well as a growing awareness of the negative environmental and social impacts, supply-side solutions appear to have reached their limits.

Demand management as a policy and strategic option for water resources management seems to have gained prominence at the same as the paradigm shift from water resources development to Integrated Water Resources Management occurred. It therefore is imperative to locate demand management within the context of IWRM to fully appreciate the contribution demand management can make towards water resources management.

1.2 Integrated Water Resources Management

The Global Water Partnership defines IWRM as:

Integrated water resources management

> Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

The advantage of IWRM as an organising concept for water management is the fact that IWRM focuses management attention on the entire water cycle. The water cycle for the purposes of this lecture note includes the human extension to the water cycle through the diversions introduced with the construction of water supply and sanitation infrastructure as well as irrigation infrastructure.

Governments, be they national, provincial or local, must manage the affairs of the country in a consistent manner to the benefit to all its citizens. These efforts are guided by policies and effected through legislation. Although legislation is critical for governance it is the policies that reflect the intention. Water policies in general are guided by a few policy objectives or principles (Savenije, 2003).

The South African water policy summarises the key objectives of the policy as providing:

> Some for all forever.

Some translate into equity, for all into access and forever into sustainability.

Access

Access measures the performance of a system against constitutionally defined rights of citizens to water. An indicator may be the coverage of the water service over the population.

Equity

Closely linked to access is the ***equity*** principle; this principle measures the performance of a system in terms of allocation of the resource or the service over its population, and the volumes involved. An indicator may include the ability to pay.

Sustainability

The ***sustainability*** principle looks at the long-term survival of the system, and how it impacts on the wider environment and on the general issue of allocating a scarce resource among competing users. Here the focus is on long-term maintenance, the (economic) productivity of water (more jobs per drop) etc.

Efficiency

The ***efficiency*** principle, finally, more narrowly measures the physical and financial performance of a system; which may be indicated by water losses, amount of unbilled water, whether cost recovery is achieved, the manner in which maintenance is carried out, response time to bursts etc. Other indicators assess the (immediate) productivity of water in productive processes such as in industry and agriculture (more crop per drop); and ask why users do or don't invest in more efficient technologies, re-use of water, treatment of effluent etc.

To attain these policy objectives a number and variety of tools are available.

1.3 Understanding Water Demand Management

Many definitions for Water Demand Management (WDM) are used. Below a number of these are given.

1. Water Demand Management is a management approach that aims to conserve water (quality and quantity) by controlling demand. It involves the application of selective incentives to promote the efficient and equitable use and allocation of water (IUCN – ROSA, 2002).
2. Water Demand Management is a process that seeks and implements appropriate and integrated ways of continuously increasing the social, ecological and economic benefits from a finite water resource and/or existing infrastructure in an equitable, resilient and sustainable manner (Hazelton et al., 2002).
3. Water Demand Management is about overcoming supply-side bias in the southern Africa water sector by striving to ensure that water is continually used optimally in order to promote equity and sustainability. (Amended definition by Hazelton et al. (2002, p2), because some stakeholders found the original definition too long.)
4. Water Demand Management is, "A management approach that aims to conserve water by controlling demand through the application of measures such as regulatory, technological, economical and social, at all spatial and institutional levels" (Nyambe et al, 2002)
5. The concept of water demand management generally refers to the initiatives, which have the objective of satisfying existing needs for water with reduced consumption, normally through increasing the efficiency of water (Gumbo et al., 2002).
6. Demand management aims at achieving desirable demands and desirable uses. It influences demand in order to use a scarce resource efficiently and sustainably (Savenije & Van der Zaag, 2002).
7. The adaptation and implementation of a strategy (policies and initiatives) by a water institution to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability (DWAF, 1999).

Seven definitions for one concept (and there are probably more) appear to be indicative of different understanding of water demand management. Some differences are more nuanced whilst other are more profound. Might this not be one possible reason for the difficulties in implementing demand management measures in water management?

> With which of the definitions are you most comfortable. If not any of them, what would your definition for water demand management be and why?

1.4 Water Demand Management measures

Approaches to demand management can be categorised into:

- Technological approaches (low-flush cisterns for toilets, low flow shower heads, leak detection and control systems in distribution networks, drip irrigation in agriculture).
- Economic approaches (pricing, taxes, subsidies)
- Social approaches (policies, legislation, awareness and educational programmes).

1.5 Costs and benefits of Water Demand Management

(Taken from Louw and Kassier, 2002; pp 51 to 59).

1.5.1 The Urban Sector

Cost to implement water demand measures in urban areas is related to

- Metering (installation, maintenance and monitoring).
- Installation of water saving devices.
- Information collection and management.
- Awareness and education programmes.
- Change of landscaping by using water efficient plants.
- Law enforcement.

Benefits of water demand management in the urban sector includes

- An increase in allocative efficiency.
- Increased end-use efficiency.
- Energy savings in the pumping of water.
- Reduction in unaccounted for water through leak detection.
- Reduction in pollution levels through the use of improved technologies.
- Reduction in purification costs through reduced volumes.
- Job creation through new skills required for water demand management.
- A reduction in the cost of treating water-borne sewage.

1.5.2 The Agricultural Sector

Cost to implement water demand measures in agriculture is related to

- The cost of new irrigation technology (for example drip irrigation).
- Increase in the cost of water.
- Structure replacement is also likely to be a significant cost item.

Benefits for the individual farmer of more efficient irrigation systems are:

- Increased yields, quality and profitability by employing improved irrigation scheduling.
- A reduction in the amount of fertiliser used through more accurate fertiliser applications resulting in higher yields and better quality products.
- Less (because of less water application) and cleaner (because of less fertiliser application) drainage water.
- A reduction in irrigation labour and managerial cost.
- Within a water market regime water can be sold or rented to other farmers or urban users and the income from this can compensate for the cost incurred to change to more sophisticated irrigation technologies.

1.5.3 Social costs and benefits

Social costs of water demand management are:

- Increased water tariffs.
- The cost of water efficient household appliances, efficient industrial processes and efficient irrigation technology.
- For the more affluent users a decrease in water consumption may lead to a decrease in consumer satisfaction (smaller gardens, swimming pools, bath tubs and other frivolous uses of water).
- A possible contraction of the agricultural sector could lead to decline in living standards through unemployment, increased crime levels, depopulation and the concomitant decrease in service levels (schools, shops, clinics).
- A reduction in water revenues that might impact on the quality of services rendered.

Social benefits

- May make water more affordable to the poor.
- Informs and empowers the communities.
- Creates job opportunities.
- Speeds up service delivery to communities without services by reallocating bulk infrastructure.
- Ensures the sustainability of water provision.
- Energy savings.
- Waste water flow reduction.
- Protection of the environment; and
- Reduction of costs by extending the life of existing water supply facilities.

Looking at the cost benefits analysis for the different sectors above, it is not always clear what the long-term benefits of water demand management would be. Furthermore, the above cost benefit analysis of WDM makes it difficult to make a judgement as to the value of WDM.

> A key question to answer is: who incurs the cost and where do the benefits go?

1.6 Constraints

Probably the most comprehensive list of constraints to water demand management is found in the Water Conservation and Demand Management (WC/DM) National Strategy Framework of the Department of Water Affairs and Forestry of South Africa (DWAF, 1999). The document lists 18 constraints. These are constraints are quoted from the policy document. They are:

- Financial constraints. Money is made available for supply side management measures but very little is made available for WC/DM initiatives.
- Resistance to change by water institutions.
- The principle often adopted in water resources management is to allocate all available water to consumers irrespective whether water is used efficiently or not.
- Officials and industry sectors protect their personal interests.
- Most consultants used by the water supply industry promote the development of infrastructure without adequately reviewing WC/DM measures as alternatives.
- Water institutions own supply side measures.
- Water conservation measures are perceived only as drought relief mechanisms.
- Fears that water conservation will result in reduced service levels.
- Supply side management options appears easier to implement.

- Existing planning practices choose the cheapest solution in implementation without regard to operating and running costs. (i.e. new housing developments).
- Lack of understanding of principles, scope and potential of demand management.
- Demand management strategies are often incorrectly perceived and implemented as punitive measures to consumers.
- Lack of integration and co-operation between various institutions in the water supply chain, particularly in the water services sector.
- Lack of ring fencing of the water services functions or the lack of integration and co-operation within the different departments of local authorities.
- Lack of knowledge and understanding of consumer and water usage patterns.
- Lack of adequate knowledge of the drivers causing growth in demand.
- The relative low price of water, particularly in the agricultural sector.
- The low level of payment for services by a significant number of consumers and users.

To this comprehensive list the constraints mentioned by Louw and Kassier (2002; page 31; after Forde & Arlosoroff, 1997) can be added.

- Lack of courageous policy making
- Disincentives for utilities to improve performance or invest in demand management.
- Strength of the farming lobby.
- Reluctance to involve the private sector and its commercial approaches
- Low profile of demand management activities ("no ribbon cutting").

> Constraints to specific SADC countries (Malawi, South Africa, Namibia, Zambia and Zimbabwe) can be found in the country reports of the IUCN commissioned Water Demand Management Programme Phase II.

1.7 Risks of Water Demand Management

Apart from the costs and constraints of WDM listed above there are a number of risks associated with the implementation of WDM measures. These risks include amongst others:

- The risk of clogged sewage systems due to the reduced water flow in the system. Sewage systems are designed to function with a certain amount of water in the system. Reduction in the flow volume and flow rate might impact negatively on the effective functioning of the system. Water demand management plans need to take this into consideration.
- Another risk is associated with the reduced revenue of water utilities due to the alternative use the "saved" water will be put. In the southern African context most of the "saved" water would probably be used to supply water to the un-serviced communities in urban areas and to emerging farmers in the rural areas.
- A further risk associated with reduced revenues is the increase in water prices to make up for the shortfall in revenues, especially in a policy environment of full cost recovery.
- Water saved in the reticulation networks might be lost from the reservoirs through evaporation.
- There is also the risk to the social fabric of rural communities should water be transferred from agriculture to urban settings.
- Demand management is a relatively new approach to water management and as such many of the implications and consequences (engineering, social, economic and environmental) are unclear (Dziegielewski and Bauman, 1992).

> In the summer of 2000/2001, the City of Cape Town, in anticipation of water shortage, initiated a very successful water restrictions campaign to reduce water consumption by 10%. However, the 10% reduction in consumption resulted in a loss of revenue of R25 million (approx. US$ 3.5 million – using an exchange rate of 1US$ ~ R7) over a four month period (Atwell & Ramsay, 2001).

1.8 Overcoming constraints

Many approaches to overcoming the constraints to the implementation of water demand management are described in the IUCN country reports, the DWAF National Strategic Framework and other literature, the details of which will not be explored here. Suffice to state that any approach needs to be carefully planned, targeted and consistently applied.

1.9 Conclusion

Indications are that water demand management is rarely implemented. Existing cultures and practices of engineering, economics and politics seem ill adapted to this new approach, and even appear, at times, to resist considering water demand management options on par with other water supply options.

Different people define water demand management differently. Although there are many commonalities amongst the different definitions, there also seems to be significant differences reflecting different understandings of WDM. It is important that for successful implementation of WDM, there need to be some common understanding of WDM within the implementing organisation.

Water demand management appears to entail a *delicate balance between maximising* the benefits, minimising the cost and mitigating the risks. No wonder that it is not a simple but a rather complicated process to implement. This teaching module recognises this complexity and the writers believe that we can only start implementing WDM if we understand the different subsystems of the water cycle and the consequences of the opportunities and threats in each of the subsystems.

Hopefully, as Integrated Water Resources Management as an organising concept in water management is accepted and entrenched, water demand management would become a tool of choice in water resources management.

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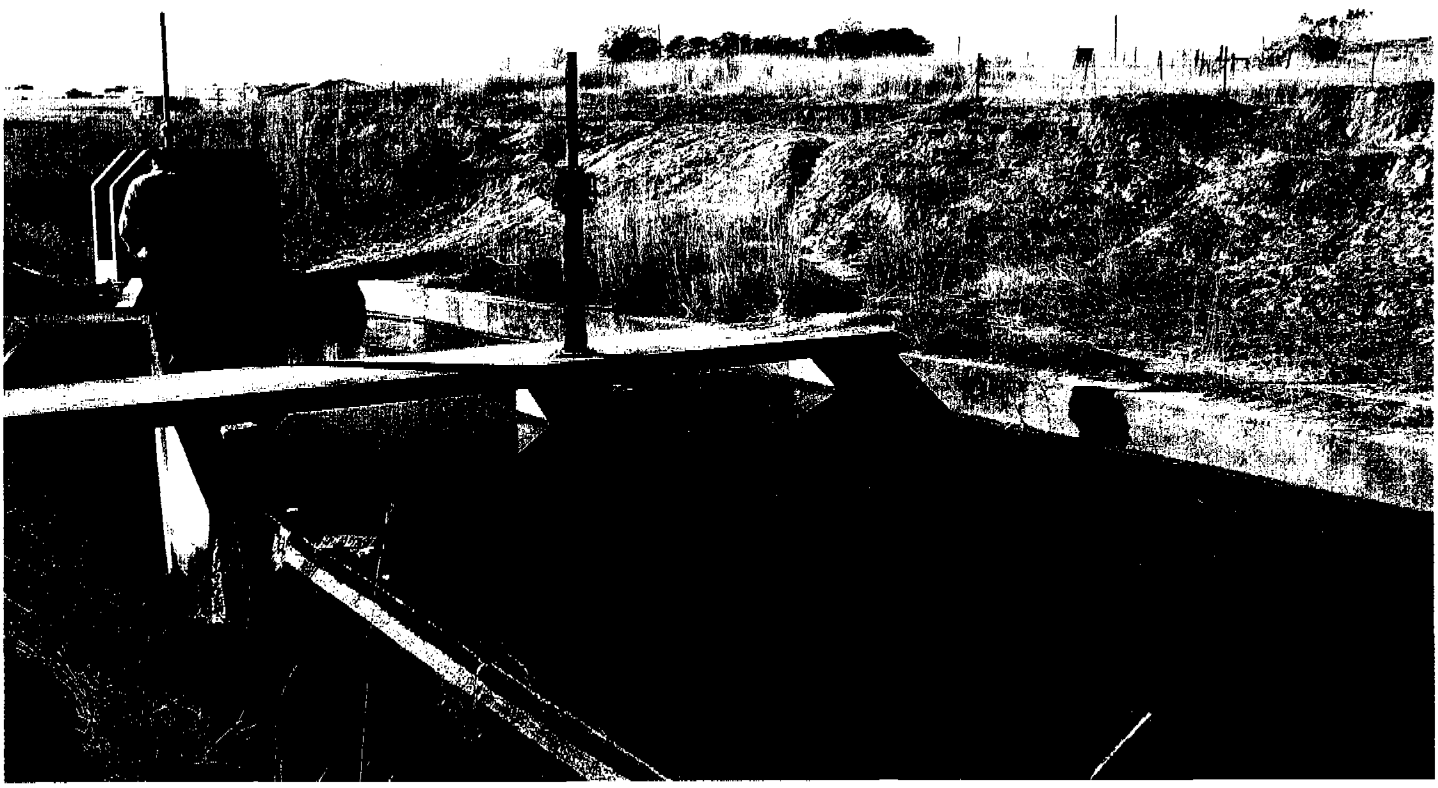
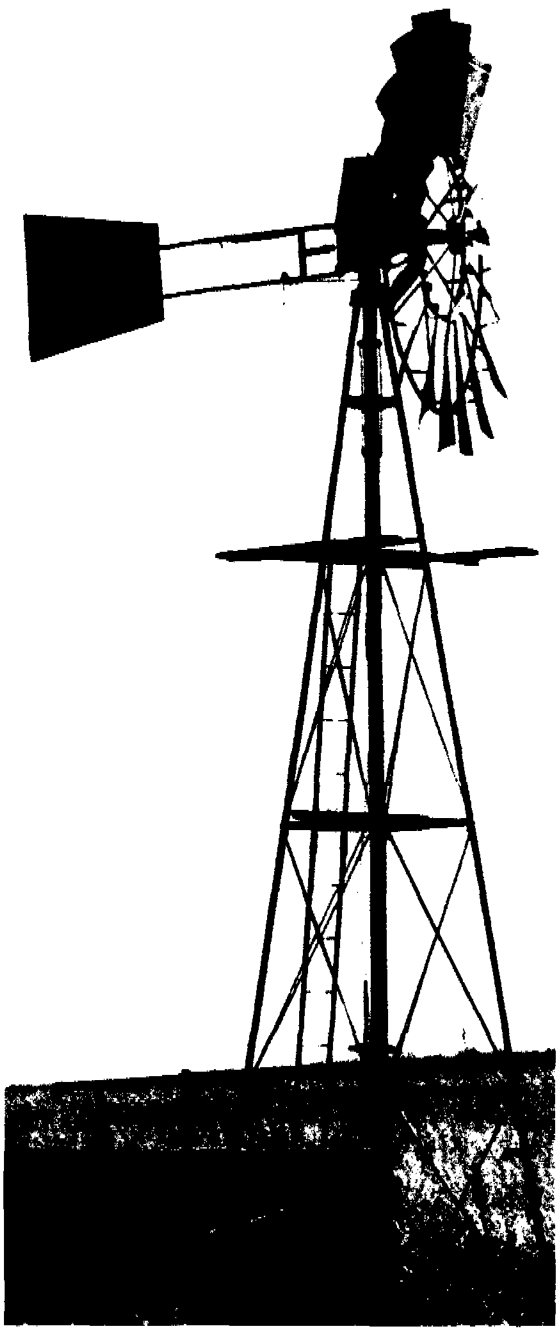


2. Systems approach to water demandmanagement

Bekithemba Gumbo & Pieter van der Zaag



2.1 Introduction

Water demand management is a suite of tools to manage a water system in a manner consistent with certain policy objectives. A water system can be a natural system of watersheds, rivers etc., but can also be a network of pipes to supply water to urban residents, or a system of canals to supply water to crops etc.

See: chapter 1

The object of Water Demand Management therefore is to manage a system. Such a system always contains more than one component.

System

> A system is an entity, which maintains its existence through the mutual interaction of its parts. (Bertalanffy, 1975)

The key emphasis in this definition by Bertalanffy (1975) is on "**mutual interaction**," in that something is occurring between the parts, over time, which maintains the system. This implies something beyond cause and effect. Rather than simply A affects B, there is an implication that B also affects A.

The developers of this course module find it important to take a systems approach to water demand management. This is because water demand management requires an understanding of the entire water system under consideration, be it an urban water supply system, an irrigation system etc.

One of the reasons why water demand management is rarely implemented, is that we often fail to understand a water system in its entirety, and that we tend to focus on certain aspects only, which are often not the causes of a system's weakness, but merely symptoms of some more fundamental weaknesses. Phrased positively, a more holistic approach to managing a water system may reveal all the benefits (including indirect gains) of implementing a combination of water demand management measures.

The benefits arising from water demand management by an end user or a water supply system may be large and often has a multiplier effect as one considers other users within a larger system such as a river basin. Box 2.1 summarises the cascading effect of water demand management benefits.

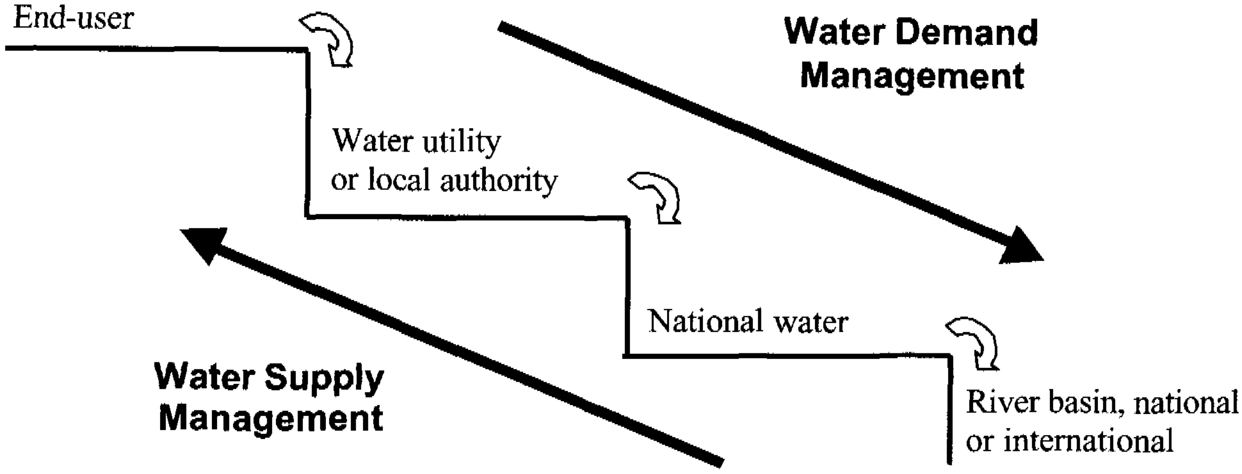
When analysing a water system it is critically important to carefully and precisely define the boundary between the system under study and its environment.

System – environment boundary

Once the system has been defined, we will do two things:

1. look inside the system, identify components, and see how these interact
2. look how the system interacts with its environment.

Box 2.1 The cascading benefits of water demand management by an end user



• Greater opportunity for other water users • Lower water use • Increase in reliability and risk reduction • Lowering the bottom line on water and energy costs • Opportunity for matching water quality and its use • Reduced return flows to public sewers and waterways • Reduced trade effluent charges	• More water available for other sectors and customers • Opportunity for re-allocation and prioritisation • Diminished burden of supply • Lower O&M costs due to reduced supply • Less influent to treat at Wastewater treatment plants	• Less water to be impounded and abstracted, hence delayed or avoidance in investment on dams and ancillary works • Reduced pollution of finite freshwater sources • Greater public access for the use of ecosystem services e.g. fish, fibre, clean water and recreation	• Sustainable development with more clean water available for ecosystem function and future generations • Responsible water resource sharing and stewardship • Enhancing conflict resolution and prevention • Trust building with downstream users and good neighbourliness

2.2 Principles of systems thinking

A systems approach to analysing a water system therefore means to have a detailed "**inside**" look at how the system functions by focusing on the interactions between its components. These components may be physical, such as pipes, but may also be non-physical, such as institutional arrangements, the knowledge of people etc. We are therefore interested in how these physical and non-physical entities influence each other through feedback loops. It is these interactions that bring the system to life.

However, we should never loose sight of the broad picture, or the **environment** in which the system operates. The system interacts with its environment, and has to respond when the environment changes. This is clearest when we think of the water source as an important external input into a water system. When there is a drought, the system has to respond accordingly. But also changes in the economy or political developments may require the system to respond. The broad picture implies looking in the upstream and downstream directions; literally when considering water, but also figuratively in terms of the wider social, economic and political context.

Look in upstream & downstream directions

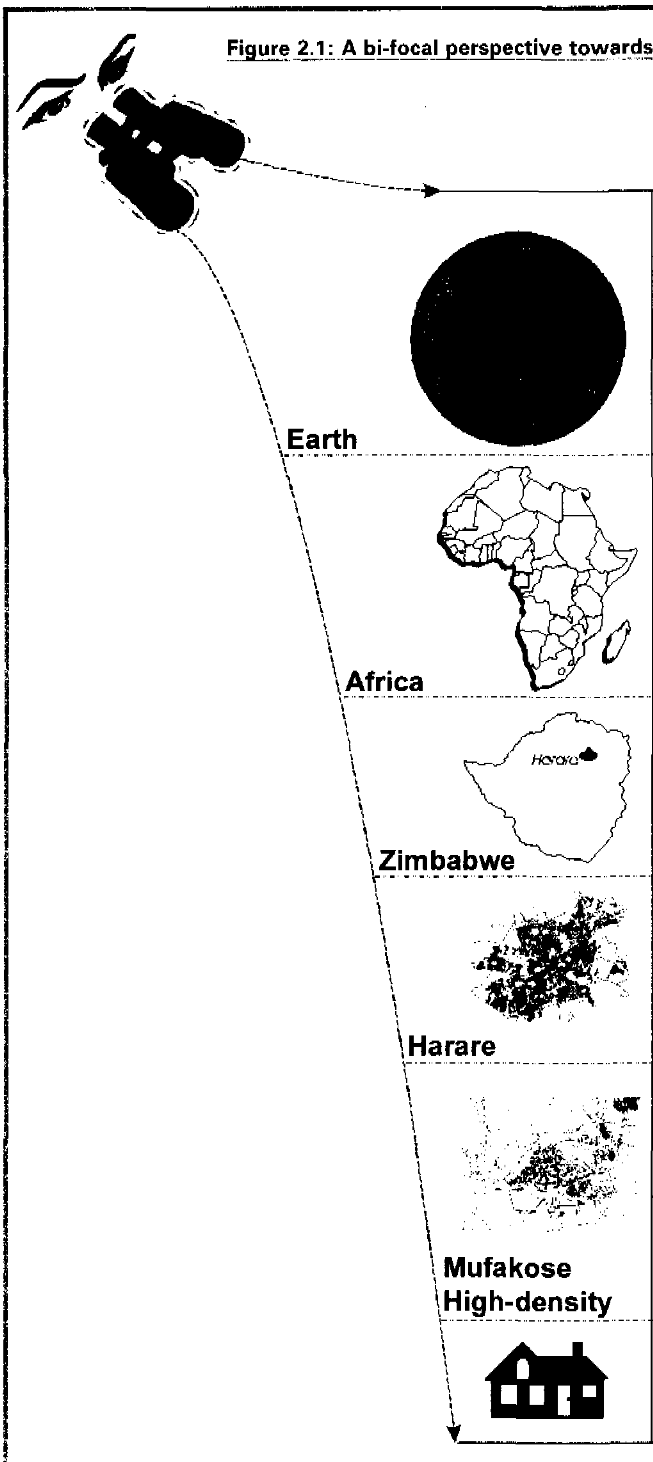
In other words, a systems approach requires a "bi-focal perspective": we use one eye to examine the broad picture, seeing the whole, and the second eye to look at the details at a micro scale (Figure 2.1).

2.3 The application of systems thinking

Systems:
1. Technical
2. Human
3. Environment
4. Feedback

The above forms the basis for applying the systems approach to water. We have to take into account the technical aspects, human relations, the operating environment and the effective utilisation of feedback. Box 2.2 illustrates the application of the contemporary systems thinking approach to an urban water supply system (Wright, 2002)

Figure 2.1: A bi-focal perspective towards a water system (Gumbo, 2003)



Administrative & Physical boundariies		Human Population 2002	Land surface area
Spaceship Earth	Global Atmosphere Lithosphere Hydrosphere Biosphere	6 Billion	510 066 00 km²
Regional or Continental	International River-basin	250 Million	30 313 000 km²
Country	River-basin	12 Million	160 000 km²
City	Stream catchment	1.5 Million	600 km²
Suburb	Stream Catchment	0.1 Million	7.0 km²
Neighour-ood	Micro Catchment	10 000	1.0 km²
Household	Superstructure Infrastructure Garden	10	200 m²

Box 2.2 Application of systems thinking to an urban water supply system

- ***technical aspects:*** how the various physical sub-systems combine and dovetail; whether certain subsystems create bottlenecks that limit the overall capacity of the system to supply sufficient water
- ***human resources and human relations:*** the technical system cannot work without knowledgeable and skilled human beings who operate various sub-systems, monitor, make decisions, and implement them; much in the same way that the various technical sub-systems dovetail, humans should also work together as a team with a clear division of labour and clearly defined interconnections.
- the ***environment*** within which the system operates: aspects external to the water system proper have direct impacts on it; think of fast economic growth that will increase the need for more water; health which impacts on population growth which in turn influences water requirements; climatic conditions such as a sequence of dry years which will diminish the availability of water; political conditions which may limit the availability of funds for proper maintenance

of the system; all these external conditions will impact on the system and will require the system to respond, e.g. its capacity may need to be extended, water demand may need to be reduced, certain parts of the physical system may need to be overhauled because of deferred maintenance etc.

- ***feedback and monitoring:*** knowledge concerning the state of the water system, and its productivity, is crucial for the system to be properly managed, and for appropriate decisions to be made: how much water is produced, of what quality, how much is delivered, how much billed, what is the level of unaccounted-for water, how many bursts, how much water leaks, do we break even, is revenue sufficient, are consumers able and willing to pay, is the tariff structure still adequate, is sufficient raw water stored to ensure uninterrupted supply, is rationing required, do certain parts of the system require upgrading etc. etc. All these questions require knowledge, based on interpretation of information, which can only be generated by means of a smart (lean and mean) monitoring system. Such a monitoring system requires measurement devices, readers, data collators, possibly computer programmes, and analysts.

2.4 Water networks as systems

Input-Output

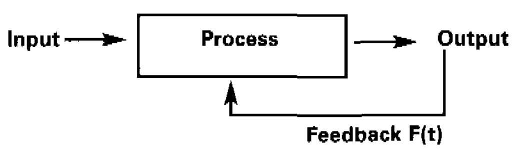
The most basic form of a water system only considers its inputs and outputs (Figure 2.2). This model describes the behaviour of the water system in terms of inputs and outputs: what happens with the output if the input is changed? Figure 2.4 gives a balance of an industry.

Figure 2.2 Input- Output model

Simple input-output models may be inadequate because water infrastructure has been created to honour a certain water requirement or demand. This means that the output of the water network is not only related to the input, but also how the network is being operated in order to satisfy the required downstream output. What is needed is to add a feedback loop, which flows in the reverse direction as the water. This feedback loop essentially models the demand for water (Figure 2.3).

Feedback loop

Figure 2.3: Input-Output-Feedback model

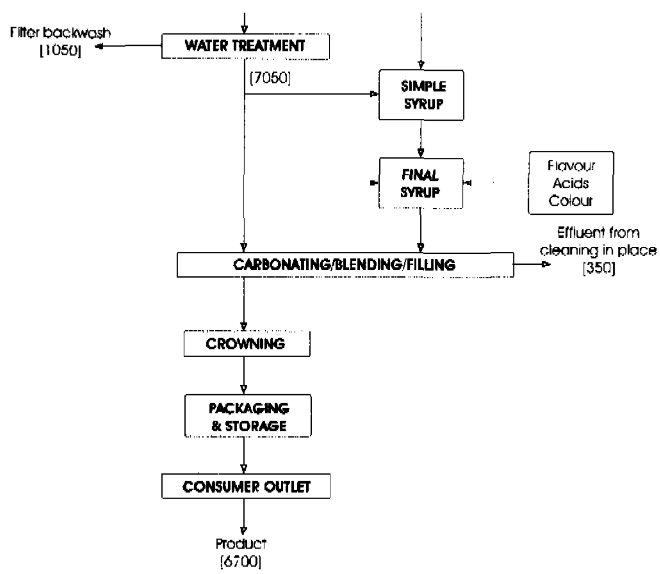


Feedback loops may take different forms. It may be physical or nonphysical. A simple example of a physical feedback loop is a toilet cistern with a floating valve: when the cistern is emptied, the valves opens and demands water from the piped system. If the network has sufficient water, water will immediately flow into the cistern until filled, when the valve automatically closes. If the system does not contain sufficient water, the cistern's demand for water will remain until such time that the water network again has sufficient water to satisfy this demand.

An example of a non-physical feedback-loop is a request from an irrigator to a dam operator to open the gate. Depending on the institutional reality (does the irrigator have a legitimate claim on water, i.e. does he or she has a water permit, did he or she pay the annual fee, can the irrigator show he or she will use the water beneficially, is the amount requested reasonable, etc.) and the operational rules (is the dam full or empty, are new inflows into the dam expected, must other requests also be considered, do some requests have priority over others etc.), the demand will be satisfied either in full, or partially, or not. Even a physical feedback may have an institutional dimension: if the household with the toilet cistern did not pay its water bill, the water authority may physically disconnect the cistern from the supply network.

A system's understanding of the operation of a human-made water infrastructure can therefore never be limited to physical water flows alone. Such a system will be a hybrid system, containing physical and non-physical parameters. Such a hybrid system will contain interfaces, where the physical and the non-physical dimensions meet (Box 2.3).

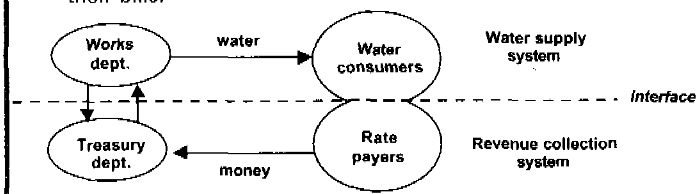
Figure 2.4 Simplified flow diagram of water in the production of soft drinks, Bulawayo, Zimbabwe (Figures in m³/month) (Gumbo et al., 2002)



Box 2.3 Hybrid systems

Consider a local authority supplying water to its residents, and collecting revenue for the services provided. In some situations, two systems may be distinguished:

1. the water supply service consisting of e.g. the works department, the physical water network and the water consumers;
2. the revenue collection system, consisting of the Treasury department, which produces bills that are sent to the ratepayers, who pay their bills.



A water supply system, a revenue collection system and their interfaces

The interfaces between both systems are clear: the water consumers are the same actors as the ratepayers, and the Treasury and Works departments are part of the same local authority. Moreover, the Treasury needs to know from the Works department how much water should be billed to whom. The Works department, in turn, requires money from the Treasury to operate its water supply system. In cases where these interfaces are not clearly defined, the water supply system may become unsustainable. There is therefore need to consider both the revenue collection and the water supply system as being, in actual fact, sub-systems of one water services system.

2.5 Subsystems considered in this course module

In water demand management different disciplinary fields often consider different systems. These must therefore appropriately be considered subsystems that are part of a more encompassing whole. The challenge of water demand management is to widen the system boundaries, so as to include the relevant disciplinary sub-systems.

Hydrologists model the generation of soil moisture, evaporation, transpiration, groundwater and surface water, the input being rainfall. This can be considered the ***hydrological system***, which often forms the basis for the conceptualisation of many water resources systems. Indicators may include the runoff co-efficient.

See: chapter 3

Engineers model the behaviour of human-made infrastructure, in terms of capacities of the system to convey or store water, or to treat raw water or effluents. Such models of ***engineering systems*** often include a term representing water generation, derived from the outputs of a hydrological system.

See: chapter 4

A water network will also contain a (more or less sophisticated) ***information and communication system*** for the collection of data required to monitor and evaluate the status of the water system, asset management, as well as for billing etc. Indicators may include: the level of unaccounted-for water, billing rates and payment levels (see Gumbo, Juizo & Van der Zaag, 2002).

See: chapter 7

Economists model flows of money, rather than water, and consider ***economic and/or financial systems***. Input terms may be one-off, such as capital investments, and revenue generated during the life span of a human-made infrastructure. Output terms may include costs of operation and maintenance, and the depreciation of the invested capital. Indicators developed may include the unit cost of producing treated water, the internal rate of return of the system etc. (see Arntzen et al., 2000; Robinson, 2002).

See: chapter 5

A water network is not an end in itself. It is intended to serve a certain purpose, namely satisfying the demand for water of a certain constituency, for instance a community of irrigators, or the residents of a city, or, at the level of the river basin, to satisfy the different demands as much as possible, taking into account the needs and rights of the various user communities. Users may evaluate the water service using various indicators, an important one being the reliability, and timeliness, of supply. Others include the water quality, and the cost of water. The intended beneficiaries have a way of communicating with those operating the water network, and provide feedback about their evaluation of system performance. Often the link between operators and users is institutionalised, defining the rights and duties of both types of actors. Operators may or may not be accountable to the user groups they are supposed to serve. Conversely, users may or may not respond to signals given by the operator to improve the beneficial use of water. This dimension may be termed the ***political/institutional system***. It is concerned with the *needs and interests* of people involved in a water system. It is the most difficult and complex part of a water network, and theleast tangible. It covers important issues such as the *demand* for water by various users, and whether various user groups manage to claim and access the resource, either through legal and institutional means, or simply by force of power, and whether in the process other groups are excluded or marginalised. It also looks at the operators of water networks, often monopolists, and to what extent they adhere to the institutional and legal rules of the game, or abuse their position, and generally how they relate to user groups, as well as to politicians and financiers (see also Gumbo & van der Zaag, 2002).

See: chapter 6

Since water demand management is premised on a holistic understanding of water, it requires a system's understanding that integrates hydrological, engineering, information & communication, economic/financial and political/institutional-related aspects.

A holistic understanding of a water system will take into account all five sub-systems identified, and how these are intertwined in the system under consideration. The point is that any water system can be understood by considering these five sub-systems, establishing balances for these, and analysing the interfaces or linkages between them.

2.6 Integration of subsystems

The linkages between the various sub-systems are essential, as these make the system as a whole perform as it does. The linkages may be well-designed and reinforce the positive attributes of the various subsystems so that performance is high. The linkages may also make the system perform worse. A perfectly designed water network without a proper system of financing its operation and maintenance inevitably will collapse some time in future. Similarly, a water network with a sophisticated information and billing system, but tariffs at exorbitant rates, will exclude the poor from accessing water. Such a system will compromise the rights of the poor to clean water and health, and will not serve its intended purpose. A water system that is operated by someone who is not in any way accountable to the users is likely to perform sub-optimally.

Water networks often leak water. A holistic approach to water resources is concerned with water losses,

Water leakages

which are considered a sink. Minimising leakages is often the most cost-effective strategy towards system's improvement. Water losses in a piped urban water supply network reduce the system's capacity, cost money, and may cause environmental problems and water borne diseases. Consequently, reducing physical water losses increases a system's capacity to deliver water, saves money and reduces environmental and health problems.

Reducing the demand for water is possible in many situations – without necessarily compromising the

Demand reduction

quality of the water service. In general, doing more with less makes economic sense, will improve access to the resource by newcomers, and may be beneficial to the environment. Especially in a situation where no prior attention to demand management was given, the first measures will be relatively cheap to implement, and have a large impact. Retrofitting of water appliances in households is a good example (Box 2.4).

Box 2.4 Retrofitting plumbing fixtures in urban water supply systems

Retrofitting plumbing fittings, such as installing low volume water closets and low volume shower roses, may reduce overall water use by 25% of domestic water consumption (Martindale and Gleick, 2001). One immediate and cheap measure that can be implemented is to reduce the cistern capacity of toilets. Gumbo (1998) estimated that water used for flushing constitutes about 30% of total domestic water use. 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, without compromising the quality of the service enjoyed. In New York 1.33 million inefficient toilets were replaced by efficient ones during 1994-1997, reducing the city's consumption by 0.3 Mm^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 (Martindale & Gleick, 2001).

Retrofitting of irrigation systems, for instance replacing furrow irrigation by drip systems, is often prohibitively costly. But the results may be astonishing: drip irrigation may more precisely provide the required amount of water at the required place, resulting not only in reduced water consumption, but often also in increased yields (Box 2.5).

Box 2.5 Retrofitting irrigation water systems

An example is a sugar estate in Swaziland, where a state-of-the-art drip system replaced sprinklers. Whereas water consumption decreased with 22%, sucrose yields increased by 15%. Overall water use efficiency (expressed in kg sucrose per m^3 irrigation water applied) consequently increased by 45% (Merry, 2001).

Combining strategies that reduce water losses and reduce water demand may be sufficient to significantly slow down the annual increase in water demand, and thus postpone the construction of new supply infrastructure.

Tracing fluxes of water is essential in analysing water systems and formulating appropriate

Money fluxes

intervention strategies. Similarly, fluxes of money are important for understanding a system's ability to cover the costs of maintenance, replacement of hardware after their life span has expired, and the construction of new supply infrastructure.

Maintenance

Often, long-term maintenance is not carried out, nor reservations made for future required infrastructure development. Money fluxes will pinpoint to the strength and weaknesses of current financial arrangements. This is naturally linked to who owns and ope ates the infrastructure. Many water supply systems cannot generate sufficient funds to cover the cost of longterm maintenance and overhaul. In such a situation, either tariffs have to increase, or other sources of money be made available, if the system has to be sustained in the long run. Other systems do generate sufficient funds, but revenue in excess to short term operation and maintenance costs is siphoned off and appropriated by the owner of the infrastructure. Such an arrangement jeopardises the system's long-term sustainability (see e.g. Gumbo & Van der Zaag, 2002; Dube & Van der Zaag, 2002).

Systems that cannot be sustained financially in the long term will gradually deteriorate and performance will suffer, which goes against the essence of water demand management. Analysing money fluxes is therefore essential for developing strategies that ensure the system's long-term financial sustainability. Financial sustainability may lead to tariff increases that cannot be afforded by the poor. Appropriate tariff design that include crosssubsidies are another major feature of analysing the financial aspects of a water system (see e.g. Kaumbi, 2000; Dube & Van der Zaag, 2002).

Cross subsidies

See: chapter 5

2.7 Conclusion and lessons

A successful system is a system that remains sustainable. The following is a good definition:

> A sustainable system is active and able to maintain its structure (organisation), function (vigour) and autonomy over time and is resilient in stress.
> Source: after Costanza (1994).

Sustainable system

More generally, a water system must be analysed against generally accepted policy principles, or objectives, of water provision. Four key principles include: access, equity, sustainability and efficiency Postel, 1992; Jonker, 2002).

See: chapter 1

Lessons:

1. Water demand management requires a system's understanding that integrates hydrological, engineering, information & communication, economic/financial and political/institutional aspects.
2. Linkages between these aspects make or break a water system. A holistic approach to water resources management therefore critically analyses these linkages. Water demand management strategies typically are geared towards improving the linkages between subsystems, so as to enhance overall system's performance.
3. Understanding the dynamics of a water net work is impossible without analysing money fluxes.
4. A systems analysis of a water network allows conclusions to be drawn concerning access, equity, efficiency and sustainability.
5. WDM is multidisciplinary in nature and its success is founded on overcoming the traditional disciplinary divide in water management.

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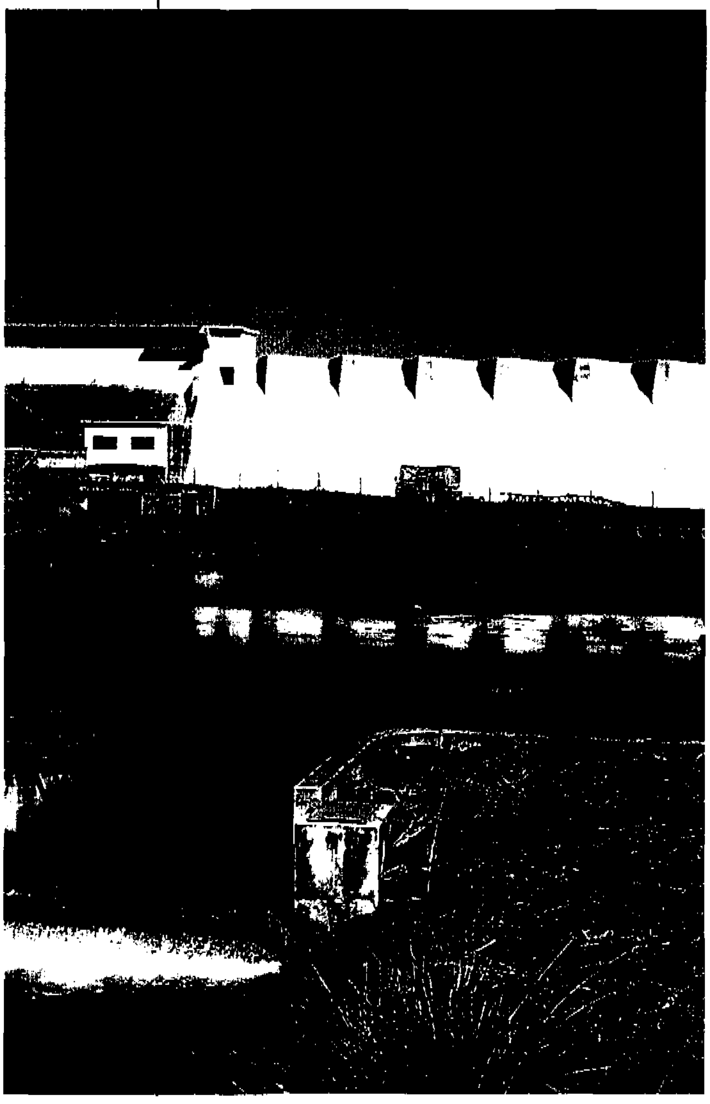
3. The hydrological system in the context of water demand management

Pieter van der Zaag



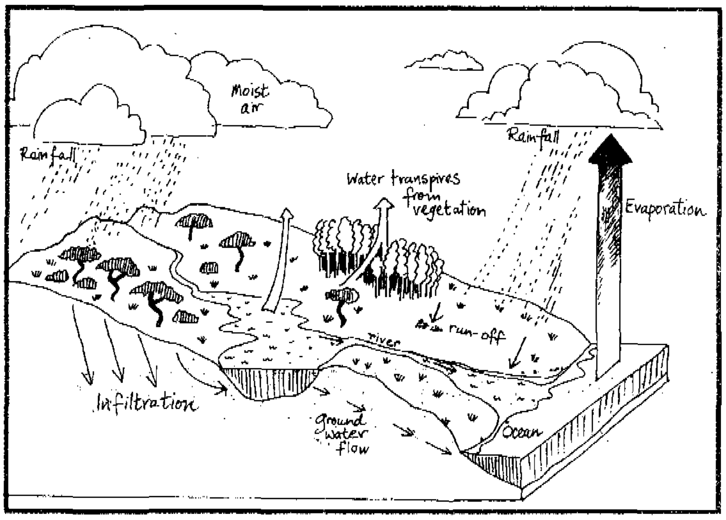
3.1 Introduction

The annual water cycle from rainfall to runoff is a complex system where several processes (infiltration, surface runoff, recharge, seepage, reinfiltration, moisture recycling) are interconnected and interdependent withonly one direction of flow: downstream.
A catchment is therefore one single system and more than the sum of a large number of subsystems.

System

Our water use is embedded in the hydrological system. *It is therefore important that we consider the* hydrological system and locate our water use in it.

Figure 3.1: A depiction of the water cycle (Pallett, 1997:20)



The hydrological system is the source of water. Whereas water is finite, it is also renewable through the water cycle. The hydrological system generates the water that we need for drinking and other domestic use, for agricultural production (both rainfed and irrigated), for industrial production, for recreation, for maintaining the environment, etc.

The hydrological system also receives return flows from human water use. This can be in a form not often recognised, namely as water vapour from transpiration of crops and evaporation from natural and man-made lakes.

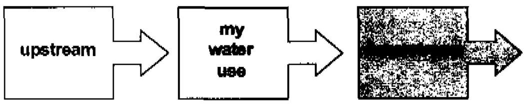
"Grey" return flows normally are more conspicuous, such as sewage water from cities and industries that flow back into rivers. Such flows may also percolate into aquifers, often carrying with it pollutants (e.g. from irrigation). In heavily committed catchment areas, downstream users may depend on return flows as the source of their water.

Why is it important to consider the hydrological cycle when dealing with water demand management (WDM)? One could argue that effective WDM measures would lessen the burden on the hydrological system, and no further considerations need to be made.

However, water use patterns will change as a result of water demand management measures. This will always have a downstream impact. Often this impact will be positive, for example when less water is abstracted, and more water remains in the system for downstream users and/or the environment. But some impacts may be unexpected. Leakages from distribution networks may recharge local aquifers, which may be heavily utilised by urban dwellers. These may have come to depend on this source of water. When leakage control has been successful, less water will percolate into the aquifer and with pumping rates remaining the same, water levels may drop.

Another case is increasing the efficiency of irrigation systems, which often leads to a more reliable, more precise and better timed flow to the irrigated crops, translating into higher yields, which are accompanied by higher transpirative water use. The net "gains" from decreased water losses and increased efficiency of irrigation systems may thus be less than superficially calculated. Downstream users who have come to rely on the return flows from inefficient irrigation may face decreased water availability.

Figure 3.2: Everybody lives downstream..., and upstream



In light of the above, water demand management requires a serious consideration of the hydrological system, and always implies "looking upstream" in order to assess water availability, and "looking downstream" in order to assess possible third party effects.

Upstream-downstream interactions

3.2 The hydrological cycle

The hydrological cycle can be studied at different spatial scales. One starts with considering a certain area (e.g. an individual plant, a farmer's field, a watershed, a catchment area, an international river basin, an ocean, the earth). It is crucial for a system's approach to carefully define the boundaries of the area under consideration, and any water fluxes that cross them. These are either inflows into the area under consideration, or outflows. Subsequently all other sources of water into the area are identified, and all types of consumptive uses, as well as any return flows from such uses.

System boundaries

It is useful to distinguish three different types of water depending on their occurrence in the water cycle (Falkenmark, 1995):

- 'white' water = rainfall and that part of rainfall which is intercepted and immediately evaporates back to the atmosphere
- 'green' water = soil moisture in the unsaturated soil layer, stemming directly from rainfall, that is transpired by vegetation
- 'blue' water = water involved in the runoff (sub-)cycle, consisting of surface water and groundwater (below the unsaturated zone).

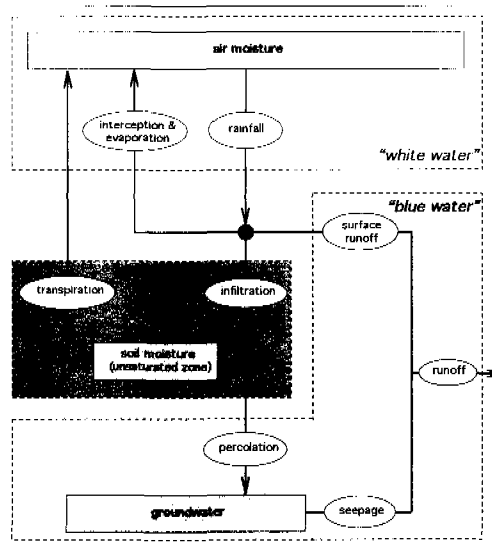
Green water

Blue water

Figure 3.3 gives a schematic representation of the hydrological cycle, distinguishing between these three flows. The processes occurring within the three "colours" of water, as well as their interconnections, determine the characteristics of each natural hydrological system.

Two aspects will be briefly highlighted in the remainder of this section, namely watershed management (which focuses on rainfall partitioning) and the relationship between groundwater and surface water.

Figure 3.3: The hydrological cycle, with 'white', 'green' and 'blue' water, and the two partitioning points



3.2.1 Watershed management

The two black points in Figure 3.2 represent the two processes that determine how rainfall is partitioned into interception (direct evaporation from the soil, leaves and other surfaces), infiltration, transpiration, percolation and surface runoff. These two "partitioning points" therefore influence how much of the rainfall ends up in our rivers, and when. They are also important intervention points by humans in the hydrological process.

The first partitioning point occurs at the surface where a drop of rainwater will either (a) return to the atmosphere as water vapour through interception; or (b) infiltrate into the upper soil layer (the "unsaturated zone") where it appears as soil moisture; or (c) runs off directly into a stream or river.

Evaporation (interception)
Infiltration
Surface runoff

The manner in which rainfall will be distributed over these three routes depends on surface characteristics, such as permeability, slope, canopy of crops etc. On impervious tarmac some rainfall will evaporate directly from the surface (interception), no water will infiltrate and by far the largest part will run off as surface water. In contrast, an undisturbed rainforest will capture much of the rainfall on its canopy before the raindrop even reaches the soil. A large part of the remaining rainfall may infiltrate and relatively little will run off directly over the surface.

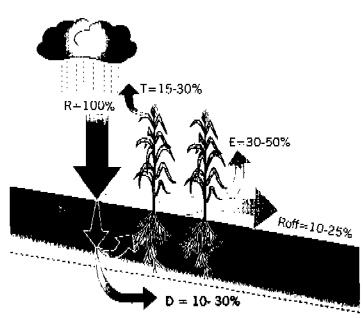
The second partitioning point is located in the upper soil layer, the so-called unsaturated zone. The water from rainfall that has infiltrated into the soil will either (a) be taken up by the roots of plants which will use it to transport nutrients to the leaves where the water will transpire into the atmosphere as water vapour; or (b) percolate deeply beyond the root zone and eventually join the water table, recharging the aquifer.

Transpiration
Percolation

If the soil is sandy, with a coarse structure, more of the infiltrated water will percolate beyond the root zone. With a well-developed root system chances are higher that the soil moisture will be taken up by the crop and transpire.

The major human interveners in the above two partitioning points are farmers who manage their soils and crops (Figure 3.4).

Figure 3.4: Rainfall partitioning in farming systems in the semi-arid tropics of sub-Saharan Africa
(Rockström et al., 2001)



Bad soil management and poor cultivating practices will have detrimental effects on the hydrological cycle: more water will run off directly, leading to high storm flows, and less water will infiltrate. Less water will therefore be available to crops and the baseflow in the rivers downstream is likely to decrease. Certain exotic (alien) species have very large water requirements (such as certain exotic trees) and because of their high transpiration, percolation is reduced. As a result base flows are affected and rivers dry up.

Exotic species

Soil and water conservation

Watershed management, understood as soil and water conservation and management, has as its principal objective to favourably influence the two partitioning points, so as to (a) increase infiltration and decrease surface runoff and the resulting erosion; and (b) increase crop production through enhanced availability of soil moisture. The resulting flow regime of "blue" water is often that storm flows have lower peaks *and carry less soil particles from erosion, and that the* baseflow is hardly affected, or indeed increases.

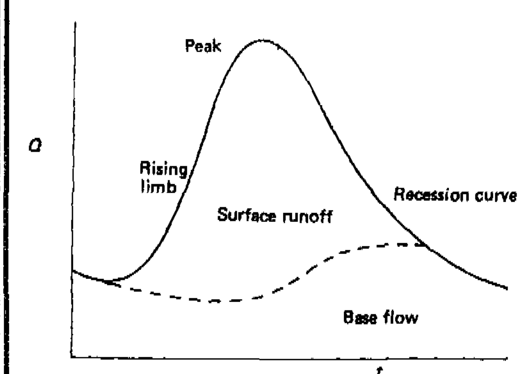
3.2.2 Groundwater as part of the hydrological cycle

Renewable groundwater takes active part in the hydrological cycle and hence is "blue water". [1]Groundwater feeds surface water and vice versa. One can say that all renewable groundwater becomes surface water and that some of the surface water was groundwater. Especially in dry climates the existence of underground storage of water is important.

The water stored in the subsoil becomes available in two ways. One way is by artificial withdrawal (pumping), the other is by natural seepage to the surface water. The latter is an important link in the hydrological cycle. Whereas in the wet season river flow is dominated by surface runoff, in the dry season rivers are almost entirely fed by seepage from groundwater (base flow). Thus the groundwater component acts as a reservoir which retards the runoff from the wet season rainfall and smoothens out the shape of the hydrograph (Figure 3.5). This also means that abstractions from groundwater will diminish the base flow in downstream rivers.

Seepage
Base flow

Figure 3.5: Hydrograph separation between surface and ground water



1 In contrast, fossil groundwater is non-renewable and can be used only once (mined).

3.3 Water balances

One of the aims of Water Demand Management is to efficiently utilise scarce water resources. WDM therefore requires one to know where the water has gone, and in what form: was it consumed by a crop or a person, or was it "lost" through leaking pipes or evaporation from the open surface before it could reach the intended consumer? Drawing up a "water budget", better known as a water balance, is an effective tool for this purpose.

In hydrology water balances are widely used. Water balances are based on the principle of continuity. This can be expressed with the equation:

$$\frac{\Delta S}{\Delta t} = I(t) - O(t) \qquad (3.1)$$

where *I* is the inflow in [L3/T] [L = unit of length;

T = unit of time
O is the outflow in [L3/T]
$\Delta S/\Delta t$ is the change in storage
over a time step [L3/T]

The equation holds for a specific period of time and may be applied to any given system provided that the boundaries are well defined. Other names for the water balance equation are Storage Equation, Continuity Equation and Law of Conservation of Mass.

The water balance equation is based on a systems understanding of the water cycle by considering its inputs and outputs. The water system interconnecting the input and the output is represented by the storage component (Figure 3.6).

Input-output system

Figure 3.6: Input-Storage-Output model

Input I(t) → **Storage S** → **Output O(t)**

The water balance consists of a flux and a stock. The flux is represented by the incoming and outgoing flows of water, and has as its unit volume per time. The stock is the capacity of the system to store the flux of water. This storage capacity has as its unit volume.

Dividing the stock by the flux, yields a useful measure, namely the average residence time of a water particle in the stock:

$$\text{Residence time} = S / I(t) \qquad (3.2)$$

Several types of water balances can be distinguished. In the following, two water balances are briefly elaborated: a drainage basin and a rainfed crop.

3.3.1 The water balance of a drainage basin *(Savenije, 2000)*

The water balance is often applied to a river basin. A river basin (also called watershed, catchment, or drainage basin) is the area contributing to the discharge at a particular river cross-section. The size of the catchment *A* increases if the point selected as outlet moves downstream. If no water moves across the catchment boundary, the input equals the precipitation *P* while the output comprises the evapotranspiration *ET* and the river discharge *Q* at the outlet of the catchment. Hence, the water balance may be written as:

$$\frac{\Delta S}{\Delta t} = (P - ET)\,A - Q \qquad (3.3)$$

ΔS, the change in the amount of water stored in the catchment, is difficult to measure. When computing the water balance for annual periods, the beginning of the balance period is preferably chosen at a time that the amount of water stored is expected not to vary much for each successive year. These annual periods, which do not necessarily coincide with calendar years, are known as hydrological years. For a hydrological year, DS/Dt may generally be neglected. Table 3.1 gives the water balance for some African rivers.

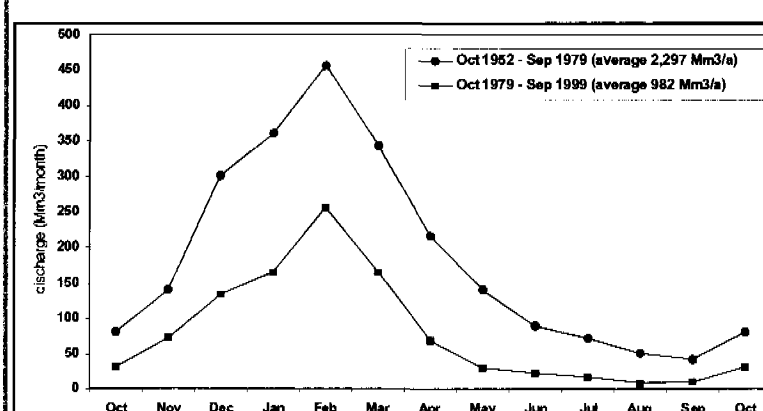
Table 3.1: Average annual water balance for the drainage basins of some rivers

River	Catchment area Gm²	Rainfall mm/a	Rainfall Gm³/a	Evapo-trans-piration mm/a	Evapo-trans-piration Gm³/a	Runoff mm/a	Runoff Gm³/a	Runoff co-efficient %
Nile	2,803	220	620	190	534	30	86	14
Zambezi	1,300	990	1,287	903	1,174	87	113	9
Incomati	47	733	34	656	31	77	4.6	10

3.3.2 The water balance as a result of human interference

Some river systems have been significantly altered due to human interference with the hydrological cycle. This is the case, for example, in the Incomati river basin (Carmo Vaz & Van der Zaag, 2003). This basin is shared by South Africa, Swaziland and Mozambique. In this basin more than half of the average amount of water generated is being consumptively used; mainly for irrigation, rural domestic use, and urban and industrial use. In addition, water is transferred out of the basin into adjacent river systems. Most of these uses required the construction of dams and reservoirs. Commercial plantations of exotic forest species (mainly for the paper industry) have increased transpiration and decreased runoff.

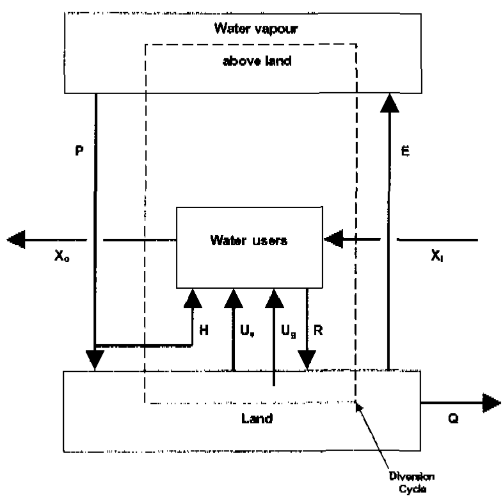
Figure 3.7: Average discharge of the Incomati at Ressano Garcia (station E23); 1953-1979 and 1980-1999 *(Carmo Vaz & Van der Zaag, 2003)*



As a result of these human interventions, the flow regime of the Incomati has been altered. Figure 3.7 shows this effect, by comparing the average runoff in the Incomati pre- and post-1980 at the border between South Africa and Mozambique, just after the confluence of the Komati and Crocodile rivers. Average runoff during 1980-1999 was less than half of that during 1953-1979.

Attempts have been made to incorporate the interference of man in the hydrological cycle through the introduction of the water diversion cycle, which includes water withdrawals and return flows (Figure 3.8).

Figure 3.8: The hydrological cycle of a river basin with the diversion cycle
(after Rodda and Matalas, 1987)



P = precipitation
$E = T + I + O$ = total evaporation from land surface and open water
Q = runoff from land to ocean
Xi , Xo = interbasin transfer into or out of the basin
H = direct use of rainwater
$Us+Ug$ = abstraction from surface and groundwater
R = return flows to surface and groundwater

3.3.3 The water balance of a crop

A simplified water balance of a rainfed crop is presented in Figure 3.9, and can be expressed by the following equation:

$$P = E + T + D + R_{off} + \Delta S/\Delta t \qquad (3.4)$$

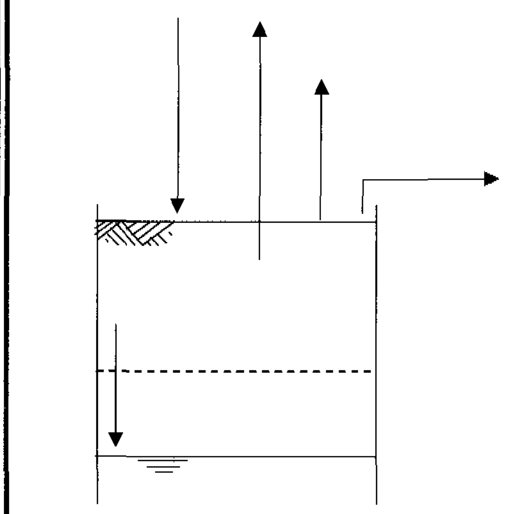
where P: precipitation (L3/T; e.g. m^3/day or, if divided by area mm/day)
E: evaporation (L^3/T)
T: transpiration (L^3/T)
D: deep percolation (L^3/T)
R_{off}: run-off (surface outflow from field to downstream) (L^3/T)
$\Delta S/\Delta t$: change of soil moisture over the considered period (L^3/T)

A similar balance could be made for an irrigated crop, by adding irrigation water as an input term.

A water balance such as given by equation 3.4 is useful, because it shows how much of the water available to the crop was effectively used by it. If we neglect the change in soil moisture ($\Delta S/\Delta t$) over an entire growing season, and collapse the evaporation losses E with the amount of water transpired by the crop T, than a measure for the water efficiency could be given as:

$$\frac{E + T}{P} \qquad (3.5)$$

Figure 3.9: Simplified water balance for a rainfed crop



3.4 Environmental water requirements

The environment requires water. In principle, the environment requires the natural flow regime, undisturbed by human interference. Over-abstraction of water and the construction of large reservoirs have in some river basins significantly affected the ecology. In some basins this has damaged the ecosystems irreversibly, thereby significantly altering the processes of water generation. This is not a desirable situation.

Ecosystems thrive on fluctuations in discharge through the year that would naturally occur. Many households live off resources generated by such ecosystems, such as fish, or require regular minor flooding of floodplains for recession agriculture. Floods also recharge groundwater, on which households may rely for their drinking water. It has now been generally accepted that the environment is a 'legitimate water user'. This is not merely a luxury, and a nice gesture to animal and plant-life. It is a survival strategy for us, human beings, and for generations to come, since water is the basis of life. We live in, and are part of, ecosystems and depend on them. Altering the natural system may even curtail its capacity to continue to generate fresh water.

In heavily committed river systems infrastructural works (such as dams) have not only decreased water remaining in the riverbeds; they have also attenuated the hydrograph. The base flow that would naturally occur is often not maintained, and regular small floods have been shut out. As an example serves the Zambezi estuary: the presence of Cahora Bassa dam, and the manner in which the dam has been operated, caused a decrease in the economically important shrimp fisheries (Gammelsrod, 1996).

Considering the environment a legitimate water user, however, poses a challenge: how much water must be reserved for the environment? The answer to this question is complex, as water for the environment should be specified spatially, temporally, and in terms of quality, so that a certain level of dynamism is assured by means of allocating water to the environment. We need criteria that can assist policy-makers in making balanced decisions in which the immediate economic interests are weighed against the interest of the environment. These criteria should generate practical operational rules, related to, for instance:

Environmental water requirements

- reservoir releases which accommodate the environment;
- water rights or permits, which contain conditionalities allowing water abstraction only if a certain specified flow is let through;
- water quality objectives and discharge permits;
- dam designs to allow for artificial floods and fish passes.

Artificial floods

The main aim should be to maintain a certain fraction of the natural base flow (zero in ephemeral rivers!) and to re-create small flood events. Large floods will occur anyway, because even in heavily committed river systems all dams will fill and subsequently spill. Allocating water to the environment inevitably means that less water will be available for other uses.

3.5 The value of water in the hydrological cycle

The value, and price, of water is a hotly debated issue. Often, the focus is on the value, and price, of a specific water service, such as urban water supply. This section provides some general thoughts about the value of water as it naturally occurs in the hydrological cycle.

Although being part of one and the same hydrological cycle, the value of water differs, depending when and how it occurs. Whereas rainfall is generally considered to be a free commodity, of all types of water it has the highest value. This is because rainfall represents the starting point of a long path through the hydrological cycle (infiltration, recharge of groundwater, transpiration, moisture recycling, surface runoff, seepage, re-infiltration) (Hoekstra et al., 2001). Rainfall therefore has many opportunities for use and re-use: in rainfed agriculture, irrigation, for urban and industrial use, environmental services etc.

Value of "blue" water

Water flowing in rivers has a lower value than rainfall. But also this "blue" water has different values, depending on when it occurs. Water flowing during the dry season (the base flow resulting from groundwater seepage) has a relatively high value, because it is a fairly dependable resource just when demand for it is highest. In contrast, peak flows during the rainy season have a lower value, although these peaks provide many important services, such as recharging aquifers, water pulses essential for ecosystems and filling of reservoirs for later use. The highest peak flows occur as destructive floods and have a negative value.

3.6 A hydrological perspective on water losses

This section deals with what are often called "water losses", which is a main concern in water demand management. The argument of this section is that a proper understanding of water losses requires a hydrological perspective. This is so because at the scale of the earth no water is ever lost! It depends on your position in the hydrological cycle, and where you put the boundaries, whether a certain water flux is considered a loss.

To illustrate this argument, two types of water fluxes that are normally considered "water losses" are dealt with in this section: evaporation from reservoirs, and water losses in irrigation schemes.

3.6.1 Evaporation losses from reservoirs

Water engineers often use the phrase "water development". This may convey the idea that engineering works, such as building a reservoir, "create" more water. This is of course impossible. What it means is that through building a reservoir, the water resources will become available for certain uses at the right time during the year (e.g. during the dry season when demand is highest, yet natural river flow lowest) and at an acceptable level of assurance of supply or reliability (much higher than the natural system would provide).

Assurance of supply

For irrigation the accepted assurance of supply is generally in the order of 75-90% (i.e. failing in one out of four to ten years), and for domestic water supply 95-98% (i.e. failing in one out of twenty to fifty years).

A reservoir can achieve such high levels of reliability by capturing water during the wet season for use in the dry season. For the highest assurance levels, water has to be captured during relatively wet years for use during dry years (through over-year storage). This means that the higher the assurance level, the larger the storage capacity of a dam relative to the annual water use (draft) from that reservoir.

In climates where annual evaporation exceeds annual rainfall, the larger the volume stored relative to its annual use, the larger the net evaporation losses (evaporation minus rainfall) from the open water surface of the reservoir. This is the situation in most semi-arid and sub-humid climates such as in Southern Africa.

Of course, these "net evaporation losses" are not lost to the earth. They are however, lost to the dam owner, and in most cases also lost to the catchment area, and not available for re-allocation by the catchment manager. To both the dam owner and the catchment manager, these evaporation fluxes from reservoirs must therefore indeed be considered "losses".

As noted, the larger the assurance of supply, the larger the volume of water stored relative to the annual water use, and hence, the larger the evaporation losses incurred. In this sense, "water development" when meaning "dam development" in actual fact means increasing the evaporation losses in a catchment, albeit that in the process more water comes reliably available to users when they need it.

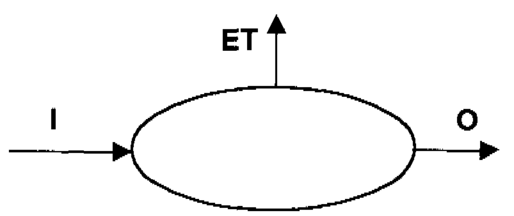
3.6.2 Water losses in irrigation systems

Take a fairly straightforward system; that of an irrigation system. Put a boundary around the irrigated area, and establish a water balance. Assume that no rainfall occurs (dry season), and that the change of moisture stored in the soil over the considered period is negligible (i.e. DS/Dt = 0; for instance the period covered starts before the first irrigation when the soil is dry, and ends at harvest when the soil is dry again) then:

$$I = ET + O \qquad (3.6)$$

Where: I = inflow of irrigation water
ET = Evaporation from soil surface and open canals
+ Transpiration of water by the irrigated crop
O = outflow of water (return flows from overflowing canals, percolation etc.)

Figure 3.10: Simplified water balance of an irrigation system



The ***irrigation manager*** aims to increase the irrigation efficiency of the irrigation system, meaning to decrease the water losses due to outflow (return flows). He views the outflow O as the water lost.

Irrigation efficiency

The ***catchment manage***r will be less concerned with increasing the water utilisation efficiency, since the return flows remain in his catchment. The catchment manager considers the evapotranspiration ET the "real" water loss.

One's position in the water cycle, and where one draws the boundaries of the water system, defines what is considered a water loss.

3.7 Conclusion: water demand management and the hydrological cycle

Water development by us, humans, affects the hydrological cycle. Fortunately, the hydrological cycle is quite resilient, and can withstand a certain degree of disturbance by human interference. However, there is a point where our interference will disturb the hydrological cycle to such an extent that the processes of water generation will be significantly altered. This may result in more frequent droughts and floods, decreased base flows, loss of soil nutrients, and less biomass production from rainfall. We have to acknowledge that we are part and parcel of the hydrological cycle and depend on it. We therefore have to limit and minimise negative impacts of our water development efforts. Viewed in this context, water demand management makes a lot of sense.

Doing more per drop

Doing more per drop of water (increasing the efficiency of water use) is good for the hydrological cycle and the environment; it implies that less water needs to be withdrawn from the water cycle, and less infrastructure needs to be built that interferes with, and alters, the natural fluxes of water.

Watershed management restores and strengthens the hydrological cycle, by promoting soil infiltration and reducing surface runoff and erosion. Biomass production is boosted, as is the valuable base flow in our rivers. Watershed management, therefore increases the value of the source of water, rainfall.

3.8 Exercises

1. Draw a water balance for a rainfed maize crop. Precipitation is 700 mm, of which 100 mm is intercepted and evaporates, 100 mm runs off into stream. Of the remaining 500 mm that infiltrates into the soil, 100 mm percolates to the subsoil and recharges aquifers.

2a Draw a water balance for Masvingo, a city of 70,000 people situated in Zimbabwe. The following data are given (Dube, 2002):

Water use in Masvingo; average 1999-2001

Type of use	m^3/day
Raw water pumped	18,650
Treated water produced	17,560
Billed domestic	11,990
Billed industry	2,860
Authorised but unbilled	??
Background losses	600
Leakage in distribution mains	1,300
Pipe bursts	500
Reservoir leakages	100

2b Draw a balance sheet of the water account of the city of Masvingo. The following data are given (Dube, 2002):

The water account of Masvingo; average 1999-2001

Type of use	Z$/day
Direct expenditure on water (O&M, including labour costs)	78,365
Capital costs	???
Revenue from billed water	141,004

What is the average water charge in Masvingo? And the cost of producing and delivering drinking water?

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4. Engineering aspects of the system

Bekithemba Gumbo

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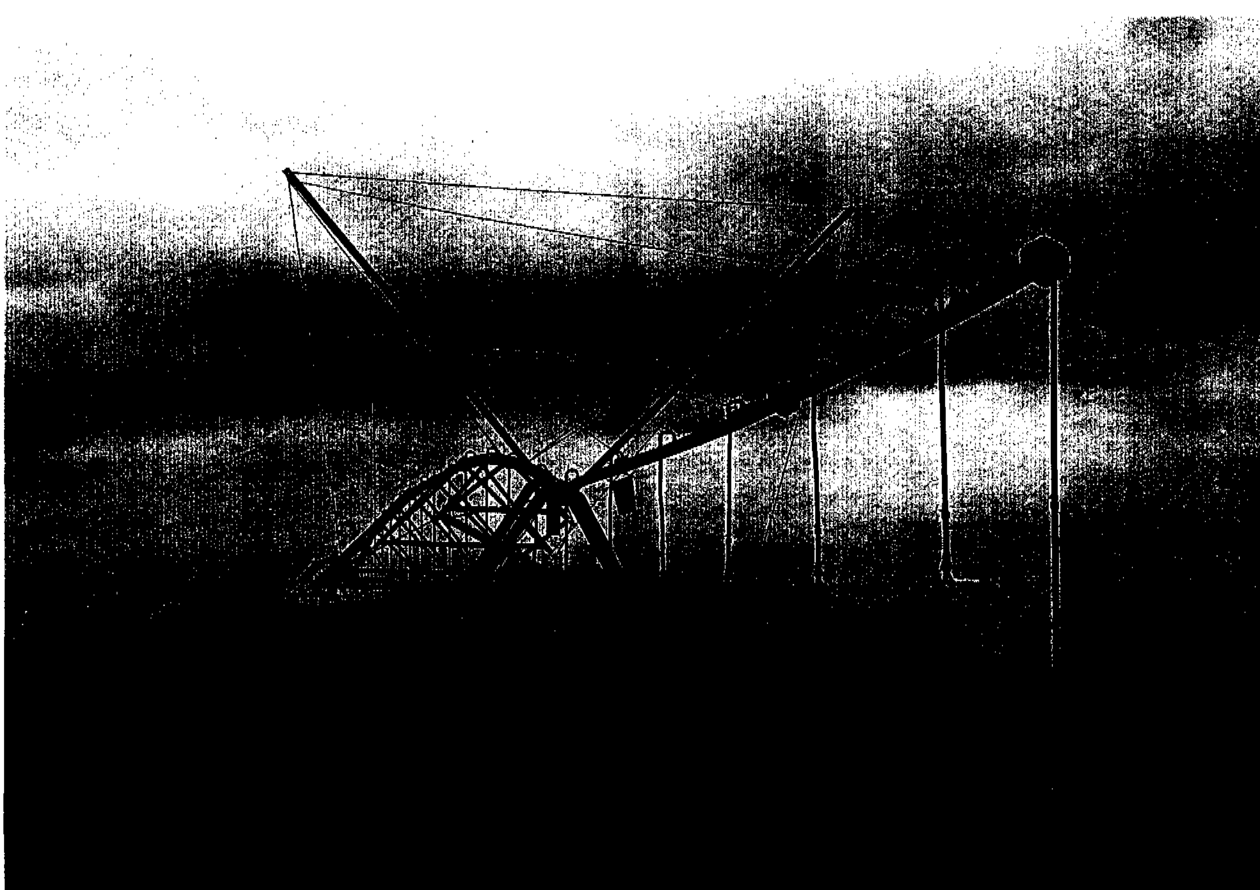


4. Engineering aspects of the system

4.1 Introduction

This Chapter focuses on the engineering aspects of water demand management (WDM). The engineering aspect is defined here as consisting of human-made works and ancillary objects (infrastructure and superstructure) deemed necessary to source, convey and distribute water to various end users (Box 4.1) and also to collect, convey, treat and dispose of return flows (Figure 4.1). The complexity of the resultant system depends on the location and quality of water required by the end user in relation to the source of water (Chapter 3). The engineering design of such systems is fairly standardised globally (Novak et al., 1996; Twort, 1993) although a more comprehensive options assessment before decision making could produce much more cost effective systems i.e. incorporating WDM in the design on new water schemes.

Box 4.1 Various (sometimes competing) water uses within a catchment *(DFID Handbook, 2003)*

- *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.

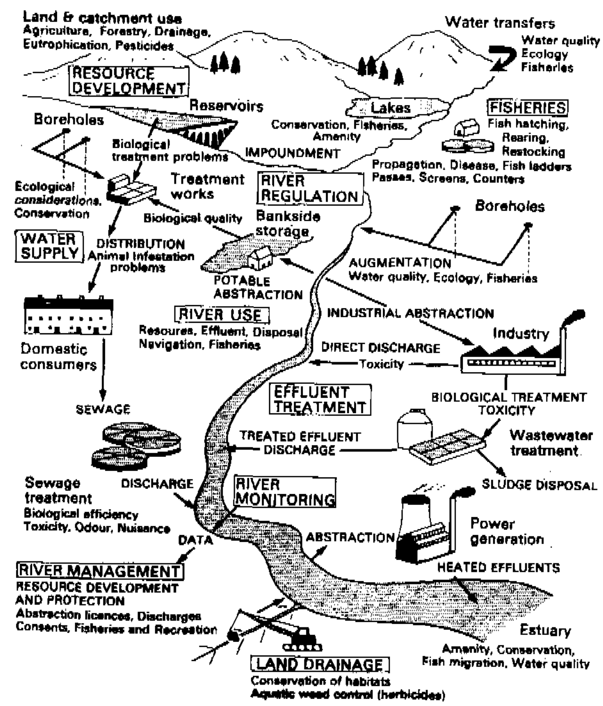
To engineers, WDM is about

(a) improving efficiency of distribution and operation;
(b) accounting for all water
(c) the efficient use of water, and management of demand for water; and
(d) controlling return flows and water pollution.

Mckenzie et al. (2002) presents the priority issues for WDM as:

- Efficient distribution and operation
  - Establishment of management zones
  - Monitoring of unaccounted for water in each zone
  - Pressure management
  - Active and passive leakage control from both the distribution and end users systems
- Accounting for all water
  - Water audits
  - Bulk management metering
  - Consumer metering
- Efficient use and management of demand
  - Selective retrofitting of public and commercial buildings
  - Tariff structures and billing procedures
  - Payment of water
- *Controlling water pollution*

Figure 4.1 General scheme of water supply and use system *Source: Schumm (1977)*



Four main water using sectors are considered in this Chapter, namely agriculture, rural, industrial and urban water. Detailed technical WDM options for the various sectors can be accessed by referring to the reader, references, and recommended websites. The DFID Handbook (2003) provides useful examples how water demand of the various users and sectors can be estimated.

4.2 Water demand management in agriculture

Water demand management in agriculture should focus on two main sub-sectors: irrigated agriculture and rainfed agriculture. Irrigation is a main consumer of "blue" water (surface and groundwater), whereas rainfed agriculture is the main consumer of rainfall, and, in fact, a producer of blue water. Both uses impact on water availability downstream.

4.2.1 Water demand management options for rainfed agriculture

Rainfed agriculture is the largest provider of basic food and fibre in the SADC region. However, rainfed agriculture regularly suffers from crop failures due to the erratic nature of rainfall in the region.

The issue in rainfed agriculture is to enhance the effective use of rainfall (increase transpiration T, decrease evaporation E and direct runoff Roff), so that with the same amount of rainfall more biomass is produced, and less water is lost.

The main strategy is to enhance the effective use of rainfall through judicious land and soil management. This is also known as "soil and water conservation" and "watershed management", and focuses on two aspects:

(a) Ensure that the soil is prepared in such a manner that the roots of the crop can fully develop, so that the soil moisture stock available to the crop is increased. This is crucial for bridging the dry spells.

(b) Ensure that more rainfall water infiltrates, and less water is lost through evaporation from the soil surface and through direct runoff.

In so doing, the productivity of water (the amount of crop produced per unit of water used) increases significantly.

Water productivity

Water productivity can be defined by

(a the amount of crop produced divided by the gross amount of water applied (rainfall) or

(b) the amount of crop produced divided by the total amount of water "lost" from the catchment (transpiration and evaporation).

Water productivity can be further enhanced in the rainfed sector by increasing the use of natural and chemical fertilisers: with the same amount of rainfall, crop production tends to increase significantly when fertilised.

The combined result of improved land and soil management and nutrient management may be spectacular: crop yields may double or even triple. This, obviously, depends on the distribution of rainfall in any given rainy season.

Supplementary irrigation

If the rains fail, the only solution is to artificially add "blue" water to the crop. This is known as supplementary irrigation. It is important to note that supplementary irrigation during the rainy season requires relatively little "blue" water. The downstream impact of supplementary irrigation is limited.

Soil and water conservation in rainfed agriculture, as well as promoting supplementary irrigation, is therefore a very important strategy in WDM: it enhances the efficiency of rainfall use. Furthermore, it is wholly consistent with Integrated Water Resources Management. As was pointed out in Chapter 3, bad soil management and poor cultivating practices will have detrimental effects on the hydrological cycle: more water will run off directly, leading to high storm flows, and less water will infiltrate. Less water will therefore be available to crops and the baseflow in the rivers downstream is likely to decrease.

Soil and water conservation and management increases infiltration, decreases surface runoff and the resulting erosion; and leads to increased crop production through enhanced availability of soil moisture.

The resulting flow regime of blue water is often that storm flows have lower peaks and carry less soil particles from erosion, and that the baseflow is hardly affected, or indeed increases.

4.2.2 Water demand management options for irrigation

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 outpaces 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 the urban sector.

Only 40% of all surface and groundwater abstracted for irrigation is believed to reach crop root systems. Table 4.1 gives indicative values for overall irrigation efficiencies for a variety of systems in South Africa and Zimbabwe.

Table 4.1 Typical overall irrigation efficiencies

Irrigation system	Typical overall efficiency	Percentage of irrigated area in South Africa	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: Rothert & Macy (1999)

Table 4.1 shows that the least efficient method is flood irrigation at 55%, while drip irrigation achieves 90%. In both South Africa and Zimbabwe, a significant percentage of land is irrigated with flood methods, 38% and 25% respectively. 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. This strategy is summarised by the phrase: "more crop per drop" (FAO, 2000). Box 4.2 gives an example of sugarcane in Swaziland, where sprinkler irrigation was replaced by state-of-the-art sub-surface drip irrigation.

Courtesy: Len Abrams (The Water Page)

Left: Small-scale irrigation in Zambia

Another strategy is to shift towards irrigating higher value crops. This results in more value added per volume of irrigation water applied. Even then, a higher value crop does not necessarily require more water. Often it is the reverse: crops like rice and sugarcane need lots of water, yet may add less value than, e.g. vegetables and flower.

Box 4.2 Water demand management at Simunye Estate, Swaziland *(Source: Mwendera 2003; Merry, 2001)*

The Royal Swaziland Sugar Corporation (RSSC), a joint Government and private sector company, developed Simunye sugarcane estate and mill in the northern Lowveld of Swaziland. Simunye (meaning "we are one" in SiSwati) is one of Swaziland's most respected businesses with 11,167 ha under irrigated sugarcane, and producing annually 170 000 tonnes raw sugar and 14 million litres potable alcohol (Merry, 2001).

The following factors were some that motivated the company to change from (relatively inefficient) sprinkler to (much more efficient) sub-surface drip irrigation (SDI):

- Provide a more even wetting pattern;
- Improve water use efficiency;
- Make water available for future expansions;
- Increase sucrose yield;
- Reduce labour inputs;
- Reduce the cost of cane production;
- Reduce maintenance costs; and
- Maximise cane production.

In the fields converted to sub-surface drip, gross water applied was consistently lower on SDI fields, whereas cane yields of SDI fields were 14-17% higher than those of the sprinkler irrigated fields during the three seasons. Water use efficiency (WUE) was between 18 and 29 % greater with SDI than with sprinkler system.

From a water demand management point of view, the benefits of converting dragline sprinkler system to SDI as Simunye were water savings, saving in cost of operation and maintenance, savings in electricity, and increase in sucrose yield (see table).

Comparison of costs and benefits before and after converting sprinkler to subsurface irrigation system

	Costs/Benefits (US$/ha)
Costs	
Without project cost	868
Convert to subsurface drip	2 542
Incremental cost	1 674

Benefits

	Parameter	US$/ha
Increase sucrose	1.5 ton Pol/ha	91
Power levelling	1.56 kVA/ha	15
O & M saving	–	219
Water saving/opportunity cost	1,450 m³/ha	162
Total benefit		**487**
IRR calculation on cash flow		29.1 %

Pol = crude sucrose

(Source: Merry, 2001)

Figure 4.2 The relative magnitude of quantities of water flowing through an "average" irrigation scheme

Source: Bos and Nugteren (1974)

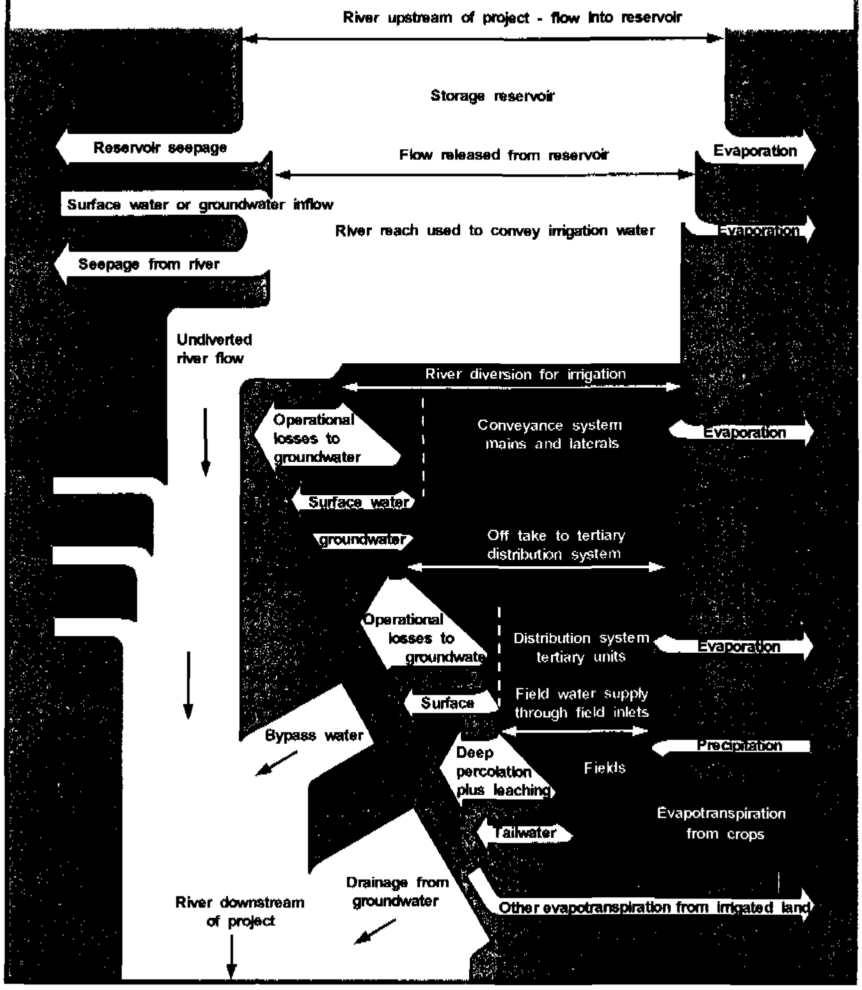


Figure 4.2 shows an irrigation water supply process and the inflows and outflows of a typical irrigation scheme. The dark part of the figure indicates the quantity of water diverted from the source of water, in this case a river. The width of the arrows downstream of the river diversion illustrates the relative magnitude of water quantities in an "average" irrigation scheme in southern Africa. Figure 4.2 also provides an indication of the relative irrigation efficiencies. This

figure 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.

The return flows 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 (Seckler, 1996). However, it should be recognised that return flows or re-cycled water can be quite saline and polluted by pesticides and fertilisers. This may prevent the re-use of the water.

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 30% to 90% and is heavily dependent on the irrigation technology used, and the operation and maintenance of the irrigation scheme.

4.2.3 Estimating irrigation water use

The Food and Agriculture Organization (FAO) has produced a software package known as CROPWAT which in conjunction with CLIMWAT (a climatic database used to determine values of reference crop evapotranspiration estimated from the Penman-Monteith method and effective rainfall) can be used to carry out detailed calculations to estimate irrigation water demand and use (FAO, 1993; 1992; 1984). An example of estimating irrigation water demand given in Box 4.3.

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 CROPWAT and CLIMWAT programmes can be downloaded from:
http://www.fao.org/WAICENT/FAOINFO/AGRICULT/agl/aglw/cropwat.htm
http://www.fao.org/WAICENT/FAOINFO/AGRICULT/agl/aglw/climwat.htm

4.3 Rural water demand management

4.3.1 Sources and water usage in rural areas

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. Small dams and rivers, for example, 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.

Box 4.3 An approximate method for estimating irrigation water demand

An estimate of the water demand and use is required for a 1,000 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 ET_0 (mm/month)	Effective rainfall Pe (mm/month)	Net irrigation demand I_{net} (mm/month)	Net irrigation demand V_{net} (million m³)	Gross irrigation demand V_{gross} (million m³)
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**

- **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 rainfall in southern African countries has a significant impact on the following:

- The type of water source used, e.g. rain water harvesting may be the main source of water during the wet season, 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 (IIED, 2000). Tables 4.2 and 4.3 provide water use figures used in a national master plan for rural water supply and sanitation carried out in Zimbabwe in 1985.

Table 4.2 Rural domestic water demand figures for Zimbabwe 1985

Description	*Average 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 hand pumps less than 300 m from the homestead	30
Wells less than 300 m from the homestead	30

Source: Inter-consult Consulting Engineers Norway (1985)

Table 4.3 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: Inter-consult Consulting Engineers Norway (1985)

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.

4.3.2 Rural water demand management options

WDM has different meanings to different people. To some, WDM in rural areas has a negative connotation. In many situations the solution to the water problem will be increasing water availability through tapping new sources of water. In many rural areas in southern Africa water use is undesirably low (Goldblatt *et al.*, 2000). If water demand management means influencing demand to reach more desirable water use patterns, water availability has to be drastically increased in rural areas. WDM in rural areas means good water management and efficient use mainly through increasing coverage, the level of service, ensuring a reliable water supply, and making more water available for productive uses (see Chapter 5).

Investigations carried out in the rural areas in Zambia indicate that there is little investment in WDM in rural areas because the services are non-commercial when compared to urban areas and hence the economic benefits are difficult to appreciate (Kampata et al., 2002). Promotion of development and maintenance of traditional water sources, however, is consistent with WDM, because by improving the existing water sources it is not necessary to undertake new developments of other water sources. In addition the reliability, water quality and service levels can be improved. The costs are often minimal compared to those of the conventional sources that would be needed to achieve the same results.

There are a number of WDM options available to rural water suppliers. These are categorised below and they range from efficient allocation of water – spatial and user strategies – numbers of people supplied to, location of e.g. standpipes in villages or homesteads, volume supplied to farmers, stock, irrigation, households, etc.

Efficient capture and storage of water:

Efficient capture mechanism – dam, aquifer, groundwater, river, weir, wetland, grasslands, mountain watershed, well field

- Efficient storage mechanism
- Artificial reservoir – dam design, location, depth to surface area ratio, water storage capacity to water consumption ratio, maintenance programme, abstraction and recharge strategy,

sedimentation management programme (in the dam and in watershed), evaporation limiting strategy
- Well field design – well distribution pattern, depth, diameter, well protection, wall and head works materials, maintenance programme, extraction and recharge strategy
- Natural reservoirs – aquifer, groundwater, river, wetland, mountain watershed – size, location, condition, management programme, abstraction and recharge strategy
- Sufficient information to understand the supply and demand inter-relationships

Efficient selection of technology
- Technology dissemination and extension is essential
- Robust technologies with minimal moving parts (e.g. Self closing push taps are better than rotary taps in terms of controlling wastage and minimising washer replacement)
- Efficient water distribution systems from storage facility to consumer
- Efficient water carriers – various pipes, canals, rivers and water containers for particular environmental conditions or economic circumstances
- Efficient maintenance strategies – regular leak detection and repairs with budgeted resources
- Efficient water delivery infrastructure – infrastructure cost, numbers of users supplied to, location of standpipes/wells in villages or homesteads, supply volume capabilities
- Promote technology innovation – focussed research funding on water use in various sectors including agriculture, households and manufacturing, competitions for school science projects
- Metering and use of prepayment meter technologies

Efficient land-use within a watershed
- Collaboration with various government departments to promote water efficiency

4.4 Industrial water demand management

4.4.1 Industrial water use

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 section introduces the concept of specific water intake (SWI) as a measure of efficiency in industrial processes. A wide variety of SWI values for different industries are provided in the Appendix of the DFID Handbook (2003). Broad WDM measures are covered for different industries and how to carry out water audits for industrial plants, supported by a number of readers. Detailed information on some industries can be obtained from the relevant publications of the Water Research Commission (WRC) of South Africa in Pretoria. A number of good practice examples are provided separately and for further reading refer to IUCN country reports and the various studies undertaken in the Phase I and Phase II projects.

Industry and mining contributes a significant share of the GDP of the SADC member states, although these sectors consume relatively small amounts of water (Table 4.4). Up to 60% of exports in some countries are from manufacturing and mining enterprises. Mining of oil in Angola and diamonds in Botswana shows how important the mining industry is to these economies.

Table 4.4 Industrial water use in SADC countries as a % of total annual freshwater withdrawals

Country*	Total annual renewable freshwater available km³/yr	Total freshwater withdrawal km³/yr	Estimated population in the year 2000 (000)	Industrial water use % of total freshwater withdrawals %
Angola	184	0.48	13,302	10
Botswana	14.7	0.11	1,651	20
DRC	1019	0.36	50,730	16
Lesotho	5.2	0.05	2,140	22
Malawi	18.7	0.94	10,160	3
Mauritius	2.2	0.36	1,205	7
Mozambique	216	0.61	17,245	2
Namibia	45.5	0.25	1,817	3
South Africa	50	13.31	44,000	11
Swaziland	4.5	0.66	1,046	2
Tanzania	89	1.17	32,422	2
Zambia	116	1.71	10,755	7
Zimbabwe	20	1.22	13,485	7
Total SADC	1784.8	21.23	199,958	9

*Seychelles with a population of about 80 000 is not included

Source: Gleick, 2000; SADC, 2000; Hirji et al, 2002

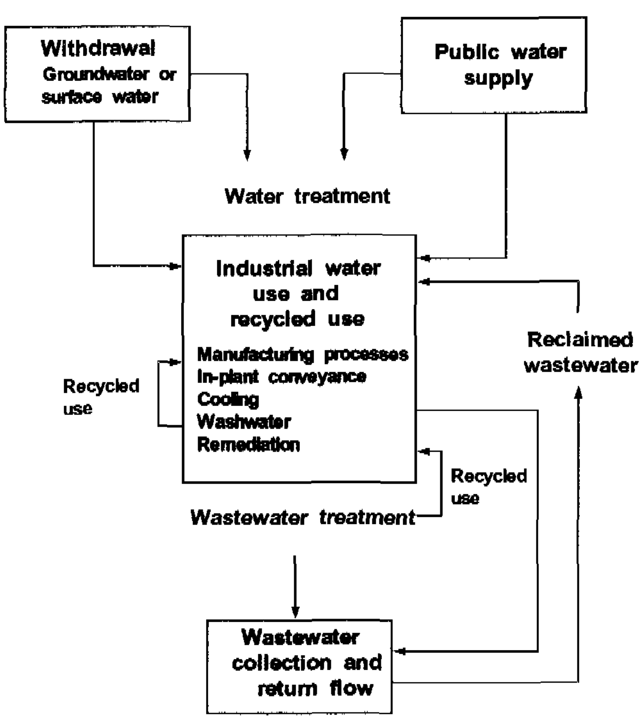
Industrial water use activities include water withdrawals from ground and surface water; deliveries from public water suppliers; consumptive use through evaporation and product incorporation (as in a bottling plant); water and wastewater treatment, recycling, releases to wastewater collection systems, 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.

Consumptive use

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 increasingly recycle water within their plants, often triggered by the high cost of wastewater treatment required to meet the provisions of statutory instruments.

After use, wastewater may be treated onsite, released to wastewater collection systems, returned directly to surface water, to septic systems, or a combination of these. Figure 4.3 shows the way in which water supply, use and treatment are related for a typical industrial plant.

Figure 4.3 Water supply, use and treatment for a typical industrial plant
Source: DFID Handbook, 2003)



Water consumption figures for industry are often expressed in terms of cubic metres of water used per unit of product produced often referred to as Specific Water Intake (SWI). For example, water use for steel production is measured as m³/tonne of steel produced; for beer it is measured in m³/m³ 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.

Some industries, e.g. the chemical industry, use different processes, different equipment and produce very different products. For these types of industry no standards are available and each process and site should be assessed on its own merits.

The DFID Handbook (2003) provides data on the water use of many different industries, in the form of lookup tables. Such tables 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 (benchmarking). 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. Box 4.4 provides an example of a planned brewery.

Box 4.4 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

Conclusion:

Look up table on clear beer breweries in the DFID Handbook, indicates 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 brewery of 6.5 m^3 per m^3 beer produced appears reasonable.

Water consumption for breweries in South Africa
(Source: DFID Handbook (2003)

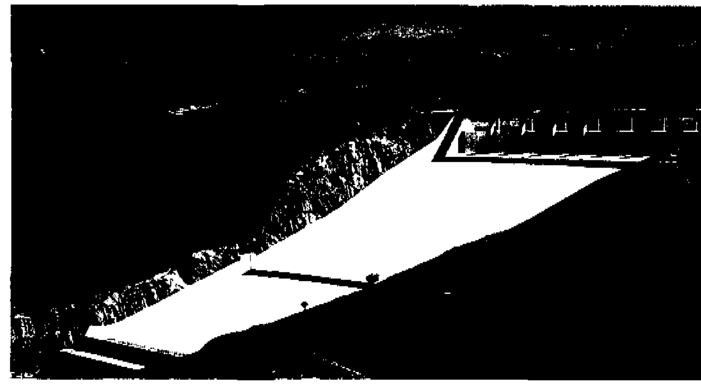
	Large breweries producing greater than 10,000 m^3 of beer per month (m^3/m^3 of beer)	Medium breweries producing 2,000-10,000 m^3 of beer per month (m^3/m^3 of beer)
Typical range	5.5 to 7.1	6.7 to 8.8
Mean	6.3	7.7

Water consumption for breweries in Europe
(Source: DFID Handbook (2003)

	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 in Africa	4*	Not available

Note:*Figure is for the Windhoek Brewery, Namibia

4.4.1 Water demand management options for industry



WDM in industry and mining can be achieved by implementing various changes ranging from simple low cost procedures such as fixing leaks and good housekeeping procedures, to more complex and expensive options such as optimising water use, investing in water efficient production equipment and *reducing the number of process steps.* Table 4.5 summarises some possible WDM measures in industry and mining. Box 4.5 gives an example of "dry-cooling" as a WDM measure in thermal power production.

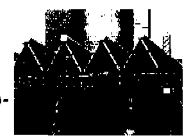
Table 4.5 Options for WDM in industry and mining sector

Repair leaks, faulty valves etc	A simple method of determining if leaks exist is to take incoming water meter readings before an after shut-down period when no water is being used. A difference in the reading could indicate a leak.
Turning off taps and hoses	Encourage workers to turn off taps and hoses when running water is not required. The fixing of hand triggers or fixed flow limiters to hoses also reduces water consumption.
Turn off water when machines are not running	Encourage workers to turn off machines and water during breaks and at the end of the day. Avoid circulating cooling water when machines are not in use.
Consider the reuse of treated effluent from outside the industry	This can reduce the total water delivered to a water services utility whilst delivering cheaper water to some industries.
Reduce the number of process steps	This involves the study of all the processes and determining where changes can be made. For example, fewer rinsing steps may be required.
Optimise process water use	Examples include using batch or stepwise (serial use) rinsing rather than overflow rinsing, introducing counter-current washing in continuous ranges, and installing automatic shut-off valves, level controls to avoid over-spill.
Recycle cooling water	Cooling water is relatively uncontaminated and can be reused as make-up or rinse water. This can also save energy as this water will not require as much heating for hot water processes. Further recycling can normally be achieved by introducing bleed-off side-stream treatment of a portion of the cooling water.
Non-evaporate cooling water and/or refrigeration type cooling processes	Such processes are relatively capital intensive but save large quantities of water. In fact their consumptive water usage is zero and the only water used is that which may be disposed of during major maintenance procedures.
Reuse process water	This requires a study of the various processes and determining where water of lower quality, possibly after treatment, can be re-used for the same part or another part of the process. For example, final rinse water from one process can be used for the first rinse of another process. Collection and reuse of steam condensate.
Using water efficient processes and equipment	Although replacing obsolete or outdated equipment with modern machines which operate at lower liquor ratios and are more water efficient requires capital investment, the savings that can be made often ensure a relatively short pay-back period.
Mechanical pre-cleaning and collecting waste in dry form	Instead of washing the floors, rather sweep up spillages and wash down only when it is essential. Not only will this reduce water use, but also the volume and concentration on contaminants to drain as the waste is disposed of as solids
Reusing water from auxiliary processes	The water used in the rinsing of ion-exchange columns and sand filters can be reused elsewhere in the factory.
Closed loop design	Initial design of new installation should incorporate closed loop systems i.e. as much as possible include internal recycling and reuse.

Source: Adapted from Barclay & Buckley (2002); Montelius et al. (2000) and Water Efficiency Manual (1998).

Box 4.5 Non-evaporative cooling as a WDM measure in a thermal power station

Around 1980 Eskom made the decision to build the Matimba power station at Ellisras, to be fired by coal supplied by South Africa's iron and steel corporation ISCOR. The area within South Africa's borders around the proposed site could not supply sufficient water for an evaporative cooled power station and a decision was made that non-evaporative cooling should be used. Overall, the technical challenge of using non-evaporative cooling at least equalled the alternative challenge of delivering sufficient water to the power station to allow it to be evaporatively cooled. Dramatic reductions in water usage from 2,0 to 0,2 kilolitres per kWh of electricity sent out have been achieved by changing the method of cooling from evaporative to non-evaporative.



Right: Non-evaporative condensing heat exchangers above forced draught fans at Matimba Power Station

Source: Hazelton et al. (2002)

WDM in industry and mining requires the application of a systematic approach to reducing intake water and the generation of wastewater. In other words, it is the implementation of measures to conserve water and to prevent the generation of wastewater. It applies to both product and process changes, and includes all inputs and waste outputs. There is always the opportunity to achieve benefits from WDM and waste minimisation in all aspects of an organisation, no matter what the size of the operation.

Table 4.6 Information required for a WDM programme in industry

Environmental information	Volume of water abstracted
	Make up water quality versus water quality requirements
	Waste analysis, flows and concentrations
	Wastewater discharge records and analyses
	Compliance requirements
	Discharge consents
	Site licence controls
	Environmental assessment reports
Design information	Process description, flow diagrams
	Design and actual water, material and energy balances for production and pollution control processes
	Piping and instrumentation diagrams
	Equipment layout and work flow diagrams
Raw material and production	Recipes
	Raw material, product specification
	Operating procedures
	Production schedules
Economic information	Water and sewer charges
	Treatment and disposal costs for all liquid waste
	Product, utility, energy and raw material costs
	O & M costs
Other information	Standard procedures
	Organisational charts
	Planning consents and conditions

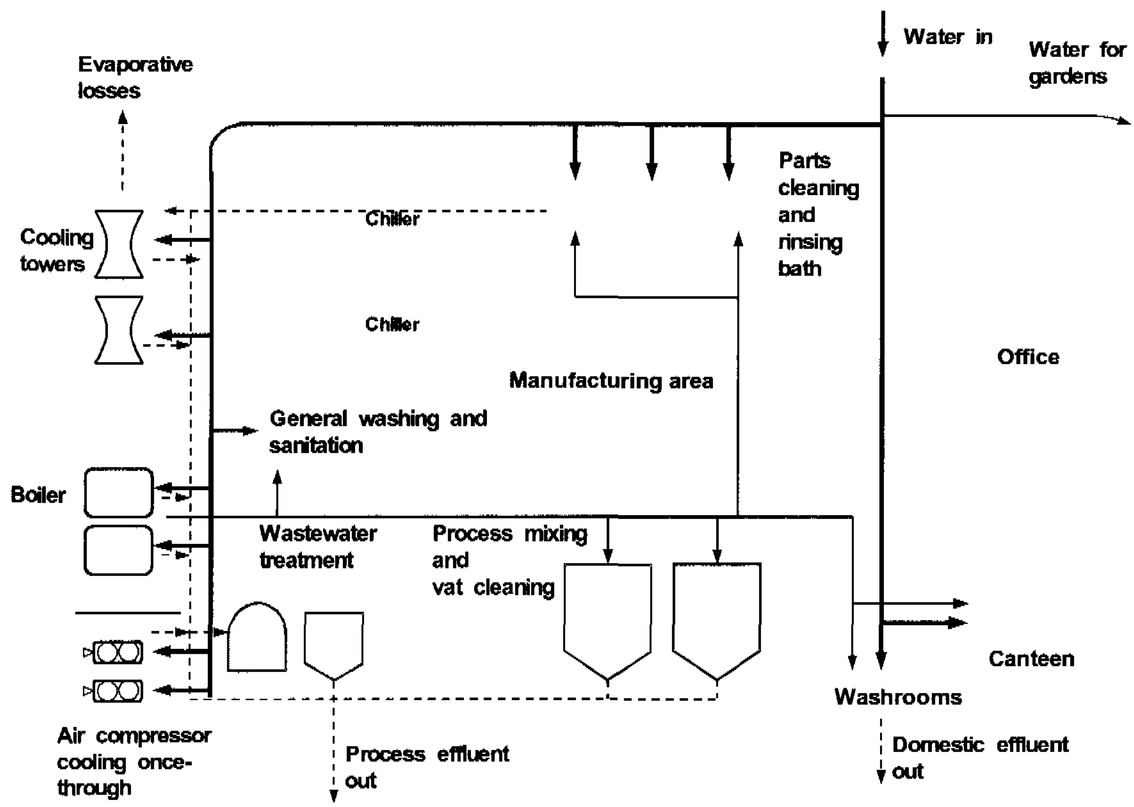
Source: Adapted from Barclay & Buckley, 2002

The best approach for a water supply utility is to motivate an industry to carry out its own WDM investigations and to negotiate implementation in a manner and within a time framework that suites both parties. Obtaining the specific water consumption of a new or existing facility can also be useful as a quick check of the water use efficiency within a facility but different production processes can result in widely differing specific water consumptions. Typical information required during the assessment phase of a WDM programme is listed in Table 4.6.

Water audit

Flow diagrams representing the flow of water, material and emissions under investigation are essential together with mass and energy balances. Carrying out a water audit of an industrial establishment is one of the key activities that assist in improving the specific water consumption of a site. An example of a simplified water audit for a generic site is shown in Figure 4.4.

Figure 4.4 Simplified water balance for a manufacturing facility (DFID Handbook, 2003)



Water balance summary

Source of water use	Quantity used (m³/year)	Percentage of total (%)
Cooling: Cooling towers, boiler	7,966	38.3
Process use: Parts and mixing vat cleaning	3,848	18.5
Domestic: Toilets, taps, showers	3,536	17.0
Once-though cooling: air compressors and pumps	2,388	11.0
Gardening	832	4.0
General washing, sanitation and maintenance	561	2.7
Leaks (detected)	416	2.0
Food preparation: Canteen	312	1.5
Sub-total	**19,859**	**95.5**
Total water delivered to site	**20,800**	**100.0**
Unaccounted for water	**941**	**4.5**

4.5 Urban water demand management

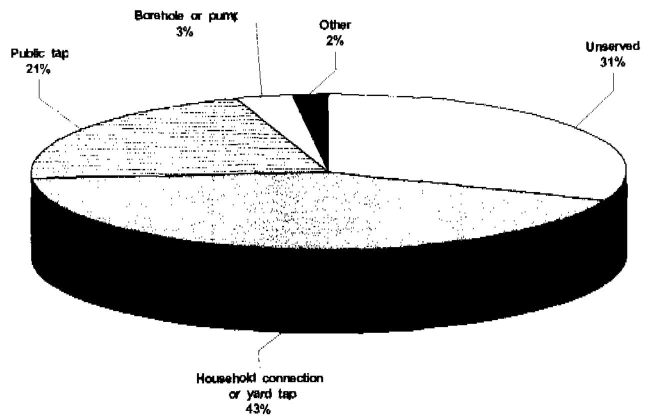
4.5.1 Urban water use categories

Urban water use categories are varied and diverse. They include:

- Domestic water use and demands including:
  - In-house use e.g. drinking, cooking, ablution, sanitation, house cleaning, laundry;
  - Outside 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 un-metered water use such as street cleaning, public parks, sewer flushing and fire-fighting;
  - Unauthorised un-metered 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 house connections, to shared standpipes, to no service at all. Figure 4.5 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 (WUP, 2001, MAWAC, 1999).

Figure 4.5 Level of service in selected African cities *(Source: WUP, 2001)*



The level of service for domestic water supply can be defined in numerous ways. The South African Government has defined four levels of service for the formally developed areas of cities. These are shown in Table 4.7.

Table 4.7 Service level categories used in South Africa

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 house hold. There should not be more than seven days interruption of the supply to any consumer per year i.e. water should be availlable 98% of the time. (ii) The provision of appropriate education in respect of effective water use should be provided.
Intermediate	Regulated roof or yard tank or a few houses sharing a high service level of service connection
High	Full or intermediate pressure yard or house connection

Source: WUP (2001)

Over the past five years performance indicators for African water utilities have been collected by the Water Utilities Partnership (WUP). One of the parameters is the 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 split between the actual customer consumption and the unaccounted for water. In the UK the per capita domestic water consumption figures range between 130 and 170 l/person/day. In southern Africa the average urban domestic per capita water consumption ranges from 35 to over 370 l/person/day (Baba, 1996).

For detail of various water consumption figures in southern Africa, refer to the DFID Handbook, 2003 and if necessary request for the WUP CD "Service Providers Benchmarking Network (SPBNET)".

4.5.2 Unaccounted for water

In urban water supply schemes there is usually 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 (UAW). UAW is caused by a variety of factors (e.g. leakage, illegal connections, and errors in metering readings).

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

Table 4.8 gives UAW figures for a number of southern African water utilities and countries. Unaccounted for water figures vary from 11% for Windhoek in Namibia up to 60% for Dar es Salaam 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 4.8 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, DRC	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: WUP (2001)

It should be noted that the figures for UAW in Tables 4.8 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.

4.5.3 Water demand management options

Technical water demand management options in the urban sector are largely related to the effort of reducing UAW. UAW 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 may include unmeasured water put to beneficial use (e.g. fire fighting, or water use from communal standpipes that are not metered nor billed) as well as water losses from the system. In cases where authorised yet un-billed water use is relatively small, unaccounted-for water may be equated with "un-billed 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 (Mckenzie et al, 2002):

- 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.

Methods by which unaccounted for water can be reduced are listed in Table 4.9.

The major sources of unaccounted for water in the majority of African cities are leakage and illegal

Table 4.9 Methods by which unaccounted for water can be reduced

Area	Issues	Actions
Metering	• Un-metered connections	• Meter installation
	• Faulty meters replacement/repair	• Meter
	• 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 maintenance of old pipes, and reservoirs	• Systematic maintenance, detection, monitoring and
	• Lack of information on pipe network	• Information programmes to public and others Standardisation of installation, material and control
	• Lack of maintenance, eg pipes, air and scour valves, pump glands or mechanical seals regulation	• Pipe database • Replacement connection policy • Adequate pressure
Operational	• Deficient operational control eg reservoirs overflowing, pipelines being over pressurised, scouring being carried out inefficiently units	• Monitoring indicators • Water distribution system automation • Designing operations control • Maintaining controls
Commercial systems	• Inefficient billing system	• Database of users
	• Poor connection and/or disconnection procedures • High level of accounts receivable	• Design/ implementation of better commercial systems
	• Low income consumers not billed	• Improved users/demand data
	• Illegal/unregistered connections	• Disconnect policies
	• Water pricing policies volume users	• Control of high

Source: Adapted from Norplan (2001)

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.

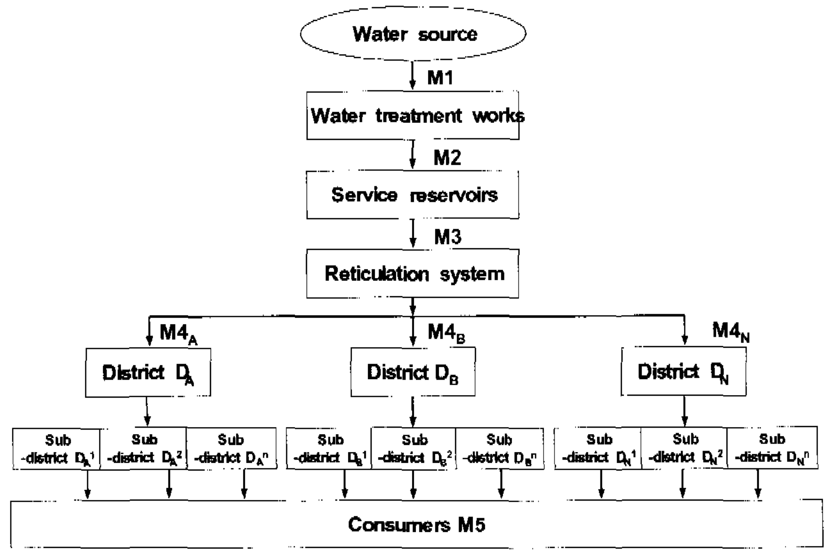
Soil characteristics. Soil characteristics can affect the running time of individual leaks. For example, in some soils water from underground leaks may show on the surface fairly quickly whilst in others leaks can run indefinitely without showing.

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.

4.5.4 Estimation of water losses in an urban water supply system

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 4.6 that assumes that water is abstracted from a surface impoundment.

Figure 4.6 General scheme of a water supply system *Source: Adapted from Lambert and Hirner (2000)*



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

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 4.6) and leaving the treatment plant (M2 on Figure 4.6) 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 (Mckenzie et al, 2002).

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 (MAWAC, 1999).

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. 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.

4.5.5 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 4.6.

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 (Mckenzie et al, 2002).

Minimum night flows

The urban water distribution system is often sub divided into sub-districts containing 200 to 3000 properties. These are shown as Da1 to Dan on Figure 4.6. 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 (Mckenzie et al, 2002).

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.

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

4.5.6 Pressure management

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.

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 = F (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.

See cases of Khayelitsha and Bulawayo in Reader (Mckenzie et al. 2002; Norplan, 2001)

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.

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. In general, reduction in pressure leads to reduced rate of escape through each leak and may also affect the number of leaks occurring.

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 30m and 60m.

For potable public water supply utilities that control a wastewater treatment plant, an analysis of the economic, environmental, and technical feasibility of making reclaimed water available is important as a water demand management measure. Apart from quantities involved wastewater recycling and reuse requires strict quality control measures.

4.5.7 Homeowner water conservation options

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

Use of Ultra-Low Volume fixtures: This measure might require an adoption of an ordinance which requires the installation of ultra-low volume (ULV) plumbing fixtures in all new construction. Also residential retrofit measures promoting installation of ULV plumbing fixtures or modifications which improve the performance of existing fixtures. One possible incentive is a partial financial subsidy to increase the installation of ULV water fixtures. Another incentive is the delivery of retrofit kits to homes.

Xeriscape Landscaping: is defined as landscaping method that maximises the conservation of water by the use of site-appropriate plants and an efficient watering system. The principles of Xeriscape include planning and design, soil analysis, efficient irrigation, practical turf areas, appropriate plant selection, and mulching.

Wise garden irrigation: Irrigation during daytime hours is generally less efficient. The sunlight and increased winds during the restricted daytime hours cause some of the water to evaporate before hitting the ground or to blow onto impervious surfaces such as sidewalks, roads and driveways. The wind also causes the water that reaches the plants to be more unevenly applied. Public education programmes can contribute in informing irrigators how they can reduce applications while still meeting the water requirements of their plants.

Meter reading: Studies have shown homes can waste more than 10% due leaking, which costs both the homeowner and the environment.

Use water efficient household appliances: Rated or eco-labelled washers that also have a water factor at or lower than 9.5, use 35-50% less water and 50% less energy per load. This saves the homeowner money on both the water and energy bills.

4.6 Exercises

Agricultural water

1. Water balance in irrigation water use

A small farmer cultivates one hectare of tomatoes during the dry season, and irrigates it with a sprinkler system. For her thesis, a postgraduate student established a detailed water balance for this field during the entire growing season of the year 2001. She found the following:

- Effective precipitation = 0 mm
- Volume of irrigation water pumped into the sprinkler system = 5,000 m^3
- Volume of water lost due to surface runoff out of the field = 500 m^3
- Volume of water lost due to deep percolation = 500 m^3
- Yield of the tomato crop for the 2001 season: 40 tons per hectare

a) Draw a water balance for the 2001 tomato crop. How much was the evapotranspiration?

b) What is the field application efficiency of the sprinkler system?

Our postgraduate student did some further detailed field measurements, and found that of the total evapotranspiration, 25% was lost due to evaporation.

c) How much of the evapotranspiration was evaporation, and how much transpiration?

During the 2002 dry season, another postgraduate student went to the same farm to establish the water balance; this was interesting because the farmer had shifted to another irrigation technology: namely a drip irrigation system. The following data were collected for the 2002 season:

- Effective precipitation = 0 mm
- Volume of irrigation water pumped into the drip system = 4,500 m^3
- Volume of water lost due to surface runoff out of the field = 100 m^3
- Volume of water lost due to deep percolation = 200 m^3
- Yield of the tomato crop for the 2002 season: 50 tons per hectare

d) What is the field application efficiency of the drip irrigation system?

The student also found that for the 2002 tomato crop, only 10% of the total evapotranspiration was evaporation.

e) Explain the difference in evaporation for the 2001 and 2002 tomato crops.

f) Explain why the 2002 tomato yield could be higher than the 2001 yield.

g) Compare the water balances for the 2001 and 2002 crops; how much water was saved by the conversion from sprinkler to drip irrigation?

2. Study the case of Simunye Sugar Estate (Box 4.3 above)

a) Infer the value of pol (= crude sucrose); expressed in US$/ton

b) Infer the opportunity cost of irrigation water, expressed in US$/m^3

Rural water

3. Rural water demand management

As a rural water supplier you are keen on implementing rural domestic water demand management in River Kadzi sub-catchment in northern Zimbabwe. Because of limited data it is important to initially estimate the water demand and use. The baseline data available include:

- 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.
- 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%.

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

a) Estimate the Total rural domestic water requirements for the Kadzi sub-catchment

b) State which technical water demand management options you will consider and why

c) For the selected WDM options list possible data and information requirements for implementation, monitoring and evaluation

NB See also Chapter 6 on Information and communication.

Industrial water

4. Industrial and mining water uses

a) Refer to DWAF (2000b); Water Efficiency Manual (1998); and DFID Handbook (2003) and any other resource material of your choice. Compile a list of different water uses in industry (note industry includes mining)

b) Refer to UNIDO (2003): Discuss and explain why WDM is important for sustainable industrial growth in the southern Africa region.

NB The exercise has to be performed in discussion groups.

5. Industrial water demand management

You are a catchment manager and there are three wet industries in your water stressed catchment namely; soft drink, dairy and paper and pulp industry. Describe an approach or strategy you will use to convince the three industries to be more water efficient in their production processes. Include the various incentives and disincentives. (Gumbo et al, 2002 (in Reader); DFID Handbook, 2003; Water Efficiency Manual, 1998)

Urban water

6. Identifying good practice in WDM projects

Read Buckle (2003) (in Reader), and/or UNHCS (2002) and/or WRP (2002). Identify and list the various technical or structural water demand management options implemented in the various examples. In your opinion from the description of the case studies to what extent did structural options influence demand as opposed to non-structural measures like water use campaigns and pricing?

7. Water loss reduction through pressure management

An example of the effect of pressure reduction on leakage for Khayelitsha, in Cape Town, South Africa, is given by Mckenzie et al, 2002 (in Reader). A pipe network is currently being operated with a water pressure of 80 m (i.e. 800 kN/m^2), and experiences losses due to leakages of 10,000 m^3/day. What would be your advice? How much are the expected benefits, in approximate terms?

8. Wastewater reclamation and reuse in Windhoek, Namibia

Refer to Van der Merwe, 1998b (in Reader) and read the section on wastewater reclamation and reuse for potable suppliers. Note the technical challenges involved in this scheme. From the background information provided and the risks involved in recycling wastewater do you believe that this system is justifiable? Can it be replicated elsewhere in southern Africa?

4.7 References

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4.8 Useful websites

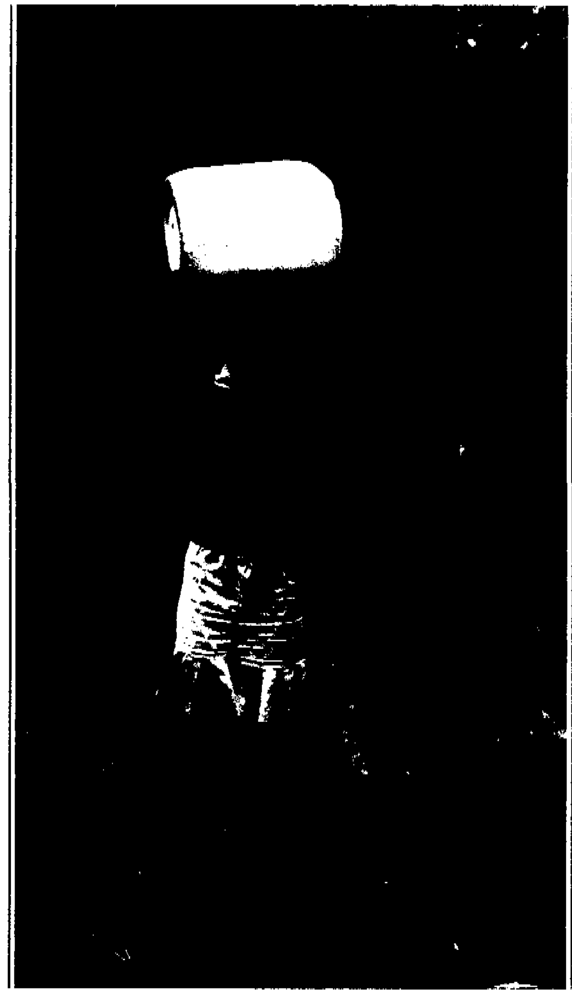
- American Water Works Association http://www.awwa.org
- Aqualoc http://www.aqualoc.net/mainframe.html
- Caroma http://www.caroma.com.au
- Con-Serv http://www.con-serv.co.au
- Conservation Education http://www.sfwmd.gov/curre/watshort/education.html
- Delrama Ltd http://www.delrama.com.au
- Department of Water Affairs and Forestry. South Africa http://www.dwaf.gov.za
- Dorf Ltd http://www.dorf.com.au
- Environment Agency (UK) http://www.environment-agency.gov.uk/savewater
- H2O House: EPA's Water Saver Home http://www.h2ouse.net/
- Hydro-Comp Enterprises http://www.hydro-comp.com/
- Pipeline Performance Technologies Pty Ltd http://www.ppt.co.za
- Rand Water http://www.waterwise.co.za
- RST Water saving Systems Pty Ltd http://www.rst.co.za
- Save-a-flush Pty Ltd http://www.save-a-flush.co.uk
- South African Department of Water affairs and Forestry http://www.dwaf.co.za

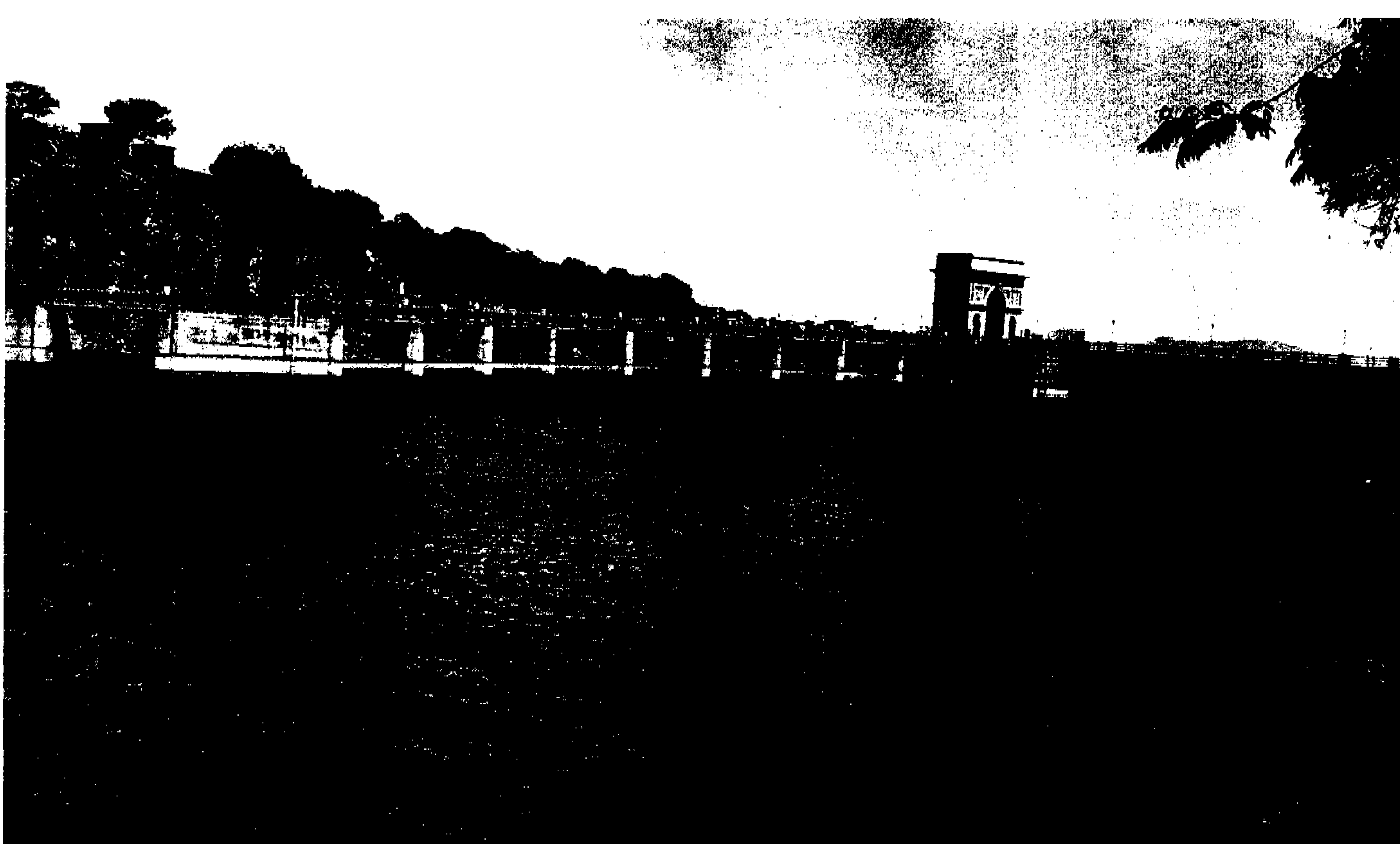
- South African Water Research Commission http://www.wrc.org.za
- South Florida Water Management District http://www.sfwmd.gov/
- Stewart Scott South Africa http://www.stewartscott.com
- United Nations Centre for Human settlements http://www.un-urbanwater.net
- Water Services association of Australia http://www.ratings.wsaa.asn.au
- Water Utility Partnership (WUP) http://www.wupafrica.org

4.9 Tools

Water Research Commission of South Africa (WRC) research projects have a variety of research products, including, where applicable, software programs designed to support specific aspect of WDM. Examples of such software available for free or at a fee are listed below. See http://www.wrc.org.za/downloads/software/default.asp for details and Mckenzie et al. (2002).

BENCKLEAK	Benchmarking of leakage model
ECONOLEAK	Economics of leakage model
SANFLOW	Background night flow analysis model
PRESMAC	Pressure management model
IMPAHLA	Asset management for the water services





5. Economics of WDM

5. Economics of Water Demand Management

Peter Robinson

Key readings for this chapter (in Reader):

Gumbo, B., 2003, Information system; the case of four cities in southern Africa

Hazelton, D., 2002. Water Tariffs & Targeted Subsidies

Norplan et al., 2001. Excerpts from *Bulawayo Water Conservation and Sector Services Up-Grading Project Final Report*; Volume 1, Bulawayo

Robinson, P.B., 2002. 'All for some': water inequity in Zambia and Zimbabwe. *Physics and Chemistry of the Earth* 27: 851-857

Rothert, S., & P. Macy, 2000. The potential of water conservation and demand management in Southern Africa: an untapped river. Paper submitted to World Commission on Dams

Key readings to be made available separately:

IUCN Water Demand Management programme reports

Louw, D B, and W E Kassier (2002). *"Costs and Benefits of Water Demand Management"*

Books

Macy, Peter (1999). *Urban Water Demand Management in Southern Africa: the Conservation Potential.* Monograph published by SIDA, Harare, Zimbabwe

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Spreadsheet:

Economics of Water Spreadsheet Exercises.xls

5.1 Introduction

5.1.1 Economics as a Framework of Analysis

Economics addresses issues associated with the allocation of resources to meet broad social objectives. While economics is often spuriously divided into compartments (like 'micro-economics' and 'macro-economics'), properly conceived economics is a framework for analysis of systems. In this sense, economic analysis can and should be used beneficially in all water supply and WDM planning exercises and is intimately linked to all the other systems being considered in this module (hydrological, political, engineering and information systems).

One of the fundamental concepts in economics is that of 'opportunity cost', which economists use to refer to the value of the next best alternative or opportunity which has to be foregone in order to achieve a particular objective. Welfare economics dictates that prices or tariffs should be set to reflect opportunity costs, because, in so doing, the price of a commodity (such as water) will reflect the value of what is foregone by using water for one purpose rather than another. This provides a signal or incentive to the consumer – when the water price is low, water is abundant and may be used lavishly; when water prices are high, water is scarce and should be used sparingly.

It is important to note that concerns about using something sparingly only arise when there are alternative or competing uses. Economic decisions are not made in the abstract but in the context of competing demands on scarce resources.

5.1.2 Different Meanings of Efficiency

This module has defined ***water demand management*** as the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource. In Chapter 1, various alternative definitions from a variety of sources on WDM were given, leading to the observation that "the common denominator in all the WDM definitions is an emphasis on efficient use of water".

See: chapter 1

An economist would immediately want to know what exactly is meant by 'efficient use'. This is because economics offers two different meanings of ***efficiency*** – the first and more obvious sense being usage efficiency and the second being allocative efficiency. ***Usage efficiency*** is the same as the everyday meaning. It refers (in the context of WDM) to people with access to water who avoide waste and use the minimum amount of water that they can to meet the need for the water required. ***Allocative efficiency***, on the other hand, refers to changing the distribution of water in order to achieve some social goal. In conventional economics, an allocation of water to different users is regarded as an 'efficient' allocation if there is no possible improvement that could raise the utility of one user without reducing the utility of another.

Water use efficiency

Allocative efficiency

In the next section, the concept of 'utility' is questioned and a different approach is given to the allocation of water, one which is relevant for broad socio-economic development in southern Africa. The narrower interpretation of allocative efficiency is important, however, for decisions about inter-sectoral allocation of water. In SADC, approximately 70% of water is used in irrigation, much of it in wasteful large-scale schemes [Rothberg & Macy (2000)]. It is not uncommon to see the proportion being projected to grow on the basis of the need to produce food for a growing population. At the same time, however, urban populations are growing even more rapidly and eventually more water will to have to be allocated to urban usage at the expense of irrigation. This does not imply that the SADC region will be unable to produce adequate levels of foodstuffs. At present, barely 50% of water used by the agricultural sector actually reaches the crops, implying that even rudimentary WDM strategies would free up large volumes of water for productive agricultural uses or for reallocation to urban, industrial and mining uses.

The problem in such discussions is that many if not most, SADC countries seem to be fixated on ***food self-sufficiency*** as a goal, rather than aiming to achieve ***food security***. The two are often related, but are by no means synonymous. Indeed, a dry country like Namibia, with a strong economy, has a much higher level of food security when it is able to use its foreign exchange to purchase food to best advantage on world markets than it would have if the proposal were to be implemented to pipe water from the Congo River, through Angola, in order to irrigate staple crops in Namibia. The distance involved would be at least 1,500 km, and the capital cost in excess of US$ 4 billion. An investment of that magnitude would place enormous stresses on the Namibian economy, while the project itself would be fraught with risks and difficulties. For a dry country, food security is best achieved through importation of basic foodstuffs. In so doing, the country is importing ***virtual water*** – water that would have been needed to produce the crops, but which arrives in the country more efficiently and at a much lower cost than the importation of water itself.

Food self-sufficiency

Food security

Virtual water

5.1.3 Increasing Demand – Equitable Access to Water

An efficient allocation of water was defined above to be one where there is no possible improvement that could raise the utility of one user without reducing the utility of another. Strictly speaking, this is the strong version of what is known as ***Pareto optimality***. ***Utility*** is used in its conventional (so-called neo-classical) welfare economics sense of 'the ability of a commodity to satisfy human wants'. Pareto optimality is concerned with an aggregative measure of welfare and suffers from the severe limitation that it does not consider how benefits are distributed. In situations where there is agreement to redress inequality, the Pareto criterion can hardly claim to be 'optimal' in any overall social sense.

The most compelling critique of this approach is offered by Amartya Sen, who criticises both the use of an aggregative approach, together with the weak condition of unimprovability, and the choice of utility as the measure of welfare. The alternative he proposes is the notion of 'capabilities', which are simply an individual's ability to perform deeds. In Sen's conception, economic development is the process of expanding the ***capabilities*** of people. An alternative but derivative concept is that economic development can be characterised as the expansion of ***entitlements***, which are defined as the commodity bundles a person is able to command.

Entitlement

Entitlements are delivered not just through market forces, but through state intervention. The role of the state can be cast as one of ensuring that the entitlements of citizens are met. Failure to do this results in situations that Sen is so critical of in his work on famines. In his book *Poverty and Famines: An Essay on Entitlement and Deprivation*, Sen shows that the conventional food deficit account of famines is theoretically unsound, empirically inept and dangerously misleading for policy. His entitlement approach highlights that it is more often the lack of access of certain groups to food than an absolute shortage of food itself which explains instances of famine, and more generally of poverty. Perhaps the most telling case study he presents relates to the Bangladesh famine of 1974, which occurred despite peak food availability in the country.

The entitlement approach applies equally to the issue of access to water. In rural southern Africa, water is the key resource needed for survival. Although most areas are vulnerable to drought, there is often no overall lack of surface and ground water. The problem is precisely one of entitlement. To paraphrase:

> "the entitlement approach to the lack of an adequate water supply concentrates on the ability of people to command water through the legal means available in the society, including the use of productive possibilities, trade opportunities, entitlements vis-à-vis the state, and other means of acquiring water".

Consistent with the capabilities approach to development, the obvious extension is to combine entitlement to both food and water by proposing that access to sufficient water to use for productive as well as household purposes be recognised as an entitlement for rural people. In some parts of southern Africa, the cost of supplying water for production would be prohibitive. However, in many parts of the region, households could be assisted to obtain at least sufficient water for household gardens and livestock watering, often at very modest costs and without significantly adding to pressures on aggregate national water resources. A variety of technologies and approaches need to be embraced to achieve this objective.

This approach would represent a significant departure from the dominant approach in rural water supply and sanitation, which emphasises clean water for domestic usage and effectively precludes exploring possibilities of providing productive water first, despite the obvious benefits of tackling poverty at its roots. In the context, the capabilities approach surely means giving priority to access to water to allow new income-earning opportunities. Households with enhanced capabilities would themselves be able to ensure adequate domestic water and sanitation, reducing dependence on governments and outside agencies and ensuring real sustainability of narrow health-centred interventions. This statement should not be taken to imply that the provision of water and sanitation is a narrow health sector objective. It should rather be seen as part of a capabilities-based strategy to tackle poverty as comprehensively as possible in the rural areas of southern Africa. In the water sector, this involves shifting from the 'health driven paradigm' to putting 'productive water first'.

Productive water first

In summary, taking seriously the objective of 'equitable use' of water (which was part of our definition of WDM) would entail dramatically changing people's access to and increasing their usage of water, both at the household level and also as an input to agricultural and other productive activities. The problem for the majority of the population in southern Africa is that they use too little water and not too much. The real challenge of altering water demand is not so much one of ensuring that those who already have access to water use it more efficiently (in the narrow sense) but that water is allocated more efficiently in the broad 'capabilities' sense of Amartya Sen.

5.1.4 Chapter Outline

In the next section, a distinction is drawn between 'economic' and 'financial' and a summary is given of the short-term and long-term gains which can be expected from implementing WDM. The concept of long-run marginal cost [LRMC] is explained and its practical application summarised.

Section 5.3 outlines how economic tools can be used in specific WDM situations, namely the planning of major water supply infrastructure, the optimisation of system losses and urban tariff design. The text is quite brief, as the idea is to ensure that a full grasp of each of these topics will be obtained by doing the quantitative exercises in Section 5.4 and participating in the group presentation exercises (based on selected key readings) in Section 5.5. The key readings themselves are listed in the reference section (5.6). Amongst these papers, the one that gives the best general overview of WDM economic and financial aspects in SADC is Rothert & Macy (2000).

See Reader

5.2 Economic and Financial System

5.2.1 Definitions of 'Economic' and 'Financial'

While the terms 'economic' and 'financial' are often used interchangeably, it is important in this chapter to make a conceptual distinction between the two. ***'Financial'*** refers to matters of interest to an accountant or a business manager, while ***'economic'*** can usefully be reserved to refer to matters which affect the broader allocation of resources. In practice, however, real situations are complicated by policy instruments having both financial and economic implications, water tariffs being a clear case in point. A commercially-oriented water utility would set tariffs at levels which are adequate to ensure that it can cover its operation, maintenance and capital costs. The utility's performance would be measured by various financial indicators, such as net profit, return on capital, credit worthiness (ability to service loans) etc.

Financial

By contrast, the economic viewpoint on tariffs is to assess their contribution to the economic welfare of consumers in relation to the costs of opportunities forgone to use the water elsewhere in the economy. Consumers are entitled to be offered water at the lowest possible cost for efficient use, and it would thus be inappropriate and unfair to raise tariffs to exceptionally high levels merely to induce lower usage of water. This would only be justified when scarce water supplies have valuable alternative uses over and above basic needs requirements. In this context, WDM is not an objective in its own right, but a means to make existing water available to those who currently do not have proper access to water and/or to delay investmenting significantly into augmenting supply. This viewpoint is the basis for the derivation of the ***long-run marginal*** cost or LRMC principle for setting tariffs (discussed further in Section 5.2.3).

Economic

Tariffs are arguably the single most important WDM instrument available to a water supply authority (see WDM definition in the box below). What happens when tariffs are raised? By how much do tariffs have to be raised to induce more efficient use of water – that is to reduce wasteful use of water while not unduly impinging on consumers' real water needs (by making essential water services unaffordable or bankrupting business undertakings)? The change in demand resulting from a tariff increase can be captured via an estimate of the ***price elasticity of demand***, that is a measure of the responsiveness of water consumption to changes in tariffs (see exercise in Section 5.5.2 for a more precise mathematical definition of elasticity). In the short-run, demand may be relatively 'elastic' as wasteful practices are eliminated or discretionary consumption (car washing, lawn watering) is reduced. Thereafter, demand will be much more 'inelastic'. This is because water is ultimately a non-substitutable item for both households and producers. Beyond a certain degree of WDM, the volume consumed is likely to remain fairly constant despite increases in tariffs.

Consumer-oriented Definition of
Water Demand Management

WDM induces changes in behaviour in water users. This is done through a number of ways. These include awareness campaigns, educating users on how to reduce water consumption, retrofitting water systems with water saving devices e.g. reducing the volume of toilet flush water from the present 15 litres to about 8 litres. However, the main tool for demand management is the price of water. The price sends a signal to the user to efficiently reduce water consumption.

(Exam response from WREM student; University of Zimbabwe)

As already noted in Section 5.1, economists are not just concerned about efficiency, but also about other objectives – equity, environment, gender etc. The issue of equity is reflected in part in the ***structure of tariffs***. Ideally, there should be cross-subsidisation between well-off consumers, easily able to pay their water bills, and poor consumers who need to be able to afford at least a minimum level of water for basic household needs. The hard-headed financial viewpoint would be concerned only with the total amount of revenue raised. Besides the equity issues, the economic viewpoint requires that the revenue be raised in such a way that consumers are given signals about the relative scarcity of water and the cost of developing new supplies, this being reflected in the overall ***level of tariffs*** which should be high enough to provide incentives to use water efficiently. Tariff design is discussed further in Section 5.3.3 below.

5.2.2 Financial Savings and Economic Gains from WDM

Short-term benefits

By reducing the volume of water that has to be delivered, WDM, in the short-term brings financial savings to the water supply utility through reductions in treatment and pumping costs. However, if the utility has a cost structure that is dominated by fixed costs, reducing demand may mean a disproportionate decrease in revenues, making the utility less viable when WDM becomes effective. There may be strong *economic* reasons to introduce WDM, but if the implication is to undermine *financial* viability, the utility may not in practice be in favour of WDM.

Social factors may play an important part in whether a utility supports and promotes consumer-oriented WDM strategies. For southern African utilities, WDM reducing water consumption would have the implication of reducing demand for treatment chemicals, which are often in short supply. For a given stock of chemicals, reducing the volume of water to supply reduces the risk of under-treating the water and thereby avoiding disease outbreaks.

Long-term benefits

In the context of rapid urban population growth rates, substantial benefits will accrue in southern Africa from WDM through making it possible to delay major new water supply projects, which are typically several times as expensive as existing sources. Investing in WDM potentially provides a much cheaper source of water than investing in a new source of supply.

To quote a prime southern African example, Windhoek water was 'produced' through WDM at US$0.10 per cu m, thereby making it possible to delay investing in a pipeline from the Okavango River, which would have delivered water at US$1.80 per cu m [Louw & Kassier (2002), pg 45].

See Reader

The contention that the largest financial savings from WDM arise through the postponement of capital expenditure on water supply infrastructure requires some explanation. There is often misunderstanding about the benefits of delaying infrastructure projects, in view of the fact that the financial or accounting costs of projects are bound to rise if they are delayed. So, when engineers are challenged about building dams before they are needed, one of the factors they point to is lower investment costs. However, such cost savings are in nominal terms. In other words, the investment cost goes up purely because of inflation. In real or inflation-adjusted terms, the cost of a project that is delayed could well be lower because of improvements in engineering processes or factors such as lower duties on imported equipment.

It is the real economic costs which are relevant to analysing the benefits and timing of alternative strategies (WDM vs supply augmentation options). From an economic perspective, the substantive point is that the main benefit of delaying a major water supply augmentation project is that the resources which would have had to be launched into the project can be used for a more urgent need in the water sector or for a productive investment (as opposed to an infrastructural one). The alternative use will generate benefits somewhere else in the economy. To invest in supply augmentation projects before they are needed is to forego benefits or, equivalently, to incur opportunity costs elsewhere in the economy. Delaying infrastructural investment through making better use of existing supplies will allow the momentum of economic growth to be maintained, whereas tying up investment resources in infrastructure projects before they are needed will slow the rate of economic growth, reducing national income and employment.

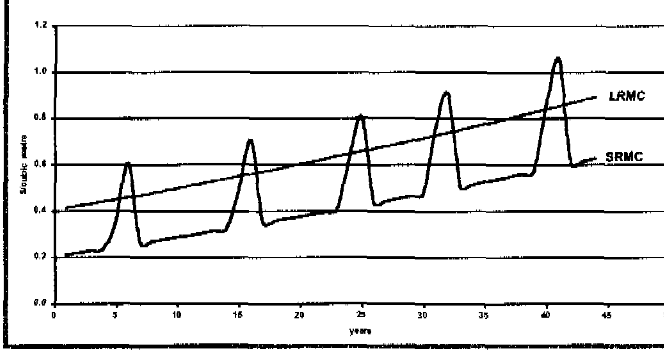
5.2.3 Long-run Marginal Cost Pricing

Marginal cost

A ***marginal cost*** refers to the cost of supplying the last unit of demand. This is a future-oriented cost and is different to an average (historical) cost which is the average cost of all the units supplied up to this point over a defined period of time in the past. Neo-classical economic theory asserts that prices promote the efficient allocation of resources when they are equal to the marginal cost of production.

When water infrastructure is provided in large "lumps" (dams, for example), the short-run costs will be unstable and to avoid this unstable 'spikiness', an averaging procedure (which results in a 'long-run marginal cost') is preferred. This is illustrated in the diagram below.

Short and long run marginal cost – lumpy investments



True long-run marginal costs are difficult to calculate, so for practical reasons, LRMCs are usually approximated by calculating ***long-run average incremental costs*** [LRAICs]. Average incremental cost is the average cost of providing future infrastructure (for example, a series of lumpy future investments) discounted to a present day cost (for details of how the calculation is to be performed, see the spreadsheet exercise in Section 5.4.1).

As LRMC is a purely forward looking measure, setting the average tariff level equal to the LRMC may result in too little or too much revenue being generated in relation to sunk (accounting) costs and the corresponding levels of debt service, as well as the requirements of accumulating resources for future investments. There are also various other objectives to be considered – for example, environment and equity – before the structure as well as the overall level of tariffs is finalised. The following sequence of steps is therefore recommended in the economics literature:

Tariff setting

- calculate the LRAIC (as a good approximation to the LRMC), and use this to establish an initial proposal for the overall tariff level;
- design a tariff structure to achieve an average tariff level equal to the LRAIC, but which also meets socio-economic goals, including environmental and equity objectives (this will involve cross-subsidies between consumer categories);
- the resulting proposed tariffs, which are based thus far on economic principles, should then be assessed in relation to financial requirements;

- the final step is to adjust the average tariff level (and possibly also fine tune the tariff structure) so that the revenue generated is neither deficient nor excessive in relation to the financial requirements of the water system.

As LRAIC tariffs are often much higher than historical tariffs, moving the average tariff to the LRAIC level would typically result in substantial financial surpluses being generated. In principle, these would be accumulated for the next investment project, which would be delayed into the future because of the impact of the high tariffs. However, such accumulation of surpluses is controversial, because it is not usually efficient to finance a new project from cash resources. The water supply utility rather has to have a strong balance sheet and sufficient liquidity to make an equity contribution to a new project, but will borrow the bulk of the finance needed for the project. Applying this perspective to the final step listed above typically results in the average tariff being reduced, leaving only the top tier in the rising block tariff scheme at or perhaps slightly above the LRAIC.

As a practical 'rule of thumb', therefore, the top tariff can be set to the LRAIC or LRMC level. This approach is adopted in the tariff design proposals given below in Section 5.3.3.

5.3 Applying economic tools in specific water demand

5.3.1 Planning Major Infrastructure

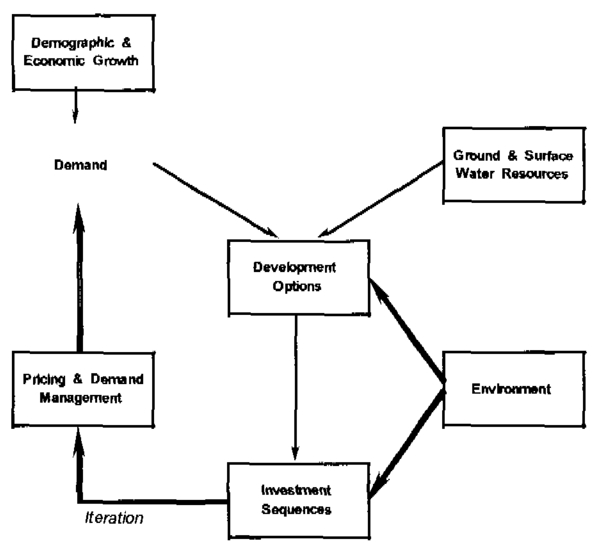
In the past, the planning of major water infrastructure was characterised by the '***supply-oriented approach***'. This took the demand projections (often only loosely based on demographic trends and economic growth prospects, with tariffs maintained at very low levels) as a 'given' and sought to identify the least cost sequence of supply augmentation investments to meet the demand up to some specified risk criterion (typically, for urban areas, 4% risk).

Many problems arose from this approach, not least the building of dams which were not used at anywhere near the levels for which they were ostensibly built in Zimbabwe three recent instances are the Mtshabesi, Wenimbi and Osborne dams – for details see Robinson (1999). Unrestrained water supply also involved considerable environmental costs (aquifer depletion and dam building causing loss of wetlands and damage to river flows, as well as increased wastewater disposal, causing pollution of streams and groundwater). Low tariffs and declining contributions from governments resulted in water supply entities becoming progressively less able to maintain an adequate level of service to existing customers, much less make the investments necessary to extend supply to potential new customers.

The preferred alternative to the supply-oriented approach may be characterised as the ***economic approach***. The starting point in the economic approach is the fourth Dublin Principle, namely the recognition that "water has an economic value in all its competing uses and should be recognised as an economic good". The most obvious implication of this principle is that water that is treated and delivered to customers should be charged for, with the prices or tariffs being set to inform consumers of the real economic opportunity costs of using water.

The economic approach adds two crucial dimensions to the supply-oriented project planning cycle (see the diagram below). Firstly, environmental considerations may influence the development options shortlist, and/or the detailed design of the options. Secondly, there is a feedback loop requiring that demand be treated as an endogenous variable (that is determined within the planning loop and not taken as an immutable 'given').

Economic approach – feedback via pricing & WDM



In this respect, the economic approach requires an iterative planning cycle. The initial investment sequence and associated LRMC should be used to assess the implications on demand of raising tariffs to LRMC levels. Coupled with assumptions about possible other demand management measures, this will almost certainly lead to a revised, lower projection of demand. The development options appropriate to this should then be reassessed, and the iterative process continued until there is consistency between the development sequence, associated LRMC, resulting tariffs and level of demand.

Note that lower demand may not simply mean delaying the first investment sequence which was identified: in principle, a different level of demand could lead to a quite different least cost investment sequence.

5.3.2 Optimising System Losses

Leak reduction

Reducing leakages in pipe systems is one of the most obvious – and satisfying – means of using existing water supplies more efficiently to meet consumer demand. Leak reduction is not a costless activity, however, and there must eventually come a stage where the additional cost of reducing leakage turns out to be more expensive than developing a new source of supply. Once the costs of leakage reduction and of alternative supply augmentation investment sequences (encapsulated in the corresponding LRMCs) have been ascertained, it is desirable for the water utility to calculate the 'optimum' level of leakage reduction, usually expressed as a component of the optimum level of ***unaccounted for water***. This level can then be set as a target to be achieved before a major new supply augmentation project should be considered.

At present, in most southern African cities, the point at which additional leakage reduction would be as costly as providing water from a new supply source is a long way off. However, as has been shown by the City of Bulawayo, pipe bursts and leakages can be significantly reduced over a relatively short period once a thorough WDM strategy is implemented. A reading exercise is provided on this in Section 5.5.4.

5.3.3 Cost Recovery and Tariff Design

Rising block tariff

The rising block tariff aims simultaneously to achieve efficiency of use of water and equitable access, at least in respect of affordable access for all to a basic needs quantity of household water, while also providing cost recovery (at least of operation and maintenance costs if not also of capital costs) for the utility. These objectives are simultaneously achieved by having a basic volume of water available at very low tariffs, and subsequent tranches of demand at ever higher tariffs which progressively increase the incentive for efficient use of water. Affluent customers with high levels of consumption charged at the highest tariffs provide the resources to cross-subsidise poor customers who can only afford to consume minimal quantities of water. Revenues from all customers in aggregate cover the overall costs of the utility.

Practical steps for designing a rising block tariff structure to achieve efficiency, equity and cost recovery are summarised in the box below. These also need to be consistent with the principles already given in Section 5.2.3. In designing tariffs, it would be ideal to have estimates of the price elasticity of demand associated with each tier of the rising block tariff. In practice, it is rare to have anything more than general indications of elasticity, so tariffs have to be designed using the utility's best estimates of the likely behaviour of its customer base.

The increasing block tariff systems: defining the functions for each block

In order to find a satisfactory 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 e.g. 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$/m3); 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. 4 times the lifeline amount) will pay the full cost of water over their entire use (ie the LRAIC, which embodies the future investment requirements – see Section 5.2.3). This means that the tariff of the third block should offset 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.

Source: Van der Zaag (2003).

5.4 Number crunching exercises

5.4.1 Delaying investment through WDM

This exercise involves working in a spreadsheet environment. It starts with a 'warm-up' section for those who are unfamiliar with Excel and proceeds through various stages which analyse key aspects of WDM. The hypothetical case study also provides an opportunity to revise associated economics topics, in particular project financing.

The write-up in this exercise is quite extensive (finishing 5 pages from here), but don't be put off by this. The intention is to spell things out in a step-by-step manner for those not comfortable with spreadsheets. Those who are should be able to move through the exercise rapidly.

Start by copying the spreadsheet *Economics of Water Spreadsheet Exercises.xls* and rename it as *Economics of Water Spreadsheet Solutions.xls*. Use the solutions sheet to respond to the following questions:

1. Initial Exercise

This exercise involves Projects 1-3, as shown in the spreadsheet.

(1) For the case of 10% discount rate, check the formulae for NPV (cell C17). Note that Excel's NPV function discounts from the first element in the range. So, if the first element is the reference point (not to be discounted) it must be pulled out of the formula, as demonstrated.

(2) What has been added to the formula to ensure the correct result when it is copied and pasted into other cells where a similar formula structure is required?

(3 Also check the IRR formula. Note that an initial 'guess' at the IRR is necessary (10%=0.1) to get the computer started on the iterative calculations which are involved. The whole range needs to be specified in the IRR formula.

(4) Use the computer to draw NPV vs discount rate curves.
Suggestion (for those unfamiliar with graph capabilities of Excel): set up a table with discount rates running in 2% steps from say cell B21 (0%) to cell B36 (30%). Use the formula discussed above to rapidly generate corresponding NPV values e.g. for project 1 in the range C21:C36. Put titles in row 20 and highlight B20:E36, then go to 'insert chart'. Use X-Y (scatter), smooth lines without data points, to plot the graph. Add a title for the graphs and ensure that the project identifiers are picked up in the legend. Choose 'new sheet' option. Change colours, legend position etc to match personal preferences.

(5) From the graph, what are the IRRs (approximately) of the three projects?

2. Water Demand Management

The spreadsheet is set up to analyse a project to expand a water supply system to match growing demand. Units are millions of cubic metres per annum (M cu m pa). The time period covered by the analysis is 20 years (2002 to 2022). Choosing 20 years is somewhat arbitrary and to offset this, a "residual value in 2022" is added (last item in the revenue panel).

The "Parameter" column D is a convenient place to make key assumptions visible e.g. the underlying unconstrained growth in demand for water (cell D7). The entries in column D for rows that are derived are formulae. For example, cell D15 is a formula to calculate the average growth rate of water sales. The formulae in row 15 give water sales in each year = unconstrained volume – demand management – non-revenue volume. The growth rate in D15 is calculated from a simple 2-point growth formula (extrapolating growth between 2002 and 2020). Those with experience in this area might like to experiment with more sophisticated growth formulae (e.g. based on a regression which would capture all of the data points between 2002 and 2020).

There are 5 main panels in the spreadsheet:

(i) **Revenue panel** – projected growth in demand for water, with the option of introducing assumptions about water demand management, together with calculations of the resulting revenue. Note that allowance is made for 'non-revenue volume': losses plus public uses (e.g. watering of parks etc), which in many urban situations are not charged for. The fixed price of 0.25 US$/cu m (cell D18) assumes that the actual tariff (denominated in local currency) will be adjusted so as to keep the US$/cu m charge constant. Strictly speaking, the aim should be to keep prices and costs constant in terms of 2002 US$ values. The spreadsheet is then specified in real terms (this is an important consideration when it comes to calculating average costs per cubic metre – see (4) below). The next row makes provision (in cell D20) for a higher tariff to be introduced when the expansion project comes on stream. The higher tariff applies to all units sold (check that the formulae ensure that this is so).

(ii) **Cost panel** – capital costs (spread over 3 year construction period) plus operation and maintenance costs. Note that O&M costs are higher for the new project, so the operators would first use the old system to full capacity (20 M cu m per annum) before using the new system. This is modelled by using "if" statements in the spreadsheet (see, for example, cells K28 and K30).

(iii) **Incremental cost panel** – this is described below in relation to exercise 5 (which discusses calculating LRAIC as a proxy for the LRMC).

(iv) **Net project flow panel** – net flows are total revenues (including the residual value) minus total costs. This "bottom line" can be discounted at different discount rates (5% and 10% have been chosen) and the IRR calculated. Note the comments made in column E and check the formulae in column D (cells D42, D43 and D44).

(v) **Financing panel** – this is analysed in detail in the third part of this exercise.

Exercises

(1) Why is the project as shown in the exercise sheet unviable? In your solution spreadsheet, increase the US$/cu m charge in the "additional revenue required" row (cell D20) so that the IRR (before financing is taken into consideration) is 8% (cell D44). What is the required resulting total tariff from 2005? What are the project NPVs at 5% and 10%?
This exercise is intended to illustrate the point that project evaluation techniques are used as much to DESIGN projects as to examine their viability.

(2) Copy the sheet "Water Project (1)" to the end of the solutions file. Do the following exercise in the resulting "Water Project (2)" sheet.

Water demand management: given that the current system capacity is 20 M cu m pa, until what year can the augmentation project be delayed if 1% demand management is achieved? (Modify cell B9 accordingly).

The way the spreadsheet is currently set up, the project still goes ahead as scheduled (construction 2005-2007, commissioning in 2008). What are the resulting NPVs and IRR? Why are they lower with WDM than they were before? Comment on the relevance of this to the observation in Section 5.2.2 that "if the utility has a cost structure that is dominated by fixed costs, reducing demand may mean a disproportionate decrease in revenues, making the utility less viable when WDM becomes effective. There may be strong economic reasons to introduce WDM, but if the implication is to undermine financial viability, the utility may not in practice be in favour of WDM".

[*Additional exercise: does the WDM formula in* the spreadsheet make sense? Experiment with other formulations!]

(3) In practice, the water utility would delay the new project once it became clear that its WDM initiatives were slowing demand growth. Adjusting the timing of the investment project so that it ties up with the reduced level of consumption arising from WDM requires quite extensive changes to the spreadsheet (4 rows in the top panel and all of the financing rows need to be changed). You may want to attempt to make these changes, or else use the new "template" which is "Water Project (3)".

Note that the same "additional revenue" parameter has been used. This leads to an 'excessive' level of profit (large NPVs at both 5% and 10% discount rates). From what year would the higher level of tariffs have to be applied for the utility to still achieve 8% NPV? Change row 20 and write the year of required tariff increase in cells B21 and D24. [You may want to experiment with other options for different levels of tariff and timings of increase(s).]

(4) Engineers designing projects often ignore the revenue side and concentrate on the cost per cubic metre as a design criterion. This is an important step when considering different technological options. However, once the least cost approach has been identified, the full project analysis should include the revenue side (not least to highlight the link between changes in tariffs and the effect this will have on demand).

The correct way to calculate the indicative \$ / cu m is to divide discounted costs by discounted volume of water (in this case the 'adjusted volume', row 11, rather than the sales volume). Why is it correct to discount water volumes? Go back to the "Water Project (1)" spreadsheet and put formulae in cells E33 and E34 to calculate the correct aggregate volume (M cu m) and in F33 and F34 to obtain the \$/cu m value at the 2 different discount rates. Copy the formulae into the other 2 sheets. Make a table of the resulting values for the 3 options (no WDM, WDM but no change in project date, full WDM) and discuss the figures. [It would be sound Excel practice to construct the table in a separate sheet, with the values being linked to the sheets for the 3 options. Then, if you make any change in one of the primary sheets, the resulting change to the unit cost will automatically be reflected in the summary table].

(5) LRMC – strictly speaking, the long run marginal cost should be calculated from the cost implications of a marginal change in demand sustained into the future. There are severe difficulties with this notion, and it is more common for the so-called LRAIC to be calculated (long-run average incremental cost). To do this, the annual increments in demand are related to the corresponding incremental costs (investment costs plus additional O&M costs) as shown in the first 2 rows of the panel.

Insert formulae similar to the ones in the previous exercise to calculate the relevant volume and unit costs. Extend your table to include a summery of the LRAIC for each of the 3 options at the different discount rates. Discuss your results.

(6) Draw a graph showing unrestricted demand and the volume when WDM is in place.

Will consumers conserve water (and hence change demand growth) in response to increased (project related) tariff increases? Is it reasonable to model WDM as a smooth annual process? Is it feasible, in your view, to achieve sustained 1% pa reductions in growth over a 20 year period? What range of measures would be required?

(7) Using the calculations as a starting point, discuss the implications of WDM for
(a) the consumer and
(b) the water utility.

3. Project financing

It is normal for the viability of projects to be assessed first and then for financing considerations to be brought into the picture. Indeed, this sequence is recommended. You will be asked why in (4) below.

The bottom portion of each spreadsheet has details of possible financing of the supply augmentation project. It is assumed that the project is financed from 3 sources:

- **equity (ie owner/shareholder contribution):** 25% of the total capital, expected returns being annual dividend payments (from the year of commissioning) of 17.5% of the capital invested;
- **commercial bank loan**: half of the remainder, repayable over 8 years, no grace period, interest rate 12% on the outstanding balance from the time of commissioning of the project;
- **development bank loan**: other half of the remainder, repayable over 10 years, 5 years grace period in repaying the capital amount, interest rate 5% on the outstanding balance from the time of the commissioning of the project.

Check that the relevant entries in the spreadsheets reflect the above assumptions accurately.

Exercises

(1) Calculate the NPV at 5% & 10% and IRR of the equity contribution, commercial and development bank loans (use panels at the bottom of main table in "Water Project (1)", introducing cell formulae to give the 'bottom line' for each of the 3 financing entities. Be careful with signs – from each financier's viewpoint, they invest in money at the beginning of the project and get positive returns later. Copy the formulae over to sheets (2) and (3). Note that in (3), the development bank loan now extends to 2027, or column AD. For consistency, rows relating to dividends and total flows also have to be extended to column AD. The extension of the project flows has already been taken into account in a rough fashion through the inclusion of the residual value.

What summary values indicate the difference between equity and borrowing from commercial and development bank sources? Which source of finance is most beneficial for the project?

Why are the NPVs and IRRs for the 3 sources of finance the same between (1) and (2) and generally lower for option (3)?

(2) What else besides contributing equity capital (and thereby leveraging debt financing) is expected of private sector participants in infrastructure projects?

(3) While the without financing project NPV vs discount rate functions are downward sloping, the overall net cash flow NPVs vs discount rate functions are upward sloping. Why? Do the overall (with financing) cash flows matter?

[Note that the equity, commercial and development bank calculations have been made from the viewpoint of each of these financiers: as noted previously, they invest money at the beginning of the project and get positive returns later. Their NPV vs discount rate functions are therefore downward sloping].

(4) Why is it that it is recommended that the viability of a project be assessed independently of its financing (with the financing only being brought into the analysis once the stand-alone viability has been established)?

5.4.2 Tariff Design Exercises

The following exercises involve a mathematical formula for the elasticity of demand, a concept which was introduced in more generic terms in Section 5.2.1. The price elasticity of demand is defined as the percentage change in demand resulting from a percentage increase in price. If the demand curve as a function of price is Q(p), the elasticity at any particular point on the demand curve is $E = (dQ/Q)/(dP/P)$. The elasticity is a negative number since demand normally decreases as price increases, and the range is often between -1 and 0. Demand curves (especially for water) typically have different elasticities at different levels of quantities – a demand curve which has a constant elasticity throughout is a very special case.

1. Project planning

A city has a steady per capita water consumption. Its population is increasing by 5% per annum. Annual water consumption in year 0 is 90% of the reliable supply capacity of the city's water system.

(a) How long does it take before the water consumption of the city reaches the limit of the supply capacity?

An engineer has calculated that developing the next water source to augment the city's reliable supply capacity will add 25% to the city's current total water costs (i.e. total investment cost is annualised and represents 25% of current annual expenditure). The city has a policy of full cost recovery.

An economic consultant has measured that the demand for water in the city has an elasticity of:

$E = (dQ/Q)/(dP/P) = -0.2$

The engineer finally recommends the council to make sure that the new water project is ready within the time specified in your answer (a). The engineer also recommends to immediately raise the water tariff by 25%, in order to finance the project.

(b) Do you agree with the engineer's timing of the new project? When should the new water source be ready for use? Explain.

However, when the water project is ready, it appears that the real cost of developing the new water source is double the amount that was initially estimated.

City council decides to stick to its policy of full cost recovery. It will increase the water tariff in order to be able to finance the cost overrun.

Mean time (before the new tariff increase), an economic consultant is asked to check the price elasticity of water demand. She finds that this elasticity now is: $E = -0.50$.

(c) Why could the elasticity E have changed?

(d) Is the water source project now necessary? When will it effectively become necessary?

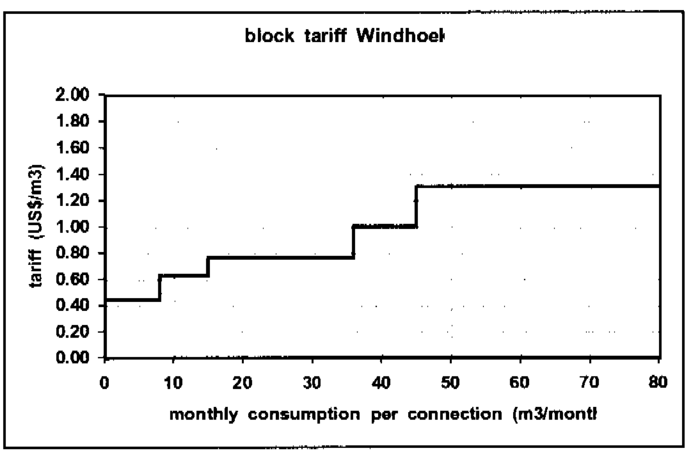
2. Rising block tariffs

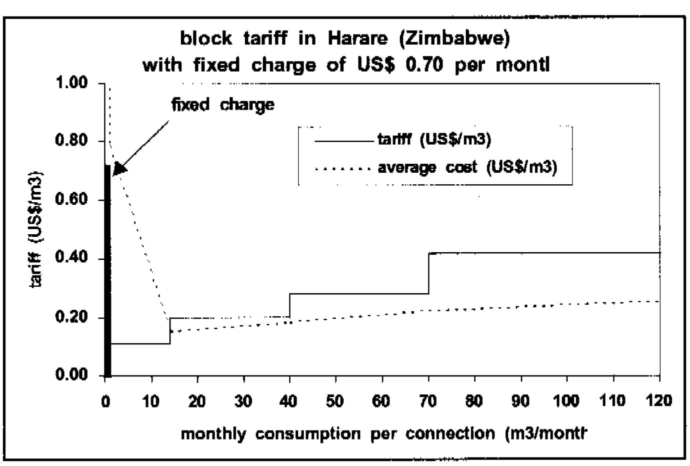
Given below are the rising block tariff structures of Windhoek and Harare in 1997 and 1999 respectively.

(a) Calculate the total water bill (US$/month) and the average cost of water (in US$/m³) for house holds in both cities that consume 1, 10, 50 and 100 m³/month.

(b) Why is accurate billing a vital component for successful implementation of rising block tariff structures?

Windhoek 1997 Consumption (m³/month/ connection)	tariff (US$/m³)	**Harare 1999** Consumption (m³/month/ connection)	Tariff	unit
0-8	0.44	Fixed charge	0.68	US$
8-15	0.62	0-14	0.11	US$/m³
15-36	0.76	14-40	0.20	US$/m³
36-45	1.00	40-70	0.28	US$/m³
45+	1.30	70-300	0.42	US$/m³
		300+	0.50	US$/m³





5.5 Group Presentations based on Readings

5.5.1 Costs and Benefits of WDM

The discussion in Section 5.2.2 gave a very brief summary view of the financial and economic benefits of WDM. Skim through the paper *"Costs and Benefits of Water Demand Management"* by D B Louw and W E Kassier and prepare a table summarising the benefits in more detail. Your group should provide specific examples of WDM benefits (from any source, including your own experience).

See Reader

> The authors of this paper have a snappy aphorism about WDM that is worth remembering:
> ***"The ultimate cost effectiveness of WDM is the deferral of waterworks. The cheapest water in the future may well be the water which was wasted in the past."***

5.5.2 WDM in SADC

Prepare a presentation on the paper entitled ***"The Potential of Water Conservation and Demand Management in southern Africa: An Untapped River"*** by Steve Rothert & Peter Macy. In your presentation, the group may wish to include answers to the following questions:

See Reader

a) Is it valid to dismiss the threat of water scarcity in southern Africa on the basis of making estimates of the overall savings which should be possible from WDM?

b) Are you concerned about experiencing water scarcity in your country during your lifetime? What can and should be done?

c) The paper documents the potential savings to water consumers in Gauteng from delaying Phase 2 of the Lesotho Highlands Water Project. Discuss what is involved from the South African perspective. In addition the implications of such a delay on the citizens of Lesotho.

d) Does the paper deal adequately with using WDM savings to provide for greater equity in access to water? What would be the implications of undertaking this on a large scale in your own country and SADC as a whole?

5.5.3 WDM in Urban Areas of SADC

This exercise calls on the group to reflect on their personal experience of WDM in the cities they have lived in, as well as reading available reports, such as the account of ***WDM in Windhoek*** (below, drawn from Macy, 1999), Bekithemba Gumbo's review of ***The Status of water demand management in selected cities of Southern Africa*** (summary table reproduced below) and/or the UN-Habitat publication ***WDM in Practice***, which contains information on Rand Water (Sebokeng, Tembisa, Kagiso and

See Reader

Boksburg Schools), Windhoek, Durban, Hermanus and Cape Metro Council.

Which urban centre is the best performer from a water perspective? To what extent does the group consider pricing to be the predominant urban WDM instrument? How important are other WDM measures?

Example – Reduction of water demand in Windhoek (Macy 1999)

In Windhoek, water demand was 242 litres per person per day in 1995, with unaccounted for water only 11%. Windhoek adopted an integrated policy on water demand management in 1994, which is financed by a 0.5 percent levy. Efforts that started in the 1950s have primarily focused on re-use of water. Nowadays, Windhoek can re-use all its waste water for the watering of parks, sport fields and cemeteries through a two-pipe system and the reclamation of waste water to a potable standard. Of all domestic water use, 13% is treated for reuse. About 60% of all water used in up-market households is for gardens. Its infiltration into lawns and gardens makes it unavailable for reuse. Large water savings in gardening can still be attained.

An important part of the water demand management programme involves appropriate tariffs. When tariffs are sufficiently high, they tend to keep exterior irrigation demands reasonable. Water tariffs were raised by 30% in 1999 and any water demand exceeding 45 m^3/month per household or enterprise was billed at US$ 1.30 per m^3.

Other water demand measures include:

- Public awareness and education
- No irrigation of gardens between 10:00-16:00 hrs (mandatory)
- Use of swimming pool covers (mandatory)
- Use of low-flush toilets (mandatory for all new buildings since 1997)
- 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 is that per capita water consumption has decreased. 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 to 7.8 M m3 yr-1.

Most of the benefits from water conservation are obvious:

- up to 30% of long-term savings can be achieved; short-term savings may be double
- less waste water has to be treated, and less energy is used
- the environment will benefit from reduced alteration of flow patterns and from less or reduced dams and other infrastructure
- financial savings from reduced capital as well as operating costs; the figure below illustrates savings due to delay in construction of "the next dam".

Decrease of water demand will delay the need for new water infrastructure *(Macy 1999: xv)*

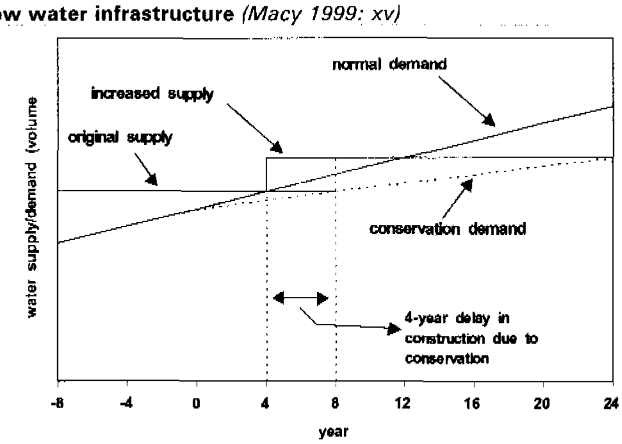


Table: Summary of performance indicators for seven cities [a]
(Gumbo, 2003)

Indicator	Bulawayo	Mutare	Maputo	Windhoek	Lusaka	Jo'burg	Hermanus[b]
Managing institution	Municipal	Municipal	Private	Municipal	Private	Municipal	
Population served (1000's)	1000	200	1700	250	2200	3500	30
Volume supplied (m^3/day)	100 000	60 000	120 000	48 000	210 000	1 100 000	10 000
Per capita gross figure (l/cap.day)	100	300	70	190	95	310	330
Annual yield from sources (Mm^3)	47.5	42.0	54.0	22.2	–	–	3.3
Average rainfall (mm/annum)460	900	800	360	900	710	760	
Altitude (m)	1420	1550	300	1600	1300	1200	500
Level of service							
% reticulated	99	90	45	97	40	90	100
% stand-posts & other	1	10	55	3	60	10	0
Number of connections	106 000	–	80 000	38 000	33 300	617 000	12 000
Length of distribution network (km)	2 100	1 100	840	1 300	2 300	8 300	–
WDM strategy	Yes (1998)	None	None	Yes (1994)	None	Yes (2001)	Yes (1996)
WDM policy	Yes	Yes	Yes	Yes	None	Yes	Yes
WDM legislation	None	None	None	None	None	Yes	Yes
Dedicated WDM section	Yes	None	None	Yes	None	Yes	Yes
% Level of UFW	20	52	65	18	55	30	11
% Domestic	55	70	80	74		75	90
Block tariff system	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Average cost of water (US$/$m^3$)0.30	0.22	0.40	0.60	0.14	0.25	0.45	
Revenue generated (National currency per annum)	Z$600 M	–	–	N$45 M	ZK50 B	–	–
Financing of WDM as a % of water account	Yes (1 %)	None	None	Yes (1 %)	None	Yes	Yes

Notes: (a) Data from various sources
(b) The population of Hermanus oscillates between 30 000 and 70 000 due to seasonal influx of holiday makers.

5.5.4 Optimising System Losses

See Reader

Read the extract from the report on the ***Bulawayo Water Conservation and Sector Services Up-Grading Project*** and prepare a presentation for the class explaining the methodology. Be sure to cover answers to the following questions:

- What economic principle is employed in setting targets for levels of leakage in the system?
- Why do these depend on assumptions about the next source of supply to the city?

5.5.5 Alternative to the rising block tariff

See Reader

Prepare a presentation on the paper on ***Water Tariffs & Targeted Subsidies*** by Derek Hazelton.

- What advantages over the rising block method does the author identify for his preferred "cost rebate/surcharge charging" method?
- Explain how his scheme works.
- Do the members of the group think this approach to setting urban water tariffs can be made to work in southern African cities?

5.5.6 Expanding demand for water in southern Africa

See Reader

Read the paper entitled ***'All For Some': Water Inequity in Zambia and Zimbabwe*** by Peter Robinson. It addresses aspects of the concerns raised in Section 5.1.3 by looking at equity issues in urban areas of Zambia and access to productive water in rural areas of Zimbabwe. Discuss the lessons which can be drawn from the case studies and whether these are relevant to urban and rural water programmes in your own countries.

Against this background, the class presentation should attempt to defend or refute the assertions given at the end of Section 5.1.3:

The problem for the majority of the population in southern Africa is that they use too little water and not too much. The real challenge of altering water demand is not so much one of ensuring that those who already have access to water use it more efficiently (in the narrow technical sense) but that water is allocated more efficiently in the broad 'capabilities' sense of Amartya Sen.

5.6 References

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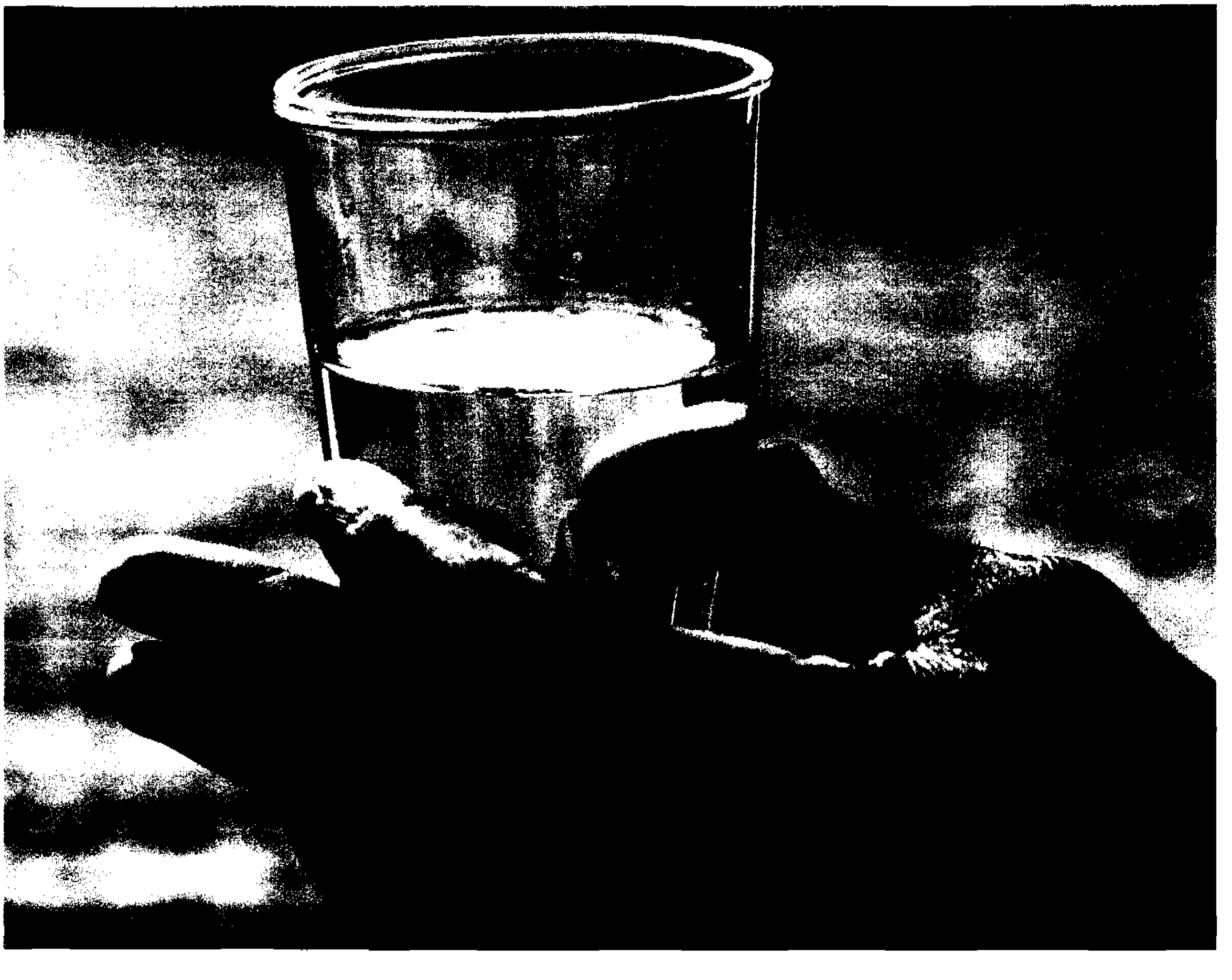


6. Political and Institutional aspects of WDM

Lewis Jonker and Pieter van der Zaag

6.1 Introduction

Ineffective water management, and the failure to implement water demand management measures, is often blamed on the "lack of political will", or on ineffective forms of governance. As the Global Water Partnership's Framework for Action (GWP, 2000) stated:

> "the water crisis is often a crisis of governance."

The 2000 Hague Ministerial Declaration reinforced this view and called for

> "good governance, so that the involvement of the public and the interests of all stakeholders are included in the management of water resources" (Rogers and Hall, 2003).

Those involved in water management often prefer to shy away from the sensitive issues surrounding governance issues, and rather focus on solving tangible problems. But in so doing, we may be scratching the surface, and fail to address underlying, and persisting, weaknesses.

In the view of the developers of this course module, we need to understand why there is this strong link between politics and water management, before venturing into opportunities for strengthening good governance. It is easy to call for "creating an enabling environment" (Rogers & Hall 2003, p.7) or "raising political will to overcome obstacles to change" (p.37). But the deafening silence that often follows shows that we don't know how to improve it.

The main purpose of this chapter, then, is to explore the link between politics and water, between governance and water management; and from there to consider institutional options that improves governance and facilitates and promotes the adoption of water demand management measures.

The chapter starts at a fundamental level by considering *needs*. Thereafter, *interests* are examined. Needs and interests form the bedrock of any system of governance, which seeks to balance the needs and interests of a constituency or community. This balancing act can only be accomplished through a feedback mechanism called *"accountability"*. Here we arrive at the Achilles heel of water governance. We ask ourselves: why is accountability a problem in water management? From here, the step towards *institutions* is small: which mechanisms of accountability do water institutions have? How can these be strengthened?

Without accountability, water institutions will be weak. Weak institutions will not be able to develop and implement strategies that influence water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource.

Box 6.1: Water, pre-paid meters and cholera in a Kwazulu township, South Africa (ICIJ, 2003)

There was a time, said Wilson Xaba, when the taps in the Ngwelezane township just ran and ran. The water was clean and free.

Ngwelezane is a two-hour drive north of Radebe's township of Nkobongo in the former homeland of KwaZulu, South Africa. Of a population of 1.5 million people, 79 percent do not have access to clean water.

Xaba leads a community group called Shona Khona, which means "Go There." It was started in response to the community's dissatisfaction with increasing service cutoffs by the municipality's "commercialized" waterworks.

In 1982, KwaZulu suffered a major outbreak of cholera. More than 12,000 cases were reported, and 24 people died. As part of a relief program, nine communal taps were erected by the apartheid government on the border of Ngwelezane. It was a historic milestone for Ngwelezane. For the first time, residents were able to access purified water. According to Xaba, some residents made personal connections to these taps and had running water in their houses. For the next 17 years, the community had free water.

Until 1998, the municipality covered all costs of water from the nine communal taps. But then the town council introduced measures for more rigorous financial management. Residents were required to pay a flat monthly rate of $4.50 for water and electricity. At the end of 1998, the nine communal taps were converted to prepaid meters. To access water, residents had to pay a connection fee of US$5. Only 700 households could afford the registration fee. Two-thousand families remained unconnected.

"They came to us and said we are wasting water," Xaba recalled. "We were not consulted, they just told us. For those houses with taps, they put meters in. Then they put the prepaid meters in. We said 'no' and then they cut our water. They said the water belonged to the municipality. They used a phrase, 'No money, no water."

In August 2000, at least four of the meters stopped working. "We could not get water from anywhere. Nobody explained anything. It took three weeks before the meters were working again. The boreholes were dry. We had no choice but to get water from the rivers."

The first cholera case in Ngwelezane was reported in August 2000. Within four months there were thousands of cases of the disease, which spreads through food or water contaminated with cholera. The causes of cholera have been understood since the mid 19th century. The disease ultimately spread to the Eastern Cape and then to Johannesburg, becoming the largest cholera outbreak in South African history before it ended in early 2002. According to government figures, about 120,000 people were infected and 265 were killed. Hemson, who was sent by the government to investigate the outbreak, said he discovered that the municipal government had put locks on people's taps, forcing them to take water from the lake and river. "That spread this cholera epidemic throughout the entire community," he said.

The local council eventually reacted by removing the prepaid meters from communal taps and charging people a flat rate of $2 to $2.50 per month for water. The South African government gave KwaZulu-Natal $2.5 million in emergency funds to fight cholera in the province. It also trucked water into the affected areas at a cost of $45,000 per month.

"It is hard to fathom how a democratic government, which prides itself with promoting seemingly progressive water legislation, could experience one of the biggest outbreaks of cholera," Cottle said. Unless the government gets rid of its policy of cost recovery, "cholera will continue to haunt South Africa for a long time to come," he said.

And it will be costly. As a result of trying to recoup its water costs, the state is now paying "tens if not hundreds of times more dealing with the health crisis," said David McDonald of the Municipal Services Project.

6.2 Needs

"Needs are necessities, the things that are essential for survival, such as food, water, shelter and clothing. Needs, unlike wants, are not absolutely unlimited. For example, it is possible to calculate the basic needs which have to be met if a person or household is to survive" (Mohr, Fourie and associates; 2000, page 8).

Water is a vital, life-giving resource, without which people would not survive. Clearly then, water is a basic need, and access must be ensured. Some authors argue that access to sufficient clean water should therefore be considered a human right (see e.g. Gleick, 1999).

It is widely accepted that governments have the duty to ensure that people have access to water. The South African Constitution, for example, states the following (cited in Bond, 2001):

> "everyone has the right to an environment that is not harmful to their health or well-being... everyone has the right to have access to healthcare services, including reproductive health care; sufficient food and water; and social security..."

Access

Providing such an important resource to people is an important responsibility, and quite sensitive: What if supply fails? What if the quality of the water is unacceptable? Hundreds of people may suffer, fall ill or even die (Box 6.1).

Generally, governments have invested significant resources to ensure access to sufficient water of acceptable standards. For urban water supply, high assurance of supply often implies large storage works, and expensive treatment works are built to ensure high quality. For irrigation the main challenge is to control and store the large volumes required to grow crops.

Such water infrastructure is never an end in itself. It is intended to serve certain purposes, namely satisfying the demand for water for a certain constituency, for instance a community of irrigators, or residents of a city, or, at the level of the river basin, to satisfy the different demands as much as possible, taking into account the needs and rights of the various user communities.

Some people consume more water than others. Whereas they need similar amounts in order to survive, they can afford to consume much more (Box 6.2). This, in itself, need not be a serious problem and could even be an opportunity: differences in water consumption due to wealth create the possibility of cross-subsidisation.

This is all pretty obvious. But why do governments assume such an important role in water provision, compared to providing other basic needs, such as food, shelter and clothing?

This may be explained by the nature of water. Unlike food and fibre, water is a fugitive resource, meaning that you have to capture it or loose it. In semi-arid countries capturing water normally requires large investments, which are beyond the scope of any individual water user. Economies of scale then dictate that a higher level institution, such as a local authority or a government department, takes charge of this.

In so doing, that institution becomes a monopolist.

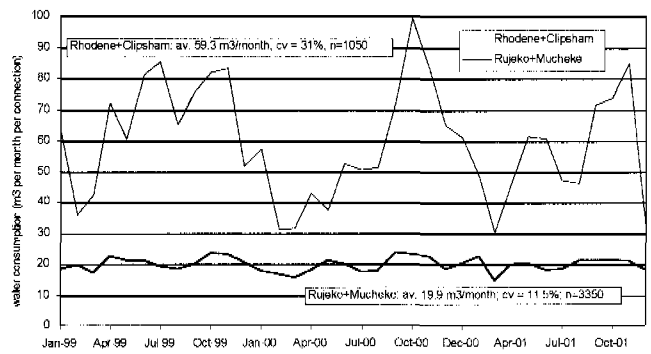
Box 6.2: Water use by affluent and non-affluent households (Dube &Van der Zaag, 2002)

Trends in domestic water use were studied in the city of Masvingo, Zimbabwe. The residential areas of Rhodene and Clipsham were considered affluent, comprising 1,050 households. The residential areas of Rujeko and Mucheke were considered non-affluent, represented by a sample size of 3,350 households. The sample represented 34% of all domestic connections in the town.

The figure shows that there is a large difference in water consumption between affluent (consuming 60 m³/month on average) and non-affluent households (20 m³/month). Moreover, water consumption fluctuates much more in affluent households (coefficient of variation CV of 31%) than that of non-affluent households (CV = 12%). 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 m³/month or more, whereas their non-affluent counterparts consume at most 25 m³/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 m³/month. This amount may be considered the basic minimum or "lifeline" amount, and is, with an average household size of 8 persons, equivalent to 50 lcd (cf. Gleick 1996, 1999).

The explanation for the observed trend 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 (200-300 m²) which puts an upper limit to the use of water for gardening 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 m² 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 non-essential uses.

Monthly billed water consumption by affluent and non-affluent households, 1999-2001



6.3 Interests

All people have interests. All people have a direct interest in having access to sufficient water of acceptable quality. User groups may be more or less successful in claiming and accessing the resource. Some well organised users may employ legal and institutional means to get the water service they want. Others may use the force of political or physical power, and in the process marginalise others.

Power

"Water allocation decisions are in a sense value-generation decisions as they influence the relative power/affluence/etc. accruing to users; since the more powerful segments of society have the highest capacity to make themselves heard, the 'squeaky wheel' strategy will probably thus serve to further concentrate power and exacerbate social inequality."
(Burrill, 1997)

Since water institutions (whether public or private) are natural monopolists, it is possible that the management activities might not be in the best interest of either the users or the water system.

Those in charge of a water system may find themselves in situations where they have conflicting interests. For example, professionalism may point to increasing the water tariff if insufficient funds for essential maintenance are generated. However, this may be politically unacceptable. So what do they do? Do they adhere to the institutional and legal rules, or do they decide to do what is politically expedient?

Those in charge of water systems may be tempted to "loosen" their link with the water users. A typical indicator of this is when water service providers fail to regularly inform water users about the state of the water system and withhold crucial information, for instance about new projects that are deemed necessary, or rather their alternatives (e.g. water demand measures). Instead they may prefer to strengthen ties with other actors (Box 6.3).

Box 6.3: Water coalitions in Mutare, Zimbabwe (Gumbo & Van der Zaag, 2002)

Since water is finite, different uses and users compete for it, and it easily obtains a value. Since water is a vital, life giving resource without which we cannot survive, it may obtain an incalculable value, even a political one. Controlling water may thus become a political rallying point. Since water is fugitive, it often requires sophisticated and costly engineering infrastructure to harness it. Taken together these three attributes of water may facilitate the emergence of powerful coalitions between engineers, financiers and politicians.

Engineering firms will be more than willing to apply their knowledge and skills to ambitious water projects, and they may tend to favour the larger supply-oriented projects as it would generate more work. To financiers, a monopolistic water supply system for a city is normally an attractive investment, since the city's residents will always need water. Politicians, finally, are likely to initiate water projects as this will portray them as the provider of a life-giving resource that enhances health, security and prosperity.

For effective adoption of water demand management it is essential to acknowledge this political dimension. As a strategy it is suggested that: (a) stakeholders should be better informed about alternative solutions to water problems; (b) a new generation of engineers trained in integrated water resources management is needed with the skills to carefully study the problem definition before rushing to solutions; and (c) financiers should be made aware of the relevance and economic rationale of demand management solutions.

6.4 Accountability

Users actively evaluate the water services using various indicators, for example the reliability and timeliness of supply, the water quality, the cost of water, etc. The intended beneficiaries have a way of communicating with those operating the water network, and provide feedback about their satisfaction or dissatisfaction of system performance. Often the link between service providers and users is institutionalised, defining the rights and duties of both types of actors. Service providers may or may not be accountable to the user groups they are supposed to serve. Conversely, users may or may not respond to signals given by the service provider to improve the beneficial use of water.

Box 6.4: Irrigator-manager communication in irrigation schemes in Taiwan

In certain irrigation systems in Taiwan, communication between irrigators and the irrigation manager in charge of their scheme is extremely limited. Delaying payment of the irrigation fee is one of the few signals that an irrigator can send to the manager. Consequently, the time between billing and payment of the irrigation fee is seen as a key indicator of customer satisfaction. In Taiwan, irrigation managers are promoted or demoted on the basis of this indicator.

In general the water service provider is the local authority with the municipal officials accountable to the councillors who in turn are accountable to the electorate. The lines of accountability and communication are theoretically relatively simple, officials – councillors – electorate. With the changes in the service delivery models (commercialised utilities, privatisation, etc), the lines of accountability have become blurred.

The communication link between users and service providers is often weak in water systems, and yet it is this link that provides essential feedback about the quality of the service provided and the state of the network. This communication link provides a feedback loop (one of the few mechanisms) through which service providers can be held accountable to their customers. And in so doing, find a balance between needs and interests.

This weak link may lead to excesses, which may ignite a strong response by users, as was the case in the Bolivian city of Cochabamba (see Box 6.5).

Feedback loops may therefore be considered a weak link of water systems. Why this is so must be related to two issues:

1. One explanation is water-related, namely that suitable alternative sources of water are absent,

or that these are insufficient or unfit. Customers of a water system therefore cannot withdraw from it, and have no other option than to accept the sub-optimal service they receive. Operators can thus continue with the manner in which they do their work.

2. A second explanation is social, namely that the relationship between operators and users is problematic. Ideally, water users should play the role of customers, whereas operators should play the role of serving them. In many water systems these roles are reversed: water users see themselves and are seen by the operators as passive recipients or subjects, while those operating the system are "in charge", direct, and command.

Box 6.5: Water war in Cochabamba, Bolivia
(Lobina, 2000)

In September 1999, the Bolivian government awarded a 40-year concession for the water and sanitation system of Cochabamba, a city with 500,000 inhabitants, to Aguas del Tunari.

Aguas del Tunari is a consortium led by International Water Limited. Aguas del Tunari increased water tariffs sharply in December 1999, provoking popular protests. The tariffs hit the people of Cochabamba where the minimum wage is less than US$100 per month. The average water bill is estimated to equal 22 per cent of the monthly pay of a self-employed man and 27 per cent of that of a woman.

Led by La Coordinadora de Defensa del Agua y la Vida (The Co-ordinator for the Defence of Water and Life), an alliance including the trade union representing minimum-wage factory workers, peasant farmers, environmentalists and youth, protests broke out in January. After protesters shut the city down for four days, the government promised it would reverse the rate increases.

As the situation remained unchanged, La Coordinadora called for a peaceful march to take place in February. The demonstrators were confronted with tear gas and more than 1,000 police and soldiers. The toll of the clashes was two young people blinded and 175 injured.

Following the upheaval, the government and Aguas del Tunari pledged to reduce and freeze the tariffs until November this year when they would start a new round of negotiations. As the population identified the foreign-owned consortium as the cause of the hikes, La Coordinadora called for the cancellation of the concession and the return of the water system to the public sector.

Exasperated by the government's failure to fulfil these requests, even more violent clashes exploded in April as peasants protesting against a law threatening popular control of rural water systems joined the angry Cochabambinos.

In a clampdown to regain control of the situation, protest leaders were arrested and confined while President Hugo Banzer declared a state of siege in the whole country, restricting civil liberties. This time, the tear gas came together with not just rubber bullets but live ammunition. On 8 April, a 17 year-old boy was shot in the head and died. Bolivian television showed an army captain firing into the crowd of protesters from behind police lines.

Only then did the government agree to revoke the concession to Aguas del Tunari, free the civic leaders arrested, reform the national water law which would affect farmers and compensate the families of the victims. Subsequently, the protests eased in Cochabamba and the rest of Bolivia.

But what caused the rate increases which ignited the water war in Cochabamba? The answer is: the cost of the Misicuni Project. The Misicuni Project involves the construction of a dam, construction and operation of a hydroelectric power station and digging of a tunnel to bring water from the river Misicuni to Cochabamba through a mountain.

Not only did the Cochabambinos have to pay in advance to cover the cost of a massive and probably unnecessary engineering project, they also had to guarantee abundant profits to operators reluctant to run any real risk. In fact, the concession agreement provided for a guaranteed 15 per cent real return. All the burden was on the people of Cochabamba.

As suggested by Bolivian Times, the generosity was most likely due to political connections. The local partner in Aguas del Tunari, ICE Ingenieros, is owned by one of the most affluent and influential men in Bolivia. His company is also a partner in the Misicuni tunnel consortium.

Recently, the government of Bolivia handed over the management of city's water supply system, including its US$ 35 million debt, to community organisations, coordinated by the secretary of the town's trade union federation. Will this organisation succeed, and transform from a protest movement to effective management? (Hazelton et al. 2002)

The challenge is to find ways to clarify the roles of water users and operators, and reinforce the feedback links between them.

This will require efforts from *both* groups of actors. Water users need indeed start seeing themselves as customers, being able to articulate their needs and demand an adequate service. At the same time they need to be responsible customers, and fulfil their duties accordingly, for instance by paying bills promptly and reporting bursts and faults without delay. Operators should see it as their main task to satisfy the customers' needs. There needs to be a reward structure that reinforces this customer focus.

Seen in this light, accountability is the key characteristic of "governance". To demonstrate this, we quote part of the definition used by the United Nations Development Programme (quoted in Rogers & Hall (2003), p.7):

> Governance comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences.

Governance

It is important to note that governance is not only about the government as the main decision-making political entity. It is a much broader concept. Governance is about how different groups of people relate to each other in society, in terms of needs, rights and duties or obligations.

Without good governance there is no accountability. Without accountability, water institutions will be weak. Weak institutions will not be able to develop and implement strategies that influence water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource.

Good governance is therefore a prerequisite for water demand management.

6.5 Water governance institutions

During the last 10 years a significant revolution in water governance has been set in motion in most SADC countries. Most SADC countries have adopted new water policies and/or enacted new legislation, as well as overhauled the institutional structure of water management. These developments are all well-documented and need not be elaborated here. It is however important to note two salient features that are common to all these country reforms, namely:

1. water management is now based on hydrological units, each with appropriate institutions;
2. water users and their representatives have a formal role in decision-making concerning water management.

Box 6.6: The user pays, Zimbabwe (Sithole, 2000)

Throughout southern Africa, the new managerial regimes treat water as an economic good and vests ownership in the state. On this basis the state has established regimes to charge for non-primary use. However, the approach in customary practice and law, throughout the region, is that water is treated as a god-given resource that all are entitled to use. The statutory law approach raises two issues at the local level – firstly, the state's title to water and secondly its authority to charge for it.

In Zimbabwe, for example, the Act vests title in the state and it requires all users to apply for a permit to use water other than for primary purposes. Difference around this was evident in the consultative meetings for the establishment of the new catchment councils under the new Water Act. Interestingly, communal land stakeholders in the Mazoe catchment area accept that there are circumstances under which payment might be justified, for example where a level of personal control is evident. They observe that the "person who impounds the water is the one who makes the river dry." Thus it is acceptable that water stored in dams but not that sourced from small weirs, boreholes and pools should be paid for.

One participant states, "this water that you want permits for, who is making it, who is its owner?" – essentially rejecting the notion that we control water that is flowing. In rejecting this, the moderator replied, "water is water, no distinction is made about source. It is use that will determine whether water is paid for." In what seems to be a veiled rejection of the state's right to charge, the chiefs in Nyadiri sub-catchment stated, "most people did not know about permits; the meeting was the first time they were being told about such issues or indeed being asked to get involved. As far as water is concerned most people follow the ways of their forefathers and are not aware that this or that use is illegal." The chief added, "our concern is for our tiny gardens", a use that is excluded from Zimbabwe's legal definition of primary. For such water use a permit is required and an annual fee needs to be paid.

As a consequence of these reforms, most SADC countries are now instituting the reforms on the ground. Due to the significant institutional overhauls that are necessary, they face many challenges.

The major overhaul involves a fundamental change in water governance, from the inherited "predict and provide" mode of water management, where well trained water engineers took charge of decision-making, to a much more inclusive process of decision-making in which water users have a formal say. This implies a major change of the water management culture in all countries.

Such a change is not easy and not automatic. Changing the policies, laws and institutions is a necessary, but not a sufficient, condition to institute the required change of water governance, and, importantly, a change in practice of all actors involved in water management, be they water engineers, industries, urban and rural water consumers, small and medium enterprises, small-scale irrigators, large-scale commercial farmers, and even rainfed producers.

One of the major challenges that are faced is the manner in which water users that hitherto had been left out of the decision-making process, will now articulate their needs and insights and bring them to the decision-making tables, for instance at the level of water user board/water point committee, subcatchment council, catchment forums and river basin commissions. This "vertical" chain, which involves the articulation of voice upward, report back downward, and holding representatives accountable to their constituencies, is notoriously fragile in a continent where the relationship between citizens and their representatives has been marred by the colonial, as well as the post-colonial, experience (Mamdani, 1996).

Here we are back at the subject dealt with in the previous section: effective institutions should have strong links between water users and water managers, at the local level (e.g. water user board, irrigation boards, water utility, local authority) but also higher up (catchment areas). One way of reinforcing such links is through greater public participation in the management of water. In this manner the communication and accountability lines gets institutionalised. Water managers and service providers get to hear first hand the needs and interest of the users and users get to understand the obligations and constraints of the service provider.

Strengthening these vertical links is a challenge, but feasible. There is a growing number of positive experiences, such as in some Catchment Councils in Zimbabwe, and some water utilities in South Africa. However there are many pitfalls and challenges remaining (Box 6.6).

The remainder of this section highlights three such pitfalls, related to (a) the differential "voice" users have (some have a louder voice than others); (b) institutional shortcuts, such as the privatisation of "weak" water utilities, and (c) technological fixes for social challenges, such as the pre-paid water meter.

The loud voice of the privileged

When most of the water is allocated, "new" water can be found within existing allocations through water demand management. Care needs then to be taken that the "new" water not be allocated by "adopting the 'squeaky wheel management strategy, whereby the users that make the most noise get the most water. This strategy will certainly not result in an optimal distribution of resources" (Burrill, 1997). See Box 6.7.

Box 6.7: The user pays, South Africa (source: http:www.icij.org/dtaweb/water)

Ronnie Kasrils got the first hint that his government's cost recovery policy was not working in 1999 during a visit to a village in the former homeland of Transkei. Kasrils, once a committed communist and soldier in the African National Congress' armed wing, had just become the minister of Water Affairs and Forestry.

His department was coordinating a project in the village of Lutsheko in which each resident was contributing R10 ($1) a month to receive basic water service. While touring the village, according to press reports at the time, he came upon a woman digging in a riverbed.

"You don't have to do this anymore – we have this project now."

"I have to," she replied. "I haven't got 10 Rand."

In February 2000, Kasrils issued a new policy, giving six cubic meters (1500 gallons) per month of free water to every household in the country.

Institutional shortcuts

Privatisation

It should be noted that there is no short-cut or quick-fix for a situation where the link between water users and providers is weak. Privatising a water utility cannot be a substitute for an ineffective public water provider that maintains a weak link with its consumers. This is because a privatised service provider needs a strong public regulator, which defends the interest of the public. And this was missing in the first place.

There is no institutional shortcut for a lack of accountability. First get accountability sorted out, and then consider privatisation as one of possible institutional options. Never do it the other way round.

Technological fixes for social challenges

Pre-paid meters have been proposed for supplying low-income households with water. This appears to be an expensive technological fix for a social issue that the water provider finds difficult to resolve, namely to force people to pay their bills, when they are unable and/or unwilling to do so (Box 6.8).

Box 6.8: The pre-paid meter, South Africa
(ICIJ, 2003)

The prepaid meters are "the most insidious device," said McDonald, who co-directs the Municipal Services Project, a research centre based at University of the Witwatersrand in South Africa and at Queens University in Kingston, Ontario. "People won't buy what they need – they'll buy what they can afford. So people are simply cutting themselves off rather than having the state come in and do it."

6.6 Conclusion

This chapter has argued that water demand management requires good water governance and effective institutions. Institutions are effective if there are strong links between users and managers, between customers and providers. This essentially promotes accountability. Accountability is needed to find a satisfactory balance between the needs and interests of all actors involved.

Such strong institutions will be able to develop and implement strategies that influence water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource; which is our preferred definition for water demand management.

To strengthen the link between users and managers, both must cooperate. The new water architecture, that is emerging in Southern Africa, poses important new institutional opportunities to implement water demand management as a "choice suite of tools".

For integrated water resources management (including demand management) to be implemented successfully, there has to be a clear and consistent message coming from national departments, catchment level institutions and distribution and supply institutions, as well as an active voice by the users, and consistent listening by these institutions.

If we spread the word that water demand management measures often are the cheapest alternatives to water shortages, the users, at least, will listen. They will have to make informed decisions, and let their voice be heard up the institutional ladder.

6.7 Exercise

Chart the water flows and "accountability flows" for a case of a water system you are familiar with. Alternatively, use the case described in Box 6.9.

Explore the following questions: Is accountability effective? If so, why? If not, why not? Can accountability be improved?

Box 6.9: Irrigation furrows in eastern Zimbabwe (Bolding et al., 1996)

In a communal area in eastern Zimbabwe, farmers have long built and used irrigation furrows, but never bothered to apply for formal water rights. Some 20 furrows exist that irrigate some 50 hectares. Two furrows stand out in size: one has a length of 1,200 metres and irrigates 15 hectares; the other is comprised of a main furrow that bifurcates into two subsidiary furrows with a total length of 1,600 metres, irrigating 10 hectares. The first mentioned furrow was built around 1900 and extended in 1932. The second was built around 1945. Irrigation in this communal area may be characterised as follows:

1. No formal water rights exist, but there is a strong sense of a historical user right to river water for irrigation.
2. The furrows are simple and straightforward earthen constructions that are adequately laid out, nicely meandering along the hill slopes.
3. The furrow intakes at the river are not permanent structures and are made of locally available materials such as rocks and sticks. They all leak and have to be rebuilt every year. There is a taboo on making the intakes in the river from concrete.
4. The furrows do not divert all water from the river. One woman irrigator explained: "the Chief doesn't allow us to take all the water". The deputy chief later confirmed this: "We can't take all the water at the intake because it may kill the water creatures (mugadzemvura)".
5. The furrows regularly experience head- and tail-problems; i.e. irrigators located near the intake of a particular furrow may find it easier to access water than those with plots at the tail end. This situation sometimes causes open conflict – however this is often avoided by the simple fact that tail-enders initiate repair and maintenance activities along a furrow, and thus increase the flow available to them.
6. Water allocation is based not on a formal 'Agritex system' but on a 'cultural' system, as an irrigator once put it. People say: "Along a furrow people just share the water". One farmer explained canal organisation thus: "We work together to construct the furrow, every year we reconstruct it in April. We are from the same village. Nobody is in charge of distribution. We give each other chances." In case of conflicts, the traditional village leaders mediate.

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7. The information and communication system

Bekithemba Gumbo

Key readings for this chapter (in Reader):

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Molden, D. Sakthivadivel, R. Perry, C.J., de Fraiture, C., *and.* Kloezen, W.H. (1998). *Indicators for* Comparing Performance of Irrigated Agricultural Systems, Research Report No. 20, International Water Management Institute (IWMI), Colombo

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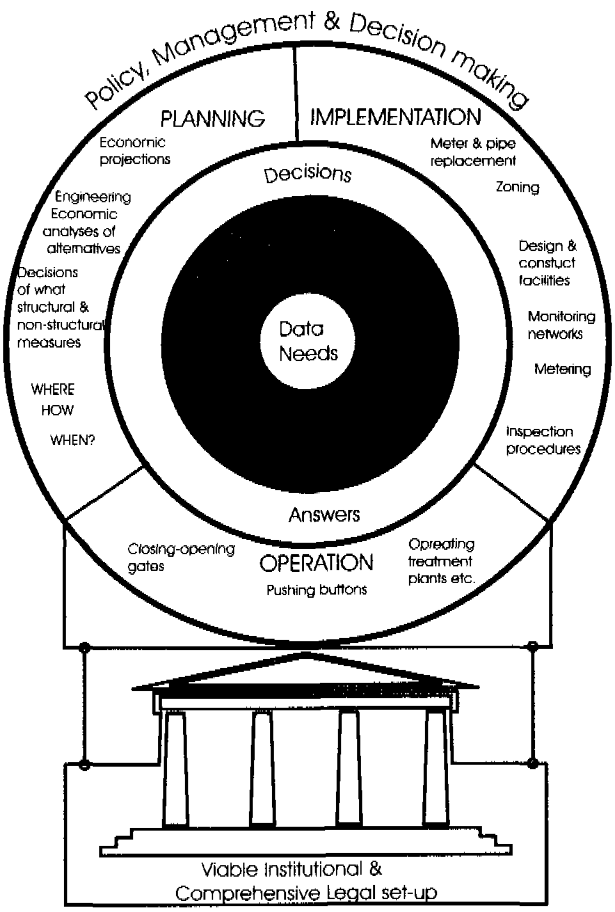
7.1 Introduction

7.1.1 Linkages

Water demand management, in the southern Africa region tends to suffer from a chronic failure to establish meaningful programme objectives due to lack of data, poor communication among stakeholders and lack of a comprehensive information system to aid decision-making. In order for any water system to function properly it requires information. This information is derived from data, such that the data has to be collected, processed and interpreted via information systems (IS) and information technology (IT) to provide this information (Johnson, 2002; Sternberg, 2002a; 2002b, Xulu, 2001). A water authority is dependent upon information to carry out its scientific, engineering and operational functions (Figure 7.1). Also important is the capacity of the water authority to communicate effectively with all the stakeholders in the water management chain (see Chapter 6).

Figure 7.1 Information system in WDM
Source: Gumbo et al. (2002)



Water demand-oriented projects adopted in the various cases within the region have demonstrated that water demand management, is not necessarily less challenging than supply-oriented management. Interventions such as water monitoring and audit systems, leakage control, replacement of old pipes, retrofitting of water appliances in households, and awareness campaigns do require political commitment, engineering inputs as well as finance, but these interventions cannot easily be 'boxed' into discrete time-and-space-bound projects. Demand-oriented solutions may require many small engineering inputs, many relatively small financing deals, and a continued commitment from politicians. Above all water authorities, utilities and users require a certain level of sophistication in order to make informed decisions on which demand management interventions to adopt, when and where to start implementation and lastly how to monitor and evaluate the response of the targeted users.

> What is decision and action without good, clear information, especially when a holistic approach is required? Public WDM awareness and mobilisation campaigns, to bring home to people the extent and the intricacies of the subject, have to be instituted.

Without a Management Information System (MIS), and without sustained communication channels for WDM, water managers and users will continue to view demand-side measures as being obscure, and elusive, and will find it difficult to decide on the many options available. They may continue to believe that WDM has little impact compared to supply-side options. This Chapter provides a basis for measuring, monitoring and evaluating WDM programmes. It suggests key data and information required for implementing and sustaining a WDM programme in the four major water using sectors discussed in Chapter 4.

Since an effective WDM information and communication system does not operate in a vacuum it has to be anchored within an effective and dynamic institution, which is guided by a healthy political and legislative framework (Chapter 6). The deliberate integration of all disciplines and functions within a water management unit and addressing systematically the critical performance areas is not simple. Several barriers exist in setting up a unified WDM information and communication system. These range from information sharing, technology, understanding, psychology, politics, geographic separation and above all the way individuals, disciplines and organisations interact (Senge et al., 1995; Dent, 1996).

7.1.2 Management information system

For water regulators, utilities and users to function efficiently information systems are required that address and integrate the operational, engineering, commercial and strategic planning functions (Sternberg, 2002a; 2002b). For example, in order to administer and control a water system commercially, an appropriate and efficient billing system must be in place, as well as an adequate customer services department. A MIS for WDM should integrate data and information in such a manner that it provides the necessary feed back for monitoring and evaluation as shown in Figure 7.2.

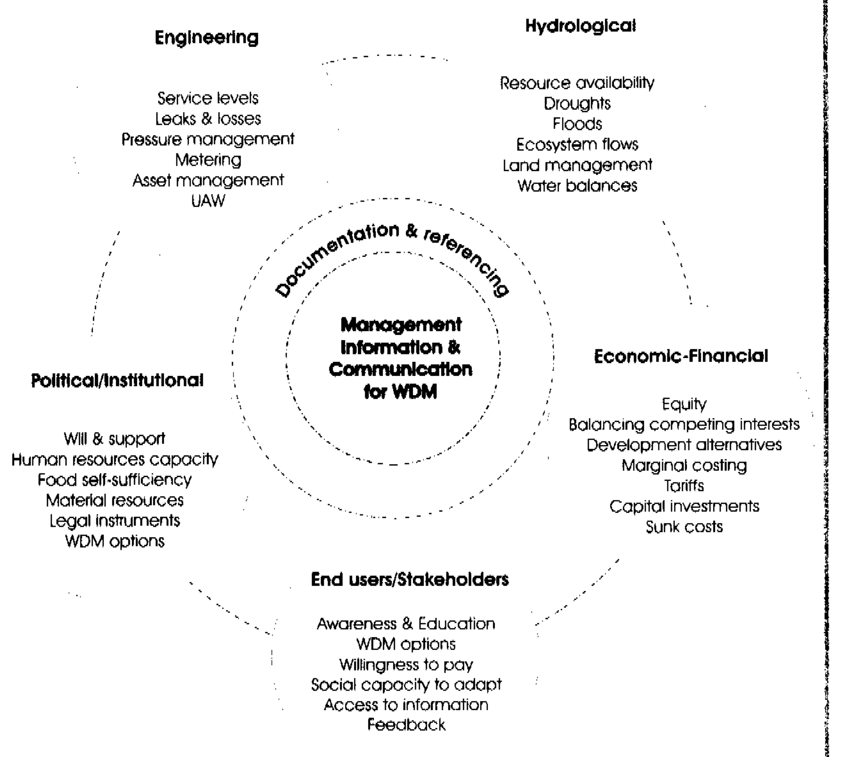
Information requirements for monitoring and evaluation will vary among water using sectors e.g.

- Policy makers and regulators
- Suppliers of bulk raw water
- Suppliers of bulk irrigation water
- Municipal water supply agencies
- Local rural water supplies
- End users or customers: large and small scale irrigators, industry, cooling water

The type of data information collected, monitoring and evaluation procedures and hence the key performance indicators will also differ from sector to sector. In the agricultural sector for example the following issues would be relevant:

- comparing the productivity (e.g. kg sugarcane per cubic metre of water (gross) applied) for different irrigation technologies (furrow, sprinkler, surface drip, underground drip) and for other types of interventions/ measures);
- establishing a cost-benefit analysis of investing in these different types of technologies and interventions;
- assessing the quantities of water gained or lost by changing from one irrigation method to another (and here we look for real water gained, not counting additional consumption of water of the crop manifested by increased fields);
- assessing the possibilities and constraints of reallocating saved water in irrigation in order to achieve equitable water distribution;
- assessing the (limited) influence of the price of water on the viability of the different types of irrigation technologies;
- assessing all other factors that may influence the choice of irrigation technologies, and thereby indirectly water productivity, such as labour, energy etc.
- any other observations and analyses (e.g. of driving forces for and against WDM) that are relevant in the context of water demand management for irrigation.

Figure 7.2 Integrated management information and communication system for WDM



Exercise 7.1 Checklist of information required for a WDM

In discussion groups list all the possible information that will be required for the implementation, monitoring and evaluation of a WDM project for

(a) an industrial water user, and
(b) a low cost peri-urban informal settlement.

7.1.3 Communication

Several policy tools can help influence water use. Regulation, pricing, investments, institution building are such tools. In communication and awareness campaigns, policy makers and other interested groups aim for behavioural changes based on new social norms and attitudes towards water use.

Figure 7.3 Publicity poster used for water conservation campaigns
(City of Bulawayo, Zimbabwe)

Traditionally, campaigns focus on providing information and knowledge to influence the individual attitudes. Knowing the consequences of his or her behaviour and realising the importance of these might convince that person to change a certain behavioural pattern. WDM is more about change of attitude and behaviour within the managing institution and other external stakeholders like its customers and regulator. Working with the corporate sector is also strategic in promoting and communication WDM projects.

There are various ways in which the corporate sector can be involved in WDM awareness raising. Examples are changing water-use practices in the private sector itself, initiating publicity initiatives with a positive environmental side effect. There is a tendency in many countries towards emphasising the ethical responsibilities of the commercial sector.

One medium through which water utilities regularly communicate with their consumers is through the (monthly) water bill. This is an important communication channel which is often neglected. Information provided in the monthly bills is normally limited to the bare essentials, namely the amount to be paid. Many customers find it difficult to understand how the bill is calculated, especially where an increasing block tariff is used. Yet, if customers would better understand their bill, they would know how to influence it, and know how to change their consumption patterns.

An example of an informative water bill is given Figure 7.4). It demonstrates how a bill can become a source of useful information.

Figure 7.4 Example of an informative water billing system used in Hermanus, South Africa

NATIONAL WATER CONSERVATION CAMPAIGN

GREATER/GROTER HERMANUS WATER
PO Box/Posbus 20 Hermanus 7200

Understand your water account/Verstaan u waterrekening

Account No / Rekening Nr	0035168007	Date of Account / Datum van Rekening	03/05/1997	Date of Reading / Lesingsdatum	06/05/1997
Name/Naam; Property Address / Eiendoms Adres	GP I.F ROUX SELKIRK STREET 45			Erf Area	
				Erf Nr	

Meter No / Meter Nr	Present Reading / Huidige Lesing	Previous Reading / Vorige Lesing	Consumption / Verbruik	Days / Dae	kl/Day / kl/Dag
30369	5,088	5,061	27	30	0,90

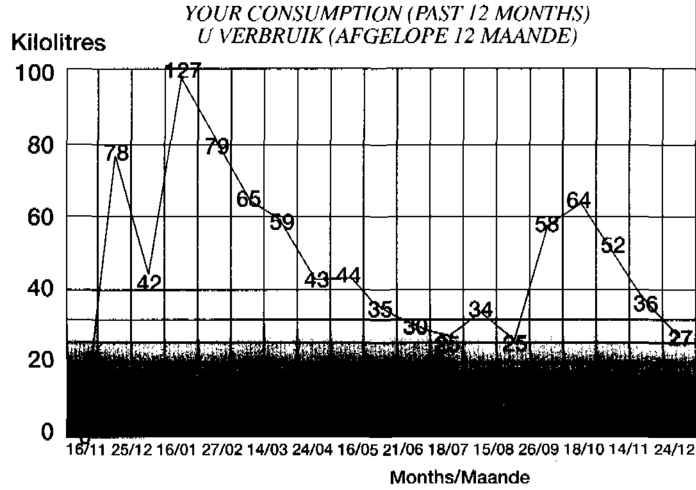
Consumption (kl) / Verbruik (kl)	Cost / Koste	Assurance of Supply / Versekering van Lewering	VAT / BTW	Total / Totaal
27	R 38,00	R 40,00	14%	R 38,92

Notice Board / Kennisgewingbord

INSULATE YOUR HOT WATER CYLINDER AND HOT WATER PIPES THIS WINTER TO SAVE WATER AND ELECTRICITY. HOTLINE 70 11 11

ISOLEER U WARMWATER-SILINDER EN WARMWATER PYPE HIERDIE WINTER OM WATER EN KRAG TE BESPAAR. NAVRAE 70 11 11

YOUR CONSUMPTION (PAST 12 MONTHS)
U VERBRUIK (AFGELOPE 12 MAANDE)



Cost Koste per kl	Cumulative cost R
	457.00
7.50	
	307.00
6.00	
	187.00
5.00	
	87.00
4.00	47.00
3.00	32.00
2.40	20.00
1.80	11.00
1.20	5.00
0.7	1.50
0.3	

A joint venture between the National Water Conservation Campaign of the Department of Water Affairs and Forestry and the Greater Hermanus Municipality.

'n Gesamentlike onderneming tussen die Departement van Waterwese en Bosbou se Nasionale Waterbewaringsveldtog en die Groter Hermanus Munisipaliteit.

Exercise 7.2 Planning a WDM communication and awareness campaign

1. Refer to Schaap & van Steenbergen (2002). Design a suitable communication and awareness programme for WDM in an urban setting. Briefly state your strategy, tools, material and the indicators you would use.
2. Gather any publicity information distributed by your local water supplier and analyse its effectiveness in relation to the guidelines provided by Schaap & van Steenbergen (2002).

Exercise 7.3 Designing an informative and communicative water bill

As part of a water demand management strategy you are commissioned by the City of Dar es Salaam to design an informative customer friendly water bill. Draw out an appropriate layout indicating clearly the type of information you think is important and necessary. Discuss the type of information that will be important and easily understood by the customers.

7.2 Monitoring and evaluation

Box 7.1 Water demand management relies on reliable data and information

To measure is to know
If you cannot measure you cannot manage
Conversely: If you do not manage you cannot measure

Monitoring is a process of tracking or measuring what is happening. This may include: measuring progress in relation to an implementation plan for an intervention, and measuring change in a condition or a set of conditions or lack thereof (e.g. changes in the willingness to pay after a water tariff increase). Monitoring is a critical management tool usually used to provide information for (UNICEF, 1991; 2001):

- short-term decision-making to improve management performance;
- accountability in terms of implementation according to plan;
- input to ongoing evaluation;
- broader advocacy to strengthen policies and ongoing management.

Evaluation is a process that attempts to determine as systematically and objectively as possible the merit or value of an intervention. The word "objectively" indicates the need to achieve a balanced analysis, recognising bias and reconciling the perspectives of different stakeholders (all those interested in and affected by programmes, including beneficiaries as primary stakeholders) through the use of different sources and different methods. The analysis of the value or worth of an intervention is usually based on a number of evaluation criteria such as relevance, efficiency, effectiveness, impact and sustainability (UNICEF, 1991; 2001).

Monitoring and evaluation requires that data have to be collected, analysed and interpreted. WDM projects are very demanding in terms of data that have to be collected and converted into useful information because WDM consists of a range of tools whose impacts upon implementation might not be apparent.

Exercise 7.4 Designing a WDM monitoring and evaluation programme

There are several basic considerations to help ensure that monitoring and evaluation of WDM is efficient and useful. Lack of careful planning may result in collection of meaningless data or the production of reports that are never used. Detailed planning at the outset, with all parties, will help ensure the impact of the monitoring work to the satisfaction of community groups and service providers. Refer to "Making monitoring simple and useful" by Shordt (http://www.irc.nl/themes/monitoring/use.html) and other recommended relevant websites provided at the end of this Chapter. In groups discuss and set-out an effective monitoring and evaluation programme for an irrigation WDM project. In your M&E plan discuss how you will ensure that the data collected is reliable and valid.

7.3 Performance indicators for WDM

7.3.1 Challenges in selection of indicators

In WDM programmes it is important to define clearly certain key variables that can be used to measure efficiency and effectiveness. There are many possible issues for which indicators can be developed related to policy, planning and design, community organization and awareness, training, involvement of women, functioning, use, cost sharing or cost recovery.

However, many organisations concerned with WDM are at a disadvantage in dealing with variables requiring detailed knowledge of users and schemes that can cover hundreds or thousands of kilometres. With limited field staff, it is difficult to survey, make plans, collect reports and monitor for large populations or over wide areas. The same, or nearly the same, is true for local governments, local boards, water service providers or utilities and committees which manage water and sanitation programmes in general. Setting up a monitoring system from scratch is time consuming and expensive. Partnerships between different organisations (central government, local government and down to communities) is important. Stimulating two-way flow of data and information between *communities* on one end and central government agencies on the other helps ensure that programmes can adapt and change to fit local circumstances. Identifying complementary monitoring programmes is essential in conserving resources especially in the SADC member countries which are resource-weak.

7.3.2 Examples of WDM performance indicators for some sectors

For WDM to be elevated at higher level especially among decision-makers there is need to come up with clear performance indicators which are based on sound data, information and knowledge systems (Gumbo et al, 2002; Rand Water 2002). Examples of such performance indicators are listed in Table 7.1 according to the main categories defining sustainable development i.e. social, health, technical, environmental, institutional and legal, financial and economic indicators. Note that the individual indicators can further be broken down into simple parameters.

Tables 7.2 and 7.3 lists typical data and information that can be use as performance indicators for the agricultural and urban water sector information and communication system for monitoring and evaluating a WDM programme. For more details refer to relevant readers.

Exercise 7.5 Performance indicators for industry
Refer to UNIDO (2002). In your opinion are the general performance indicators used globally for industrial production adequately incorporate aspects of water use efficiency and WDM.

Table 7.1 Possible performance indicators for a WDM programme

Category	Indicator
Social	• Population served • Willingness and ability to pay by the users • Water as a "free" resource • Level and sense of ownership of public infrastructure (e.g. minimal vandalism to public works) • Education and training on WDM in schools and tertiary institutions • Water awareness
Health	• Adequate water supplies to ensure basic hygiene (e.g. South African basic "free" water policy) • Low levels of un-accounted for water
Technical	• Low levels of physical or system losses • High level of recycling and reuse (closed loop systems) • High number of known connections, metered and un-metered • Comprehensive water metering policy and implementation strategy • High level of service, reticulated, stand posts, wells etc. length of distribution mains • Efficiency in water use (SWI, crop per drop etc) • Asset and information management system • Cleaner production with savings not only in water but also energy and other resource inputs
Environmental	• Environmental integrity, including sufficient ecological flow water requirements • Reduced or eliminated wastewater discharges into natural water systems
Legal and institutional	• Presence of a water demand strategy at regional, national and local levels (e.g. City of Windhoek WDM strategy) • WDM is incorporated in policy and most legal statutes and master plans • Dedicated unit within institutions dealing directly with WDM (e.g. City of Bulawayo Water Conservation and Leak Detection Unit)
Financial and economic	• Increased revenues from water and decreased expenditure • *Healthy financial bottom-lines i.e. water pays for itself* • Benefit cost ratio of more than one for WDM projects • Rising block tariff system or more transparent equivalent • In-house financing of WDM i.e. forms part of the normal O&M costs
Political	• Material support by top management and shareholders for WDM interventions • Political will and enthusiasm to implement WDM

Table 7.2 Checklist of data and information required for WDM programme in irrigated agriculture

Category	Data	Unit
Description of sector/field	Soils (e.g. waterholding capacity)	
	Crop, and crop variety	
	Irrigation technology used	
	Size of sector, layout etc.	
	Labour input required (for irrigation-related operations)	
	Energy input (if applicable)	
	Any other qualitative observation	
Climate	Epan or ETo (daily or monthly data)	mm/month
	Transpirative demand	mm/month
	Rainfall and effective rainfall (daily or monthly data)	mm/month
	Estimate of irrigation demand	mm and m^3/ha
Irrigation water	Gross irrigation water applied (daily or monthly data)	m^3/ ha
	Estimate of efficiency	-
	Net water applied	m^3/ha
	Estimate of water "lost"	m^3/ha
	Estimate of water lost due to return flows (seepage, spills)	m^3/ha
	Estimate of water lost due to soil evaporation (NOT crop transpiration)	m^3/ha
Yield	Yield (per season/year)	kg/ha
	Unit price of produce (world market price/book value/real price at which produce was sold)	US$/kg
	Total value of yield	US$/ha
	Productivity of irrigation water	kg/m^3
	Productivity of irrigation water	US$/$m^3$
Costs	Water price	US$/$m^3$
	Energy cost (if applicable)	US$/$m^3$ or US$/ha/yr
	Labour cost (irrigation- related)	US$/ha/yr
	Other irrigation related cost	US$/ha/yr
	Estimate of recurrent cost directly for irrigation	US$/ha/yr
	Estimate of capital cost of irrigation technology used	US$/ha/yr
	Estimate of total irrigation cost	US$/ha/yr
	Estimate of total irrigation cost	US$/$m^3$
	Apparent added value of irrigation water	US$/$m^3$
	Fraction of water price to apparent value of irrigation water	-
Observations/ Subjective or qualitative analysis	Observations relevant to this case in connection with water use, crop yield, productivity, water demand management etc.	

Exercise 7.6 Verification of suitable performance indicators for irrigation

Molden et al. (1998) outlines IWMI's external and other comparative performance indicators that allow for analysis of irrigation performance across systems. The purpose of these indicators is to understand the current situation with respect to productive utilisation of land and water, to compare relative performance of systems, and to identify where performance can be improved. Compare and contrast the information provided in Table 7.2 and suggested indicators for water efficiency and use provided in the report by Molden et al. (1998).

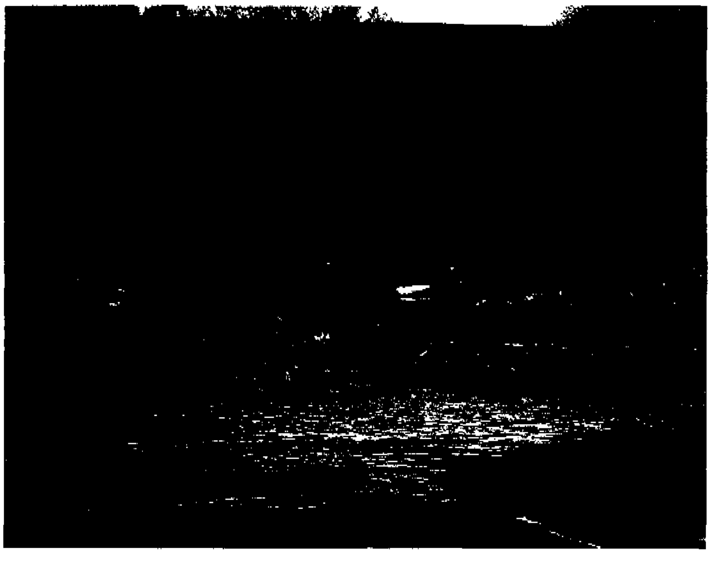


Table 7.3 Checklist of data and information required for WDM programme involving leak detection and repair in an urban sector

Description	Units
Number of service connections	No.
Length of transmission mains	km
Length of distribution mains	km
Average system pressure	m
Unavoidable connection losses at 50m of pressure	litres/connection/hr
Unavoidable mains losses at 50m of pressure	litres/km/hr
Leakage from service reservoirs	% volume per day
Leakage through mains burst	m3/hr at 50m pressure
Leakage from connection pipe burst	m3/hr at 50m pressure
Average running time of connection pipe burst	Days
Average running time of mains pipe burst	Days
Average cost of repairing mains burst	$
Average cost of repairing connection pipe burst	$
Monthly water supplied to the zone or district	m^3
Estimated monthly real losses	m^3
Purchase price of water from bulk supplier	$/m^3$
Selling price of water	$/m^3$
Frequency of service connection bursts per 1000 connections at 50m pressure	Bursts/1000 connections/yr
Annual frequency of mains bursts per km of mains at 50m of pressure	No/km of mains/yr
Pressure leakage exponent for flow through mains and connection leaks	–
Power exponent for calculating number of mains leaks for different pressure (cubic relationship is normally adopted)	–
Cost of basic sounding per km of mains	$/km mains
Cost of leak noise correlator per km of mains	$/km mains
% of mains requiring leak noise correlator to detect leaks	%

Source: Mckenzie et al. (2001). ECONOLEAK Model inputs

Exercise 7.7 Designing a management information system for a small town

Refer to Gumbo et al. (2002) (in Reader) and Rand Water (2002). You have been contracted to design a suitable MIS for WDM for a small town of 60 000 inhabitants, with 6000 water connections. The level of UAW is estimated at about 40%. Produce a plan of the probable MIS and explain how it is going to be operated. Include in your discussion in groups what would be the advantages and risks associated with your plan.

7.4 Setting up a MIS for urban water demand management

7.4.1 Data required for water demand management

The data required for WDM can be categorised into three broad categories, namely, *commercial data, network data and mission specific data*. Commercial data is defined as all data describing a consumer connection. Network data being all data representing the infrastructure that conveys water from source to consumer including bulk conveyance and storage, distribution pipes and reservoirs, pump stations, and valves. Mission specific data is all peripheral data required to satisfy a certain specific mission or goal. This may include water quality, return flow and effluent characteristics, cadastral and other GIS based datasets.

Within a commercial database four attributes can be distinguished. Firstly the **Plot and property database** i.e. data associated with each plot (commercial, industrial, residential or informal). This data forms the basis for many commercial and engineering functions such as tariff assignment, billing and demand analysis. The most fundamental of all databases is the **connection database**, which comprises of a unique number or permanent identifier for each water connection – usually a concatenation of plot/property and a unique identifier. It should not be associated with a meter serial number as this generally changes with time. A **meter database**, which includes data relating to a meter like its size, make, serial number and installed location. Lastly a **customer database** consisting of the name and identification number of property owner responsible for the water account, by default or a tenant leasing the property responsible for consumption and payment thereof (Xulu, 2001, Hydro-comp, 2001). *Commercial data* is the essence of billing consumers for measured consumption and is not only required for the production of bills but also allows the provider to trace queries and manage debt. Reliable data will mean accurate bills, satisfied customers, maximised revenue, real water consumption and efficient meter management. This is the cash register of water provision and the essence of water balances or audits and monitoring of unaccounted-for water (Xulu, 2001; WMS, 2001).

Network data enables the accurate representation and modelling of system performance. This in turn provides a more efficient means for demarcating meter and pressure zones thereby prioritising and reducing unaccounted-for water. *Mission specific data* can be used to improve the database and information derived there from like a GIS based system, linked to a street address and other cadastral information, information on consumers on pension or social welfare etc. It is also apparent that some of the data requires updating irregularly e.g. service interruption reports and most of the network data whilst some of the commercial data requires monthly updates preferable e.g. meter readings, abstractions debtors and creditors records. Also once captured most of the data is semi-permanent e.g. water source yields, customer details and infrastructure data.

7.4.2 Derived information for water demand management

From a well-designed and structured database a lot of important information for WDM can be derived. The processing path deriving information from data must be short and rapid. The amount of processing of data for reporting and archiving purposes varies with the particular requirement and software and hardware. Data can be reported and stored in its "raw" state whilst in other areas summaries and derived statistics are preferred. Output information required for water demand management can be classified into three categories, namely, information for **monthly operation support** (short-term), **quarterly management support** (medium-term) and **strategic planning decision support** (long-term). Monthly operation support information includes; water produced, imported or exported, water supplied, used and unaccounted-for, water billed, income and expenses. Quarterly management support information for WDM includes; unaccounted-for water, early warning exception reports, onset of drought and water conservation and water use restriction plans, planned maintenance and stock control and monitoring of performance versus targets. Lastly planning decision support information includes; meter and piping installation and replacement, upgrading and extensions, design, performance and tariff policy development and plant refurbishment.

Lost cost software solutions

The Water Research Commission (WRC) of South Africa has initiated and supported numerous projects which have given birth to various low cost software solutions which can be applied in WDM programmes (Mckenzie and Bhagwan, 1999; Mckenzie et al., 2001). Examples of such packages include: Background Night Flow Analysis Model, Economics of Leakage Model, Pressure Management Model and Benchmarking of Leakage Model.

7.5 References

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Xulu, M. (2001). Benefits of commercial and network data validation: A case study, Hydro-Comp Enterprises, Woodmead, Johannesburg

7.6 List of useful websites

Following is a list of monitoring and evaluation web sites that WDM designers and implementers can access to complement their knowledge in basic principles of monitoring and evaluation.

- American Evaluation Association: http://www.eval.org
- International & Cross-Cultural Evaluation Topical Interest Group (I&CCE): http://www.wmich.edu/evalctr/ICCE/
- Collaborative, Participatory, and Empowerment Evaluation Topical Interest Group: http://www.stanford.edu/~davidf/institute.html
- American Society for Training & Development: http://www.astd.org/virtual_community/research/
- Australasian Evaluation Society: http://www.aes.asn.au/
- Canadian Evaluation Society: http://www.evaluationcanada.ca
- European Evaluation Society: http://www.europeanevaluation.org
- Organisation for Economic Co-operation and Development's Development Assistance Committee Working Group on Evaluation: http://www.oecd.org/dac/Evaluation/htm/evalcrit.htm
- United Kingdom Evaluation Society: http://www.evaluation.org.uk
- International Fund for Agricultural Development Evaluation Knowledge System (EKSYST): http://www.ifad.org/ifadeval/public_html/eksyst/toc/index.html
- International Labour Organisation; http://www.ilo.org/public/english/bureau/program/eval/index.htm
- United Nations Educational, Scientific and Cultural Organisation's Bureau of Programming and Planning: http://www.unesco.org/bpe/
- United Nations Office of Internal Oversight: http://www.un.org/Depts/oios/
- UNFPA's Office of Oversight and Evaluation: http://www.unfpa.org/publications/evaluation/index.htm
- UNHCR's Evaluation and Policy Analysis Unit (EPAU): http://www.unhcr.ch/evaluate/
- UNICEF's Division of Evaluation, Policy and Planning (EPP): http://www.unicef.org/reseval/
- UNDP's Evaluation Office: http://www.undp.org/eo/
- The World Bank Operations Evaluation Department: http://wbln0018.worldbank.org/oed/
- The World Bank Institute: http://wbln0018.worldbank.org/wbies/wbievalu.nsf/

8 Linkages: water networks as holistic systems

Pieter van der Zaag

Case studies for this chapter that are available in the Reader:

Asmal, K., 2003. *Arid African upstream safari: A trans boundary expedition to seek and share new sources of water*. Chapter 3 in: J. Dooge, J. Delli Priscoli, M.R. Llamas (eds.), *Water and ethics*. UNESCO, Paris

Carmo Vaz, A. & P. van der Zaag, 2003. *The Incomati river basin: scope for demand management in a heavily committed basin*. Unpublished paper

Gumbo, B., and P. van der Zaag, 2002. *Water losses and the political constraints to demand management: the case of the City of Mutare, Zimbabwe. Physics and Chemistry of the Earth* 27: 805-813

Matsika, N., 1996. *Challenges of independence; managing technical and social worlds in a farmer-managed irrigation scheme*. In: E. Manzungu & P. van der Zaag, *The practice of smallholder irrigation; case studies from Zimbabwe*. University of Zimbabwe Publications, Harare; pp.29-46

Mkandla, N., 2003. *What is the next additional water supply source for Bulawayo?* Unpublished paper

8.1 Symptoms and root causes of weaknesses in water networks

Water demand management is mainly concerned with making water networks function better. The word better here implies that they are efficient; provide equitable access to all, respond to changing societal needs and are sustainable over time. Water demand management strives to create such resilient, responsive quality water networks.

Water networks will be able to achieve these objectives when they combine the following elements in a manner that reinforces the network's capabilities and objectives:

- an environment that generates water and can absorb return flows (the hydrological sub-system)
- structures that control water (the engineering sub-system)
- skills, knowledge and information (the information sub-system)
- money (equitable tariffs, sufficient revenue, judiciously allocated etc.) (the economic sub-system)
- needs and interests of all participants involved (the political sub-system).

If these five elements or sub-systems are combined in the best possible way, that is to say, the linkages between them are strong and mutually reinforcing, a water network will perform effectively and be able to achieve its objectives.

However, most, if not all, water networks perform below their potential. This is because one or more of the subsystems is weak (e.g. the environment generates too little water; the control structures (e.g. pumps, pipes and valves) are incapable of meeting the water requirements; data on water production and consumption are unreliable; the tariffs are inadequate; those operating the system are not responding to societal needs).

If one subsystem is weak, it will affect the entire water network. The other subsystems will be negatively affected by the weak part and also become debilitated. This leads to a fragile water network that cannot maintain its structure and function over time, and that cannot respond to changing societal needs.

Box 8.1 provides an example that focuses on the dilemma of achieving cost-recovery.

So what do we do when we are asked to improve an existing water network, for example, if it fails to provide sufficient clean water to all its customers all the time?

What often happens is that the focus is on the most apparent shortcoming of the water network (e.g. the water network fails to produce sufficient water).

Box 8.1: Limits to cost-recovery and privatisation in Nelspruit, South Africa (ICIJ, 2003)

In Nelspruit, a three-hour drive east of Johannesburg, the water providers and the water drinkers have had quite enough of each other. The Greater Nelspruit Utility Company (GNUC), a consortium concisting British water company, Biwater, and a local black empowerment company, Sivukile Holdings, has a 30-year concession to provide water and sanitation services to a population of 240,000.

Brian Sims, GNUC's managing director and head of Biwater in South Africa has worked all over the world. "Never in my life have I seen such a culture of non-payment than here in Nelspruit," Sims said in disgust. "People simply don't pay. We are suffering massive losses." In the summer of 2002, GNUC instructed its lawyers to proceed with legal action against 796 households in Nelspruit that were more than $300 in arrears on their water accounts. "Letters of demand have been sent out. This is the beginning of a process to break the culture of non-payment in the townships," GNUC commercial manager Harold Moeng said.

The Anti-Privatisation Forum is fighting to force the municipality — now called Mbombela — to cancel the GNUC contract and introduce a flat rate of US$3 a month for all municipal services in the municipality and its surrounding townships and villages. "If it's necessary, we'll use violence," a member of the Forum warned. "If they [GNUC] come into the township to cut our water supplies or take our goods, we'll vandalise their cars and beat up their workers." The threat of violence is the latest in a series of obstacles and setbacks for the concession, which has seen youths marching on councillors' houses in the townships, the destruction of water meters, illegal water connections and one of the highest rates of non-payment in the country.

Like the rest of South Africa, Nelspruit is really two cities. Old Nelspruit is white and prosperous with average annual incomes of US$13,000. The surrounding townships are poor. About 60 percent of households have an income of US$100 per month or less. When GNUC took over in 1999, residents in the old town enjoyed First World living conditions: wide and well-maintained tree-lined streets, libraries, parks, superior medical facilities, good schools and a high-level of municipal services. By comparison, non-existent or low-level basic services, dirt roads and inferior schools and medical facilities characterised the townships.

The municipality privatised its water operation because it needed $38 million to bring water and sewage networks to the townships. Since then, GNUC said it has laid 90 kilometers of new water pipelines and 17 kilometers of new sewage pipelines. It has installed 7,240 new water meters and made 5,000 new water connections. But Sims acknowledged that Biwater can no longer afford to implement its full obligations under the water concession, and the company has suspended all capital expenditure programs. Even with the suspension, water rates increased in 2002 by 18 percent. Sims blamed the problems on the "culture of non-payment" in the township, fueled by trade unions and their allies like the Pan Africanist Congress. It costs the consortium US$111,000 every month to supply clean water to Kanyamazane township, which is part of Nelspruit, Sims said, but the consortium receives only US$5,584 in revenue. Only about 20 percent of residents pay their bills. They collectively owe the utility US$1.8 million in unpaid water bills. "There is only one solution: we have to get people to pay," Sims said, adding that even those township consumers who can afford to pay for water don't.

But a journey into the poor areas of Nelspruit tells a different story. It becomes clear that most people, at least, don't pay because they cannot afford to pay. People were used to a flat rate of about US$7.50 for all services before privatisation, said Sam Sambo of the South African Municipal Workers Union. Now, they get individual water bills of up to US$20. "It's beyond their ability to pay and that's why only one out of every five residents pays their bills," Sambo said.

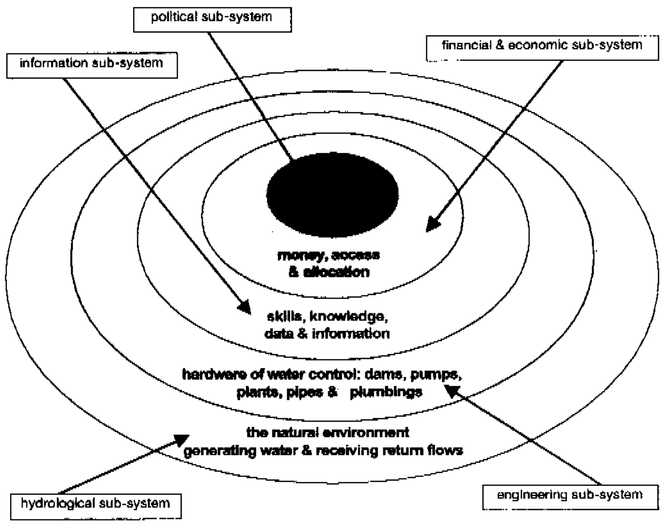
The Pan Africanist Congress initiated a campaign in 2001 called "Operation Vulamanzi," or Operation Open Water, to reconnect water to all residents who had been cut off for not paying their bills. Even so, "debtors" receive their water through the so-called "trickler system" in which GNUC installs a disc-like device with two tiny holes that allows water only to dribble into the pipes. "People can still access their free [6 cubic meters] of water every month. In fact, they can get even more," said Harold Moeng, GNUC's commercial manager. But the trickler makes life very unpleasant for those who can't pay. Call it war by water pressure.

Then the solution will be largely determined by the (narrow) understanding of the problem, and, in this example, the suggested solution will invariably be to enlarge the capacity of the network by adding new pipes, dams etc.

This solution may indeed address the problem, and lead to a more effective and resilient water system. However, it is also possible that the constrained capacity is only a symptom of deeper problems in the network (leaks, for example, that are caused by deferred maintenance etc.). Hence other solutions are necessary to improve the system's performance in a more sustained manner.

Thus, the tendency is that if the scope of the problem analysis is too limited, the answer in many cases will be a costly supply-sided solution ("if all we've got is a hammer, the solution will always be a nail"). The symptom will be addressed and for some time the water network may perform well, but since the underlying problems persist, eventually the same symptoms will recur, and a next round of narrow problem analysis and conventional solutions are likely to start.

Figure 8.1: A layered understanding of a water network



8.2 Problem analysis

In this course module a case is made for understanding water networks holistically. If a water network is performing below expectations, the first step should be to carefully analyse the problem, with a mandatory check on how the identified problem relates to the five sub-systems.

Problems in water networks often manifest themselves in a "physical" manner: too little water available in the source etc. But frequently, there are underlying, more deep-seated, weaknesses in the system that will persist if these are not addressed. The following approach is recommended:

1. Consider a water network as a layered onion (Figure 8.1).
2. Check all the layers/sub-systems of the onion, as to how they relate to the identified problem.
3. Establish cause-effect relationships in the form of a problem tree.
4. Identify measures and interventions that are required to effectively address the root cause of the problem.
5. Prioritise measures, in terms of cost and impact, and
6. Formulate an intervention strategy and package of measures based on the prioritisation.

8.3 Cause-effect relations: the problem tree *(Source: MDF, 1998)*

A properly planned intervention addressing the real needs of target groups, is necessarily based upon a correct and complete analysis of the existing situation. The existing situation should be interpreted according to the interests and activities of parties concerned. Often, different parties involved have different visions on the same reality.
The following three stages in the analysis process will be distinguished:

- problem analysis (the image of reality)
- analysis of objectives (the image of a future, improved, situation)
- strategy analysis (the comparison of different 'objectives chains').

This section is illustrated by a simplified example (MDF, 1998).

Problem analysis

The problem analysis is of major importance with regard to project planning, since it strongly influences the design of a possible intervention.
The procedure for a problem analysis includes:

- the precise definition of the frame and the subject analysis;
- an analysis of a problem situation;
- the identification of problems and the establishment of a cause-effect hierarchy between the problems
- the visualisation of the cause-effect relations in a diagram.

In this problem analysis, cause-effect relations are established between negative states about an existing situation. The analysis aims to identify high priority bottlenecks. Experts, informal groups and institutions and organisations concerned contribute to this analysis. The analysis is presented in the form of a diagram, or a problem tree, in which the relations and hierarchy among all identified problems are expressed: each stated problem is preceded by the problem(s) which cause(s) it, and is followed by the problem it causes itself.

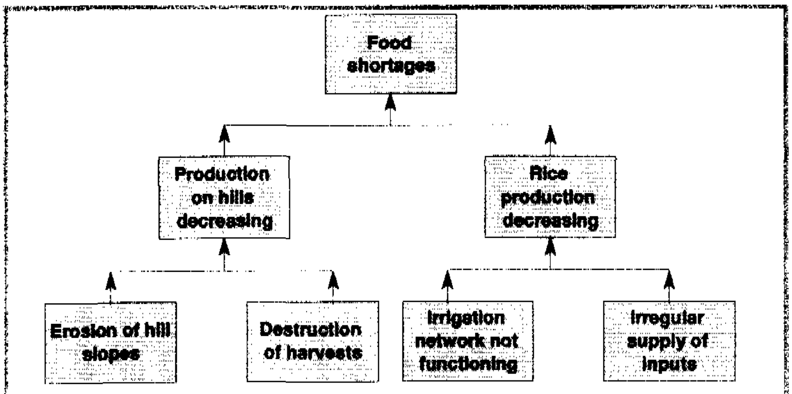


Diagram of problems (example)

Analysis of objectives

The analysis of objectives follows the problem analysis. The analysis of objectives is usually based on a participatory analysis and a number of reports and other documents for factual and therefore more objective information.
The procedure for objectives analysis includes:

- the translation of each problem in the problem tree into a realised positive state (the objectives);
- verification of the hierarchy of objectives;
- visualisation of means-end relationships in a diagram.

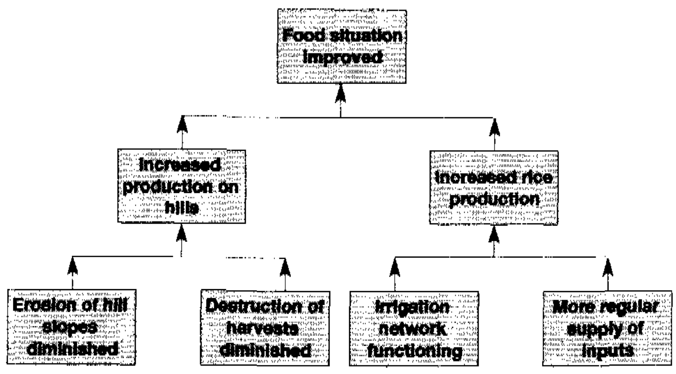


Diagram of objectives (example)

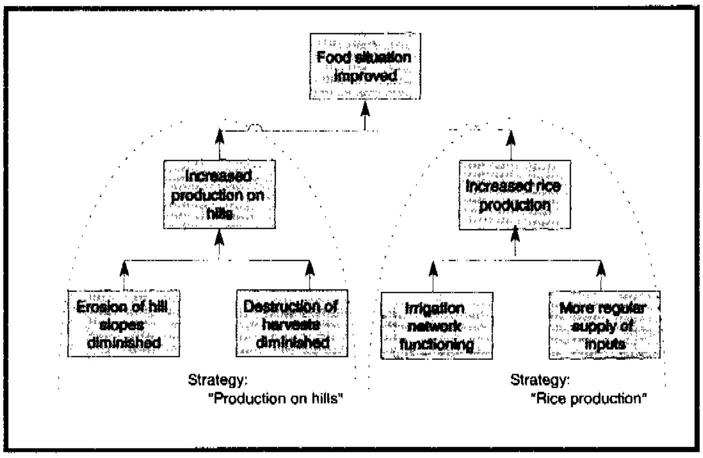
The negative states of the diagram of problems are converted into positive states. For example, 'low agricultural production' is converted into 'agricultural production increased'. All these realised positive states are presented in a diagram of objectives visualising a means-end hierarchy.
This diagram, or objectives tree, provides a general and clear view on the desired positive future situation. Often such a diagram reveals many objectives that cannot all be reached by the intervention that is being planned. Therefore, choices have to be made.
Certain objectives seem unrealistic or not feasible within the context of the intervention, so that other solutions need to be generated for the problem concerned.

Strategy analysis

The procedure for strategy analysis includes:

- identification of the different possible strategies contributing to an overall objective;
- choice of a strategy for the intervention.

In the diagram of objectives, the different clusters of objectives sharing the same nature can be considered to be strategies. Out of these strategies, one (and sometimes more) will be chosen as the strategy for the future intervention. Based on a number of criteria, the most pertinent and feasible strategy is selected. Criteria may include available budget, significance of the strategy, likelihood of success, period of time to be covered, etc. The selected strategy is to be elaborated upon in the planning phase of the project.



8.4 Exercise: draw a problem tree and formulate an intervention strategy

- Form a small group of 2-4 participants and select a case study
- Formulate an intervention strategy based on the steps suggested above.

Background information is available for the following cases:

River basin

– Incomati	Arid African upstream safari: A transboundary expedition to seek and share new sources of water (Asmal, 2003) *and/or* The Incomati river basin: scope for demand management in a heavily committed basin (Carmo Vaz & Van der Zaag, 2003)

Urban water system

– Mutare	Water losses and the political constraints to demand management: the case of the City of Mutare, Zimbabwe (Gumbo & Van der Zaag, 2002)
– Bulawayo	What is the next additional water supply source for Bulawayo? (based on Mkandla, 2003)

Irrigation system

– Mundotwe	Challenges of independence: managing technical and social worlds in a farmer-managed irrigation scheme (Matsika, 1996)

8.5 References

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Gumbo, B., & P. van der Zaag, 2002, *Water losses and the political constraints to demand management: the case of the City of Mutare, Zimbabwe. Physics and Chemistry of the Earth* 27: 805-813

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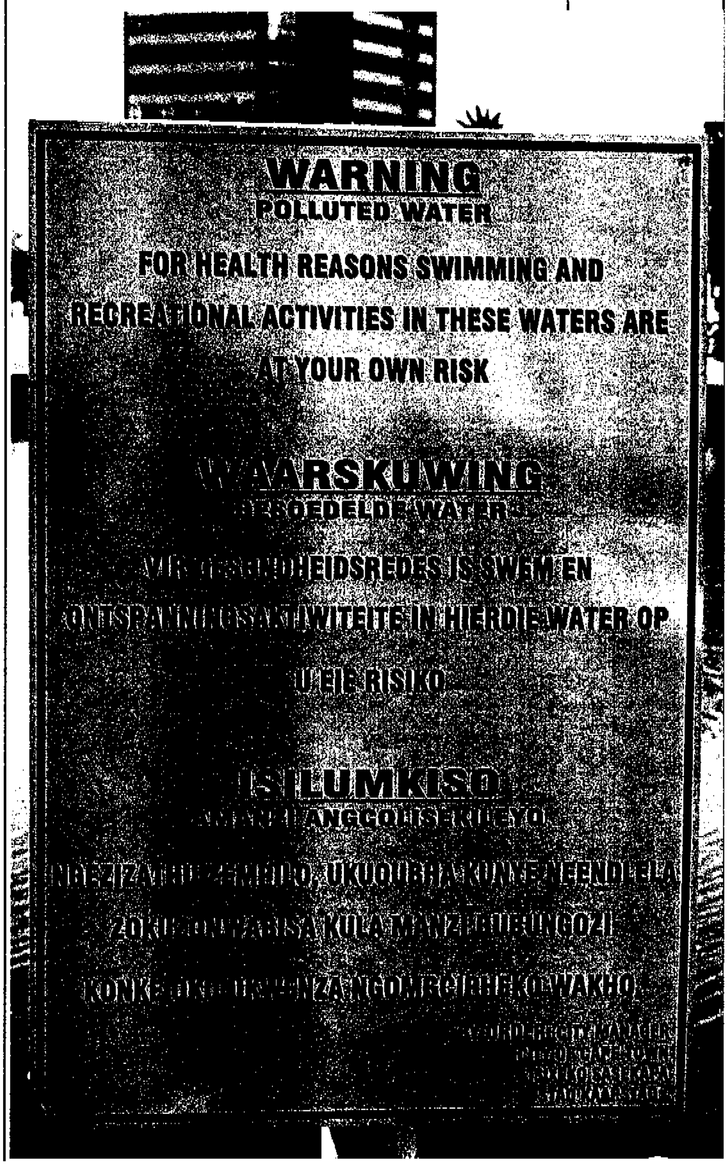
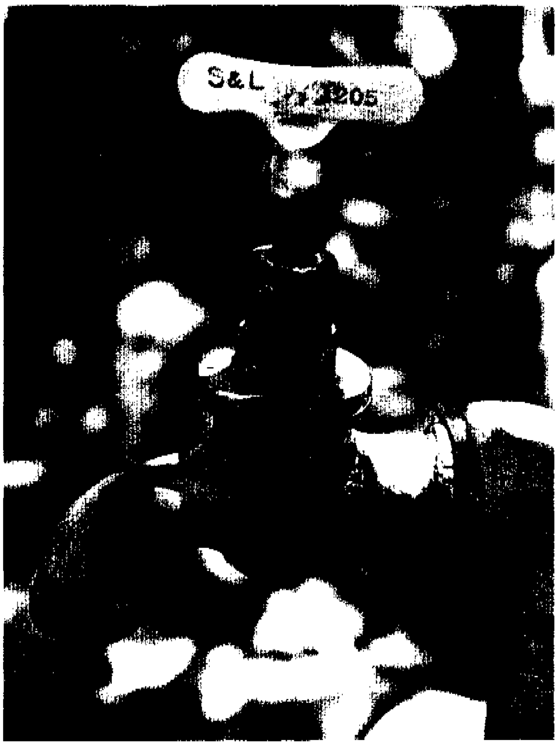


9. Field study exercise: generic outline

Pieter van der Zaag



9.1 Aim

The aim of the field study exercise is:

- to confront participants with a real water network
- to apply the acquired knowledge and skills in practice
- to experience the opportunities and constraints of water demand management
- to work in a team
- to analyse the water network holistically, i.e. "peeling the onion", taking into account the five sub-systems identified
- to develop an intervention strategy
- to "sell" and defend the proposed strategy to key stakeholders of the network studied.

The duration of the field exercise is six full days

Depending on the participants / target audience of any course that will be organised, the field study exercise can, in principle, be done for any type of water network, i.e. urban water supply system, or parts of an urban water supply system (e.g. peri urban informal settlement, high density area), irrigation system, industrial water system etc.

9.2 Structure

All participants of the course (c. 12-20 participants) work as one group on this exercise. They will sometimes work in plenary sessions, in well-defined small groups and individually. The generic structure of the exercise will be as follows:

Day	Individual tasks	Sub-group tasks	Plenary tasks
1	Background reading	Prepare data collection	Make plan, division of tasks, formation of sub-groups
2	Collect existing/ new data (incl. interviews)	Collect existing/new data (incl. interviews)	Report-back by sub-groups; Preliminary interpretation of data; refine data needs
3	Compile collected data	Preliminary interpretation of data; write up of sub-group report	
4	Collect additional data	Interpretation of data; adjust sub-group report	Report back by subgroups; analysis of sub-systems, problem tree, intervention strategy
5	Actively participate in plenary and sub-group	Identify recommended interventions, estimate their costs and their financial and non-financial benefits	Analyse and integrate systems interventions, estimate their costs and their financial and non-financial benefits
6	Actively participate in plenary		Define implementation priorities; finalise consolidated report; present and defend

9.3 Possible sub-groups and their briefs

Irrespective of the type of water network or water system of the field study exercise, it seems reasonable that sub-groups will be formed that will focus on parts or aspects of the network under study.

In principle there are two ways to form sub-groups:

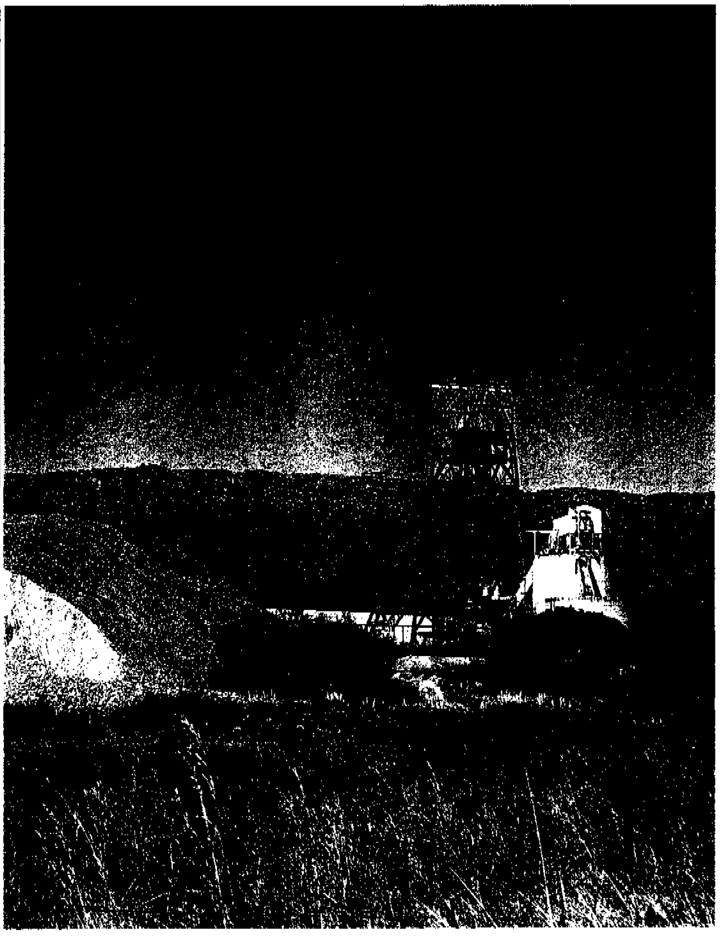
1. **Sub-divide the network in identifiable parts**
   Each sub-group studies a part of the network, while taking a holistic perspective, considering all sub-systems identified in this course. Depending on the network, the following parts could be distinguished: source and return flows, main system, management, groups of end-users.
2. **Make a thematic subdivision**
   Each sub-group takes a theme or sub-system, and in studying this sub-system the sub-group covers the entire network. The most obvious themes/sub-systems to be considered are as given in the present course, namely hydrology, engineering, economics & finance, political & institutional and information & communication. However, the final definition of sub-systems or themes must also depend on the network under study and its specific characteristics and problems.

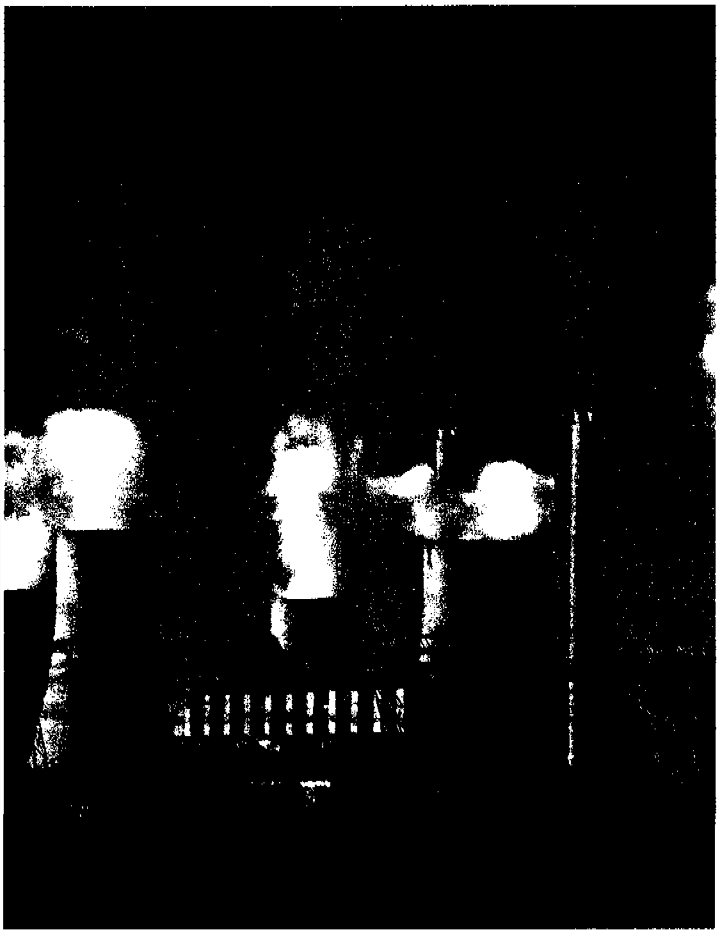
It is not known which approach would be most effective. Typically, in the first approach (work holistically within each sub-group), the sub-groups will consist of multi-disciplinary teams, but will only achieve a partial view on the water network. In the second approach, it is more likely that mono-disciplinary groups will be formed, but these will study the entire network.

Both approaches therefore have their advantages.

9.4 Resources required

- Background information about the specific water network
- Active cooperation of key stakeholders during the exercise
- Access to key stakeholders, information sources, physical infrastructure
- At least two facilitators: one from the institution offering the course, one from the water network under study
- Suitable work place for students, with appropriate infrastructure (e.g. computers, printers)
- Accommodation and food
- Transport (from bicycles to 4WDs, depending on the type of network)





Notes

The guidelines available in this series are:

1. Policy Makers and Regulators
2. Bulk Suppliers of Untreated Water
3. Bulk Suppliers of Potable Water
4. Subsistence Farming and Dense Settlement Rural Communities
5. Large-scale Irrigators
6. Municipal Water Supply Agencies
7. Users of Industrial Process Water
8. River Basin and Catchment Management Organisations
9. Monitoring and Evaluation of Water Demand Management Programmes

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