WATER RE-USE SYMPOSIUM
17 November 2000

The need to conserve water through re-use is crucial, given the finite nature of this resource and increasing demands for it in domestic, agricultural and manufacturing activities. This is particularly so in a water-poor country like South Africa where drought is a regular concern.

However, the 29th (1996) session of the CODEX Committee on Food Hygiene (CCFH) noted that there are significant hygiene implications in the re-use of food processing water. The committee noted further that the practice of water re-use was increasing and that guidelines on the re-use of processing water would be useful. In August 1999 the CODEX Committee on Food Hygiene issued a revised discussion paper on “Proposed Guidelines for the Hygienic Re-Use of Processing Water in Food Plants”.

The African Center for Energy and Environment (ACEE), the University of Pretoria (UOP), the International Water Association (IWA) and the International Life Sciences Institute (ILSI) jointly hosted a one day symposium on Friday 17th November 2000 in Pretoria, on water-related issues with particular emphasis on the re-use of water in the food and beverage industries with the above paper as a starting point.

ABSTRACTS

PUBLIC HEALTH IMPLICATIONS OF WATER RE-USE IN THE FOOD ANS BEVERAGE INDUSTRY, **Richard Carr, Global Health Leadership Fellow, Water Sanitation and Health , World Health Organization, Geneva, Switzerland**

Freshwater is an important commodity; population growth in water scarce regions will increase its value. Within the next 50 years it is estimated that 40% of the world’s population will live in countries facing water stress or water scarcity. This number does not include people living in arid regions of large countries where there is enough water but it is not uniformly distributed e.g., China, India and the United States.

Industry (particularly the food and beverage industry) is the second largest consumer of freshwater resources. Growing competition between agriculture and urban centers for high quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will also increase the pressure on this resource. Reuse of water can help to reduce some of this pressure. For example, the single largest use of freshwater is for agriculture and the nutrient and water content of wastewater make it particularly well suited for use in irrigation.

Freshwater scarcity is already a problem in South Africa. Over the next 25 years, freshwater resources per capita in South Africa will be cut almost in half (i.e., from 1,206 m^3/year in 1995 to 698 m^3/year in 2025). Industry and society in general will have no choice but to adopt water reuse strategies - food security and continued economic development depend on it. Fortunately, there are many opportunities for water reuse in food and beverage production.

Poorly planned water reuse can have adverse health effects on both product consumers and industry workers. Safe water reuse is made more challenging by recently recognised water and foodborne pathogens that pose special problems either because of the severe health effects they can cause (e.g., *E. coli* 0157:H7, *Listeria monocytogenes*) or because of their resistance to traditional treatments such as disinfection (e.g., *Cryptosporidium*). Establishing management processes such as microbial risk assessment, implementing well-designed HACCP programmes, and selecting appropriate water treatment technologies can be effective mechanisms for reducing the health risks associated with water reuse in the food and beverage industry.

A PERSPECTIVE ON THE HEALTH SECTOR LEGISLATION RELATED TO THE USE OF SAFE WATER IN FOOD PROCESSING, Francina Makhoane, Department of Health

The Directorate: Food Control, in the Department of Health, is the national authority responsible for ensuring the safety of foodstuffs sold, manufactured or imported into South Africa as is stated under Section 2 of the Foodstuffs, Cosmetics and Disinfectants Act (Act No. 54 of 1972). This involves drafting and publishing legislation that governs the microbiological and chemical safety of foodstuffs and related matters. Accordino to the Foodstuffs Act, a foodstuff is any article or substance (except for a drug as defined in the Drugs control Act, 1965 (Act No. 101 of 1965) ordinarily eaten or drunk by man or purporting to be suitable, or manufactured or sold, for human consumption, and includes any part or ingredient of any such article or substance or any substance used or intended or destined to be used as part or ingredient of any such article or substance. This definition does not, per se, include water used in food processing or food manufacturing. However, the way in which such water is used in food processing plants may directly or indirectly affect the safety of the foodstuffs manufactured. As a result, some legislation published by the Minister of Health was formulated in such a way that it inhibits the use of water, in food processing plants, in a way that will render food unsafe for human consumption, from a microbiological and a chemical point of view. References to the

legislation that is set up nationally for controlling the use of water in food processing plants include, the Foodstuffs, Cosmetics and Disinfectants Act, 1972, and the regulations governing general hygiene requirements for food premises and the transport of food as promulgated under the Health Act, 1977 (Act No. 63 of 1977). The Directorate: Food Control also makes use of standards as set out in Section 7.3 of the Recommended International Code of Practice - General Principles of Food Hygiene (CAC/RCP 1-1969, Rev. 2 (1985) Codex Alimentarius Volume 1) with the intention to be in line with international practice.
A discussion of the relevant legislation and other guidelines/code of practice was the theme of the presentation.

WATER DEMAND MANAGEMENT AND SOCIAL ADAPTIVE CAPACITY: A SOUTH AFRICAN CASE STUDY, P.J. Ashton and B. Haasbroek, Division of Water, Environment and Forestry Technology, CSIR, P.O. Box 395, Pretoria 0001, South Africa

During the last century, rapid growth in South Africa's population, combined with rapid urbanization and industrialization, has resulted in a progressive decline in the volume of water available per capita each year. Simultaneously, water quality has declined as a result of increased pollution levels and has further reduced the quantity of water available for use.

South Africa recently embarked on far-reaching reforms of the water sector and the country's water law. The new policies, strategies and legislation shift the focus of water resource management away from the exploitation of water resources towards a greater emphasis on efficient and effective resource management. This process aims to redress the inequities of past political dispensations, strengthen the ability of water users to adapt to the changing circumstances, exert greater control over the extent of water use, and establish the so-called "Reserve" where both the ecological and basic human needs components will be held sacrosanct. Water Demand Management (WDM) strategies are a key component of national efforts to achieve natural resource reconstruction and sustainable water resource management.

Empirical evidence suggests that South African society must adopt new coping strategies to deal with the escalating demand for water. The few successes achieved to date are insufficient and must be expanded before water resource management can become truly sustainable.

WATER PINCH: A STRATEGIC TOOL FOR WATER MANAGEMENT IN THE FOOD PROCESSING INDUSTRY, **Chris Buckley and Chris Brouckaert, Pollution Research Group, School of Cjhemical Engineering, University of Natal.**
Water pinch is a formal and methodical technique for optimising water and effluent management in a complex manufacturing system. It sets about by firstly identifing all water using processes. Secondly, a set of key quality criteria is identified. This set is used to decide if a particular water stream may be used as a feed to a particular process. Thirdly, process related constraints, loads and limits are defined for each water using process. The water pinch technique then enables the optimum water network to be defined by allowing water cascading, recycles and reuses **without the installation of any water / effluent treatment equipment.** It also defines the critical

water quality variable and concentration leading to the limiting network and identifies the critical processes leading to the **water pinch**. This will also define the minimum water requirement for the process system. By examining the criteria associated with the **water pinch processes**, possibilities for further reduction in water consumption can be examined. Finally, the type and optimal placement of treatment processes can be examined to achieve the desired trade-off between capital expenditure, operating costs and water consumption. Throughout the whole procedure the necessary water and product quality criteria are always maintained._

Public Health Implications of Water Reuse in the Food and Beverage Industry

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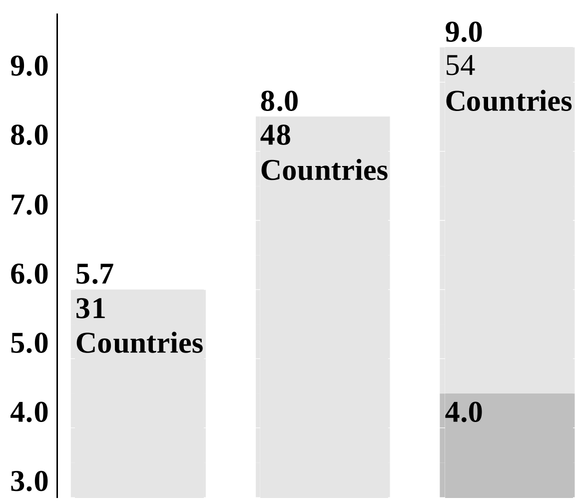
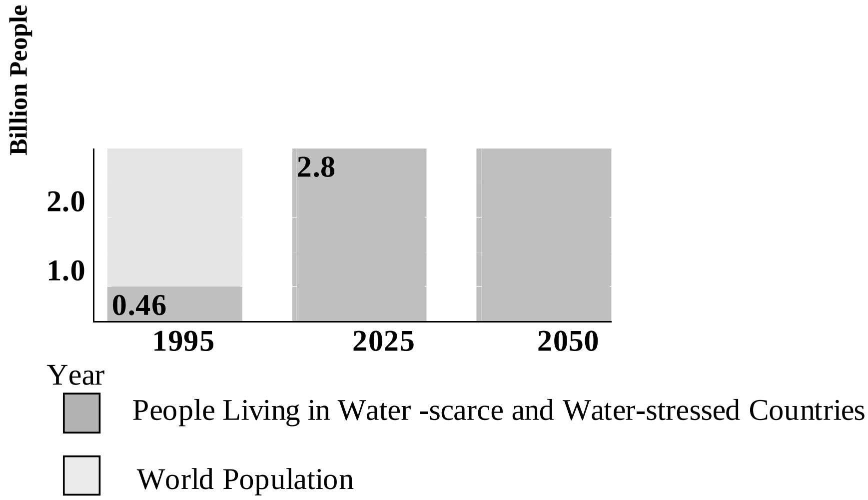
Paper presented at ILSI Seminar: Re-use of Process Water in the Food and Beverage Industries, November 17, 2000, Pretoria, South Africa

Introduction

Freshwater is an important commodity; population growth in water scarce regions will increase its value. Within the next 50 years it is estimated that 40% of the world's population (see Figure 1) will live in countries facing water stress or water scarcity (United Nations Population Fund, 1997; Gardner-Outlaw and Engleman, 1997). This number does not include people living in arid regions of large countries where there is enough water but it is not uniformly distributed e.g., China, India and the United States.

Figure 1
Population in Water-scarce and Water-stressed Countries, 1995-2050





Sources: Hinrichsen et al., 1998; United Nations, 2000

Industry (particularly the food and beverage industry) is the second largest consumer of freshwater resources (Abramovitz, 1996). Growing competition between agriculture and urban centers for high quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will also increase the pressure on this resource. Reuse of water can help to reduce some of this pressure. For example, the single largest use of freshwater is for agriculture and the nutrient and water content of wastewater make it particularly well suited for use in irrigation.

Freshwater scarcity is already a problem in South Africa. Over the next 25 years, freshwater resources per capita in South Africa will be cut almost in half (i.e., from 1,206 m^3/year in 1995 to 698 m^3/year in 2025) (Gartner-Outlaw and Engleman, 1997). Industry and society in general will have no choice but to adopt water reuse strategies - food security and continued economic development depend on it. Fortunately, there are many opportunities for water reuse in food and beverage production (see Table 1).

Table 1 Examples of water reuse in food and beverage production

Process	**Potential Water Sources**	**Possible Water Reuses***
Crop production	Wastewater/sludge	Aquaculture
		Irrigation
Food processing	Condensate water	Direct preparation of product
	Cooling water	Product washing
	Fluming water	Production of ice, hot water, and steam
	Equipment rinse water	Air conditioning and humidity control
	Product rinse water	Starting-up, rinsing and cleaning of processing equipment
	Permeates from membrane filtration	Cleaning and disinfection of processing facilities
	Sanitization water	Boiler feed water and fire extinguishing

*Different microbiological, chemical, physical, and organoleptic water quality standards will be required for each category of reuse to prevent product contamination/deterioration and exposure of workers to potentially harmful contaminants.
Source: Codex Alimentarius Commission, 2000

Worldwide, contaminated water is responsible for many disease outbreaks and has also been related to the spread of microbial foodborne disease. Microbial foodborne disease is common in many parts of the world - and an important fraction of this is associated with the consumption of raw fruits and vegetables.

In the last ten years the frequency of foodborne disease outbreaks has increased in some industrialized countries such as the United States (Altekruse et al., 1997). It is difficult to know whether increases in food poisoning are due to improved monitoring/reporting or due to other factors such as changes in the supply chain. Changes that may contribute to the increase in diseases associated with the consumption of raw fruits and vegetables in industrialized countries (Hedberg et al., 1994) and foods in general (Altekruse and Swerdlow, 1996; Altekruse et al., 1997) have been described. These factors include:

Globalization of the food supply - while advances in agronomic practices, processing, preservation, distribution and marketing have enabled the raw fruit and vegetable industry to supply high-quality produce to many consumers all year round, some of these same practices have also expanded the geographical distribution and incidence of human illness associated with an increasing number of pathogenic bacterial, viral and parasitic microorganisms (WHO, 1998).

Introduction of pathogens into new geographical areas – outbreaks of shigellosis in Norway, Sweden and the United Kingdom in 1994 due to contaminated lettuce imported from southern Europe (Frost et al., 1995; Kapperud et al., 1995) and cyclosporiasis in the United States which was linked to consumption of contaminated raspberries imported from Guatemala (CDC, 1996).

The development of new virulence factors by microorganisms - *E. coli* 0157:H7 was first documented as a cause of foodborne illness in 1982 - see Armstrong, Hollingsworth, & Morris, 1996. *E. coli* 0157:H7 subsequently has caused numerous outbreaks worldwide, including a 1996 outbreak in Japan that resulted in over 6000 cases linked to the consumption of contaminated radish sprouts (Ministry of Health and Welfare of Japan, 1997).

Population changes – decreases in immunity among certain segments of the population and increased life expectancy.

Changes in agricultural practices - use of untreated wastewater and manure or partially treated manure slurries as fertilizers for the production of fruits and vegetables is a major contributing factor to contamination that causes numerous foodborne disease outbreaks (WHO, 1998). Similarly, failure to vaccinate farm animals against endemic diseases (e.g. *Brucella spp.*) can lead to transmittal of the disease in animal products (e.g. brucellosis in milk) (WHO, 1995a).

Water reuse must be conducted in a manner that does not adversely affect the health of the workers and the product consumers. It is likely that new standards and systems to guarantee microbiological safety will need to be developed. The goal of this paper is to outline some of the potential microbial public health issues associated with water reuse in the food and beverage industry and to describe procedures that can help to ameliorate many of these health risks.

Selected Health Issues Associated with Water Reuse

Several microbiological issues regarding the safety of water reuse in food and beverage production need to be monitored to ensure that this practice does not lead to an increase in illness in the workers or food consumers. This paper will focus on the use of disinfection techniques for food and water, indicator organisms, viable but non-culturable bacterial states, biofilms, measuring cell death and 'tail' survival and emerging pathogens.

Disinfection

Disinfection can be extremely effective in reducing pathogens in water and food products. For some water reuse situations, disinfection will be necessary to avoid contamination of food products. The key is to identify target levels required for disinfection and the critical points and processes where water needs to be disinfected in order to avoid contamination of food products and minimize health risks to workers. Technologies for disinfecting both water and food products have been discussed in previous publications (WHO, 1999; WHO, 1998; WHO, 1995a).

The effectiveness of the disinfection process is dependent on the quality of the water, the type of disinfectant, contact time and the resistance of the microbe. Suspended solids, the presence of dissolved organic and inorganic matter, the temperature, and the pH of the water all can affect the disinfection process (Yates and Gerba, 1998). Water quality characteristics are important because disinfectants can react with substances other than microbes in the water and pathogenic organisms may gain protection by adsorption to particles. For example, disinfection frequently fails when suspended particulate matter in the water (as measured by turbidity) exceeds a value of five (WHO, 1999). Likewise, the properties of the disinfectant can be affected by the properties of the water. For example, the efficacy of free chlorine diminishes above a pH of 7 but chlorine dioxide becomes more effective (Yates and Gerba, 1998). Some disinfectants (e.g., chlorine, chloramines) leave a residual that can help prevent contamination in the distribution system; others (ozone, ultraviolet radiation) do not. In general, disinfection is most effective at eliminating bacteria, less effective for viruses, and the least effective for protozoa such as *Giardia* and *Cryptosporidium*.

Special care must be used when using wastewater, sludge or animal manure for production of edible crops. Numerous studies have shown that pathogens can survive for long periods of time on fruits and vegetables in the field. For example, Ascaris ova sprayed on lettuce and tomatoes remained viable for one month and *E. coli* 0157:H7 can remain viable in cow manure for up to 70 days when conditions are favourable (Beuchat and Ryu, 1997; Rudolfs, Falk, and Ragotzkie, 1951; Wang, Zhao and Doyle, 1996). Additionally, pathogens may escape the lethal effects of disinfection in the crevices, creases, pockets, and openings of the skin, or they may be partially protected by adherence to surface wax on raw fruits and vegetables (Lund, 1983; Adams, Hartley and Cox, 1989). In some cases the internal tissues of the fruit or vegetable may be contaminated. For example, alfalfa seeds and sprouts can be internally contaminated and thus surface disinfection does not remove the pathogens. Sprouts are also grown under conditions that can facilitate the regrowth of bacterial pathogens and, therefore, special precautions should be taken with this crop. Alfalfa sprouts have been implicated in several outbreaks of *Salmonella* and *E. coli* 0157:H7 in the United States (USDA, 1999).

Indicators

Health protection strategies usually rely on monitoring water quality and specifically the measurement of indicator organisms in the water or on food surfaces. Faecal coliforms, total coliforms, E. coli, and bacteriophages are all examples of organisms that when present are thought to indicate microbial contamination of the water or food product. While these indicators have been useful in predicting possible health risks in many circumstances, there is no perfect indicator organism. Bacterial indicator concentrations generally do not correspond to virus or protozoa levels in the media. Similarly many bacterial indicators are used to assess the presence of faecal contamination. Pathogens that are not of faecal origin may still be present in the water or on the food but may not be detected. Also, indicators can only be measured at discrete times and cannot be monitored continuously. Sporadic microbial contamination can thus escape periodic monitoring of indicator organism concentrations. This is particularly important when highly infective pathogens (i.e. pathogens that can cause infections in low doses) such as Cryptosporidium are present in the water supplies.

Therefore, microbial indicators of contamination should be used in conjunction with other monitoring activities. For example, the turbidity of the water can be continuously monitored. High levels of turbidity are frequently associated with higher microbial concentrations, particularly protozoan cysts and viral particles (WHO, 1999). Disinfection contact time and disinfectant residual concentrations can also be continually monitored as indicators of reduction of microbial contamination. Indicator monitoring may be most effective at critical control points in the process (see discussion of HACCP).

Viable but non-culturable states

A phenomena commonly known as viable but non-culturable state has been described for many bacteria including *Campylobacter, E. coli*, *Salmonella enteritidis*, *Vibrio cholerae*, *Vibrio* spp., and *Legionella pneumophila* (Rollins and Colwell, 1986; Chowdhury et al., 1994; Roszak, Grimes, & Colwell, 1984; Oliver et al., 1995) . The bacteria are still viable (exhibit low levels of metabolic activity) but fail to develop colonies on most traditional solid culture medium. Moreover, pathogens in this viable but non-culturable state have demonstrated the ability to return to an active potentially disease causing state (Colwell et al., 1985). However, there is some question as to whether bacteria actually enter a viable but non-culturable state or whether it is a simple failure of the methods used to recover stressed organisms. For other pathogens, e.g., *Cryptosporidium* and some viruses, detection methods are unreliable or have not yet been developed (Clancy et al., 1999). What is important from a public health perspective is that the apparent absence of culturable pathogens does not equate to zero public health risk.

Additionally, some viruses have been rendered non-infective because of DNA damage induced by solar radiation may have enzymes (or their bacterial hosts may have enzymes) that use other light wavelengths to repair the damaged DNA and thus become infective again (Weinbauer et al., 1997).

Biofilms

Some bacteria have the ability to colonize equipment, gasket surfaces, and distribution systems, forming biofilms. Biofilms contain colonies of bacteria surrounded by protective layers of polysaccharides. Usually these films harbor spoilage bacteria (e.g., *Pseudomonas spp.*) which generally pose little health threat but can contaminate food and accelerate spoilage. However pathogenic bacteria including *Listeria monocytogenes, Salmonella*, *E. coli* and *Legionella* can also form biofilms or become entrapped in them (Cooper, 1998; Lin et al., 1998). Protozoa provide the habitats for the environmental survival and reproduction of *Legionella* species which can proliferate intracellularly in various species of protozoa. Invasion and intracellular replication of *L. pneumophila* within protozoa in the environment play a major role in the transmission of Legionnaires' disease. Growth within protozoa enhances the environmental survival capability and the pathogenicity (virulence) of Legionella (Atlas, 1999).

Bacteria in biofilms become more resistant to disinfection, chemicals, and temperature. In some cases they may enter a viable but non-culturable state which makes them difficult to detect. Moreover, surfaces where biofilms form may be difficult to test for microbial contamination or swabbing surfaces may not be efficient enough to dislodge the embedded bacteria (Cooper, 1998).

Legionella colonization occurs frequently in large water distribution systems, even when potable water sources are used, and has been associated with outbreaks of Legionnaires' disease in hospitals, hotels, nursing homes, industrial plants, and homes (Lin et al., 1998; Stout and Yu, 1997; Stout et al., 1992).

Biofilm formation can be controlled on equipment surfaces by thorough and frequent cleaning and using equipment with smooth, highly polished surfaces. Lin et al., (1998) described several methods for controlling the formation of biofilms in distribution systems, including copper-silver ionization; superheat and flush procedures; UV irradiation, instantaneous heating systems; hyperchlorination; ozone; redundant disinfection processes; and frequent monitoring after disinfection.

Measuring cell death and 'tail' survival

The heat resistance of a microorganism can be quantified by determining its time to decimal reduction (D value), the time that it takes to inactivate 90% of the population at a given temperature. This value can be derived from a plot of $\log_{10}$ survivors versus elapsed time (Katzin et al., 1943), which is assumed to result in a straight line. This concept though originally developed for heat inactivation has been applied to other inactivation systems.

Although originally widely assumed to be a straight line and therefore a result of first order kinetics, explanations for this remain contentious (Gould, 1989). Published data have frequently suggested that this is not the case (Cole et al., 1993). The reported deviations from first-order inactivation have included shouldered death curves in which the initial death rate is slower and, of greater concern for the food industry, tailing in which a sub-population displays greater heat resistance than the majority population (Cerf, 1997).

Tailing deviations are often viewed as a result of experimental difficulties when thermal inactivation assessments are made. However, results indicate that the assumption that log-linear thermal death kinetics occur, which generally is made in food processing, is not always valid and that the deviations sometimes observed in practice should not always be dismissed as experimental artefacts. In current practice, margins of safety are generally sufficient for low-level tailing and there is not a problem, but this could change with the increasing trend toward minimal processing (Humpheson et al, 1998).

Pathogens of concern

Many of the pathogens of importance to the food and beverage industry can be transmitted through water. For example, *Salmonella*, *Shigella*, *Escherichia coli, Campylobacter, Lysteria monocytogenes, Yersinia enterocolitica, Vibrio cholerae, Vibrio spp*., Hepatitis A, Norwalk viruses, Rotaviruses, *Giardia*, *Cryptosporidium*, *Cyclospora, Ascaris*, and various trematodes have all been associated with foodborne outbreaks. Other pathogens such as *Staphylococcus aureus*, *Clostridium spp*., and *Bacillus cereus* are ubiquitous soil organisms or can be spread from contaminated food handlers (see Table 2) (see WHO, 1998 for information regarding foodborne outbreaks involving these pathogens). This paper will focus on several pathogens that have either recently been identified as problems (e.g., *E. coli* 0157:H7, *Cryptosporidium*), are particularly dangerous (e.g., *E. coli* 0157:H7, *Vibrio cholerae*, *Lysteria monocytogenes*), have very high prevalence (*Campylobacter*, Hepatitis A, Norwalk virus, trematodes) or are resistant to treatment processes (*Lysteria monocytogenes*, Hepatitis A, Norwalk viruses, *Cryptosporidium*, *Giardia*).

Escherichia coli 0157:H7

Escherichia coli 0157:H7 was first recognized as a foodborne pathogen in 1982 (Riley et al., 1983). Since then it has been implicated in numerous food and waterborne disease outbreaks. Cattle seem to be a natural reservoir for this organism and therefore many of the foodborne disease outbreaks have been associated with the consumption of contaminated undercooked beef or dairy products. Numerous outbreaks also have been attributed to the consumption of contaminated fruits and vegetables, apple cider and drinking water (WHO, 1998; CDC, 1996b; Kondro, 2000). Contamination of raw fruits and vegetables may occur as a result of contact with untreated or improperly treated cow manure. *E. coli* 0157:H7 has been shown to remain viable in cow manure for up to 70 days, depending on the initial concentration and temperature (Wang, Zhao, and Doyle, 1996).

E. coli 0157:H7 is particularly dangerous because it causes hemolytic uremic syndrome (responsible for 85 – 95% of all cases of this condition in North America, see Griffin, 1995), a sometimes fatal condition. It is estimated that *E. coli* 0157:H7 causes 73,000 illnesses and 600 deaths per year in the United States alone, 85% of which are thought to be foodborne (Mead et al., 1999; Armstrong, Hollingsworth, and Morris, 1996). This represents a significant increase in cases since 1981 when this pathogen was not recognized as a cause of water or foodborne illnesses.

Campylobacter

In recent years *Campylobacter jejuni* has become a more frequent cause of food and waterborne illness. In some countries it is now the number one cause of acute gastroenteritis (WHO, 1995). This organism is frequently associated with improperly treated animal manure and has important animal host reservoirs including wild birds, poultry and other domesticated animals (FDA, 2000a). Most of the outbreaks associated with this organism are due to consumption of contaminated foods of animal origin, particularly poultry, but Campylobacter outbreaks also have been associated with consumption of raw fruits and vegetables (Bean and Griffin, 1990). Several major outbreaks of *Campylobacter* enteritis have been linked to the ingestion of contaminated food, milk, or water (WHO, 1999). In the United States, it is estimated that *Campylobacter* causes almost 2.5 million illnesses per year, 80% of the cases are thought to be foodborne (Mead et al., 1999). In a small percentage of cases, infection with this organism can trigger Guillain-Barré Syndrome, a debilitating autoimmune reaction that can cause acute neuro-muscular paralysis (Buzby, Roberts and Allos, 1997)

Listeria monocytogenes

Listeriosis, caused by *Listeria monocytogenes* is particularly dangerous for the elderly, pregnant women/fetus, neonates, and immunoimpaired persons. The clinical manifestations include septicaemia, meningitis, encephalitis, osteomyelitis, endocarditis, abortion, and stillbirth or malformation of the fetus. The overall fatality rate is 30%, but may be as high as 70%. The pathogen is ubiquitous, and is found in a wide range of foods, including milk and milk products, seafood, meat, meat products, and vegetables. Some 1 – 10% of humans are carriers (WHO, 1995). The organism also is frequently found in sewage/sludge and can survive in the soil (Beuchat and Ryu, 1997). Listeria may also be more resistant to disinfection than some of the other bacterial pathogens (e.g., *E. coli*, *Salmonella*, *Shigella*) (WHO, 1998).

Vibrio cholerae

In the 1990s, cholera reemerged as a major infectious disease as epidemics were reported in Africa, Asia, and South America. From 1991 to 1996 WHO estimated that there were between 70,000 and 160,000 cholera cases in Africa alone (WHO 1997). The 1991 epidemic in Latin America caused 750,000 cases and 6500 deaths (PAHO, 1991). Cholera is primarily spread via faecally contaminated water and food. In 1970, a cholera epidemic in Jerusalem was traced back to the consumption of salad vegetables irrigated with raw wastewater (Shuval et al., 1986). Cholera infections have also been linked to the consumption of contaminated seafood in the United States (CDC 1991; CDC 1996c) and elsewhere. There is also evidence to suggest that *Vibrio cholerae* may be indigenous to some natural waters and able to survive on the surfaces of phytoplankton, zooplankton, and marine algae (McMichael et al., 1996). *Vibrio cholerae* is generally considered to be less hardy than other bacteria in field conditions (e.g., *E. coli* and *Salmonella*) (European Commission, 1998) and is not particularly resistant to chlorine or other disinfectants. Therefore, disinfection of water and food products may be effective in controlling the spread of this pathogen.

Cryptosporidium and Giardia

Parasitic protozoa such as *Cryptosporidium parvum* and *Giardia lamblia* have recently been recognized as important causes of water and food-borne disease outbreaks associated with faecal contamination. These pathogens are particulary difficult to control because they are resistant to chlorine disinfection, persist in the environment, infect other animal hosts and may be difficult to diagnose and treat (WHO, 1993). Cryptosporidium outbreaks have occurred worldwide due to contamination of drinking water, recreational waters and food. Cryptosporidium has been linked to a disease outbreak resulting from the consumption of unpasteurized apple juice and oocysts have been detected on cilantro, lettuce, radish, tomato, cucumber, carrots and in oysters (Millard et al., 1994; Monge and Chinchilla, 1996; Fayer et al., 1999). It has been estimated that there are 2,000,000 Giardiasis and 300,000 Cryptosporidiosis cases per year in the United States, of which 10% are thought to be foodborne (Mead et al., 1999).

Ascaris

The use of inadequately treated wastewater in irrigation is especially associated with elevated prevalence of intestinal helminth infection. For example, in Mexico, irrigation with untreated or partially treated wastewater was directly responsible for 80% of all *Ascaris* infections and 30% of diarrhoeal disease in farm workers and their families. However, when wastewater was adequately treated the risk of *Ascaris* infection was minimal (Cifuentes et al., 2000). *Ascaris* ova can survive for long periods of time in soil and on crop surfaces and are particularly resistant to disinfection. Additionally, the ingestion of very few viable *Ascaris* ova may be enough to cause infection. Therefore, care must be taken to prevent crop contamination with these parasites in the first place, i.e., by proper wastewater treatment prior to irrigation of crops (WHO, 1989).

Trematodes

Trematode infections are caused by parasitic flatworms (also known as flukes) that infect humans and animals. Infected individuals transmit trematode larvae in their faeces. Infections with trematode parasites can cause mild symptoms such as diarrhea and abdominal pain or more rarely, debilitating cerebral lesions, splenomegaly and death depending on the parasite load. In many areas of Asia where trematode infections are endemic, untreated or partially treated excreta and nightsoil are directly added to fish ponds. The trematodes complete their lifecycles in intermediate hosts and subsequently infect fish, shellfish, or encyst on aquatic plants. Humans become infected when they consume the fish, shellfish, or plants raw or partially cooked. WHO estimates that more than 40 million people throughout the world are infected with trematodes and that over 10% of the global population is at risk of trematode infection (WHO, 1995b). Proper treatment of wastewater and excreta before it is introduced into fish ponds and thoroughly cooking fish, shellfish and plants are methods of breaking the lifecycle of these parasites. Freezing fish that will be eaten raw and irradiation of infected flesh also can inactivate trematode metacercariae (WHO, 1995a).

Viruses

Viruses can be excreted in large numbers by infected individuals and are frequently found in water (Cliver, 1997; WHO, 1999). Although viruses cannot replicate outside of their hosts, some enteric viruses appear to have considerable ability to survive in the environment and remain infective (WHO, 1999). Viruses also can be difficult to detect and are frequently fairly resistant to disinfection. Specific viruses such as Norwalk-like viruses and Hepatitis A viruses have been implicated in water and foodborne disease outbreaks. For example, it has been estimated that Norwalk-like viruses cause 23,000,000 cases per year in the United States, of which 40% are thought to be foodborne (Mead et al., 1999). Hepatitis A has been linked to many foodborne outbreaks including an epidemic affecting 300,000 consumers of contaminated clams in China (Lees, 2000) and has been identified on numerous occasions in raw produce (WHO, 1998).

Table 2
Selected pathogens of concern to the food and beverage industry

Agent	Disease
Bacteria *Bacillus cereus* *Campylobacter jejuni* *Clostridium botulinum* *Escherichia coli* *E. coli* 0157:H7 *Helicobacter pylori* *Legionella pneumophila* *Leptospira* (spp.) *Listeria monocytogenes* *Salmonella* (many serotypes) *Salmonella typhi* *Shigella* (several serotypes) *Staphylococcus aureus* *Vibrio cholerae* *Vibrio (spp.)* *Yersinia enterocolitica*	 Diarrhoea, vomiting, (liver failure and death more rarely) Gastroenteritis, long term sequelae (*e.g*. arthritis) Botulism Gastroenteritis Bloody diarrhoea, hemolytic uremic syndrome Abdominal pain, peptic ulcers, gastric cancer Legionnaire's disease Leptospirosis Listeriosis Salmonellosis, long term sequelae (*e.g*. arthritis) Typhoid fever Shigellosis (dysentery), long term sequelae (*e.g*. arthritis) Diarrhoea, nausea, vomiting Cholera Gastroenteritis, death in immunocompromised Yersiniosis, long term sequelae (*e.g*. arthritis)
Helminths *Ancylostoma* (hookworm) *Anisakis* (herring worm) *Ascaris* (roundworm) *Clonorchis* (liver fluke) *Diphyllobothrium* (fish tape worm) *Fasciola* (liver fluke) *Fasciolopsis* (liver fluke) *Gnathostoma* *Paragonimus* (lung fluke) *Taenia* (Tapeworm) *Trichinella* *Trichuris* (whipworm)	 Hookworm Anisakiasis Ascariasis Clonorchiasis Diphyllobothriasis Fascioliasis Fasciolopsiasis Gnathostomiasis Paragonimiasis Taeniasis Trichinellosis Trichuriasis
Protozoa *Balantidium coli* *Cryptosporidium parvum* *Cyclospora cayetanensis* *Entamoeba histolytica*	 Balantidiasis (dysentery) Cryptosporidiosis, diarrhoea, fever Persistent diarrhoea Amebiasis (amebic dysentery)

Agent	Disease
Giardia lamblia	Giardiasis
Toxoplasma gondii	Toxoplasmosis
Viruses	
Adenovirus (many types)	Respiratory disease, eye infections
Astrovirus (many types)	Gastroenteritis
Calicivirus (several types)	Gastroenteritis
Coronavirus	Gastroenteritis
Enteroviruses (many types)	Gastroenteritis,
Coxsackie A	Herpangina, aseptic meningitis, respiratory illness
Coxsackie B	Fever; paralysis; respiratory, heart, and kidney
Echovirus	disease
Poliovirus	Fever, rash, respiratory and heart disease, aseptic
Hepatitis A virus	meningitis
Hepatitis E virus	Paralysis, aseptic meningitis
Norwalk virus	Infectious hepatitis
Parvovirus (several types)	Infectious hepatitis
Reovirus (several types)	Gastroenteritis
Rotavirus (several types)	Gastroenteritis
	Not clearly established
	Gastroenteritis

Sources: National Research Council, 1998; Hurst et al., 1989; Sagik et al., 1978; Edwards, 1992; and WHO, 1998.

Processes for Minimizing Adverse Health Effects of Water Reuse

There are many processes that can help to minimize potential adverse health effects of water reuse in the food and beverage industry. This paper will focus on three key areas: the use of microbial risk assessments; implementation of HACCP programmes; and selected water treatment technologies. These processes are complementary and therefore can and should be used together to minimize potential adverse health effects that may be associated with water reuse during food and beverage production. Additionally, it is important that food and beverage manufacturers follow the CODEX Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants (CODEX Alimentarius Commission, 2000).

Quantitative Microbial Risk Assessment (QMRA)

Microbial risk assessment is a process that attempts to describe the risk or probability of infection or disease based on an evaluation of the potential hazards, the potential routes of exposure to these hazards, and the likelihood that the exposure at a certain dose will result in infection or illness. The resulting probability of disease is then compared to policy decisions on risk acceptance. Different countries have proposed different levels of tolerable risk; for example, the US Environmental Protection Agency suggested that water be treated with the goal of insuring a high probability that the population consuming the water not be exposed to a risk of infection exceeding 1 in 10,000 per person per year from infectious agents transmitted through drinking water (Regli et al., 1991). In general, tolerable levels of risk should be based on the local epidemiological, sociocultural, and environmental conditions of the country.

The first step of the microbial risk assessment process involves hazard identification.

A hazard is a pathogenic organism or toxin produced by the organisms in the food or water. Different hazards may be identified at several steps of a process and therefore may be helpful in identifying critical control points (see HACCP section below). In some cases a risk assessment may be needed for each identified hazard (WHO, 2000). The second step in the risk assessment process is hazard characterization. This step determines the relationship between a pathogen and any adverse effects and may include a dose-response assessment. Dose-response information for certain pathogens may be available from volunteer studies or in some cases from epidemiological investigations. For many pathogens reliable dose-response information will not be available or will not be valid for vulnerable populations such as children or immunocompromised individuals .

The third step of the risk assessment process is the exposure assessment. Exposure assessment requires information on the concentrations of pathogens in the food or water and the route(s) and amounts of exposure to the consumers through the food or water.

The fourth step, risk characterization combines the information from the hazard identification, hazard characterization, and exposure assessment steps to produce an estimate of the risk of illness attributable to the food/water/pathogen source.

After an estimate of the risk is determined risk management is used to evaluate the acceptability and accuracy of the risk assessment. In deriving a risk estimate any uncertainty factors, e.g., missing data or knowledge and variability factors that could affect the magnitude of the risk, must be considered. If the risk is deemed to be too high to be acceptable the process must be modified in such a way that the risk of adverse health outcomes is reduced.

This process should result in the identification of the realistic hazards that must be addressed as part of the HACCP programme. For more thorough discussions of the QMRA process in wastewater use in agriculture, see Blumenthal et al., 2000; in food see Lammerding and Fazil 2000; and in drinking water treatment see Havelaar, 1994.

HACCP

HACCP, the Hazard Analysis and Critical Control Point system, is a systematic approach to identification, assessment and control of hazards (CODEX Alimentarius Commission, 1997) during production, processing, manufacturing, preparation and use of food, water, or other substances to ensure that the food, water or other substances are safe when consumed or used. The HACCP system incorporates safety control into the design of the whole process rather than relying solely on end-product testing. Therefore, the HACCP system provides a preventive and thus a cost-effective approach to product safety. Initially created for the food processing industry, HACCP has subsequently been applied to a number of different processes including drinking water treatment, aquaculture production, and the use of sewage sludge in the agriculture industry (Havelaar, 1994; Garret, Lima dos Santos, and Jahncke, 1997; Godfree, 2000). In the United States HACCP programs are or will be required for all seafood processors, meat and poultry plants, manufacturers of fruit and vegetable juices and dairy products (FDA, 2000b).

Application of HACCP systems in many different manufacturing or treatment processes has led to more efficient prevention of adverse health effects associated with the consumption or use of the products. For example, the implementation of an industry wide HACCP program for seafood processors in the US is thought to have averted 20 – 60% of the normal number of seafood-borne illnesses (Birley and Lock, 1998). A similar program for the prevention of food-borne Listeriosis in the US reduced the incidence and mortality of this disease by 44% and 49% respectively over a period of four years (Billy, 1997). The US government estimates that the financial benefits due to the reduction of illness from implementing HACCP programmes in the seafood industry range between 1.4 and 2.5 billion dollars per year and in the meat and poultry industry from 7 to 27 billion dollars over a 20-year period (Cato, 1998). The HACCP system can be applied throughout the entire food production process, from primary production to product consumption. Its implementation should be guided by scientific evidence of risks to human health. The successful application of HACCP requires the full commitment and involvement of management and the workforce. It also requires a multidisciplinary approach. This multidisciplinary approach should include, when appropriate, expertise in agronomy, veterinary science/medicine, production, microbiology, public health, food technology, environmental health, chemistry, and engineering, according to the particular situation. The HACCP system consists of the following seven principles (CODEX Alimentarius Commission, 1997):

Identification of hazards and assessment of their severity and probability of occurrence (hazard analysis).

Determination of the Critical Control Points required to control identified hazards.

Specification of critical limits to assure that an operation is under control at a particular CCP.

Establishment and implementation of systems to monitor control of the Critical Control Points.

Establish the corrective action to be taken when monitoring indicates that a particular Critical Control Point is not under control.

Establish procedures for verification to confirm that the HACCP system is working effectively.

Establish documentation concerning all procedures and records appropriate to these principles and their application.

Water Treatment Technologies

In many cases, water that is recycled or reused will need to be treated to improve its quality particularly when it comes into contact with food or beverage products or is used to clean surfaces that will come in contact with the products. Among other requirements the CODEX guidelines specify the following:

Reuse water shall be safe for its intended use and shall not jeopardise the safety of the product through the introduction of chemical, microbiological or physical contaminants in amounts that represent a health risk to the consumer;

Reuse water should not adversely affect the quality (flavour, colour, texture) of the product;

Reuse water intended for incorporation into a food product shall at least meet the microbiological and, as deemed necessary, chemical specification for potable water. In certain cases physical specifications may be appropriate;

Reuse water shall be subjected to on-going monitoring and testing to ensure its safety and quality. The frequency of monitoring and testing are dictated by the source of the water or its prior condition and the intended reuse of the water; more critical

applications normally require greater levels of reconditioning than less critical uses;
The water treatment system(s) chosen should be such that it will provide the level of reconditioning appropriate for the intended water reuse;
Proper maintenance of water reconditioning systems is critical;
Treatment of water must be undertaken with knowledge of the types of contaminants the water may have acquired from its previous use; and
Container cooling water should be sanitised (e.g., chlorine) because there is always the possibility that leakage could contaminate product.

The fundamental purpose of water treatment is to protect the consumer from pathogens and from impurities in the water that may be injurious to human health or offensive. Where appropriate, treatment should also remove impurities which, although not harmful to human health, may make the water unappealing, damage pipes, plant or other items with which the water may come into contact, or render operation more difficult or costly (WHO, 1999).

These purposes are achieved, by introducing successive barriers, such as coagulation, sedimentation, filtration and advanced treatments, to remove pathogens and impurities. The final barrier is often disinfection (WHO, 1999). Table 3 provides an overview of water treatment technologies and their applications.

Table 3. Overview of Representative Unit Processes and Operations Used in Water Reclamation

Process	**Description**	**Application**
Solid/liquid separation		
Sedimentation	Gravity sedimentation of particulate matter, chemical floc, and precipitates from suspension by gravity settling.	Removal of particles from turbid water that are larger than 30 μm.
Filtration	Particle removal by passing water through sand or other porous medium.	Removal of particles from water that are larger than about 3 μm. Frequently used after sedimentation or coagulation/flocculation.
Biological Treatment (Wastewater)		
Aerobic biological treatment	Biological metabolism of wastewater by microorganisms in an aeration basin or biofilm process.	Removal of dissolved and suspended organic matter from wastewater.
Oxidation pond	Ponds up to one metre in depth for mixing and sunlight penetration.	Reduction of suspended solids, BOD, pathogenic bacteria, and ammonia from wastewater.
Biological nutrient removal	Combination of aerobic, anoxic, and anaerobic processes to optimize conversion of organic and	Reduction of nutrient content of reclaimed water.

Process	Description	Application
	ammonia nitrogen to molecular nitrogen (N_2) and removal of phosphorus.	
Waste stabilization ponds	Pond system consisting of anaerobic, facultative and maturation ponds linked in series to increase retention time.	Reduction of suspended solids, BOD, pathogenic bacteria, and ammonia from wastewater. Facilitates water reuse for irrigation and aquaculture.
Disinfection	The inactivation of pathogenic organisms using oxidizing chemicals, ultraviolet light, caustic chemicals, heat, or physical separation processes (e.g. membranes).	Protection of public health by removal of pathogenic organisms.
*Advanced treatment*Activated Carbon	Process by which contaminants are physically adsorbed onto the surface of activated carbon.	Removal of hydrophobic organic compounds.
Air stripping	Transfer of ammonia and other volatile components from water to air.	Removal of ammonia and some volatile organics from water
Ion exchange	Exchange of ions between an exchange resin and water using a flow through reactor.	Effective for removal of cations such as calcium, magnesium, iron, ammonium, and anions such as nitrate.
Chemical coagulation and precipitation	Use of aluminium or iron salts, polyelectrolytes, and/or ozone to promote destabilization of colloidal particles from reclaimed water and precipitation of phosphorus.	Formation of phosphorus precipitates and flocculation of particles for removal by sedimentation and filtration.
Lime treatment	The use of lime to precipitate cations and metals from solution.	Used to reduce scale-forming potential of water, precipitate phosphorus, and modify pH.
Membrane	Microfiltration, nanofiltration,	Removal of particles and

Process	Description	Application
filtration	ultrafiltration	microorganisms from water.
Reverse osmosis	Membrane system to separate ions from solution based on reversing osmotic pressure differentials.	Removal of dissolved salts and minerals from solution; also effective for pathogen removal.

Source: Adapted from Asano, 1998.

Conclusion

The food and beverage industry is faced with numerous challenges regarding freshwater use. In many countries the incidence of foodborne outbreaks has increased in recent years. Clean water is essential for producing safe food and beverage products. However, freshwater is itself in short supply in many areas; therefore, there is a need to reuse precious freshwater resources. Poorly planned water reuse can have adverse health effects on both product consumers and industry workers. Safe water reuse is made more challenging by recently recognised water and foodborne pathogens that pose special problems either because of the severe health effects they can cause (e.g., *E. coli* 0157:H7, *Listeria monocytogenes*) or because of their resistance to traditional treatments such as disinfection (e.g., *Cryptosporidium*). Establishing management processes such as microbial risk assessment, implementing well-designed HACCP programmes, and selecting appropriate water treatment technologies can be effective mechanisms for reducing the health risks associated with water reuse in the food and beverage industry.

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WATER DEMAND MANAGEMENT AND SOCIAL ADAPTIVE CAPACITY: A SOUTH AFRICAN CASE STUDY

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ABSTRACT

During the last century, rapid growth in South Africa's population, combined with rapid urbanization and industrialization, has resulted in a progressive decline in the volume of water available per capita each year. Simultaneously, water quality has declined as a result of increased pollution levels and has further reduced the quantity of water available for use.

South Africa recently embarked on far-reaching reforms of the water sector and the country's water law. The new policies, strategies and legislation shift the focus of water resource management away from the exploitation of water resources towards a greater emphasis on efficient and effective resource management. This process aims to redress the inequities of past political dispensations, strengthen the ability of water users to adapt to the changing circumstances, exert greater control over the extent of water use, and establish the so-called "Reserve" where both the ecological and basic human needs components will be held sacrosanct. Water Demand Management (WDM) strategies are a key component of national efforts to achieve natural resource reconstruction and sustainable water resource management.

Empirical evidence suggests that South African society must adopt new coping strategies to deal with the escalating demand for water. The few successes achieved to date are insufficient and must be expanded before water resource management can become truly sustainable.

INTRODUCTION

Water is recognized worldwide as the most fundamental and indispensable of all natural resources (Hudson, 1996; Gleick, 1999). Almost every country faces a growing challenge in meeting the rapidly escalating demand for water that is driven by burgeoning populations (Biswas, 1993; Gleick, 1993; 1998). Water supplies continue to dwindle because of resource depletion and pollution, whilst demand rises fast because population growth is coupled with rapid industrialization, mechanization and urbanization (Falkenmark, 1994, 1999; Rosegrant, 1997; Gleick, 1998). This situation is particularly acute, and will worsen more rapidly, in many arid regions of the world where water scarcity, and associated increases in water pollution, limit social and economic development and is often linked closely to poverty, hunger and disease (Falkenmark, 1989; Gleick, 1998). This precarious situation contrasts sharply with those countries that can mobilize sufficient human, financial and technological resources to overcome the adversities posed by water scarcity, thereby maintaining human welfare.

Like most other African countries, South Africa's population has grown dramatically during the past century. Despite obvious iniquities in previous political dispensations, this growth has been accompanied by an equally dramatic increase in the demand for water. Based on *present* population trends and patterns of change in water use, South Africa will reach the limit of its economically usable, land-based water resources sometime between the years 2020 and 2030 (Basson *et al.*, 1997; Ashton, 1999). This sobering prospect emphasizes the urgent need to find a sustainable solution to the problem of ensuring secure and adequate water supplies.

An examination of South Africa's water resources and the historical development of water resource management strategies demonstrates how these policies and strategies have been shaped to cope with the pressures of economic growth in a situation where water supplies and water demand are unevenly distributed. This analysis also provides a basis to determine whether or not the new water policies and legislation (DWAF, 1997; Republic of South Africa, 1997; 1998; Muller, 2000) will change the public's attitude to water. The strong emphasis placed on water demand management (WDM) in South Africa's water law provides a logical framework for natural resource reconstruction and the embodiment of the principles of sustainable water resource management throughout South and southern Africa (Asmal, 1998; Harris & Haasbroek, 1999). However, effective implementation of these policies and strategies remains the key to success.

OVERVIEW OF WATER AVAILABILITY AND WATER DEMANDS

South Africa is an arid country with an annual average rainfall of 497 mm, far less than the world average of 860 mm. Rainfall is both highly seasonal and unevenly distributed, and some 65% of the country receives less than 500 mm of rainfall per year (DWAF, 1986). Most rainfall is concentrated along a narrow region on the southern and eastern coastline and declines sharply from east to west and south to north. The steep east-west and north-south rainfall gradients are matched by equally steep gradients in potential evaporation (DWAF, 1986; Midgley *et al.*, 1995; Basson *et al.*, 1997). Annual average potential evaporation across South Africa amounts to some 1800 mm/year, exceeding annual average rainfall by approximately 360%. As a consequence of these features, South Africa has been rated as one of the twenty most water-deficient countries in the world (McKenzie & Bhagwan, 1999).

These climatic features result in low and unevenly distributed quantities of surface runoff reaching the river systems (**Figure 1**). Total runoff to stream and river flows is estimated at some 50,150 Mm^3/year (Midgley *et al*., 1995; Basson *et al*., 1997). Over 60% of the runoff originates from less than 20% of the land area and 70% of the country contributes less than 50 mm of runoff to stream and river flows each year (Midgley *et al*., 1995).

Low and erratic rainfall, combined with high average temperatures and rates of evaporation, contribute to low rates of ground water recharge (DWAF, 1986). South Africa has few primary aquifers or high-yielding geological formations and most ground water occurs in small, scattered amounts in secondary, fractured rock aquifers

(Conley, 1995; Basson *et al*., 1997). Despite the fact that ground water supplies are small and often contain high concentrations of dissolved salts and minerals, they are critically important for many rural communities and farming enterprises located in the drier regions of the country (DWAF, 1986).

The expanding agriculture, mining, energy, industry and urban sectors of South Africa tended to develop in areas that are poorly supplied by surface water resources (DWAF, 1986; Conley, 1995; Midgley *et al*., 1995; Basson *et al*., 1997). The previous political imperatives to build and maintain water supply schemes to support the predominantly white farming community contributed to the uneven spread of demand for water. Seasonal river flows, combined with limited supplies of ground water and growing demands for water in areas located relatively far from suitable water sources, led water resource managers to concentrate on developing large storage reservoirs and water transfer schemes (DWAF, 1986; Basson *et al*., 1997). The combined capacity of the large and small water supply reservoirs in South Africa amounts to some 37,000 Mm^3. This is equivalent to almost 74 % of the annual average runoff and represents an unusually high level of "resource capture" (Midgley *et al*., 1995).

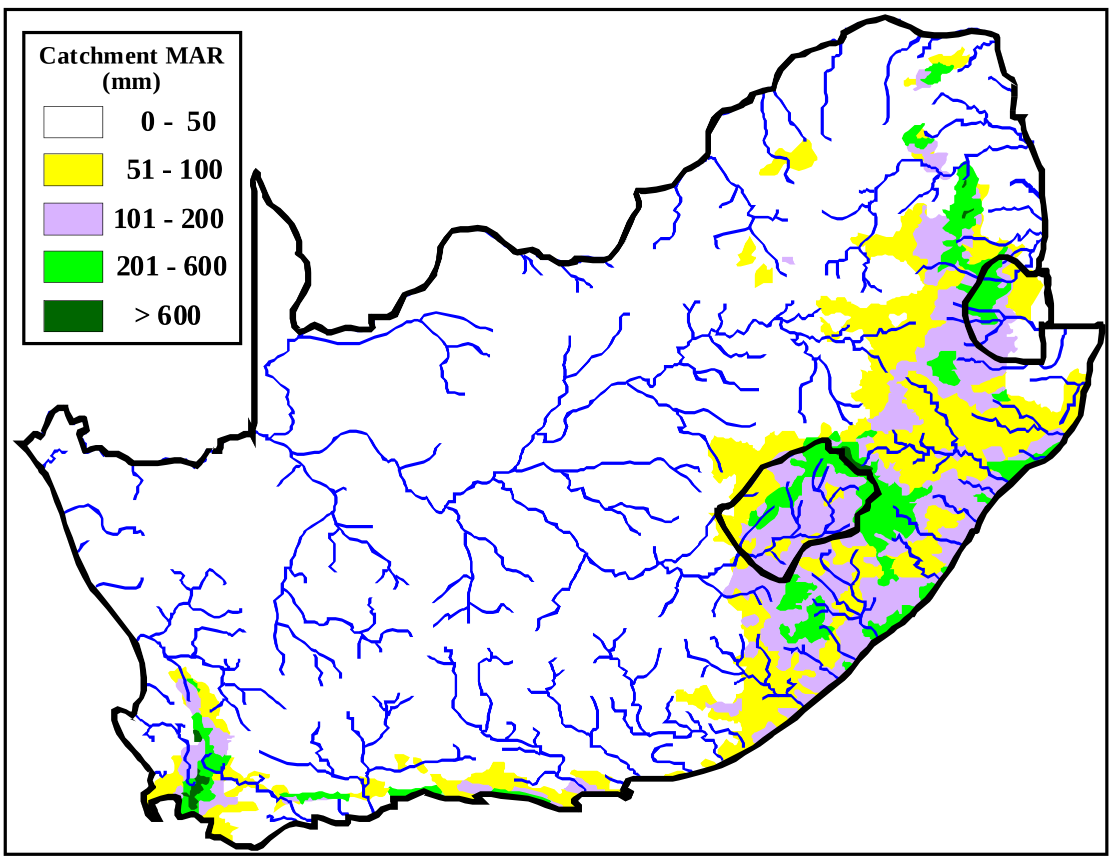

Figure 1: Map of South Africa showing the distribution of mean annual runoff (MAR, mm). Map drawn from WR90 data taken from Midgley *et al*. (1995).

Initially, most of the larger reservoirs were built to meet the agricultural sector's growing demands for irrigation water (DWAF, 1986). However, this emphasis has shifted to providing ever-greater proportions of the water required for urban and industrial development (Conley, 1995; Basson *et al*., 1997) and all water storage reservoirs are now considered to be multi-purpose (Pallett, 1997). The complex South African bulk water supply infrastructure now ranks as one of the most sophisticated in the world (McKenzie & Bhagwan, 1999).

Estimates of anticipated future uses of South Africa's water resources suggest that demands for water in each sector of the economy will increase by between 28% (for the agricultural sector) and 219% (for domestic use) over the next 30 years (Basson *et al*., 1997; **Table 1**). In several areas, water demand has already exceeded the available supplies and progressively larger volumes of water have had to be transferred from those catchments where water is still available. Further developments and projected increases in water demand at current rates of development will become increasingly difficult to satisfy.

Table 1: Estimated annual volume of water used by each sector of the South African economy during 1996, plus projected water requirements for 2030, with an indication of the percentage increase in each sector. Data taken from Basson *et al*. (1997).

Water Use Sector	**Water Demand (Mm^3/year)**				**Overall Percentage Increase**
	1996		**2030**		
Urban (domestic water use)	2,171	(10.8 %)	6,936	(22.8 %)	219.5 %
Mining, Industrial and Energy	1,598	(8.0 %)	3,380	(11.1 %)	111.5 %
Irrigation and Afforestation	12,344	(61.6 %)	15,874	(52.2 %)	28.6 %
Environment (*****)	3,932	(19.6 %)	4,225	(13.9%)	7.5 %
TOTAL	20,045		30,415		51.7 %

***** Environmental water use is relative to the total water use in different regions and does not reflect the size of the water resource available.

The calculations of future water use appear not to include all the water used by informal farming operations and rural communities, or the water needed for shared watercourses (SADC, 1995) and "ecosystem maintenance". These amounts could increase the volumes by 20-30% above the original estimates (Pallett, 1997). If valid, these conclusions suggest that the effective limit of the country's exploitable resources will be reached within 15 to 30 years (Basson *et al*., 1997; Pallett, 1997; Ashton, 1999; **Figure 2**). Clearly, catchments where water is in short supply will experience water stress long before other, better-watered catchments. Nevertheless, catchments with larger and more reliable water supplies will also experience escalating water stress as greater quantities of water are transferred to water-short catchments.

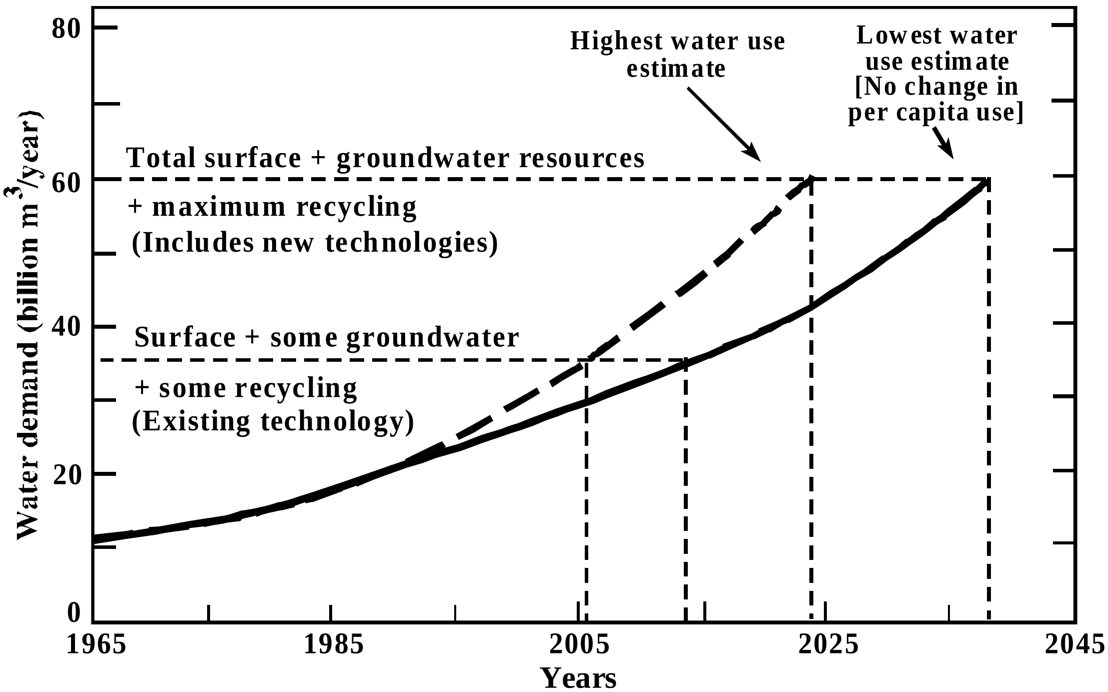

Figure 2: Diagram showing highest and lowest projections of water demand in South Africa, against the quantities of surface water, ground water, and recycled water that are available with existing technologies and with new technologies. (Redrawn from Ashton, 1999).

Over the past century, most of South Africa's urban, mining, energy and industrial development has been concentrated in the mineral-rich upper catchments of the Orange, Limpopo, Olifants and Komati river systems (DWAF, 1986). This is South Africa's "industrial and economic heartland" and accounts for over 65% of the GNP. The water demand accompanying this economic development has been coupled with increasing quantities of effluent discharge (DWAF, 1986; Basson *et al.*, 1997). Continued political isolation and "separationist" policies ignored many of the needs of South Africa's citizens and neighbours, further compounding the problem. Significantly, it seems that the water available in these international rivers may have been over-allocated, making it difficult for South Africa to meet her international obligations.

South Africa's political transition to democracy added additional complexities. There is now a pressing need to redress the many inequities of the past and to provide safe and wholesome supplies of water to those communities who presently rely on unreliable water sources whose quality is often dubious (Asmal, 1998). These needs and aspirations *must* be met (DWAF, 1998a, 1998b, 1998c, 1999a) even though the demand for water will escalate more rapidly and increase the pressure on dwindling resources. Whilst the amount of water required to meet the basic human needs of all South Africans is relatively small, additional water is needed to grow food and provide for the material needs of the growing South African population.

Treatment and re-use of domestic and some industrial effluent has the potential to "extend" the available water supplies for domestic and industrial purposes (Commission of Enquiry, 1970; DWAF, 1986, 1999a; Harris & Haasbroek, 1999). This approach has proved very successful in the case of Namibia's capital city, Windhoek (Heyns *et al.*, 1998). However, gradually deteriorating water quality requires progressively more sophisticated forms of treatment to ensure that the water is wholesome and safe for use. These treatment costs eventually become uneconomic when compared to alternative supplies (Basson *et al*., 1997).

Overall, the medium-term "picture" of water resource availability in South Africa is bleak. Nevertheless, these problems must be resolved for South Africa to achieve the necessary social and economic development that society demands. This will require a major shift in the public's attitude towards water, and new perspectives and innovative approaches to water resource management are therefore both critically important and pressingly urgent.

RECENT DEVELOPMENTS IN WATER RESOURCE MANAGEMENT

South Africa's political transition created a broad awareness that new water laws were needed to redress the iniquities of previous political dispensations and take account of its unique situation. This set the stage for a comprehensive process of public participation leading to the development of new water resource management policies and legislation (DWAF, 1997, 1998a, 1998b, 1998c, 1999a; Republic of South Africa, 1997, 1998). The new South African National Water Act (Republic of South Africa, 1998) ranks with the best in the world in terms of its scope and intent, as well as the democratic and participative manner in which it was developed. In character, the Act aims to balance long-term water resource protection and water resource utilization, whilst promoting economically sound development, and ensuring that all water use is equitable and sustainable in the long-term.

The National Water Act replaces rights to the use of water based on land ownership with a system of administrative authorizations. This is a fundamental and critically important change to the country's water resource management policies and approaches. All water will now be managed within the framework of the Integrated Water Resource Management (IWRM) philosophy, on a catchment basis, through appropriate institutions including the Department of Water Affairs and Forestry, Catchment Management Agencies and Water User Associations.

The basic approaches of IWRM promote equitable access to, and sustainable use of, water resources by all stakeholders at catchment, regional, national and international levels (Harris & Haasbroek, 1999). Statutory Catchment Management Agencies (CMAs) will be formed to manage all water resources within defined Water Management Areas (WMAs), a tangible move towards implementing the strategies of IWRM and achieving objectives outlined in the National Water Act (Harris & Haasbroek, 1999). Nineteen WMAs have been gazetted over the entire country (DWAF, 1999b) and one CMA will be established in each area. The approximate sequence, in which water will be allocated to meet the demands of different water users, and the authorities responsible for this process, are shown in **Figure 3**.

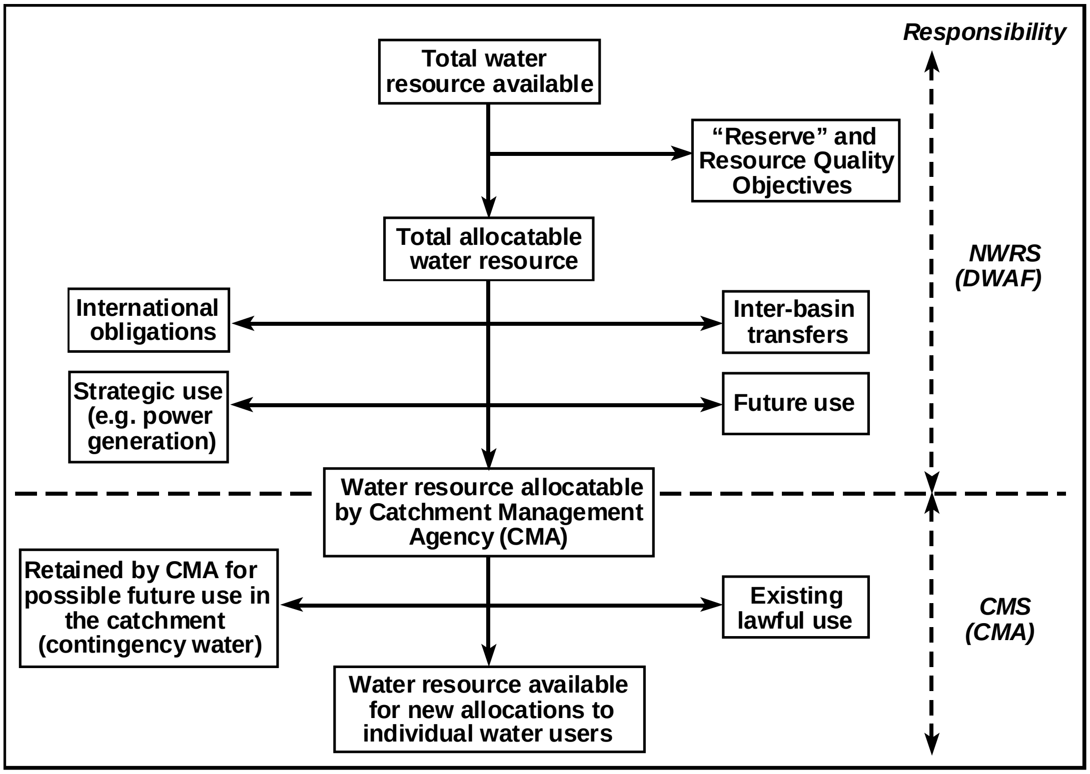

Figure 3: Schematic diagram showing the approximate sequence in which water will be allocated to meet different demands and the authorities responsible for each activity. (NWRS = National Water Resource Strategy; CMS = Catchment Management Strategy; DWAF = Department of Water Affairs and Forestry; CMA = Catchment Management Agency).

The available data show that the demand for water in South Africa has grown by 4-5% per year since 1930. This is approximately double the rate of population growth and is clearly unsustainable (Basson *et al*., 1997). In response to this worrying situation, the new National Water Act (Republic of South Africa, 1998) places heavy emphasis on water conservation strategies, including water demand management. These new initiatives aim to minimize or retard the growth in water demand through improved education and more efficient use of the available resources (McKenzie & Bhagwan, 1999; Watson *et al*., 1999).

RECENT DEVELOPMENTS IN WATER DEMAND MANAGEMENT

To date, there are few examples where water demand has been successfully controlled within a community (e.g. van der Linde, 1998). In contrast, many attempts have been unsuccessful (Schreiner, 1998), either because demand management was attempted in isolation or because the techniques used were not effective at the same magnitude across all water use sectors. Typically, the strategies developed for specific situations have not been integrated into a regional or national approach (Harris & Haasbroek, 1999).

The Department of Water Affairs and Forestry recently launched the Water Conservation and Water Demand Management Framework (WCWDMF), comprising a series of concerted efforts to develop and implement coherent strategies for water conservation and water demand management (DWAF, 1999a). Central to these strategies is the development of suitable mechanisms to ensure sufficient water is reserved for the aquatic environment so that the ecological integrity and functioning of aquatic systems is not compromised to a point where water supplies and other benefits fail. Aquatic ecosystems will be maintained according to a pre-defined condition or management class that allows appropriate (and controlled) levels of exploitation of the water resource (Schreiner, 1998; DWAF, 1999a). The process of defining management classes for each river system and then providing quantitative estimates of the "Reserve" is still continuing. In the interim, preliminary estimates of the "Reserve" are being carried out in the absence of a classification system. Importantly, the success or failure of these approaches depends largely on the effectiveness of individual water resource managers and the institutions (CMAs) that must be created to implement these strategies.

In normal every-day practice, water resource managers can choose from a wide range of technical, economic and social interventions to manage water demand. Typical examples of such strategies are listed in **Table 2**. Individual options or combinations of options can be selected according to specific objectives, or the perceived urgency or need of the situation. Each approach (technical, social and economic) can then be applied within appropriate timeframes for each water use sector (Harris & Haasbroek, 1999).

Table 2: Summary of different water demand management methods and approaches that are appropriate for implementation during different situations or operational phases. Adapted from Johnson (1995) and Harris & Haasbroek (1999).

Method	**Typical Operational Phase when Strategy / Approach is Applied**		
	Crisis: (Drought / Non-payment)	**Normal Operations**	**Long-term (Planning and Design)**
Technica	• Pressure reduction • Scheduled use • Valve closure	• Flow control • Manipulate orifices	• Metering • Loss control • Plumbing devices
Social	• Appeal • Social persuasion • Advertisements	• Legislation • Licences	• Consumer education • School education programmes
Economi	• Fines • Punitive measures	• Differential tariffs • Tradable allocations	• Supply and demand economics • Marginal prices

The success or failure of each WDM strategy depends on the commitment of water resource managers to implement the chosen strategies, and the willingness of individual water users to abide by the conditions of each strategy. It is important to note that the "water resource manager" who decides what strategy to employ will often also be the end-user, for example within a specific industry. In turn, the public's willingness to accept a particular strategy is controlled by the degree to which individual water users perceive the strategy to be "justified" by the prevailing circumstances, and the perceived "legitimacy" of the implementing institution. These measures take time to implement and their consequences also take time to impact on patterns of water use. Ideally, emphasis should be placed on a fully integrated approach that combines both short-, medium- and long-term considerations (Harris & Haasbroek, 1999).

South Africa's new Constitution (Republic of South Africa, 1996) guarantees all citizens the right of access to sufficient water for basic human needs. The South African Government recently interpreted this as being equivalent to a quantity of 25 litres per person per day (DWAF, 1999a; Republic of South Africa, 1998). The City of Durban has taken direct steps to enforce this principle by ensuring that the first "lifeline" amount of water (6000 litres per household per month) is provided free-of charge. This is equivalent to 50 litres per person per day for a family of four. Thereafter, the principle of "the more you use the more you pay" applies and this helps to subsidize the costs of supplying water to the poorer sectors of the community. With water services accounts paid by 93% of all account holders, the Durban City billing system is structured so that all households (both rich and poor) receive the first 6000 litres per month free. An important additional benefit has been a decrease in the overall demand for water to the extent that it is now (in the year 2000) equal to the 1996 demand levels (Kasrils, 2000a).

Clearly, large local authorities such as the City of Durban have a broad base of ratepayers that allows them to provide "free" water to the poorer sectors of the community. However, it will be extremely difficult for smaller municipalities and local authorities, particularly those in remote rural areas, to emulate the example set by Durban. This is because these smaller local authorities have much smaller financial resources and simply cannot afford the development and maintenance costs needed to sustain free water supplies.

The Greater Hermanus Water Conservation Programme is an excellent example of an integrated water demand management programme that successfully reduced annual water consumption by some 16.5% (van der Linde, 1998). The Hermanus Municipality used a suite of short- and long-term technical and economic techniques, combined with an intensive education programme, to enhance awareness in all water users and reduce water consumption to within target levels. In the process, water users not only accepted the rationale for the water demand management programme, but also demonstrated their individual commitment to the process. This change in behaviour, or adaptation, of the Hermanus society is considered to be the key to the success of the entire programme (van der Linde, 1998).

Similar developments in other societies have given rise to the concept of "social adaptive capacity". This is seen as an index or measure of the ability of a society to adapt its patterns of (water) resource use to increasingly scarce supplies and achieve a sustainable measure of social stability. In particular, it embodies the range of social mechanisms that enable a society to develop and adopt new strategies and actions allowing it to cope with water deficits that occur when escalating water demands exceed the supplies provided by conventional engineering solutions alone (Turton, 1999b; Turton & Ohlsson, 1999). There is compelling evidence that a sound understanding of the key insights and concepts embodied in "social adaptive capacity" will help to identify possible solutions to the looming water crisis that faces southern Africa (Turton, 1999b; Turton & Ohlsson, 1999).

WHAT IS SOCIAL ADAPTIVE CAPACITY ?

The theoretical background

The theoretical basis for "social adaptive capacity" in the context of water resource management is contained in a conceptual model developed by Turton (1999a, 1999b) and Turton and Ohlsson (1999). The key concepts embodied in the model described by Turton (1999a, 1999b) and Turton and Ohlsson (1999) have been modified and condensed into a single diagram for improved clarity (**Figure 4**). The definitions and explanations of important terminology used in the ensuing discussion have been adapted and modified from Turton (1999a) and Turton and Ohlsson (1999), and are listed in **Appendix I**.

Two important concepts help to explain the progressive changes in a country's development as the population grows and industrialization increases (Turton & Ohlsson, 1999) by linking the process of water resource development with the changes that take place in social interactions. The term *first order resource* refers to the natural resource (water) that is becoming scarcer relative to population over time. The term *second order resource* refers to the set of potential "adaptive behaviours" and strategies that are drawn upon from the broader social context by decision-makers (Turton & Ohlsson, 1999). The implications of these concepts pertaining to both water resources and the responses of society are summarized below.

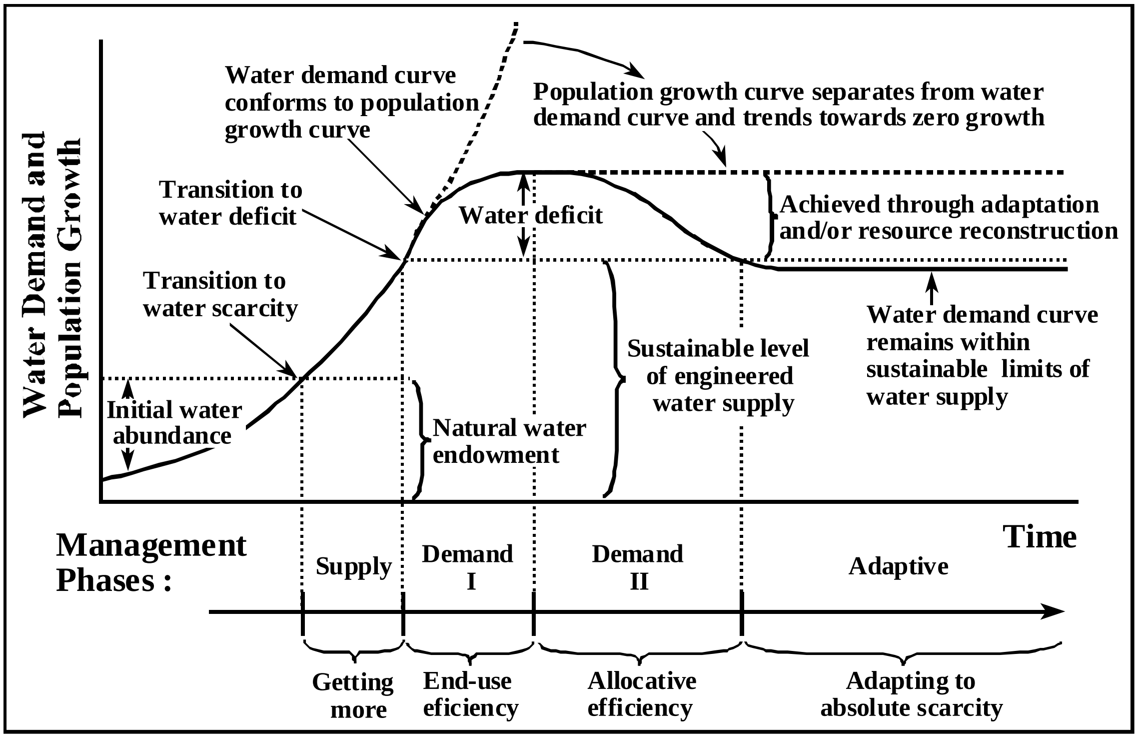

Figure 4: Schematic representation showing how water demand induced by rising population growth must be realigned with the maximum level of sustainable water supply, through improved end-use and allocative efficiencies that are driven by social adaptations and resource reconstruction. (Diagram modified from Turton and Ohlsson, 1999).

In terms of the first order resource, the left-hand side of the theoretical pattern presented in **Figure 4** shows a series of typical changes that take place when an increase in water demand is caused by an increase in population numbers. Initially, population numbers are low relative to the quantity of water available. The available water supplies are sufficient to meet all demands and represent a situation of "water abundance" (Turton & Ohlsson, 1999). In this situation, water demands increase proportionately as the population grows. However, as soon as the demographically induced water demand exceeds the available limits of water supply, the society enters a situation of "water scarcity" where the resource becomes increasingly inadequate (Turton & Ohlsson, 1999).

Water resource managers typically anticipate and respond to this transition by developing new sources of water, often located at increasing distances from the demand centres. This situation is called the "supply phase" and has also been referred to as the "hydraulic mission" phase of the country (Turton, 1999a). In effect, this is the time when a series of increasingly complex engineering solutions are developed to mobilize water and resolve the impending crisis in water supplies. The resulting situation has been called "structurally-induced water abundance" (Turton, 1999a) and any further increase in water demand can only be met by increasingly more difficult and expensive water supply schemes (Basson *et al.*, 1997; Turton & Ohlsson, 1999).

In terms of the second order resource, the transition from initial water abundance to water scarcity is characterized by distinct patterns of social behaviours (Turton & Ohlsson, 1999). When run-of-river abstraction can no longer sustain the water demands of economic and population growth, the general public turn to the government of the day to provide sufficient water. The government takes over the role of water supplier, "de-linking" water users from the water resource, and the general public gradually loses perspective as to the real value of the water that is supplied to them.

Where water demand continues to increase in tandem with population growth, the levels of water supplies that can be mobilized by conventional engineering solutions are soon exceeded and a situation of "water deficit" ensues (**Figure 4**; Turton & Ohlsson, 1999). Any further growth in water demand worsens the degree of water deficit experienced. This point usually marks the onset of determined efforts to control and manage water demand through the imposition of stringent water conservation measures and strategies aimed at improving the efficiency of water use. Typically, these strategies try to "buy enough time" for society to adjust structurally to the growing water deficit (Turton, 1999a, 1999b).

From a social perspective, this second transition is reflected in a change in the general social consciousness around water resources, and is often driven by a growing understanding of the issues of ecological or environmental sustainability and an expanding environmental lobby. In addition, there is often a marked (and sometimes abrupt) change in public perceptions as the public begin to reject unilateral decision-making around the distribution of water and demand to participate in water resource management decisions. Water resource managers now have to act as the executors of a "water trust" that is governed in the public interest. This creates new goals, where efficiency of supply and efficiency of use are important, and the management focus shifts from infrastructure management to water resource management (Turton, 1999a; Turton & Ohlsson, 1999).

If attempts to control water demand are unsuccessful, water resource managers are forced to implement progressively stricter measures and to re-allocate water to more productive sectors of the economy, the so-called "allocative efficiency" (**Figure 4**). In such situations, water resource managers must develop innovative ways to allocate water within society and keep water wastage to an absolute minimum (Turton & Ohlsson, 1999; FAO, 2000).

When water deficit becomes prevalent, radical reforms are needed across all water use sectors if water demand patterns are to be separated from population growth. The concerted and sustained effort needed to maintain the overall water demand within the sustainable limits imposed by engineering solutions (**Figure 4**) requires the full commitment and participation of civil society (Turton & Ohlsson, 1999). If successful, the shift in water demand away from a demographically induced pattern of continual increase to one that remains within sustainable limits of supply corresponds to the idea of "reflexivity" proposed by Turton (1999a) and Turton and Ohlsson (1999). This is a clear indication of a society's ability to adapt to conditions of absolute water scarcity (Turton, 1999a; FAO, 2000). This also reflects the success of "resource reconstruction" efforts (**Figure 4**) where the available water would have been allocated to the most efficient and effective water use sectors (Turton & Ohlsson, 1999).

In terms of the basic theoretical framework provided by Turton (1999a) and Turton and Ohlsson (1999), *effective* social adaptive capacity is based on effective water demand management strategies and techniques, and rests upon two core components, namely: A "structural component" that includes intellectual capital, institutional capacity and infrastructure, and is responsible for generating effective technical solutions or "coping strategies" that will control water use effectively and efficiently, and
A "social component" that can be measured in terms of the willingness and ability of a society to accept the technical solutions as being both legitimate and reasonable, and the society's commitment to the process of implementing these solutions.

The factors influencing reflexivity (and, ultimately, natural resource reconstruction) are shown schematically in **Figure 5**. Here, social adaptive capacity and its two sub-components are of central importance to this discussion (Turton, 1999a; Turton & Ohlsson, 1999). Whilst economic adaptive capacity and environmental adaptive capacity are important components of reflexivity and natural resource reconstruction, a detailed examination of these features is beyond the scope of this chapter.

Clearly, if a society's water demands remain linked to population growth, the quantity and quality of water available for each person will decline as the population increases (Ashton, 1999; FAO, 2000). This situation is clearly unsustainable. Ideally, the rate of population growth should also decline and trend towards zero and reduce demographic pressure on the available water resources (**Figure 4**). Theoretically, this population level would then reflect the "carrying capacity" of the available water resources and the associated social and technical capacity of the society. However, a scenario of zero population growth seems unlikely in the modern African context since population growth rates have remained at high (though variable) levels throughout the last century and show no signs of decreasing consistently towards zero.

Is there any "proof" that Social Adaptive Capacity exists in South Africa ?

Against the theoretical background, we can examine the available evidence to determine whether or not South African approaches to water resource management and water demand management reveal any proof of social adaptive capacity. Turton (1999a) and Turton and Ohlsson (1999) have suggested that evidence of "water resource reconstruction" would provide at least some empirical evidence that "social adaptive capacity" is present within a society (Turton, 1999a; Turton & Ohlsson, 1999).

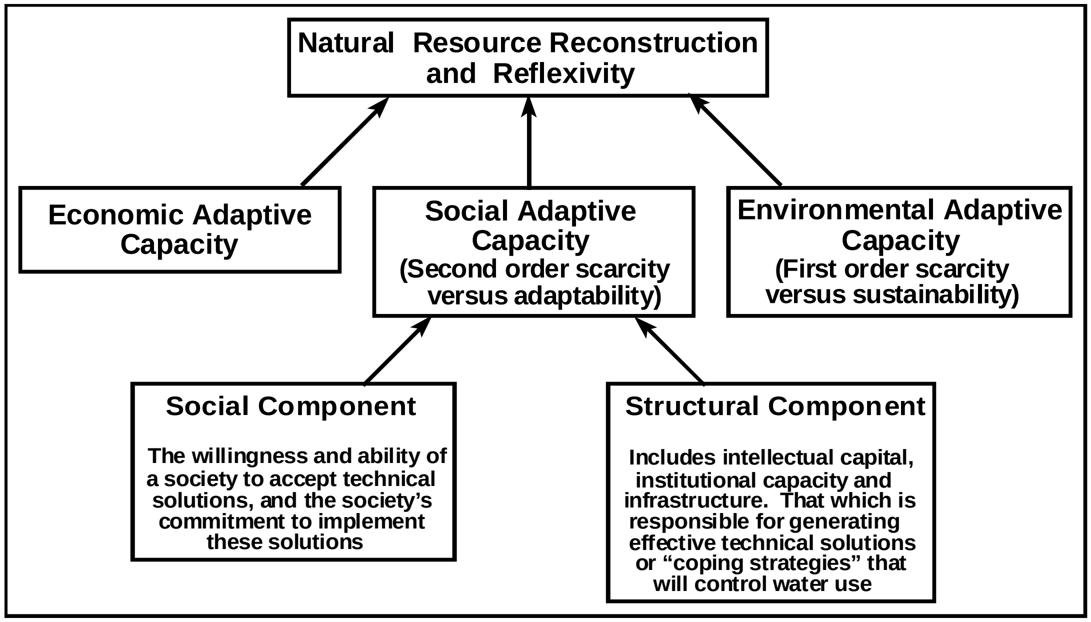

Figure 5: Factors influencing reflexivity and natural resource reconstruction.

Earlier, emphasis was placed on the fact that the "structural" and "social" components needed for effective social adaptive capacity (**Figure 5**) rely heavily on public perceptions of the legitimacy of the authority responsible for implementing water demand management strategies, and on the "acceptability" of the strategies proposed for implementation (Lundqvist, 1999; Turton, 1999a). In South Africa, the engineering response to the onset of water scarcity was clearly demonstrated by a dramatic increase in dam construction and the development of inter-basin transfer schemes to deliver sufficient water to the major demand centres during the latter half of the twentieth century (DWAF, 1986; Conley, 1996; Basson *et al*., 1997; Pallet, 1997).

The change in the "social conscience" surrounding the exploitation of water resources that provides evidence for the start of the demand phase in South Africa's water resources management history, originated in three arenas:

The change in government in April 1994 prompted the establishment of a new Constitution which assured access to water to all the citizens of South Africa;

A growing population and an expanding economy, accompanied by escalating water demands, led water resource planners to appreciate the increasing urgency of a looming water deficit; and

An increased understanding of the need to protect water resources as natural systems, and that each resource has a defined carrying capacity with a so-called "threshold" that, if breached, could potentially lead to total failure of the resource.

South African water resource managers have clearly realized the urgent need for concerted actions to curb the growth in water demand. However, several historical circumstances continue to force South Africa to remain partly within the supply phase of water resource management. Of particular importance are the estimated 8 million people in rural areas of South Africa who still do not have access to clean water. In addition, approximately 20 million rural people do not have access to adequate sanitation facilities. Since 1994, the South African Government has spent an estimated R3.6 Billion on additional (new) water supply schemes to provide potable water to an estimated 5.6 million rural people who previously had no formal water supply system (Kasrils, 2000b). Whilst these supply phase developments will have to continue, concerted efforts are now being made to ensure that all new water supply systems are both effective and efficient.

Despite the need to continue the development of water supply systems in South Africa, different water user sectors have started to draw up water conservation and demand management plans and strategies, as required by the new National Water Act. This constitutes the first formal evidence for entry into the initial stages of the demand management phase of South Africa's water resources management history. Already there is clear evidence in the form of new "end-user efficiency" strategies in the major urban centres of the country as well as in certain parts of the agricultural sector. However, whilst the need for these measures is driven by the realisation that water resources are becoming scarcer, there are also clear financial and economic constraints caused by South Africa's status as a developing country.

Financial and economic features, combined with the relatively inefficient use and distribution of water to some urban areas, provide a strong impetus to the current drive towards an improved end-user efficiency stage in the water demand management phase. In Gauteng for example, it is estimated that some 25% of the water supplied to users is lost through reticulation and plumbing leaks. Another cause of water loss and inefficiency is attributed to poor maintenance, where Municipal Councils fail to maintain and repair water infrastructure (Kasrils, 2000a). Financial incentives/disincentives and social suasion have proven to be the most effective measures that help to initiate and maintain end-user efficiency in urban centres.

If a society does indeed possess social adaptive capacity, this should be evident in institutional capacity and infrastructure, as well as the related intellectual capital to generate effective technical solutions or "coping strategies" (Turton, 1999a; Turton & Ohlsson, 1999). As we have seen (**Figure 5**), both the structural and social components must be present simultaneously if social adaptive capacity is to be truly effective. Therefore, we need to seek out and evaluate the evidence for the presence of these components.

Evidence for the "Structural Component"

Although South Africa has demonstrated a large intellectual capacity for managing and coping with water resources, there is still a pressing need to enlarge the "knowledge pool" even further as the country draws closer to a situation of water deficit. To cope with this realization, many partnerships have been forged between South Africa and the international community, as well as amongst different stakeholder groups within South Africa. Locally, the government has established several partnerships with public utilities, the private sector and NGO's, whilst the principal international partnerships include the European Union and neighbouring countries in the SADC region (Kasrils, 2000b).

Many local government institutions have had insufficient capacity to cope with local level water supply and demand management, mainly due to inadequate levels of funding and a shortage of skilled personnel. However, the government has pledged to empower and train local government structures and assist local authorities to assume full responsibility – as Water Service Authorities – for providing water services. At the same time, all water users need to be educated how to look after their water, and to monitor, manage and maintain it (Kasrils, 2000b). The lack of institutional capacity in some local authorities has forced the Department of Water Affairs and Forestry to be directly involved in a large number of projects to provide water services to millions of people in poor rural and peri-urban areas (Kasrils, 2000b).

The establishment of Catchment Management Agencies (CMAs) to manage all water resources within hydrological regions (water management areas), will effectively decentralize water resource management at the planning and implementation level, and will also provide appropriate financial perspectives (DWAF, 1998a). The Board of each CMA will consist of representatives from different stakeholder groups and funds derived from water sales will be used to develop and manage water resources within the water management area. Each CMA must also develop and implement suitable water demand management strategies and this will help to ensure that the importance of effective resource management is communicated to the people in the water management area. In this way, the adverse impacts of any misuse as well as the potential benefits from positive management practices will also be felt directly by the users in the water management area (DWAF, 1998a).

Against this background of policy developments and institutional changes in South Africa, and our improved understanding of water resource management, it seems that the basic structural components are largely in place for a move towards the adaptive phase as water deficit draws closer. Whilst appropriate water demand management strategies have not yet been fully implemented, it is accepted that the effective implementation of such strategies, as well as the overall effectiveness of catchment management agencies, will be pivotal in determining whether or not South Africa will be able to adapt structurally to growing water scarcity.

Evidence for the "Social Component"

The social component of social adaptive capacity relies on two key concepts:

The willingness and ability of the general public to accept technical and other solutions as being both legitimate and reasonable, and

The commitment of the general public to implement these solutions.

Although South Africa is still in the first stage of the demand management phase of its water resources management strategy, some positive results have already derived from the implementation of end-user efficiency measures. At this stage, these signs can only be measured as a slight drop in the overall demand for water. In the cases of Hermanus and Durban, there are clear signs that the initial measures taken have had a positive effect in reducing the demand. The buy-in from water users is based mostly on financial concerns, from the understanding that saving water can also save money.

Unfortunately, financial incentives on their own only have a limited potential to reduce the demand for water because of large inequalities in financial potential that still exist between the different socio-economic strata of South African society. This feature, and the apparent inequities in the pricing of water from new supply schemes, compared to existing urban water supplies, will make financial incentives difficult to implement. For example, in the larger cities, one cubic metre of purified water costs approximately 50 cents (this includes the costs of bulk water capture, storage, treatment and delivery, as well as waste water treatment). In contrast, the residents of rural areas have to pay approximately double this amount because they have to be supplied with water through other, smaller systems (Kasrils, 2000b). Whilst this cost is not a high price to pay for water, it can amount to a considerable percentage of a family's income if they are very poor. Here, the Durban Metropolitan Council's approach of supplying everyone with a basic "lifeline" amount of water free of charge seems intuitively correct. This feature also emphasizes how important it is to take into account a person's ability to pay when financial instruments are being considered for water demand management. Here, too, a strong distinction must be made between those who cannot pay and those who will not pay.

In South Africa, water supply and distribution usually consists of three levels or tiers of supply. The first tier of water supply comprises the primary extraction of water from the water resource, and may include both ground and surface water, as well as water that is used directly or indirectly. Examples of indirect first tier water use include the reduction in run-off that arises from forests and plantation crops (such as sugar cane). Typically, first tier water includes all of the water supplied by the Department of Water Affairs and Forestry from state-owned raw water schemes and also includes water that is abstracted from rivers for irrigation agriculture. Second tier water supply is the wholesale (bulk water) distribution of either raw (untreated) water, or water that has been treated to ensure that it is safe for normal domestic use. Typically, water boards or water utilities fulfil this function. Third tier water supply is the subsequent retail sale of treated water (typically potable water) to individual consumers; individual municipalities typically carry out this function.

Communication plays an extremely important role in the process of monitoring water use within every user sector. The Hermanus case study demonstrated that residents who were provided with informative monthly accounts for service delivery and use were able to monitor their own water consumption and compare this with the average consumption figures achieved by other residents. This simple act of providing additional, useful information was seen as a firm demonstration that "everyone was part of the same team".

In summary, many lingering socio-economic inequities and related factors continue to hamper full expression of the social component of social adaptive capacity in South Africa. Although the Department of Water Affairs and Forestry continues to conduct extensive publicity campaigns designed to inform the general public that water is a critically important resource that is vital to all forms of life, there are still opportunities to improve and intensify the communications process. For example, in addition to the more general communication process, the public should also be informed of the successes and failures achieved in efforts to reduce water consumption. In tandem, these two communications strategies should form the core of a social persuasion process to communicate and emphasize the urgent need for water demand management in South Africa.

CONCLUSIONS

In South Africa, there is a growing awareness amongst water resource managers and, to a lesser extent, the public, that the country's freshwater supplies are an indispensable finite resource that must be protected and managed carefully. It is also clear that both the quantity and quality of water available per person will decline as the population of South Africa continues to grow. The overall demand for water in South Africa is a product of the skewed levels of social development, which is itself a product of previously racially skewed access to natural resources such as water. Consequently, South African water resource managers face considerable difficulties when they attempt simultaneously to improve the lot of the poor by providing them with formal water supplies (thereby increasing water demand), whilst trying to reduce the overall (national) demand for water.

This realization has enormous social, economic and environmental implications and provides the driving force behind the adoption of new policies and legislation that are designed to reverse past inequities and to continue to provide adequate water supplies to meet the growing demands for water. More than ever before, a growing awareness of the vulnerability of the country's freshwater resources is forcing water resource managers to review the ways in which water resources have been developed in the past and to derive more innovative and equitable ways of adapting to the inevitable scarcity (Basson *et al*., 1997; DWAF, 1998a, 1999a).

Given the rate at which development took place in South Africa during the last century, it was inevitable that the growing demand for water would eventually exceed the capacity of the available supply systems. Unfortunately, whilst this feature was foreseen and regularly announced by water resource managers, this was not acted upon *by politicians* until relatively recently. The growing awareness of the need to sustain development in economic and environmental terms, coupled with the change in government in 1994, led to a series of dramatic changes in water resource management policies and legislation. Promulgation of the new National Water Act introduced bold and imaginative measures to broaden public participation in management of the country's water resources. The need to meet basic human needs and maintain the integrity and functioning of the aquatic environment now enjoys priority in the new Water Act.

So far, most efforts to reduce water demand have been based on two considerations: first, environmental sustainability and, secondly, the financial cost of new systems compared with the benefits of delaying capital expenditure for new water supply infrastructure. Indeed, water demand management is often seen as one scenario within a larger framework of possible water supply management projects. However, if water demand management strategies are not fully integrated with social and economic initiatives, if will always be difficult to implement these scenarios with maximum efficiency. The new integrated strategies that are under development now will help to guide these initiatives and thereby enable them to expand the concepts of water demand management beyond the limits posed by technical measures alone.

The theoretical framework provided by the concepts of social adaptive capacity and natural resource reconstruction show that South African water resources management approaches fit the characteristics of a typical supply phase situation. The change in government in 1994 marked a formal change in the country's social consciousness and its approach to water resource management. Simultaneously, this event also initiated a complex series of social and technical processes that sought to redress past inequities, address the needs of a growing population and an expanding economy, and incorporate ecological considerations in the management of the country's water resources. In effect, these processes also marked the onset of the end-user efficiency stage in South Africa's water resources management history.

Several reasons have been offered as justification for the onset of the end-user efficiency stage of water demand management in South Africa. However, the available evidence suggests that the potential financial benefits and, to a lesser extent, the long-term social benefit of such practices, provided the major incentives. However, the successes attributed to financial measures may prove to be short-lived where significant socio-economic inequities continue to exist. Integrated strategies and programmes, such as those being developed as part of the National Water Demand Management and Conservation Strategy, must span the widest possible spectrum of approaches if water demands are to be reduced effectively.

Reviews of information for the different South African water demand sectors reveal very little evidence for improved end-user efficiency. In addition, virtually no evidence was found to suggest that inter-sectoral allocation efficiency has received any attention. Therefore, whilst the sweeping South African water law reforms have great potential to improve the efficiency and effectiveness of water resource management, little progress has so far been made with the initiation of large-scale actions to curb water demand and improve water use efficiency in all water use sectors.

The key strategies outlined within the new National Water Act must be fully implemented if South Africa is to prove that it is indeed socially adaptive. In particular, strong partnerships must be forged between the state and the public, whilst the implementation of catchment management agencies must be finalized. These processes must ensure full public buy-in and commitment if they are to be successful and the importance of ensuring that all water users are fully informed cannot be over-emphasized. The Hermanus case study provided excellent evidence that communication campaigns provide important tools that help to achieve success.

Clearly, the efforts made to date must be encouraged, supported and extended if South Africa is to become truly reflexive in its water demand patterns. Whilst water use will need to be controlled strictly in all water use sectors, there is good evidence that a growing water deficit will exert increasing pressure on the country's processes of economic and social development. Considerable effort will also be required to circumvent the added threats to water resources that are posed by global climate changes and the HIV/AIDS pandemic that is sweeping the African continent (Whiteside & Sunter, 2000). This will require far more emphasis on the adaptive phase. New technologies and approaches that can cost-effectively "create" new freshwater sources will need to be developed. We anticipate that these approaches will have to form the driving force behind the shift in water resource management that will be needed to support economic growth as the country enters a situation of water deficit in future.

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APPENDIX I

Definitions and terminology

The theoretical concept of "social adaptive capacity", as it can be applied to water resource management, has been described in a model presented by Turton (1999b) and Turton and Ohlsson (1999). The specific definitions of the various terms used by these authors are listed alphabetically here for clarity.

Adaptive behaviour	A clearly demonstrated response to the changing level of water scarcity that can take any one of a number of forms.
Coping strategies	The input from decision-makers, usually in the form of some policy or set of strategies such as water demand management, that seeks to manage water scarcity in some form or another.
First-order resource	The natural resource (in this case, water) that is becoming either scarcer (or more abundant) relevant to population over time.
Resource capture	The process by which social groups shift resource distribution in their favour over time.
Second-order resource	The set of potential "adaptive behaviours" that are drawn upon from the broader social context by decision-makers.
Structurally induced water scarcity	The simultaneous occurrence of both a first-order resource abundance and a second-order resource scarcity, where the social entity is unable to develop or adopt appropriate coping strategies to make use of the available water.
Structurally induced water abundance	Where both a first-order resource scarcity and a second-order resource abundance occur simultaneously. For example, when a social entity has adapted to water scarcity by generating a suitable set of coping strategies. Being socially adaptive and technically innovative induces relative water abundance.
Water Abundance	The existence of both first-order and second-order resource abundance simultaneously.
Water deficit	The condition that prevails when the consumption of freshwater within a social entity exceeds the level of sustainable supply.
Water poverty	Where both a first-order and second-order resource scarcity occur simultaneously; i.e., a prevailing condition of water scarcity and low levels of adaptive capacity.
Water scarcity	A decrease in the volume of water available per capita over time.
Water surplus	The prevailing condition that exists when the consumption of freshwater within a given social entity is within the level of sustainable supplies.

RISK AND SAFETY ASSOCIATED WITH THE RESUE OF FOOD PROCESSING WATER

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1. INTRODUCTION

One of the problems in discussing or presenting a paper in the reuse of water is the possible differences in interpretation of the terms used. Terms such as reuse, recycling, reconditioning, reclamation and closed loop may be used and it is difficult to know exactly what is meant without definition of the different terms. For the purposes of this paper reuse will imply the use of water which has been through a treatment process to improve its quality to a state where it can be used again. Recycling will imply reuse of water directly without intermediate treatment. This would be possible in a cascade process or counter current process where it moves from relatively clean to a relatively contaminated state. Reconditioning would be defined as the action of treating the water or effluent to improve its quality for reuse. Reclamation would be the recovery of water out of the process perhaps out of material which becomes product which could be available for any of the other processes.

Another problem in delivering a paper is to be sufficiently generalised that the comments have broad applicability without losing so much detail that they have limited usefulness. This appears to have been one of the problems faced by the CODEX guidelines, which give a very useful background but require supplementary guidelines for specific industries.

CHARACTERISTICS OF FOOD EFFLUENTS

One of the overriding characteristics of food effluents is that they are biodegradable and tend to ferment or putrefy. This may occur with greater or lessor rapidity depending on the nature of the process, the products involved and the precautions taken.

Some effluents may not have much biodegradable material in them. In the fruit industry, for example, in the washing-process the water may be contaminated by dirt but not by much else. However, once one gets into juice extraction or slicing of the fruit any effluent arising will contain high carbohydrates, sugars and be highly prone to acidic fermentation. Similarly in vegetable processing the washing of root crops can be associated with dirt in the wash waters which tends to limit the ability to recycle. The slicing of potatoes for chips or vegetables for canning can release starches and carbohydrates which again can ferment although not in as a highly acidic way as with the fruit.

Breweries are also associated with high carbohydrate wastes with the presence of sugars, alcohols and acids.

The meat and poultry processing industries and abattoirs are associated with the generation of blood, wash waters containing blood and proteinaceous matter and in certain parts of red meat abattoirs highly contaminated streams containing paunch contents or was down from the lairages can occur.

The dairy industry is characterised by wastes which are readily spoilable and contamination by micororganisms needs to be avoided at all costs.

One of the challenges facing the food industry is therefore to conserve water and reuse it where applicable without contaminating the production process. In recycling the time cycle should be sufficiently short so that the effluent leaves the system before it has had time to degrade. Alternatives to this would be disinfecting the recycle stream to prevent the growth of organisms or treating the recycle stream completely to the stage where the water is perhaps fit for general reuse.

One of the general problems with the handling of food effluents is that treatment plants need to be sized and planned in such a way that faulty batches of material can be disposed of successfully without overloading any of the handling systems or treatment plants.

CHEMICAL IMPURITIES

Chemical impurities may be inorganic or organic and may enter effluents and water used in the food processing industry in a number of ways. Contamination can arise from processing of the products themselves. An example would be where dilute streams of sugar or fruit juice may be washed out of process vessels. The water would then contain biodegradable organic impurities. There are also processes where inorganics such as salt may be added to the product as preservatives. In the overall processes of the factory there may be cooling systems, boiler treatment systems, deionising or water softening systems which generate inorganic waste products through chemicals used for regeneration and these would contaminate the effluent unless the streams were segregated.

As mentioned previously food industries tend to produce effluents which have a relatively high organic load which is sometimes difficult to treat because of nutrient balance or other reasons. This load is largely biological and reuse relies on treatment processes being adapted to the type of effluent being generated. Some streams at dairies and abattoirs have a high oxygen demand but complete degradation is relatively slow. In general however non biodegradability is not a problem.

BACTERIOLOGICAL IMPURITIES

As food processing wastes tend to be biologically degradable they behave as a good substrate for the growth of organisms. Apart from the anaerobic and aerobic organisms which spontaneously establish and develop in such effluents these could also include pathogens. These would be included in the total organisms count and there could also be coliforms, E. coli, faecal streptococci or staphylococci or Legionella. Organisms can also develop which can disrupt the process such as wild yeasts or other organisms which will cause the product to ferment or spoil. Recycling or reuse carries the risk of re-inoculation through a closed loop and active steps need to be taken to prevent such contamination.

METHODS OF TREATMENT

There are a number of methods of treatment available, these being biological or physico chemical. Amongst the physico chemical processes used for higher grade reclamation and reuse, activated carbon or membrane processes are frequently employed.

Biological treatment

It has been mentioned previously that food processing wastes tend to be highly biodegradable. What is foodstuff for man or animals is also food for microorganisms so that constituents present in food by their very nature degrade readily. If one is treating water for reuse one would therefore need to eithr prevent biodegradation or allow it to carry out effectively to completion under controlled conditions so that the water from the treatment process was then essentially stable. Measurement of effluent strength is generally done in terms of chemical oxygen demand (COD) or biochemcial oxygen demand (BOD) which is the measurement of the amount of oxygen required to fully treat the effluent. With individual organic compounds one can calculate by stoichiometry how much oxygen would break it down into final products of carbon dioxide, water etc and this would produce an oxygen demand. In practice it is not possible unless one knows the complete chemical makeup of a stream to calculate a chemical oxygen demand and it is therefore measured chemcially in a laboratory. The sizing of the biological process would be such as to supply sufficient oxygen under optimum conditions of residence time and food/microorganisms ratios to breakdown the biological load and render the water essentially stable so that it could be further treated for reuse.

In general preventing biological breakdown may be difficult unless compounds or methods can be found which inhibit degradation without upsetting the main process. However there are applications where through temperature or residence time one can safely practice this.

It should be noted that although biological treatment is an important step in the reuse process it would not generally stand alone. Other processes such as clarification, filtration, activated carbon or membrane processes may be required with some form of disinfection to achieve the standards required. All of this costs money and it would normally require a careful financial analysis before committing to a full reclamation process. In general it would probably be found to be cheaper to use the municipal supply although this may be overridden by shortage or special quality requirements.

Physico-chemical Treatment

Depending on the application for reuse it could be possible in certain circumstances to use physico-chemical treatment. This would encompass settling out matter which is suspended in the water followed by filtration to remove finally divided particles. These processes can be carried out with the addition of coagulating chemicals such as aluminium sulphate or a synthetic coagulant to flocculate, settle and remove solids thereby assisting the separation process and rendering it suitable for secondary treatment processes. In many cases solids removal is sufficient for limited reuse.

Activated Carbon

Depending on the requirement for reuse if a high grade reuse is required it may be necessary to use activated carbon to remove trace organics from the water. Activated carbon contacting is a relatively expensive process and if the water is highly contaminated the carbon quickly becomes saturated and requires regeneration. Because of this its use is normally only practiced on water which is relatively pure and has a low demand for the carbon adsorbent.

Membrane Processes

In recent years membrane processes have become more economically competitive. Their use is practised if the food industry for concentrating juices and generally they are economically viable were the value of the product is high. However with reducing operating pressures and development of superior membranes the situation is becoming more common where a membrane process such as ultra filtration, hyper filtration or even reverse osmosis can be justified in a recycle system or reuse process in a particular factory. It should be born in mind however that a membrane process merely concentrates the contaminants and does not remove them so that one produces a purified stream which can be reused in the factory and a concentrated stream which maybe a brine stream or an organically enriched stream which requires further treatment or disposal.

6. DISCUSSION

In assessing the risks in the reuse of water in the food industry one should bear in mind the major characteristics which have been discussed briefly in this paper. By their very nature food effluents biodegrade readily. If one is looking at a recycle stream one should bear this in mind. A large tank with a recycle pump pumping recycled water round and round continuously without makeup could lead to a situation where the long residence time allows growths of fungi, slimes or other organic problems which may cause blockages and possible contamination of the main process. Any recycle stream should therefore operated in such a way as to reduce the retention in the system to a stage where biological breakdown does not become a problem. The second principle which should be applied is the one of moving from clean to used in a preliminary washing process for fruits and vegetables provided the residence time is not too long. This implies a regular makeup and discharge bearing in mind the problems mentioned in the previous section on excessive residence times causing contamination. Possibly some sort of disinfection for prevention of biological growth.

In general unless one uses a membrane process which at this stage is still relatively expensive, the principle is that one cannot practically increase concentrations unless the product is significant. Thus is one has a dilute pure sugar stream one could perhaps by a membrane process concentrate this up to a useable level. However in general once water has been used to wash or clean something down the product becomes unusable and is lost to the process. This implies that where applicable dry methods should be used when operating a process.

Another practice to be considered is containing spillages rather than washing them down the drain. Once food hits the floor it can not be used. This is an obvious comment but one has had personal experience of a number of factories where belts running misaligned cause dropping of materials to the floor which are then lost and represent perhaps a significant loss in efficiency. Care and attention to such detail and the positioning of catch trays can save product which can then be used rather than be diluted and put down to an effluent drain. Bear in mind that breakdown of the organics in a biological treatment process represents loss of product and a cost to treat it and the value of the water may not warrant the cost of the removal of the organic load.

CONCLUSIONS

The company employing the writer has recently put in a bid to operate a reclamation plant in Namibia. The plant has a cost of approximately 100 million Rands and employs sophisticated treatment processes for the reclamation and reuse of wastewater effluent. The process consists of flocculation, settling, filtration, granular activated carbon beds, membrane treatment and disinfection using ozone in two stages as well as final chlorination. This is not untypical of the complexity of the process one needs for complete reuse although in this case the situation is complicated by the fact that faecal contamination is present. Because of this another principle which obviously needs to be applied is segregation of treatment streams to avoid this possibility in food factories. Reuse of wastewater whatever the source is possible if one throws enough money at it but it generally becomes uneconomic when serious contamination has occurred unless no other water source is available.

Other speakers will talk about closed loop segregation of effluent streams and breaking the process down into manageable sections and perhaps this is the best approach to start with.

In general it does no make sense economically and practically to collect all the effluent from a particular factory and treat the water back to potable standard. Treatment of effluents is better done by a municipality that can get economies of scale and dilution of effluents with specific problems.

WATER PINCH ANALYSIS: A STRATEGIC TOOL FOR WATER MANAGEMENT IN THE FOOD PROCESSING INDUSTRY

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Summary

Water pinch analysis can be used to guide water and effluent management decisions while at the same time improving the efficiency of processes. It can be used for the initial design of the process, or as a tool to guide process modifications due to changing circumstances (financial, process or environmental). The procedure enables the minimum amount of water to be determined by considering the introduction of recycle loops and reuse cascades. It then highlights the operations that should be investigated for the improvement of their internal efficiencies of water management.

Keywords

Waste minimisation, water pinch

INTRODUCTION

The drive in industry is towards environmentally sustainability. To achieve this it is necessary to reduce the environmental impact per unit of money spent by a factor of 10. A reduction in environmental impact of factor 4 is considered achievable using current technology. The balance of the reduction will have to be achieved by changing the attitudes and habits of the population and rethinking the provision of goods and services (Jackson, 1996). Cleaner production is the approach used to achieve this objective. For current processes, the hierarchy of pollution prevention measures is: replace, reduce, recover, reuse, recycle and finally, treat. This approach must be used whenever any waste minimisation options are being contemplated.

Prior to developing or modifying configurations, it is necessary to consider the interactions between the three main factors of a reuse/recycle system, ie effluent source, treatment process and reuse process. Water pinch (Wang and Smith, 1994, 1995a, b; Olleson and Polley, 1997), is a convenient tool for the rational analysis of a water network in order to identify bottlenecks, and where recycle/reuse loops should be located. In simple terms, the current water and effluent network should be analysed to determine if the optimal flow configuration is being used. For sufficiently simple systems, a graphical approach can be used, in which the pinch diagram is a plot of stream concentration as a function of mass flow. The pinch diagram is constructed by considering the process requirements or constraints, and not the current effluent flows and qualities. If the optimal network is not being used, then simple measures such as effluent rerouting, cascading and recycling (without any treatment) should be considered. The pinch analysis will also lead to the identification of the pinc*h point*, is the bottleneck in the effluent/water network, and which sets the minimum water requirements for the network of processed. The pinch point might correspond to the quality of the inlet water, the outlet water (final effluent) or some intermediate quality. Once an optimal arrangement has been achieved with existing processes, it will be necessary to modify the processes for any further reduction in the water requirements, so that they are able to use or produce streams of different qualities. Alternatively, additional cleanup processes must be introduced, to modify the quality of the streams so that they will be acceptable to the current processes. The pinch analysis will also reveal the process streams that should be modified (treated). A consequence of the analysis is that streams on either side of the pinch should not be treated and reuse on the same side of the pinch point. Streams should be treated and reused across the pinch point. This emphasises the importance of segregating streams and treating them to a particular reuse standard. Such systematic analysis will also avoid treating too great a flow, or treating a stream to an excessively high standard.

A further consideration, prior to a detailed investigation into reuse/recycling, is to ensure that a total cost accounting procedure is used to evaluate the costs associated with all effluent streams. It stands to reason that if the accounting procedures are not true and accurate, then the decisions made using financial considerations will also not be true and accurate. For example, if a very inexpensive chemical such as sodium chloride is used as an ion exchange regenerant, the motivation for recovering and reusing it is very low. It is only when it is noted that, for instance, a downstream vessel is suffering from chloride induced stress corrosion, due in part to the chloride load from the ion exchange plant, that the true benefits of reducing sodium chloride consumption become evident. When the savings that accrue due to reduced stress corrosion are offset by the costs associated with the reduction of sodium chloride use, by using nanofiltration for example, then the true financial picture emerges.

WATERPINCH

There are four general approaches to water minimisation.

Process changes
Replacing the technology employed in a process can reduce the inherent demand for water. Examples might be replacing a wet cooling system with air coolers or increasing the number of stages in a washing operation. Sometimes it is possible to reduce water demand by changing the way existing equipment is operated, rather than replacing or modifying it.

2) Water re-use
Wastewater from one operation can be directly used in another operation, provided the level of contamination from the previous process does not interfere with the subsequent process. This will reduce overall fresh water and wastewater volumes, but not affect contaminant loads in the overall effluent from the system.

Generally, re-use excludes returning, either directly or indirectly, to operations through which it has already passed, in order to avoid build-up of minor contaminants which have not been considered in the analysis.

3) Regenaration re-use
Partial treatment of wastewater can remove contaminants which would otherwise prevent reuse. The regeneration process might be filtration, stream-stripping, carbon adsorption or other such processes. In this case both volumes and contaminant loads will be reduced.

4) Regeneration recycling

Recycling refers to the situation where water is re-used in an operation through which it has already passed. In this case, the regeneration step must be capable of removing al contaminants which build up in the system.

Targeting minimum water

The water pinch analysis methodology provides a systematic way of applying the above basic techniques to achieve the minimum use of water in a particular system of operations. It should be noted that pinch analysis is only useful for a system of several such operations, it cannot be applied to a single operation.

In principle, the analysis starts from consideration of the water requirements, in terms of quantity and quality, of each process in the system, and these have to be established beforehand. Quality is represented by the concentration of critical contaminants, and the effect of each process on the water it uses is represented by the load of contaminant that is transferred to the water that passes through it. The concept is more easily understood in the context of the design of a new system; using it to reduce water consumption of an existing system brings in some additional considerations.

New System design

Limits on the contaminant levels for each process, together with contaminant loads introduced by each process would be established by the designer. From this data, a composite water demand curve can be plotted on concentration/contaminant–load axes (Wang and Smith, 1994), which allows determination of the minimum fresh water supply which is able to satisfy all the process requirements, using *water re-use only*. This minimum water requirement is called the *target*, and the critical process concentration limit which prevents any further reduction of the target is called the *pinch-point*.

Once the pinch point and the target supply have been determined, it is relatively straightforward to design a water re-use cascade which will achieve the target. The resulting network of flows between the operations can then be evaluated in terms of cost, practicability and operability and trade-offs established between water use and other such engineering criteria.

Only at this stage will the use of regeneration processes be considered, and their only justification in the overall scheme will be to *overcome the limitation imposed by the pinch point*, so as to further the water supply target. Thus it can be demonstrated that to offer any benefit to the system, a regeneration process must take water of a quality worse than the pinch concentration, and regenerate it to a quality better than the pinch concentration. This is referred to as *appropriate placement* of the regeneration process.

Modification of an existing system

Somewhat different considerations apply when using water pinch analysis to improve water use in an existing system.

The first is that flow and concentration data for the various operations will be available as measurements from the existing system rather than design specifications. These will have the advantage of being proven in practice, but the disadvantage that, as they probably come from a non-optimal system, they do not represent genuine limits for the processes. If they are treated as such, it may well happen that the pinch analysis will not be able to come up with significant water savings.

Secondly, unlike the new design which starts from a clean slate, any changes towards a more efficient configuration are likely to incur costs, so it is advantageous to retain as much of the existing equipment and pipework as possible.

Hence, the approach that is usually adopted involves imposing process constraints that reflect the current operation of the system, and determining the re-use network which will achieve minimum water use within those constraints. One of these constraints will constitute a *psuedo-pinch*, and, since this constitutes the chief obstacle to achieving lower water use, it will be subject to closer investigation to determine whether it can be relaxed. If is can, the relaxed limit is substituted and the pinch point will probably move to another part of the system, whereupon the process is repeated.

In this way the retro-fit design evolves from the prior configuration of the system along a path which only has to consider the most critical parts of the system. It is probable that this evolution will stop short of achieving the minimum target for the system, at some point where the additional water and effluent savings no longer justify the additional expense of modifications.

Regeneration processes, once again, are not considered until all practicable re-use opportunities have been exhausted, and are only considered with appropriate placement in mind. The same ideas apply to replacing existing equipment: if this is to be justified purely in terms of reducing water consumption, then only equipment which affects the position of the pinch point should be considered.

It should be mentioned that, in a non-optimal system, introducting an inappropriately placed regeneration process, or replacing some water-inefficient equipment may result in overall water savings, however these savings will have been achievable by simple re-use.

THE FOOD INDUSTRY

As may be seen from the above discussion, water pinch analysis is a very general methodology, and it should be applicable to any industry. Adaption to any particular system chiefly involves dealing with the water quality and quantity limitations for the operations involved. The experience of the authors has been in the chemical industry, and we have no specific understanding of the particular considerations that must be taken into account in food processing. Clearly there will be operation where avoiding contamination is of particular concern. It may be that, for such processes, it would be better to work with risks of contamination in the place of contaminant concentrations, or it may be that such high risk processes should be completely excluded from the analysis, which will then deal only with more peripheral water-using processes.

There has been a proposal to prepare an ILSI monograph, in collaboration with the

Water Research Commission, on the application of water pinch analysis in the food industry. The suggested program will investigate two plants to establish a protocol for undertaking such investigations. Once the protocol has been prepared, it would then be based on the experiences drawn from all these investigations. This plan will rely heavily on input from the food industry players.

CASE STUDY

With no food industry cases that we can report, the following case study is taken from the agrochemical industry. It was chosen to illustrate that water pinch analysis can be applied to batch processes as well as to continuous processes.

Sanachem is a South African subsidiary of Dow Chemicals, manufacturing insecticides and herbicides. Its Kwazulu-Natal factory is situated about 30km north of Durban. Toxic effluent arises from water used in the production of mono-sodium methyl arsenate (MSMA), alachlor and bromoxynil octanoate. These products are manufactured in batch processes, which typically involve a sequence of several stages in different reactors. The water is used either as a solvent of for product washing. Disposing of these toxic effluents is a major problem, as there is no suitable landfill site in Kwazulu-Natal, and it has to be transported at considerable expense some 800mk to Port Elizabeth. Waste-minimisation to reduce the amount of toxic effluent is consequently a topic of considerable interest.

The illustrative example presented here is based on part of the operation at Sanachem, however certain aspects have been simplified for greater clarity of presentation, as well as for commercial confidentiality. We considered the production of an agrochemical which contains three organic components, identified as A, B and C, which are synthesised in batch reactors. All three reactions form NaCl as a by-product, which has to be separated from the main products. In the case of A, the reaction takes place in an organic solvent, so that water is required purely for washing out the salt. For B and C, however, a portion of the required water is used as the reaction solvent, and further quantity is used for washing the product. While investigation this secondary washing of B and C, it was found that the salt load removed from the products was essentially zero, as a result of the extreme immiscibility of the organic and aqueous phases. However, it was considered that the washing step could not be discarded, as it constituted a quality control precaution in case of process glitches. The timing of the reaction and washing sequenced was considered to be fixed by the product requirements: that is, there was no freedom to change the sequence to optimise the use of water.

The term targeting refers to the procedure of determining the minimum possible values of fresh water and effluent for the system as a whole. Wang and Smith (1995b) presented a graphical targeting method. This procedure consists of dividing the problem into concentration intervals and time intervals, with boundaries set by the endpoints of the individual processes, and grouping together the streams that are required or availabel for reuse in each subinterval. Water which is available is reused, where possible, in its own subinterval. Any surplus can be reused in higher concentration intervals in the same time interval, or stored for reuse in a later time interval; but cannot be used in lower concentration intervals, or for previous times. Any shortfall can be made up from lower concentration intervals, either from the same or previous time intervals, or from fresh water. The eventual surplus becomes the system effluent, and the accumulated fresh water make up constitutes the system intake. This procedure identifies what storage must be provided to achieve the minimum targets; provision of storage can be traded off against water use and effluent production.

The solution to the problem had two relevant aspects. For the first operational sequence no effluent is available for re-use and consequently fresh water must be supplied for the early processes in the sequence, irrespective of concentration considerations. For subsequent cycles, it is possible to use effluent from previous cycles if provision is made for storage. Figures 1 and 2 illustrate corresponding water use networks for these two cases.

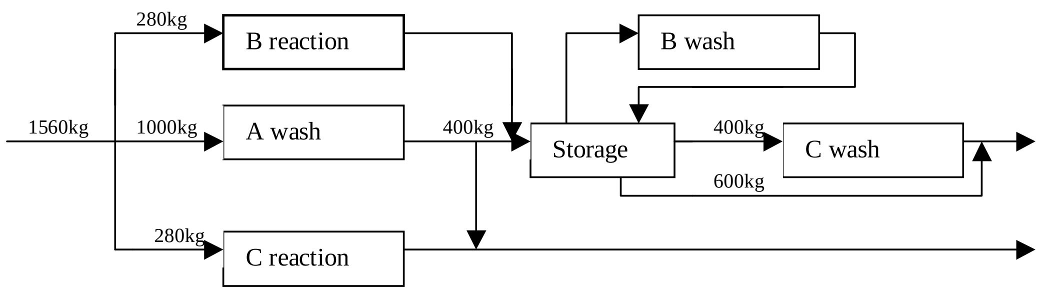

Figure 1: Case study – water use network for first production cycle

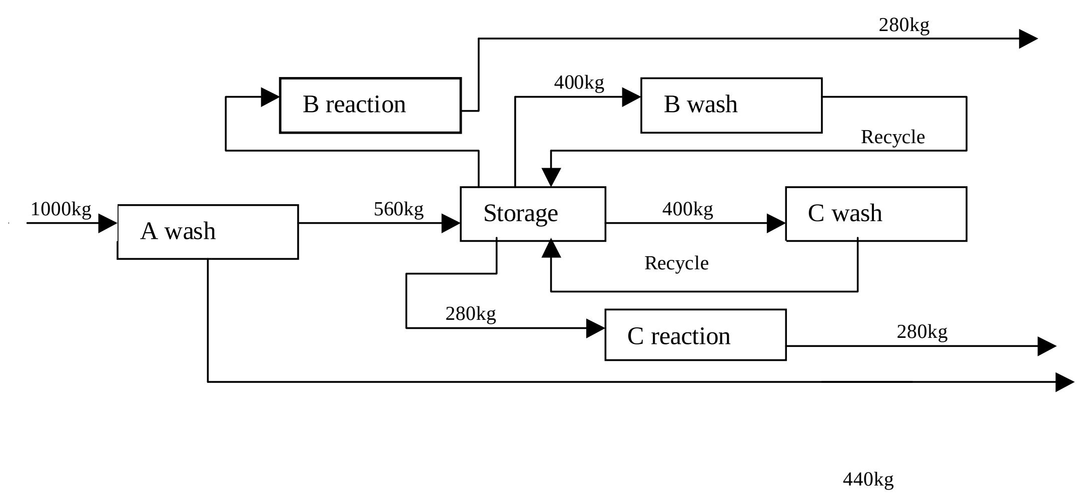

Figure 2: Case study – water use network for subsequent cycles

During the course of these investigations, an overall reduction of 96kl per month of toxic effluent, 216kl of non toxic effluent and an increase of 25% in production capacity (due to reduced batch times) were achieved as a result of the pinch analysis, together with other waste minimisation measures.

CONCLUSIONS

Water recycling and reuse are becoming increasingly important. Cleaner production and sustainability will become the criteria by which designs are judged. Pinch analysis is a tool which provides a logical and systematic framework for determining the best allocation of resources in a process, or system of processes. Thermal pinch analysis has already evolved into a mature and powerful methodology for dealing with energy resources; water pinch analysis is a relatively new field, and is evolving rapidly. Although it presents itself as an engineering design tool, it may also prove valuable as a regulatory tool, particularly in a co-regulatory context, by providing an objective determination of the water requirements of a process. Clearly, the fundamental approach must be applicable to resources other than energy and water, which suggests a fertile field for future development.

At this time there is no practical experience of the application of water pinch analysis in the South African food industry. The proposed ILSI monograph represents an attempt to address this lack, and the authors would like to invite industrial partners to participate in the project.

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