DOMESTIC WATER CONSERVATION TECHNOLOGY IN ARID REGIONS

Muhammad Z. A. Khan

Assistant Professor, Civil Engineering Department, King Abdulaziz University P.O. Box No. 9027, Jeddah 21413, Saudi Arabia

and

Mohamed J. Abdulrazzak*

Assistant Professor and Vice Dean, Higher Studies and Academic Research, Faculty of Meteorology, Environment, and Arid Land Agriculture, King Abdulaziz University, P.O. Box 9034, Jeddah 21413, Saudi Arabia.

الخلاصة :

إن المحافظة والترشيد في إستعمال المياه في المناطق ذات الطقس الجاف سوف يتيح الفرصة للإستفادة المثلى من المياه المتوفرة وذلك من خلال التقليل من المياه المفقودة والحد من كمية الطلب على المياه اللازمة والمياه الصحية وتكلفة معالجتها بالإضافة إلى موارد الطاقة .

والهدف من هذا البحث هو إجراء دراسة تفصيلية لطرق المحافظة وضوابط الترشيد المتبعة في الدول المتقدمة والنامية وإستراتيجيات المتابعة ومناقشة ملاءمتها لظروف المملكة وتطبيقها للحد من الزيادة في إستعمال المياه في المستقبل وسوف يتطرق البحث إلى دراسة لوسائل المحافظة وضوابط ترشيد إستعمال المياه التالية ، إستعمال الأجهزة والمعدات التي تساعد على التقليل من إستهلاك المياه ، الطرق الإقتصادية التي تربط سعر الماء بكمية المياه المستهلكة ، طرق توزيع المياه على فترات متقطعة في المدن والتنبيه بالنسبة لأفراد المجتمع من ناحية أهمية المياه ومشاكل توفرها في المستقبل وخصوصاً في المناطق الجافة ، تطبيق نظام السباكة الحديثة وصيانتها بصفة دورية في المباني ، تطبيق نظام العقوبات المالية على المتسببين في تسرب المياه ، تطبيق الأنظمة التي تحدد مناطق تسرب المياه في شبكات توزيع المياه ، الإستفادة من النباتات الصحراوية والنباتات ذات الإحتياجات المائية القليلة في تزيين الحدائق ، تطبيق نظام المبرات الإقتصادية والإدارية التي تشجع على الحد من إستهلاك المياه في المدينة .

وقد ناقش هذا البحث ملاءمة طرق المحافظة المختلفة الآنفة الذكر بالإضافة إلى التوفيرات المالية من جراء تطبيقها للوضع الحالي المملكة العربية السعودية .

*Address for correspondence.

0377-9211/86/040405-12$06.00
© 1986 by the University of Petroleum and Minerals

ABSTRACT

Water conservation in arid climates can result in efficient utilization of existing water supplies. Conservation techniques reduce water loss, help curb demand, and reduce wastewater volume as well as the associated treatment costs, and can help reduce energy consumption. A comprehensive review and discussion of the methods, strategies, and experiences utilized in developed, as well as developing, countries for achieving conservation goals are presented. The impact of such conservation measures as: the installation of water saving devices; water metering and pricing schemes; water rationing and public awareness programs; strict plumbing codes; penalties for wasting water; programs designed to reduce leakage from public water lines and within the home; water efficient landscaping; and economic and ethical incentives, are addressed in detail. Cost savings, with particular reference to Saudi Arabia, in relation to some conservation techniques, will be presented.

DOMESTIC WATER CONSERVATION TECHNOLOGY IN ARID REGIONS

INTRODUCTION

The water resources of arid and semi-arid regions of the world are usually a major limiting factor in the development of sound economic and social structures. These regions may be faced with serious water shortages due to increases in population, expansion of industry and irrigated agriculture, contamination of coastal aquifers by salt water intrusion, pollution of surface groundwater resources, uncontrolled extraction and depletion of groundwater reserves, and high evaporation.

The benefits of water conservation are many and varied. Some of the most important are: protection of the already limited existing supply; replenishment of depleted aquifers through reduction in the amount of pumpage; reduced costs to the consumer; extension of the life of water treatment and distribution facilities; and storage.

The need for water conservation practices, programs, and management is most essential for arid regions due to the scarcity of water resources and the increase in water consumption as a result of improved standard of living, and the increasing costs of water and wastewater treatment. Water conservation programs are normally being carried out in the water-rich and developed regions of the world in order to meet long-range water requirements. Even though water availability has a major impact on the development programs of arid regions, little effort is being directed towards implementation of water conservation programs.

To highlight the various conservation practices that would be of major benefit to arid regions of the world, and to Saudi Arabia in particular, this research will address three main objectives: to carry out a comprehensive literature review of the presently available practical and feasible conservation practices for domestic use, to select a water conservation technology specifically suitable for Saudi Arabia, and to suggest a tentative demonstration and implementation conservation program.

LITERATURE REVIEW

Water conservation measures for domestic purposes reviewed in this section are primarily consumer and utility oriented. However, the main focus of conservation efforts in arid as well as non-arid regions has been on household water use. Although household use comprises only 5–20% of the total water use, in comparison to 70–90% for agricultural use, it is important to focus on this aspect because the costs involved in supplying water to households are much higher than for irrigation water supply. Industry is responsible for 1–5% of the total water use. Water used in the home is consumed in two major areas: toilets and showers, and comprises 60–70% of the total (Table 1). Other important areas of water use include washing machines and dish washers.

Installation of water saving devices [3–6, 9] such as low volume flush toilets, reduced pressure shower heads and air assisted showers, front-loading clothes washers, and faucet aerators (Table 2) have resulted in 20–70% water use reduction and substantial economic savings in residential and municipal buildings. Another method of water use education is water system auditing. Leaky plumbing fixtures such as dripping faucets, leaky toilets and showers, can result in a water loss of 20–30% of the total daily water use in a home [2, 21, 22]. Water loss through leaks in the main water supply system can range from 12–50% [18]. Such losses can be monitored and prevented through water system auditing to detect leaks in the main water supply system, master meter testing, system inventory, and quantification.

A variety of public conservation programs have been employed. Among these are: water metering, price increases according to use, rationing, pressure reduction [24, 25], education and awareness campaigns [8, 25], penalties for wasting water, and water conservation incentives. Such public programs have resulted in substantial reduction in water use. In addition, the use of drought resistant and low water requirement plants, shrubs, and vines [20] in home landscaping can result in substantial water savings, without loss of any greenery or shade.

Several procedures, approaches and design manuals [10–12, 14, 16, 17] based upon the drought conditions in South Africa, California, Colorado and other places were developed for utilization and in meeting similar emergency conditions. Some socio-economic and water conservation models [4, 6, 10, 15, 17, 19] for studying the impact and effectiveness of water conservation devices and measures, were developed in

Table 1. Distribution of Household Water Usage (Without Lawns)

Usage	Average [29]	Reference [5]	** Saudi Arabia [30, 33]	Reference [7]	England [34]	Reference [31]	Reference [32]
	L/P/D (%)	L/P/D (%)	L/P/D (%)	L/P/D (%)	L/P/D (%)	L/P/D (%)	L/P/D (%)
Toilet	55.5 (34.1)	34.8 (21.6)	74.8 (48)	9.5 (40)	35 (27)	95 (39)	65 (31)
Bath/shower	39.9 (24.5)	18.6 (11.5)	32.1 (21)	75.6 (30)	25 (19)	76 (32)	24 (12)
Lavatory/sink	19.6 (12.0)	37.9* (23.5)	7.9 (5)	11.3 (5)	40 (31)	37 (15)	63 (30)
Laundry	37.7 (23.2)	39.8 (24.7)	27.9 (18)	37.8 (15)	25 (19)	34 (14)	40 (19)
Dishwashing	—	—	13.6 (8)	11.3 (5)	—	—	5 (2)
Miscellaneous	10.1 (6.2)	30.3 (18.8)	—	11.3 (5)	5 (4)	—	13 (6)
Total	162.8 (100.0)	161.4 (100)	156.3 (100)	156.8 (100)	130 (100)	242 (100)	210 (100)

L/P/D = Liters/person/day
G/P/D = Gallons/person/day; (1 gallon = 3.78 liters)
* = Includes dishwashing
** = Local data (more data are being collected in Jeddah in a separate study).
(%) = Percentages of the total water use.

Table 2. Summary of Consumer Oriented Domestic Water Conservation Practices [18].

Water conservation method	Conventional water use	% water use reduction	Example units	Relative cost	Effectiveness
Toilet	19 L/use	10–90	Biphonic, air assisted, foam assisted toilet drums [24]	Low to medium	Effective when used properly
Shower	19 L/use	7–80	Flow limiting, air assisted [23, 24]	Low	Limited to new construction or replacement of worn fixtures
Washer (clothes)	140 L/use	20–25	Wash recyle, front loading [23]	High	Limited by cost & public acceptability & local ordinances
Sink	12 L/min	30–50	Low-flow faucets, Aerated, [23, 24]	Medium	Limited to new construction or replacement of new fixtures
Washwater recycle	—	up to 40	—	High	Limited by cost & public acceptability
Pressure reducing valves	—	10–30	–	Medium	Applicable in areas having pressure exceeding 80 p.s.i.
Elimination of garbage disposal	—	1–2	—	Low	Minor reduction in water use
Public education and awareness	—	Little direct reduction	—	Medium	Effective in conjunction with other measures

studying the local conditions. Factors such as the average price paid by the user per 1000 gallons of water used, number of family members residing in the household, number of bathrooms in the household, household knowledge of water-saving devices, total household income and water-intensive appliances or activities taking place in the home, are used in these models to project the water use as well as the effectiveness of the water conservation measures.

WATER RESOURCES OF SAUDI ARABIA

The water resources of the country [27, 33, 37] consist mainly of annual surface runoff estimated at 2400 million cubic meters; groundwater in the shallow alluvial aquifers is estimated to be 500 000 million cubic meters and water from desalination is estimated at 1314 million cubic meters. The available water is expected to serve a population of 7.46 million projected for the year 1990 and a population of 10.72 million in the year 2000, as well as meeting agricultural and industrial water requirements. The projected water needs for various purposes, up to the year 2000 (1420H) are presented in Table 3.

Table 3. Total Projected Water Needs in Saudi Arabia up to Year 2000 [36]

Category	Demand		% of the total
	Mm^3/year	$10^3 \times m^3$/day	
Urban	2000	5479	12.5
Agriculture	13 500	36 986	84.4
Industry and other	500	1369	3.1
Sub-total	16 000	43 834	100.0
Urban re-use	750	2000	4.7
Net demand	15 250	41 834	

To meet the future requirements for various sectors, estimated at 15 250 million m^3/year, it is expected that it will be necessary to rely heavily on the exploitation of groundwater. Although conflicting values of the annual recharge to the shallow and deep aquifers have

Table 4. Future Domestic Water Demand in Saudi Arabia [28]. (After MAW, 1985).

	Year 1990				Year 2000			
	Persons in thousands	Liter per person per day	Per day in 1000 cubic meters	Per year in million cubic meters	Persons in thousands	Liter per person per day	Per day in 1000 cubic meters	Per year in million cubic meters
Riydh	1700	360	619	225	2420	410	992	362
Jeddah	1500	380	570	207	2100	430	903	329
Makkah	960	330	317	115	1350	370	500	182
Madinah	500	310	155	57	750	350	262	96
Taif	540	300	162	60	810	320	360	95
Dammam	530	380	201	74	800	430	344	125
Hail	95	300	29	10	144	320	46	17
Buraydah	177	305	54	20	264	325	86	32
Unayzah	67	305	21	8	107	325	35	13
Abha–Khamis Mushayt	195	300	59	22	290	320	93	34
Tabuk	126	310	39	14	176	350	62	23
Jauf	39	300	12	4	69	320	22	8
Qurayyat	22	300	7	3	37	320	12	5
Hufuf	396	305	121	44	592	325	192	70
Jizan	82	310	25	9	120	350	42	15
Qatif	233	310	72	26	269	350	94	34
Jubail	203	350	71	26	272	410	112	41
Yanbu	102	350	36	13	150	410	62	22
Totals	7467	*322 (345)	2570	939	10 720	*358 (391)	4219	1503

* Average water use.

( ) The average of cities of Riyadh, Jeddah, Makkah, Madinah, Taif, Dammam, Jubail, Yanbu.

been reported [27, 33, 36], it can be approximated as 2000 million m^3/year. Consequently, the net annual deficit is approximately 13 250 million cubic meters, resulting in the existing water reserves lasting for approximately 33 years at the year 2000 level of demand.

Even though future urban water demand constitutes only a small portion of the water requirement, conservation efforts can result in a decrease in the rate of domestic water consumption and substantial monetary savings. The saving in cost is attributed to the costs associated with distribution and treatment facilities.

The annual estimated future water demand for domestic purposes in the major cities of the Kingdom for the year 1990 and 2000 is presented in Table 4. It appears that if the present usage patterns, attitudes, policies and regulations are continued, the annual domestic water requirement will rise from 939 million cubic meters in the year 1990 to 1503 million cubic meters in the year 2000. The average per capita use will be 322 liters, for 1990, while the average per capita use in the year 200 will be 358 liters (Table 4).

Table 5 gives a general idea of water use in different sectors of a community. This helps to identify major areas of consumption and areas of potential savings.

Table 5. Water Use for Various Purposes [34]

Usage	Rate
Domestic	300 liters/person/day
Schools	30 liters/child/day
Hospitals (outpatient)	2 liters/patient/day
Offices	30–60 liters/person/day
Swimming pool	24 liters/person/day

CONSERVATION IN DOMESTIC PER CAPITA USE BY THE YEAR 2000 IN SAUDI ARABIA

Based upon the conservation efforts, as reported in the literature and discussed previously, the projected water consumption of around 400 liters/person/day in the year 2000 for the major cities in the Kingdom can be reduced by one half to one third by applying the various conservation methodologies. The effect of different water conservation efforts are presented in Table 6. The analysis shows that with reasonable conservation techniques, some leakage reduction and public awareness programs, water use can be reduced to approximately 195 liters/person/day. In addition, by implementing major conservation and water recycling programs, the daily water consumption can be reduced even further to 150 liters/person/day. A reasonable figure of 200 liter/person/day can be assumed for the 1990 daily domestic water use calculations. The impact of water-saving devices in terms of reduced water consumption and lower wastewater generation, as well as the associated annual cost savings, are presented in the following sections.

Table 6. Expected Effect of Water Conservation Efforts on Domestic Water Use in Saudi Arabia

Number	Water conservation efforts	Percentage reduction, based upon literature	*Adjusted water use (L/P/D) based upon single effort	Combined effect of different conservation efforts (L/P/D). 1+2	1+2+3	1+2+3+4
1.	Water saving devices and low pressure in water mains	30	210			
2.	Public education: water and use awareness	10	270	210		
3.	Excess water use penalty (pricing, meter, leakage) and reduction in plumbing fixtures	15	255		195	
4.	Reuse of gray water	10	270			150

*Assuming a present average domestic water use of 300 L/P/day.
L/P/D = Litres/Person/day

Cost of Supply and Installation of Water Saving Devices in New as well as Existing Buildings

Based upon the surveys of the supply and installation of such devices it was found that the average cost of water saving shower heads, toilets, and faucets in an average size building was about SR 2190 (US $ 600).

A local plumbing fixture supplier in Jeddah, indicated this price as SR 5100 (US$ 1400) for the same items mentioned before. This price for a water consumer is quite high. It will take several years to recover this cost, because the annual water usage charges do not exceed more than SR 200 (US$ 55). For the Water Authority, however, it is much cheaper to subsidize these devices than to explore new sources of water supply (wells, desalination, waste-water reclamation), treat the water and supply to the consumers. This system of subsidizing the installation of water saving devices for new and existing buildings is being practiced in several states, in the US, such as Arizona, Neveda, California, Texas, New Mexico.

The cost of water-saving devices in Saudi Arabia can be calculated as shown in Table 7.

Table 7

Year	Population	No. of houses* $\times 10^6$	Total cost** SR $\times 10^9$	Cost/year*** SR $\times 10^9$
1990	7.467×10^6	1.240	6.33	0.422
2000	10.720×10^6	1.78	9.09	0.606

* Average household 6.0 persons/house
** Saving devices cost SR 5110/house (US$ 1400/house)
*** Assuming useful life of 15 years.

The cost per cubic meter of water treatment and delivery in Saudi Arabia in the major cities such as Jeddah, Makkah, Taif, and Riyadh (verbal communication with the water Authorities) is about SR10–12. In the southern regions, where water is supplied by water tankers, the cost ranges from SR 5 to 140 m^{-3} [34].

Savings From Reduced Water Use and Associated Wastewater Treatment

In order to have an idea about the costs (capital as well as operation and maintenance) related to wastewater collection, transportation, pumping, treatment, and disposal facilities in the Kingdom, local contractors and the concerned authorities in the three major cities (Taif, Jeddah, and Madinah) were contacted. The cost data included about six sewage treatment facilities in Jeddah, two in Madinah, and one in Taif. The capacities of the sewage treatment facilities ranged from 500 m^3/day to 70 000 m^3/day over a useful design life of 20–30 years. A regression analysis of the capital cost (1984 year) versus facility capacity data gave the following equation with a correlation factor of 0.94.

$$Y = A \cdot (X)^B \quad (1)$$

where:

A = 0.7386, B = 1.143
Y = Capital cost (excluding the cost of collection system) of sewage treatment facility, million of Saudi Riyals
X = sewage treatment plant size in 1000 m^3/day.

Local data collected related to the operation and maintenance costs of the wastewater collection and treatment systems (sewer pipes, pumping station, and sewage treatment plant), when combined with Equation (1), gave the following Equation (2).

$$T = 0.04[A(X)^B + 14.28(p)] + 0.5(M) \quad (2)$$

where

T = Total annual cost in million Saudi Riyals over the design life(normally 20–25 years) of the facility.
A, B, X = Previously defined
p = Cost of collection system in million, SR/1000 m^3 daily flow.
M = O&M cost of sewage treatment facility in million, SR/1000 m^3 daily flow.

Using Equation (2), the total annual wastewater collection and treatment cost for a 10 000 m^3/day flow, will be about SR 11.12 million or SR 1100/m^3 flow.

The impact of water use on wastewater generation and the associated facilities will not be great in 1990, because most of the wastewater systems presently under construction are already designed for the 1990 water use. Only 0.5% reduction in the total wastewater returning to the sewerage system may result in economic benefit or savings. In the year 2000, lower water use and economical design of the wastewater systems may result in 2% flow reduction of the total wastewater returning to the sewerage system. In the year 1990, the return wastewater flow factor can be assumed as 0.7, while in the year 2000 as 0.5 (due to more green areas, etc). The wastewater flow reductions in the year 1990 and 2000 can be computed as shown in Table 8.

Table 8

Year	Water consumption (m^3/year)	Wastewater generation factor	% of total wastewater flow into the sewer	*% of flow reduction	Wastewater flow reduction (m^3/year)	**Economic savings (SR)
1990	544×10^6	0.7	30	0.5	1.085×10^6	1.193×10^9
2000	978×10^6	0.5	40	2	3.912×10^6	4.303×10^9

*Reduced water use and economical sewerage systems design.
**1100 SR/m^3.

Table 9. Estimated Annual Cost Savings Due to Conservation Measures in Saudi Arabia

Year	1990		2000	
	Without conservation (1)	With conservation (2)	Without conservation (3)	With conservation (4)
Annual water use (m^3)	939×10^6	*544×10^6	1.5×10^9	**978×10^6
Annual water reduction (m^3)	395×10^6		525×10^6	
Annual waste water reduction	1.085×10^6		3.912×10^6	
Annual saving due to water reduction	SR1.975×10^9		SR2.62×10^9	
Annual saving due to waste water reduction	SR1.193×10^9		SR4.303×10^9	
Total Annual savings	SR3.168×10^9		6.92×10^9	
Wastewater, collection treatment and disposal cost SR1100/m^3/year. Assuming water production cost SR10/m^3, but for cost savings use SR5/m^3.				

*Using a population of 7.46 million and water use of 200 L/p/day
**Using a population of 10.72 million and water use of 250 L/p/day

The annual cost savings in the year 1990 and 2000 are 3.168×10^9 and 6.92×10^9 respectively (Table 9) not including the cost (SR) of cost conservation devices and public awareness program expenses. The net cost savings, after deduction of saving devices, are shown in Table 10.

Table 10

Year	Annual cost saving (SR)	Annual water saving device cost (SR)	Net annual savings (SR)
1990	3.168×10^9	0.422×10^9	2.746×10^9
2000	6.92×10^9	0.606×10^9	6.314×10^9

Substantial costs are saved due to the use of water conservation devices and some public awareness.

POSSIBLE FACTORS AFFECTING WATER USE AND CONSERVATION PROGRAMS IN SAUDI ARABIA

Literature review has revealed that there are several conservation programs such as public education, metering, pricing, and water saving devices can be implemented to reduce domestic water consumption. The impact of such programs will be addressed below.

Public Education and Water Awareness

Public awareness is one of the most important and effective methods of water conservation and management. Effective conservation techniques cannot be implemented without the cooperation of the general public, and particularly those who are involved in the

consumption and use of large quantities of water. To achieve this purpose, all public awareness programs must have two important functions; first to educate the public about the current water situation and how important it is to conserve; and secondly to provide information and suggestions on how they, as water consumers, can help in conservation efforts.

Residential conservation programs can be implemented on the community level. Government officials or social workers could travel to communities to point out local sources of water waste, demonstrate to the people efficient water use practices, and highlight the costs involved in obtaining good water quality for various uses and how much saving would result from conservation procedures. Some of these might be installing automatic pumps to prevent water storage tank overflow or repairing of leaking or broken plumbing; etc. These officials could distribute water-saving devices or perhaps hire employees to install these devices where the homeowners lack the skills to do it themselves.

For villa owners, nurseries could be required to offer a variety of water-conserving desert plants which provide beauty and shade while using a minimum of water. Homeowners could also be educated in planning landscapes that are useful and beautiful yet water efficient.

The residents of communities involved in water conservation programs can be encouraged through reinforcement followup. For example, announcements on television could be made that a certain community has reduced its water consumption by so much by fixing leaks, using water wisely. A system of monetary rewards might be feasible for exceptional conservation practices.

Unfortunately, there is little information available about the level of public awareness or residential conservation programs for Saudi Arabia, if there are any. The Ministry of Agriculture and Water (MAW) through its water resources department has initiated a special program to bring to public attention the problem of water resources in the country and the need for conserving water. This effort was directed towards publishing a series of short books for farmers, housewives, students, and the general public, explaining the historical importance of water and different methods of saving and conserving water. Currently the Ministry is implementing a series of public awareness advertisements for television in which many of the most common residential problems are brought out, along with suggestions on how the residents can help solve these problems. The films are presently being collected and should appear on television in the near future.

The public can also be made aware through the use of newspaper advertisements, publications and pamphlets written for all levels of understanding, including books for children, as has already been done by the Ministry of Agriculture. Billboards along roadsides might be another method. Quantitative water use reduction through public education cannot be directly measured, but this is the key to the success of any conservation implementation programs. Also, such programs should be implemented over longer periods of time and should be reasserted on a regular basis.

Water Pricing, Metering, Rationing, Penalties for Wasting, Low Pressures, and Water-Saving Devices

There is a tendency towards less water use, when costs of supplying water or charges are high [34, 35]. A study carried out in Jeddah [34] for villa water users, showed the following relationship:

$$P=(4.26)(e^{-0.23Q}) \tag{3}$$

where

P = price in SR/m^3
Q = quantity in m^3/month/person

The above relationship was not applicable to apartment buildings.

Charging a fee for the amount of water used by the consumers is the most effective method for encouraging people to conserve water. There are several methods employed including flat rate, step rate, peak rate, etc. All of these are effective methods for helping people to be aware of how much water they are using and encouraging them to conserve. Water consumption in metered areas (charged according to actual water use) is almost 50% less than in the unmetered areas [31]. The water savings outweigh the revenue savings from the consumers.

Rates of water use increase with increase in pressure. This is partly due to leakage and partly due to the increased volumes of flow through fixture units per unit of time. For example, the water use rate has been known to increase by as much as 30% for every 20 pounds per square inch (psi) change in line pressure. Pressure in excess of that required for satisfactory service should be avoided where ever possible. A combined effect of water main pressure and income level (based upon data from several European cities) was expressed as follows [34].

$$U = 1.41(P) + 11.67(I) + 22.9 \text{ litre/day} \quad (4)$$

where

U = water use/person
P = average water pipe pressure in meters (head above ground level)
I = income, thousand of US dollars/person

It appears from the above equation that as the pressure and the income level increase the water use also increases. Using lower water main pressures can result in substantial cost savings and water conservation. The MAW has instituted a charge of SR 0.5/m^3 for the first 50 m^3, but this is a small cost as compared to the estimated production and delivery cost of SR 10–12/m^3.

In some cases, for undue wastage of water (in Makkah), a fine of SR 100 Riyals per incident was charged to the water wasters. Higher charges for regular use and high-pressure usage situations and penalties for water wasters would result in reduced water use. Water-rationing programs such as watering every third day for lawns and gardens during the hot summer months will also help reduce water consumption and encourage conservation.

Installations of water-saving devices can result in as much as 50–70% water savings. Water-saving devices should be distributed to homeowners free of charge or at minimal cost along with instructions and incentives to use less water. There are a number of devices designed for household water use efficiency. Toilet dams and bottles, for instance, can reduce the average amount of water used for flush from between 5 and 7 gallons to approximately 2.5 gallons. Use of a front-loading automatic washer, as opposed to a top-loading model, can reduce the amount of water used per load by as much as 40%. Water-saving shower heads, aerators, and pipe valves can also be installed.

IMPLEMENTATION OF WATER-CONSERVATION PROGRAMS AND RECOMMENDATIONS

Implementation of water-conservation programs and policies in the urban, agricultural, domestic, and industrial sectors of the community will result in extended preservation of the water resources for use over a longer period of time. Initiation of one or more of the programs (in Table 11) is essential to achieve this goal.

The impact of each of these programs, both individually and in combination with other concurrent programs, should be carefully studied in order to determine which will form the most appropriate and water-efficient conservation programs for Saudi Arabia.

CONCLUSIONS

Arid regions in general, and Saudi Arabia in particular, face potential water shortages due to increases in

Table 11. Suggested Domestic Water Conservation and Implementation Program

S.#	Conservation program	Name of agency	Time of implementation	Action
1.	Consumer education program	Ministry of Information, Ministry of Education	1–4 years	Films, pamphlets, newspapers, incentives
2.	Water leak system surveys and correction	Ministry of Agriculture and Water. (MAW), Ministry of Municipality & Rural Affairs	Continuous	Studies and surveys needed to correct systems
3.	Water-meter installation and calibration and high price structures	Ministry of Agriculture & Water	1–5	Studies and surveys needed to find feasible water use rates and to calibrate meters
4.	Building codes requiring water saving devices (new construction and existing)	Ministry of Municipality and Rural Affairs, Saudi Arabian Standards Organization	1–5	Studies, surveys and forming codes
5.	Low water use plants	All agencies	1–3	Studies and implementation
6.	Research and demonstration projects	King Abdulaziz City for Scientific Research and Technology	Continuous	Sponsor studies in Water use, conservation and implementation methods

development and improvement of living conditions. Unless drastic measures are implemented to conserve water and educate the public about the scarcity of their water resources, future demands will increase, resulting in accelerated exploitation of groundwater, expansion of desalination capacity and generation of more wastewater, resulting in contamination of the environment. In this paper, different technological solutions and policy alternatives to reduce the present and future water demands in the country have been explored, as well as the monetary savings which can result from the implementation of conservation measures. Serious efforts are needed by responsible government agencies, as well as private agencies associated with the distribution, treatment, and use of water, to adopt effective conservation programs.

ACKNOWLEDGMENT

The authors would like to express their sincere appreciation to Dr. Omar Abu Rizaiza for his support and encouragement and to the Water Resources Department of the Ministry of Agriculture and Water for the use of data and information.

REFERENCES

[1] 'The Impact of Water Saving Device Installation Programs on Resource Conservation', Pennsylvania State University; Office of Water Research and Technology, Washington, DC, 1977.

[2] 'Investigation of Performance Characteristics for Sanitary Plumbing Fixtures', *National Bureau of Standdars, Building Science Series 22.* Washington, DC: US Department of Commerce, 1970.

[3] M. D. Witt, *Water Use in Rural Homes, Small Scale Waste Management Project.* Madison: University of Wisconsin, 1974.

[4] R. L. Siegrist, 'Minimum Flow Plumbing Fixtures', *Journal of the American Water Works Association,* 1983, p. 342.

[5] R. L. Siegrist, *et al.*, 'Characteristics of Rural Household Wastewater', *Journal of the Environmental Engineering Division, American Society of Civil Engineers,* **102** (1976), p. 553.

[6] P. W. Fletcher, *et al.*, 'Water Conservation Methods to Meet Pennsylvania's Water Needs', *Journal of the American Water Works Association,* 1978, p. 201.

[7] J. E. Flack, 'Residential Water Conservation', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **107(WRI)**, (1981), p.

[8] R. F. Astrack, *et al.*, 'Managing a Public Involvement Program', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **110(2)** (1984), p.

[9] B. C. Lippiatt and S. F. Weber, 'Water Rates and Residential Water Conservation', *Journal of the American Water Works Association,* **74** (1982), p. 278.

[10] R. K. Blatchley, 'Residential Water Conservation—Discussion', *Journal of Water Resources Planning and Management Division, American Society of Civil Engineers,* **108(WR2)** (1982), p.

[11] R. A. Berk, 'Water Shortage: Lessons in Conservation from the Great California Drought, 1976–77'. Cambridge, Massachussetts: Abt Books, 1981; *Journal of the Water Pollution Control Federation,* **54** (1982), p. 220a.

[12] Task Committee on Water Conservation, American Society of Civil Engineers, 'Perspectives on Water Conservation', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **107** (1981), p. 225.

[13] American Water Works Association, *Water Conservation Management.* Denver, Colorado: American Water Works Association, 1981.

[14] W. J. Hopp and W. P. Darby, 'In-home Conservation and Wastewater Management', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **107** (1981), p. 401.

[15] B. Blackwelder and P. Carlson, 'Survey of the Water Conservation Programs in the Fifty States, Model Water Conservation Program for the Nation'. *Office of Water Research and Technology Report No. OWRT-C-10010-C(1),* 1982; *Government Reports and Announcements Index,* **83(13)** (1983), PB83-167866.

[16] J. Rubinstein, *et al.*, 'Water Conservation and Capacity Expansion', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **110(2)** (1984), p.

[17] T. M. Walski, *et al.*, 'Calculation Effectiveness of Water Conservation Measures', *Journal of the Environmental Engineering Division, American Society of Civil Engineers,* **111(2)** (1985), p.

[18] G. A. Gagnon, 'The Role of Water Audit in Water Conservation', *Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers,* **110(2)** (1984), p.

[19] R. L. Clouser, *et al.*, 'Household Water Use: Technology Shifts and Conservation Implication', *Water Resources Bulletin, American Water Resources Association,* **16(3)** (1980), p.

[20] *Drought Resistant Plants.* Tuscon, Arizona: Southern Arizona Water Resources Association, 19.

[21] S. M. Mira, 'Sources and Control of Residential Water Wastage in Jeddah City', *Senior Research Project, Civil Engineering Department, King Abdulazziz University, Jeddah,* 1980.

[22] A. Al-Mohorjy, 'Sources and Control of Residential Water Wastage in Makkah City', *Senior Research Project, Civil Engineering Department, King Abdulazziz University, Jeddah,* 1980.

[23] *Water Conservation Bulletin No. 198.* Sacramento, California: California Department of Water Resources, 1976.

[24] Energy Resources, Inc., 'Household Water Conservation and Wastewater Flow Reduction', *Environmental Protection Agency Report NTIS PB-265 578,* 1976.

[25] Washington Suburban Sanitary Commission, *Water Conservation/Wastewater Reduction Customer Education and Behavioral Change Program, Hyattsville, Maryland,* 1974.

[26] *Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities, EPA Project No. 17090 DAN.* Washington, D.C.: Office of Research and Monitoring, 1971.
[27] *Seven Green Spikes.* Ministry of Agriculture and Water, Saudi Arabia, 1980.
[28] *Water Atlas.* Riyadh: Ministry of Agriculture and Water, 1985.
[29] M. Brandes, 'Characteristics of Effluents from Gray and Black Water Septic tanks', *Journal of the Water Pollution Control Federation*, 1978, p. 2547.
[30] M. A. Ghazi, 'Development of Water Resources and the Rationalization of Their Exploitation in Saudi Arabia', *Proceedings of the Conference on Development of Water Resources and its Uses.* Riyadh: Ministry of Planning, 1982.
[13] F. P. Linaweaver, *et al.*, 'A Study of Residential Water Use, Johns Hopkins University', *Report prepared for the Federal Housing Administration and Housing and Urban Development (USA)*, 1967.
[32] S. Cohen, *et al.*, 'Demonstration of Waste Flow Reduction from Households', *EPA-670/2-74-071.* Groton, Connecticut: Electric Boat Division, General Dynamics Corporation.
[33] N. O. Mustafa, *Water and Its Development in the Kingdom of Saudi Arabia.* Jeddah: Tihama Publishing Company.
[34] Development Analysis Associates, 'Water and Power Requirements for Saudi Arabia', *Report prepared for the Saline Water Conversion Corporation, Saudi Arabia*, 1977.
[35] H. E. Babbitt, J. J. Donald, and J. L. Cleasby, *Water Supply Engineering*, 6th edn. New York: McGraw-Hill, 1962.
[36] *Fourth Development Plan of the Kingdom of Saudi Arabia 1405–1410H (1985–1990).*
[37] O. Abu-Rizaiza, 'Municipal, Irrigation and Industrial Future Water Requirement in Saudi Arabia', *PhD Dissertation, University of Oklahoma*, 1982.

Paper Received 8 December 1985; Revised 7 May 1986.