WSTA 5th Gulf

WATER CONFERENCE

24-28 March 2001 - Doha, Qatar

CONFERENCE PROCEEDINGS Vol. I

State of Qatar

Ministry of Municipal Affairs and Agriculture
Qatar General Electricity and Water Corporation
Qatar University

Secretariat General - GCC

Water Science and Technology Association (WSTA)

Under the patronage of

His Highness Shaikh Jassim Bin Hamad Al Thani

The Crown Prince of the State of Qatar

WSTA 5th

Gulf Water Conference

"Water Security in the Gulf"

29 Dhu'I-hijja, 1421 H – 3 Muharram 1422 H

24 - 28 March 2001

Doha - State of Qatar

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Organized by

Water Science and Technology Association (WSTA)
The Secretariat General - The Cooperation Council (GCC) for the Arab States of the Gulf.
Ministry of Municipal Affairs and Agriculture, Qatar
Qatar General Electricity and Water Corporation, Qatar
University of Qatar, Qatar

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INTEGRATED WATER RESOURCES MANAGEMENT AND PRESERVATION RECENT YEMENI EXPERIENCE

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ABSTRACT

Present water resources situation indicate the serious dimensions of the water crisis in Yemen, which is primarily manifested by the scarcity of water resource, depletion of groundwater, low efficiency of water use and low coverage of water and sanitation services. In view of the above, important initiatives have been taken by the government recently including the establishment of the National Water Resources Authority (NWRA) as the sole government agency and central planning institution for the national water resource development and management; and the adoption of the national water resource strategy both of which are aimed at sustainable management of the limited water resources of the country. The paper reviews the overall water sector situation in the country and what has been done by the water sector institution towards the implementation of the strategy. It was found that the activities that had been undertaken by these institutions are limited to the formulation of sub-sectoral policies and plans of action such as national water policy, draft national water law, irrigation policy, watershed management policy, water quality criteria and standard. However the most challenging of this exercise which is the implementation of these policies and enforcement of the law - not started yet. Factors determining conditions of successful implementation of the policies and plans of action and the commitment of government, political leaders and the community as a whole towards it is discussed. Attention is also given to the fundamental issues which water sector suffers from such as water pricing based on both micro and macro economic factors, organizational responsibilities, human resource development, private sector participation, enforcement of laws, regulations and policies. Continues monitoring to determine the effectiveness of proposed policy is an important part of the exercise as without that, the policy would loss its direction. Capacity building and staffing NWRA for water policy planning and management should be within the government's commitment priority.

Key words: Water Resources Situation, Water Resources Strategy, Policies and Plans of Action, Sustainable Water Resources Management

1. INTRODUCTION

The long term economic development of Yemen is very much dependent upon the sustainability of water resources in the country. Water is needed for not only quenching the thirst of growing population; it is also needed for sustaining agricultural and industrial development. Both of these are ultimately linked to meeting the population's need for food and manufactures, in addition to providing employment. Water is thus intrinsically connected to development.

Historically, Yemen managed its water resources superbly. This was largely because the traditional agriculture system, which was based on terraced farming, rainwater harvesting, and spate irrigation, was highly sustainable. These systems not only ensured conservation by allowing aquifer recharge but also provided protection against such hazards as erosion. Yemen also had a well-developed system of social norm regulating the allocation of surface water resources.

In the last couple of decades, the rapid increase in population (3.6% per annum) has put increasing pressure on the water resource base of the country. These tendencies have been made worse by the government policies that promoted expansion rather than efficient use and sustainable management. Examples of such policies include drive towards self-sufficiency in agricultural products augmented by ban on import of fruits and Qat, and the provision of incentives to private sector for groundwater development rather than conservation. The tendencies towards uncontrolled groundwater development were also aided by the availability of money from Yemenis working abroad to finance drilling of wells. Together, these developments resulted in water resources being exploited beyond the limits of sustainability.

The magnitude of the problem was not well understood until the water level started to drop very sharply and groundwater quality degradation started to take its toll on human health and the environment. However, the most significant factor in bring the water crisis to the fore was the urban water shortages that hit many important cities in Yemen during the last decade. These crises often pitted the highly articulate urban communities against large segments of rural population, and therefore, drew a lot of attention.

1.1 The purpose of the Paper

The purpose of this paper is to outline that the recent initiative in the water sector aimed at developments in the water sector aimed curbing the current water crisis in Yemen. A general review of the water situation is given before describing detailed strategy/ policy issues and options to meet the challenges in the water sector. The strategic options for pulling the country out of the crisis are then discussed. In particular, the paper describes what has been done by the water sector institutions towards the implementation of the National water strategy.

1.2 Methodology

The methodology adopted in preparing this paper has been focused on the recent water sector policy reforms and their impact in the water resources situation. This will be carried out through collecting, reviewing and analyzing all related data and studies including:

The National Water Resources strategy, and related sub Sectoral strategies and policies; Water Resources Assessment, development, planning and management at a regional and national level (including socioeconomic aspects); Stakeholders participation in water resources planning and Management; Public awareness education/campaign on Water savings/ conservation method; Institutional and regulatory framework for water resources management, including appropriate systems of incentives; Ta'iz region water resources management action plan will be demonstrated as a "case study".

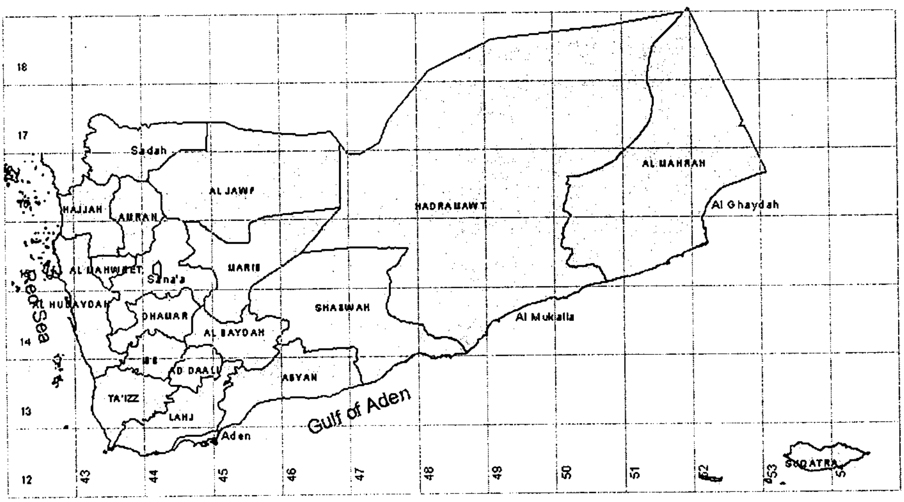

Fig. 1 Location Map of Yemen

2. REVIEW OF CURRENT WATER SECTOR SITUATION

2.1 Present Water Resources Situation

Yemen has predominately a semi-arid climate. Rainy seasons occur during the spring and the summer. The climate of Yemen is strongly influenced by the mountainous nature of the country. Rainfall ranges from less than 50 mm along the coastal area-Red Sea, Gulf of Aden and Arabian Sea to a maximum of 500 - 800 mm Western highlands and decreases steadily to below 50 mm inland.

The total renewable freshwater resources of the country are estimated at 2.5 BCM/year of which 1.5 MCM is surface water and 1 BCM are groundwater. The estimated per capita share of renewable water resources is less than 140 m3 and it will continue decreasing in the future as population increases. The per capita share in Yemen constitutes only 14% of the standard per capita water needs of 1100 cubic meters.

Despite the low levels of availability in relation to its population, Yemen's total annual water consumption is estimated at 3.4 BCM. This implies a deficit between water use and renewable water resources of about 0.9 BCM this deficit is met by over exploitation of the groundwater aquifers, resulting in sharp decline in groundwater tables in a number of water regions. If groundwater extraction continues at the present rates, several aquifers will be depleted. As a result, many population centers will have no water for domestic purposes, and agriculture will disappear in these areas.

Agriculture accounts for 90% of water use. Irrigated area is in the order of 0.5M hectares, of which 75% is irrigated by groundwater, some estimates indicate that Qat consumes about 30% of the total water use. Irrigation efficiency is low (30-40%). Municipal use accounts for about 6% of total water use.

It is estimated that 45% of urban households are connected to the public water network and the rest of households are supplied with water from the private sector. Unaccounted for water range from 30-50%. Public sewerage coverage is only 10%. In rural areas, considerably less than half of households have access to, safe sanitation.

2.2 Sources of the Water Crisis

A number of the groundwater regions in the country are experiencing heavy over pumping. In addition to quantity, water quality is also becoming a major concern because in the absence of regulation ever increasing quantities of urban and industrial wastewater are being dumped into aquifers. Thus, the water has become the most limiting constraint on the development process.

This problem is the consequence of both water policies that have been pursued in the past, and the failur to take the necessary actions. The key factors that had contributed to the present water crisis are technological, social, institutional and economic factors.

The technological factors are related to the introduction of modern drilling rigs, dip pumps which began in a large scale since the 1970. In the past, most of the water wells for all purposes of use were shallow and hand- dug wells thus self-limiting in terms in the amount of water extracted. At present, the total number of wells are more than 55,000 and about 150 drilling rigs extracting over one billion m3 of groundwater every year.

The social factors of the crisis include the rapid population growth, over 3.6% annually and rapid increase in food consumption. In addition, Qat by itself consumes about 0.5 billion m3/year.

The economic factors contributing to the crisis are the government's policy, which encourage agriculture expansion by providing incentives for excessive use of water. The government subsidized diesel fuel, electricity used for pumps and other agricultural inputs. Finally, some of the high cash and water consuming crops (fruits, vegetables, Qat etc.) are favored by import bans that raise their profit margins and hence their attractiveness for farmers.

The institutional factors contributing to the crisis are generally characterized by the absence of water legislation and water rights, fragmented and weak institutions for controlling and protection of groundwater abstraction etc.

3. INSTITUTIONS INVOLVING IN WATER SECTOR MANAGEMENT

The water sector is managed by public and private sectors. The public sector is represented by five main institutions. In general, these institutions are fragmented and suffer from weak structures, and lack interactive coordination, which required addressing the water sector challenges in an integrated manner. Such situation clearly indicates the serious dimensions of the water crisis in Yemen.

Brief description of these institutions are presented below:

The National Water Resources Authority (NWRA): NWRA has been established by a Presidential Decree in October 1995, as the sole governmental agency and a central planning institution for the nation water resources development and management. More details on NWRA will be discussed later on this report.

The Ministry of Electricity & Water (MEW): The National Water Supply and Sanitation Authority (NWSA) in the MEW is responsible for Urban water supply and sanitation including household connection, pricing and billing. The General Authority for Rural Electricity and Water Supply (GAREWS) in the same ministry is responsible for rural water supply. In general GAREWS plans and implements rural water supply projects and assigns operation and maintenance functions to local authorities.

The Ministry of Agriculture and Irrigation (MAI): In general the General Department of Irrigation (GDI) help farmers in planing, constructing, and implementing irrigation projects and assigns operation and maintenance functions to local authorities. The Department for Water shade Management (DWSM) is responsible for watershed management.

The Environmental Protection Council (EPC): EPC is charged with promulgating and monitoring guidelines to maintain the quality of the environment. The Council does not have means to systematically monitor and enforce adherence to these standards.

The Private Sector: In fact, water resources development and supply activities are dominated by the private sector. Probably, more than 95% of the currently existing wells are owned by the private sector. More than 50% of the domestic water supply services are provided by this sector particularly in main cities. This sector suffers from poor organization, low efficiency and low quality services. This is mainly because of the absence of government's role in coordinating, regulating, supervising, and this important sector.

4. RECENT DEVELOPMENTS IN THE WATER SECTOR

4.1 Prioritization of Sustainable Water Resources Management

The present water crisis is essentially the result of more than 30 years of ad- hoc water policies, which encouraged development projects, particularly in the agriculture sector. It is only in the late eighties- early nineties that the Government became aware of the adverse effects of the economic incentives that are given to the agricultural sector without the parallel introduction of effective measures to control and regulate the use of the water resources. This increasing Government awareness of the water problem has been reflected both in the previous and current Five –Years Development Plans (1996-2000 & 2000 - 2005) in which the need for an efficient management of water resources has been recognized as a national development priority. In this plan, the Government has outlined the following main objectives for the water sector towards the ultimate goal of attaining sustainable development of the available water resources:

(a) Protect resources from over-exploitation, quality degradation, and ir reversible damage.

(b) Allocate water among different using sectors to sustain economic growth with equitable distribution of benefits and balanced democratic distribution.

(c) Satisfy society's needs for food, and ecological stability by meeting drinking water requirements; by providing for safe disposal of wastewater and solid waste; by increasing productivity per units of land and water; and by maintaining an ecological balance.

In order to achieve the above objectives, the government has taken the following important initiatives:

4.2 The Establishment of the National Water Resources Authority (NWRA)

As mentioned above, water problems facing the country today are attributable at least in part to fragmented institutional structure of the water sector. A number of institutions operated independently in the absence of a coherent national strategy. The functional interests of these institutions negatively affected balanced water resources management and allocation. In the second half of this decade, when the impacts of water shortages started to become more pronounce, the government recognized the need of an effective role in co-ordination sectoral activities in an integrated manner if the above objectives are to be realized and, to this effect the government recognized the need for a coherent institutional framework.

To achieve these objectives, NWRA was established by a Presidential Decree in October 1995. NWRA was given the sole responsibility for management of water resources and policy formulation both at the national and regional levels. Its mandate includes allocation of water aiming sectors, undertaking studies and investigations for water resources assessment, control of overexploitation of water resources and their protection from pollution. In addition NWRA is also responsible for licensing and monitoring of groundwater development, and for raising the level of awareness regarding water issues.

In addition to the government support, NWRA is also provided technical and financial support by donors (UNDP, the Netherlands Government, and the World Bank) The Program is aimed at building the managerial and technical capacity of the National Water Resources Authority to meet the sectoral objectives-to ensures sustainable development of Yemen Water resources. The program is also aimed at strengthening the capacity building efforts of users' agencies such as NWASA, GAREWS and the General Department of Irrigation of the MAI towards efficient Water Resources Management.

In accordance with its mandate, NWRA has undertaken preparation of a number of policies and plans at both the national and regional levels. These are discussed below.

4.3 Formulation of the National Water Strategy

The Objectives of the Strategy are: Protection of water resources from depletion and pollution, Optimal utilization of water resources to achieve the highest value for water after insuring water needs of each citizen for domestic needs and Provision of water to meet the demands of society for all purposes.

This comprehensive strategy is set for the long-term objectives and principles. The strategy recognizes that each citizen has the right of access to water to meet the basic needs. Accordingly, water use for domestic supply is given first priority, industrial use second priority whereas agricultural use is accorded third priority. The strategy was approved in 1998.

In addition to general principles, the National Water Strategy identifies areas where action is required. These are: (i) Water Resources Development and Management; (ii) Legislation and Institutional Set-up; (iii) Public Awareness; (iv) Capacity Building and Performance; (v) Health and Environment Standards; (vi) Private Sector participation; (vii) Investment and Water Pricing and (viii) Research and Development.

4.4 The Draft National Water Law

This is another important part of the ongoing water resources management initiative. The law has been submitted to the parliament recently after the Cabinet had approved it. The Law defines the following:

(i) Basis and principles of water resources management; (ii) roles and functions water basin committees; (iii) water use priorities; (iv) servitude rights; (v) water rights; (vi) system of permits; (vii) technical criteria and standards for water use; (viii) means and procedures to be followed to enhance water resources conservation, rationalization of uses, protection against pollution, flood protection, and water resources development; and (ix) system of citation procedures and penalties.

4.5 Draft National Water Resources Policy

Resolution of water problems and conflicts come through adoption and implementation of a national water policy. The draft policy is aimed at implementing the components of the national Strategy which is also a guidance to all water related institutions and water users and thus it is supplemented with a set of sub sectoral policies, action plans and implementation schedule. The draft policy will be submitted to the cabinet by the end of January 2001.

4.6 Water Resources Management Regions and Districts

NWRA has completed a study on countrywide division of water management regions. The results of the study, which is presented in a simplified hydrogeological map, comprise a total of 14 water management regions and 31 water management regions and Districts. This work will be submitted soon to the Governoment for approval.

Ta'iz water Resources Management Action Plan (TWRMAP): NWRA embarked upon a program for preparing regional water resources management action plans. Initially four priority water management regions (Ta'iz, Sana'a, Lahj/Abyan and Hadramout) have been selected. The Ta'iz plan has been completed and will be submitted to the Cabinet by the end of January, (More details of the plan is described in Annex 1. Or write here summary of the plan).

Proposal on measures to be implemented in critical aquifers. This has been submitted to the cabinet and NWRA is awaiting approval.

Definition of national water quality criteria and standards: NWRA has formulated national water quality standards. This exercise was conducted in collaboration with a committee representing relevant ministries; authorities and NGO's had formulated this document. Cabinet approval for the document was obtained early, 2000.

Public Awareness Campaign on Water issues: NWRA has made special efforts to enhance the general level of awareness in the country about water issues. This has been done by pursuing the following activities: production of a wide range of printed materials (posters, stickers, leaflets, brochures, etc.), mass media, Bill boards on main streets, meetings and co-operation with local authorities, Organize/ hold seminars, workshops on hot water related issues, work with group of stakeholders in co-operation with NGO's at the community level.

Regulating Water Resources Exploitation: This is one of the most important functions of NWRA. In order to be able to discharge these responsibilities in an efficient and effective manner, NWRA is making the necessary preparations. All the necessary documents, licenses, permits, various forms, instructions related to water resources development, use etc are in progress. At present NWRA is already issuing licenses and permits for well drilling and other water use.

4.7 The Ministry of Electricity and Water

Urban and Rural water supply and sanitation sector reform policy:

One of the key objectives these policies intended to achieve is the provision of an adequate supply of safe water and the sanitary disposal of liquid wastes to the largest number of people as quickly as possible. The Urban and Rural water supply and sanitation strategy which consists of 11 components is designed to implement the above mentioned policies, which is to advance the sector towards the day of full service coverage for all of Yemen's people.

4.8 The Ministry of Agriculture and Irrigation (MAI)

The MAI represented by GDI and DWSM in close cooperation with NWRA had formulated the following documents:

- Irrigation water Policy and action plans
- Irrigation law (draft)
- National Watershed management policy

In broader sense the objectives of these policy documents are: to develop, conserve and protect the natural resources (soil, water and plant etc.); Integrated watershed management; and Legal and institutional capacity building that would enable the responsible institutions to be functional and enforce their mandates. With the exception of the Irrigation law, the Government in 1999/00 had approved all the above documents.

Environmental Protection Council (EPC)
Key policy actions that has been under taken by EPC during the last five years include:

- Environment protection law
- The National Environmental Action Plan (NEAP).

This is in addition to specific related studies and measures. EPC formed part of the committee who had formulated water quality and wastewater discharge standards.

4.9 The Private Sector

At this stage the role of private sector is limited to water resources development and supply and in a very disorganized manner with no clear policy. Actually, the on going water supply policy reform is providing a good an opportunity for full participation of the private sector and local community.

5. WHAT NEXT ?

No doubt that the activities that has been under taken at this stage by the water sector institutions and in particular by NWRA towards the implementation of the National water strategy are very important. Nevertheless, these activities are limited to the preparation of the required documents such as guide lines, strategies, policies, laws, action plans etc. However, the most challenging part of this exercise is the implementation of these policies and action plans within the specified time frame. This has not started yet.

Factors determining the conditions for successful implementation of the policies and action plans are the readiness for change, commitment and motivation of the responsible organization(s), determined and continuous support of the relevant ministries and agencies, and the support of the community at large.

Above all, the political will is needed for successful translation of good intentions embodied in policies and plans into concrete action. The water crisis facing the nation is so serious that it requires strong support from the national leadership. This is so because the water sector suffers from fundamental issues such as the economic pricing of the scarce resources based on both micro and macro economic factors, organizational responsibilities, Human Resource Development, decentralization and active private sector participation, and discipline in the enforcement of laws, regulations and policies.

Government's strong commitment to implement the national water strategy is extremely important if water sector objectives are to be successfully met. It must be clear here that if the above policy measures and plans of action are not implemented, the situation might become completely irreversible thus jeopardizing the productivity investments already made in the sector. Implementation of various policy decisions and measures will require heroic efforts by the Government and the people of Yemen given the fact that the country is facing frustrating constraints.

The impact of concerted efforts to conserve water resources will be felt in almost every department of the Government. Major institutional and administrative changes will be required. The sectoral development plans may require substantive revisions. Research and extension systems will have to be enlarged. The funds for implementation will have to be provided. Thus, the Government support is imperative.

Continuous monitoring will be required to determine the effectiveness of proposed policy and strategy. Without appropriate monitoring, the policy would lose its direction. All possible means should be tried to make NWRA functional. Staffing the NWRA for water policy, planning and management will be an enormous task. At present national personnel are not available in adequate numbers, but every effort should be made to build up the nationally recruited staff as quickly as possible. Even if some staff is available, they will not be able to carry out the analytical functions required in support of planning for water resources management. This situation would need to be remedied through human resource development in the water sector.

6. CASE STUDY: TAIZ WATER RESOURCES MANAGEMENT ACTION PLAN

6.1 Background

Ta'iz, the ancient capital city of Yemen is facing the most severe water crisis in Yemen. This crisis reached its peak in 1995 when water was supplied to the population of the city once in forty days. Even the emergency wells drilled since then had improved the situation only temporarily since related fundamental issues had not been addressed properly. The annual groundwater recharge is 15 MCM whereas the annual groundwater abstractions in the region is around 41 Mm3, which is much more than the annual recharge. Agriculture is the largest water consumer, over 27 MCM or 60% of the total annual consumption is utilized by this sector. Estimated Annual Domestic consumption exceeds 18 MCM/year or 45% of the total annual consumption. The high growth rate (8%) of urban population would put high pressure in the future on water resources of the region, and on the city water supply and sanitation infrastructure. Average domestic Water demand for the Taiz region in year 2020 is 34 MCM. Present industrial consumption is estimated at 5 BCM/year. If the present industrial growth rate is to continue, water requirement in Year 2020 would raise up to 27 MCM. The fundamental issues comprise crisis in urban water supply, groundwater depletion, rural-urban conflict over water, infringe pollution, limited access to potable water in rural areas poor water use efficiency, poor performance of the public utility, centralized organization, poor defined water rights, lack of appropriate incentives for conservation and protection of water resources and environment, weak institutional set up etc. To correct the situation and inline with high priority to secure water, the water resources management action plan was carried out in the Taiz region including the city.

6.2 Planning Process

The Planning process started by dividing the study area into 8 water resource management planning zones **(Fig. 2: Location Map of Taiz Water Management Zones)**, taking into account not only Hydrogeological boundaries, and water resource availability but also the level of water resources degradation by pollution, cropping patterns and socioeconomic factors. The objective behind this division was to (a) give greater 'voice' to local stakeholders in the management of, so to speak, their 'neck of the woods', and (b) to responds to their concerns by targeting water management measures at local conditions.

Data collection, processing and their application in an appropriate manner are some of the strongest tools in planning process. Thesw data help Planners in identifying critical issues, draw management objectives and formulation of strategies. Studies that have been carried out in the Taiz region include: hydrogeology and land use, well inventory survey, agriculture and water use survey, socioeconomic survey and urban water use survey. This is in addition to the preparation of a number of technical notes that dealt with various aspects of planning.

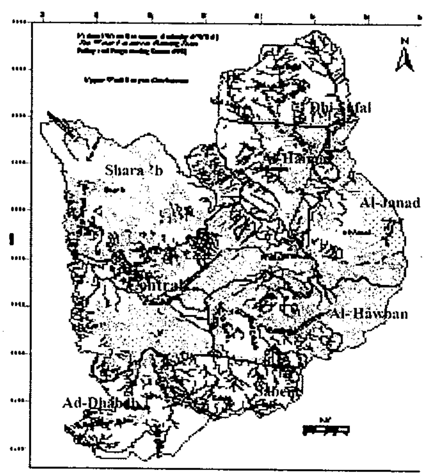

Fig. 2 Location Map of Ta'iz Water Management Zones

6.3 Stakeholders' Involvement in the Planning & Implementation Process

The planning process in the Taiz region has been carried out with active involvement of stakeholders. The involvement was made through:

(1) Stakeholders participation team (SPT)/ NWRA branch office in Taiz

(2) The Planning team (PT) in Sana'a, NWRA head office.

(3) Stakeholders contact group.

The SPT created stakeholders contact groups in each of the water management planning zones. In addition, contact groups were also created for industry and urban consumers. These groups served as a liaison between the SPT and the community, just as the SPT itself served as a link between the planners PT and the stakeholders.

The Taiz Water resources Management Action Plan is already finalized. Soon workshop on the outcome of the plan will be held in the Taiz City as well as in selective rural areas representing the present management zones.

As mentioned above the stakeholders' participation is not limited to the planning process. But we need much more effort to involve them in the implementation process because without that it is impossible to go further. To succeed on that the involvement of actors from inside and out NWRA needed as an example let's take The Rural Urban Water Transfer (RUWT), which is one of the measures proposed in the Taiz water resources management action plan.

6.4 Rural - Urban Water Transfers - Seven-point framework:

The urban population in the city of Taiz is raising rapidly. Large quantities of water will be needed in the future to meet domestic needs alone. Additional water will be needed for industry. Clearly, **rural - urban water transfers** would have to take place as much larger scale and in more organized manner than at present. It would be difficult to transfer additional supplies of water from rural areas if the atmosphere of distrust and hostility that mars relations between rural communities and the Governoment now, also persists into the future. Such atmosphere could possibly changed if the proposed rural-urban water transfers broadly adhere to the Seven - point framework presented below:

a) There should be **Clearly defined water rights** (for sectors and individuals within sectors)

b) Except for water supplies needed for drinking and sustaining health/wellbeing), the remaining **water should be allocated for products with higher income.**

c) **The water rights should be tradable** and to the extent possible, there should be **direct compensation** of individuals willing to transfer their water rights to other (e.g. to the urban sector).

d) Water rights **transfers must be Verifiable.** Farmers sell their quota. It should not be possible, for instance, for farmers to sell certain water rights and then continue to abstract the same amount of ground water for irrigation as before.

e) A mechanism must be devised for **Monitoring compliance** with the agreement and punishing violators

f) **Local communities should actively participate in designing the rules;** in fact the mechanisms that govern water transfer must be adopted with community consent.

g) Regulatory role of NWRA to ensure **resources sustainability and allocation equity**

The framework proposed above is general and would allow several different institutional arrangements. **RUWT** evolves a creation of institutional mechanism. The Seven points involve the creation of this mechanism. Thus, the implementation process needs creation of institutional framework. More effort and involvement from the Monitoring and Implementation Sector (MIS) of NWRA is necessary but it will not be sufficient. In addition to that there must be involvement from out side like NGOs. This represents a future financing need that should be given priority.

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International Water Law and the Use of Shared Water Resources

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INTERNATIONAL WATER LAW AND THE USE OF SHARED WATER RESOURCES

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ABSTRACT

Natural scarcity, rapidly growing demands and ineffective management interventions for resource conservation and protection are some of the leading factors behind the alarming water situation in many countries of the ESCWA region ([1]). Moreover, for countries which rely heavily on surface water inflow from shared international rivers, the water problem is further complicated by growing stresses in the upstream-downstream relations. The severity of the region's water problem is clearly manifested by the frequent water shortages in major cities and in important agricultural basins in several member countries.

Shared groundwater aquifers, especially those holding significant quantities of fossil groundwater, are understandably gaining increasing attention as sources of additional supplies and many ESCWA countries have already undertaken important steps to better use and manage these resources.

This paper highlights the main principles of international law of relevance to shared international waters, with special emphasis on shared groundwater. It also highlights the drives, benefits, and constraints of cooperation regarding shared groundwater aquifers, and ESCWA efforts to further develop capacities and enhance cooperation among its Member States in this important field.

1.0 BACKGROUND

The region served by ESCWA covers a total land area of about 4.75 million km^2 of which about 97.7% is desert land with semi-arid and extremely arid climate.

Naturally, water in this region is a particularly scarce resource. Only few member countries (Egypt, Iraq, Lebanon and Syria) have perennial river flow, which is mostly generated outside their territories, while the remaining countries have only sporadic seasonal flash floods and are more dependent on groundwater.

Natural scarcity is further worsened by rapidly growing demands, unsustainable water use patterns, increased water pollution and weak management institutions.

A further complication arises from increasing insecurity of the historic water rights of some member states to international rivers. Evidently, the right of downstream countries to uninterrupted flow is increasingly undermined by adverse upstream decisions being taken without downstream consultation, and leading to the prevention, reduction or control of the quantity and/or quality of water flow across borders. Today, the main river basins of the Nile, Euphrates, Tigris, and Jordan and tributaries continue to be under riparian tensions (often disputes) especially in the absence of basin-wide water agreements.

The gravity of the situation cannot be underestimated. About 136.5 BCM (or 78%) of the region's annual renewable water resources of about 176 BCM flow from outside the region and are the main source of water for some 70% of the region's population (year 2000 forecasting based on UN, 1996).

On the other hand, many groundwater basins containing large regional aquifers are shared by countries in the Arabian Peninsula, Iraq, Jordan and Syria. Often, shared aquifers, especially those containing non-replenishable fossil water, contribute significantly to current demand in many member countries. Hence, cooperation mechanisms need to be developed for the benefit of all riparian states.

Clearly, shared aquifers in the region are likely to increase in importance as the water deficit grows. However, it is argued that averting the potential disputes which may arise among sharing states over these aquifers requires the establishment of cooperation mechanism for aquifer development and management.

Member states' cooperation on shared waters has been particularly modest or non-existent, especially when compared to the extensive water development efforts in the region. Practically, only a handful of agreements or protocols have been concluded in the region since the post colonial era. And all of these have been over surface waters. In the field of groundwater, ESCWA has been actively involved to develop this cooperation through projects aiming at development of databases for some of the shared basins (e.g. the basalt aquifer between Syria and Jordan and the Paleogene aquifer in Arabia.

In comparison, in central and western Europe, there are some 150 bilateral and multilateral agreements that are either in force or have recently been signed to manage some 290 international rivers, lakes and aquifers (ECE, 2000). As may be noted, the few water agreements in the ESCWA region are bilateral and, given the acrimony and weak cooperation among most riparian states, basin-wide agreements are not likely to be reached in the near future unless special efforts are exerted in this direction.

Because of the importance of shared water resources to the well-being of the region's population, ESCWA's Natural Resources Section (NRS) has been actively involved in various efforts aiming to *enhance Member States' capacity to manage their shared surface and groundwater resources and strengthen their cooperation to achieve sustainable development and utilization of these resources*. By promoting and highlighting the needs and benefits of cooperation and proposing mechanisms to develop and strengthen cooperation, the water stresses could be gradually relieved so that the opportunities for sustainable development and rational and equitable utilization and management of shared waters are improved. In this regard, regional organizations can play an important role by helping countries of the region approach their shared water problems with fewer constraints on rational and equitable utilization and management.

Thus, in the current work program (2000-2001), ESCWA's efforts in this regard commenced with an Expert Group Meeting (EGM) that was held between 8 and 11 June 2000 to address the *Legal Aspects Of The Management Of Shared Water Resources in the ESCWA Region*. The paper on hand is also part of ESCWA's continued contribution to this issue. ESCWA's efforts will continue with the preparation of a Groundwater Management Charter (GMC) for the region and Guidelines for Cooperation in the Management of Shared Aquifers (GCMSA), both planned for the next biennium.

2.0 GROUNDWATER USE AND DEPENDENCY OF THE REGION ON GROUNDWATER RESOURCES

Table (1) shows that the annual renewable groundwater recharge in ESCWA member countries is about 18.5 BCM, representing some 11% of the region's 169 BCM total annual renewable water resources.

Table (1) Renewable water availability and groundwater use in the ESCWA region (ESCWA 1999a).

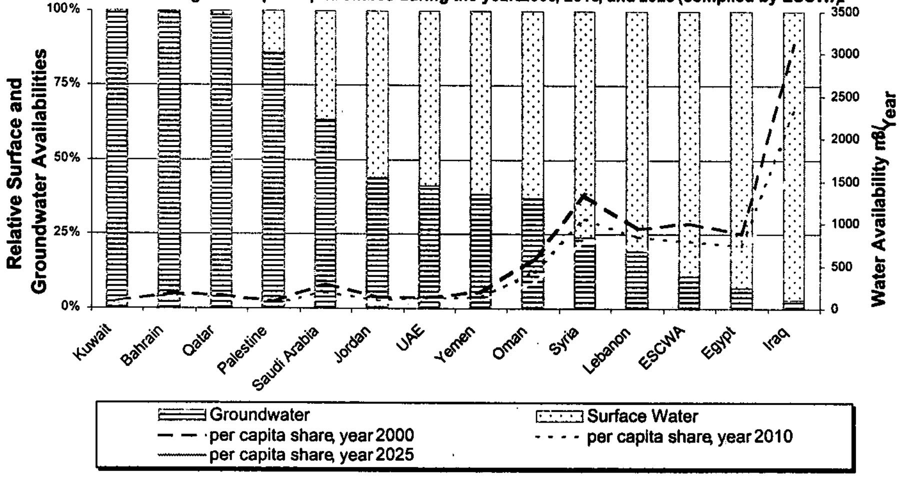
Country/ Area	Renewable Water Resources (MCM)			Ground water use, MCM	GW significance, in terms of:	
	Surface water	Ground water	Total		*renewable GW* **to** *total renewable water*	*GW use* **to** *total demand, year 2000*
Bahrain	0.2	100	100.2	258	99.80	91.49
Egypt	55,500	4,100	59,600	4850	6.88	7.11
Iraq	70,370*	2000	72,370	513	2.76	0.78
Jordan	350	277	627	486	44.18	39.13
Kuwait	0.1	160	160.1	405	99.94	68.64
Lebanon	2,500	600	3,100	240	19.35	17.00
Oman	918	550	1,468	1644	37.47	89.01
Palest. Auth.	30	185	215	200	86.05	40.40
Qatar	1.4	85	86.4	185	98.38	53.31
Saudi Arabia	2,230	3,850	6,080	14430	63.32	81.23
Syria	16,375*	5,100	21,475	3500	23.75	20.43
UAE	185	130	315	900	41.27	41.28
Yemen	2,250	1,400	3,650	2200	38.36	61.61
Total, BCM	150.71	18.54	169.25	29811	10.95	16.46

* The flow of rivers may be lower due to upstream abstractions.
** WSI = Water Use/ Available Water

This is at the region level. However, for member countries with little or no perennial rivers, groundwater recharge is the main form of annual replenishment, accounting for nearly 100% in Kuwait, Bahrain and Qatar (Table 1). Figure (1) depicts this important role of groundwater graphically.

On the demand side, the dependency of member countries on groundwater withdrawals is much more obvious. In 1996, groundwater withdrawals, in relation to the safe yield ranged from twofold in Bahrain, Jordan and Yemen to sevenfold in the UAE ([1]). However, groundwater utilization in several ESCWA member States remains less than the replenishment rate.

Figure (1): Groundwater vs. surface water contributions to annual renewable water resources in the ESCWA region and per capita shares during the years 2000, 2010, and 2025 (compiled by ESCWA)



Current groundwater use data (Table 1) generally indicate that the present level of abstraction stands at about 29.8 BCM/ year which exceeds the annual replenishment of about 18.5 BCM by about 11 BCM, or 60%. Thus, considerable groundwater mining in the region continues, with irrigation the main user, accounting for 49% in Jordan to 70% in Yemen and most GCC countries.

Furthermore, because of groundwater mining, the actual contribution of groundwater to the total demand or use in the region is more than 16% (Table 1). At country level, groundwater abstractions from renewable shallow and non-renewable deep aquifers are currently the main source of water in Jordan, Yemen and the GCC countries. In quantitative terms, groundwater contribution to total demand ranges from less than 1% (in Iraq) to more than 90% (in Bahrain).

To sum, by the year 2025, ESCWA estimates that the water deficit in the region will reach 69 BCM or about 36% of the renewable plus non-conventional supplies. It is postulated that this deficit will have to be met largely from fossil groundwater in deep shared aquifers.

3.0 BASIC PRINCIPLES OF INTERNATIONAL LAW PERTAINING TO SHARED WATER RESOURCES

Decades of legal development have produced numerous principles which have been interpreted and refined by scholars, national legislatures and societal development, and which have come to form international law on water resources. In essence, five basic principles or theories are advanced:

- The theory of limited territorial sovereignty,
- The principle of community of interests,
- Classical principle of *Sic Utere Tuo Ut Alienum Non Laedas* (not to cause significant harm).
- The principle of reasonable and equitable utilization,
- The principle of prior notice and good faith negotiation.

These principles cover a broad period of time in terms of international acceptance, and although they were applied primarily to surface water they are also applicable to groundwater resources.

i) The Theory of Limited Territorial Sovereignty

This theory is founded on the two important theories of international law which underlay classical relations among nations; namely: absolute territorial sovereignty and absolute territorial integrity. Although neither is widely accepted or practiced today in the international community, they are discussed here in order to highlight the foundation upon which much of contemporary international water law is based.

According to **the theory of absolute territorial sovereignty**, which is mostly asserted by upper riparian states, a state has at its disposal the waters which flow over its territory without being able to demand continuous free flow from other riparian countries. In other words, states have the right to *unrestrained use of resources found within their territories, regardless of the consequences of such use across borders.*

This theory, which is also known as the «Harmon Doctrine», after the name of the US Attorney-General in 1895, who upheld it when he was asked whether the United States was obliged to allow Mexico the enjoyment of part of the Rio Grande Rio, the frontier river between the two countries. The Harmon Doctrine gives no regard to extraterritorial effects resulting from states actions to exploit resources within their jurisdiction, so long as there is no established law to the contrary.

The theory of absolute territorial sovereignty has been upheld by only few authors (Wolfrom, 1964; pp.31-33) and the great majority of international jurists and states reject it on the basis of the principle of *sic utere tuo ut alienum non laedas* (use your own [right] so as not to cause injury to another). In practice, States have rarely invoked this theory ([1]) and, nowadays, it has been largely abandoned. The accepted norm is that upper riparian states are obligated to consider the rights and interests of lower riparian states, as well as to attempt to reconcile any disputes over water resource use or modification projects.

According to the **theory of absolute territorial integrity** a state has the right to ask for the uninterrupted, continuous natural flow of the waters coming from other riparian countries. Consequently, no one has the right to change the natural course of a river which flows over its territory.

This theory favors downstream riparian states by totally immobilizing *de facto* any possible development by the upstream state ([2]). Hence an upstream riparian state may not harness a section of an international river if it will not harm another riparian state. A state may not use an international river in a way which alters its course, flow rate, volume or quality in the territory of another state.

However, like the theory of absolute territorial sovereignty, this theory has received little support amongst legal publicists and in state practice. It is regarded as inequitable in its allocation of water resources, as well as in its biased preference for downstream states, particularly because it does not require lower riparian states to compensate upstream states for preserving the waters.

The theory of limited territorial sovereignty: acknowledging the impossibility of the two preceding theories (the Harmon doctrine and the absolute territorial integrity), the practice of which led to impasses, the majority of states felt the necessity to accept limitations on sovereignty. Thus the theory of limited territorial sovereignty was born. According to this theory, a state can freely use the waters flowing through its territory on the condition that this utilization would not be prejudicial to the territory or to the interests of another riparian state. The riparian states have reciprocal rights and obligations in the utilization of the waters of international rivers. Tenets of conventional law (Wolfrom, 1964; pp.35-40) and international jurisprudence (Wolfrom, 1964; pp.44-45, 51-61) have sanctioned this, which is now generally accepted, theory. One can maintain that limitations on sovereignty can only be voluntary and that it is therefore absolutely necessary to draw up an agreement. But the basic question has in fact only been postponed. For is the drawing up of an agreement purely voluntary or is it in execution of a preexisting obligation?

ii) Principle of *Sic Utere Tuo Ut Alienum Non Laedas* (Obligation Not to Cause Significant Harm)

Customary international law obligates states not to use, or allow using of, their territory for acts contrary to the rights of other states. That is, acts which will cause significant or appreciable harm to other states. This principle, often expressed as *sic utere tuo ut alienum non laedas*, receives wide recognition today as a general principle of international law. It is applied in numerous treaties and other international instruments. Moreover, international funding agencies (e.g. the World Bank) will not provide financial support for projects that are likely to cause appreciable harm to the territory of other states.

When considering whether one state's action harms, or will harm, the territory of another, a majority of international instruments and publicists suggest that the harm must be "significant" before international water law may be invoked. For an injury to rise to the level of "significant" harm, it must have significant and consequential effects upon public health, economic productivity, or the environment of another state.

iii) Principle of Reasonable and Equitable Use

This principle is a utilitarian concept, employing a cost-benefit analysis, which attempts to maximize the beneficial use of the shared water resources while limiting the burdens. It is grounded on the principle of no significant harm, where detrimental consequences are not ultimately prohibited but rather weighed against the benefits gained. Under this principle, each riparian state is entitled to a reasonable and equitable share in the beneficial uses of an international water resource. This principle is widely accepted as a general rule of customary international law and applies to groundwater resources.

Significantly, this principle is a blend of the principles of absolute territorial sovereignty and territorial integrity in that it recognizes and evaluates the shared and competing interests of all riparian states. The use of the resource is then determined by balancing competing social and economic factors of interested riparian states and by considering the physical aspects of the entire water resource system.

Under the Helsinki Rules, relevant factors for judgement of what might be reasonable and what might not, may include: geographic, hydrologic, hydrographic, climatic and ecological circumstances; prior, existing, and potential uses of the waters; social and economic needs of each state; feasibility of alternatives to the proposed project; and compensation of one state as a means for resolving conflict.

iv) The Theory of Community of Interests

The community of interests theory goes a step beyond the principle of reasonable and equitable use in that it advances the goal of achieving the most optimal use and development of a shared water resource. Fundamentally, this theory seeks to achieve economic efficiency and the greatest beneficial use possible, though often at the cost of equitable distribution and benefit among the sharing states. So it represents the most progressive of the water rights theories. National boundaries are ignored and the entire basin is regarded as one economic and geographic unit. Which means that, in the case of a navigable river, for instance, all riparian States will have full equality in the use of the whole course of the river and no riparian State will have any preferential privilege over the others.

In view of the scientific developments over the last decades, the hydrological regime of rivers and the physical factors which govern them have become known with great precision. Legal norms have been based upon them. International rivers are considered by the natural sciences to be part of a natural unity which is the hydrographical basin.

Recent doctrine tends to systematize the norms governing the use and exploitation of international rivers and lake waters on the basis of the notion of the basin. The treaties on the Basin of Lake Chad of May 22, 1964, on the Basin of the Niger of November 25, 1964, and on the Basin of the River Senegal of December 17, 1975, are some examples in this sense. This theory was also followed in the Lake Lanoux Arbitration of November 16, 1957.

While the community of interests theory may be regarded as the most efficient and advantageous for the management of shared natural resources, its acceptance within the international community is sparse, although it is widely favored by international jurists and state practice.

v) Principle of Prior Notice and Good Faith Negotiation

In considering the principles of *no significant harm*, reasonable and equitable use, and community of interests, states are further obliged to make timely notification to other states prior to embarking on efforts to exploit shared water resources. Data and information must accompany the notification to enable the notified state to objectively evaluate the project's potential effects.

In the event that the notified state's analysis suggests that significant harm will result from the notifying state's actions, or if a dispute arises because of opposing conclusions, the states involved are obligated to jointly verify the findings and to attempt to reach an acceptable solution. Of particular importance, such consultations and discussions must be conducted in good faith and with the intention of achieving a resolution acceptable to all concerned. Specifically, any deliberation arising from dispute over the exploitation of a shared international resource must be a sincere intention towards a friendly solution in order to promote trust and cooperation amongst the parties.

Good faith negotiation requires the notifying state not to proceed with the planned activity, or to suspend progress of the activity, until the dispute is resolved or until the notified state has had a "reasonable" period of time to respond.

4.0 OCCURRENCE OF SHARED GROUNDWATER AQUIFERS IN THE ESCWA REGION

Groundwater in the ESCWA region is found in numerous aquifer systems with storage and yield characteristics that depend on each aquifer's areal extent and its hydrologic and hydrogeologic properties (ESCWA 1997). Because of the similarity in the geologic history of the region, the same rock unit would often form a producing aquifer in two or more countries. That is why many of the major aquifers are shared between two or more member states (e.g. the Paleogene aquifer in the Arabian Peninsula or the basalt aquifer between Syria and Jordan) and with non-member states (e.g. the Nubian Sandstone between Egypt and other North African countries). Some hydrogeological units in the region are also vertically interconnected. Numerous investigations have been carried out for these aquifers, at the individual state and sub-regional levels.

Our objective in this section is not to provide a detailed description of the hydrogeology of the shared aquifers but rather to point out their occurrence and potentials for sharing. However, before proceeding, an overview of the magnitude and significance of shared groundwater resources is warranted.

Studies of total groundwater storage in the region give extremely variable estimates. To illustrate these discrepancies, the values reported by Abu-Zeid (1993) and AbdelMajeed (1997) are shown in Table (24).

Table (2): Groundwater resources in the ESCWA region

Country	Underground storage (billion m^3)[a]	
	AbuZeid (1993)	Abdel Majeed (1997)
Iraq, Jordan, Lebanon, Palestine and Syria	12	110
Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE & Yemen	860*	362*
Egypt (from Nubian sandstone basin)	6,500**	11,400***
Total	7,372	11,872***

a It is not clear whether this is the total storage or the exploitable storage. The latter depends on the technology and economics

* Including Sudan, Somalia and DeJibuti. No single number for Egypt is given.

** CEDARE estimates that the total storage in the Nubian Sandstone Aquifer System at 150,000 BCM.

*** The estimates for the Arabian Peninsula seem to be conservative, as recent investigations by Komex (1997) in south-eastern Yemen indicated that groundwater storage in the Paleogene aquifer could be in the order of 2,000 BCM.

Despite these discrepancies, it can be said that considerable quantities of groundwater are stored in major aquifers in the region. Noting that the current groundwater extraction are estimated at around 30BCM per year, it is envisaged that groundwater will have an expanding role in offsetting the deficit and meeting the growing demands, especially in those countries facing difficulties with their surface water supplies.

It is to be noted, however, that having a considerable *total* reserve is one thing and having that reserve available at the countries and localities where it is most needed is another. In other words, the question of where and for what purpose can shared aquifers be developed remains to be workout on a case-by-case basis.

4.1 Major Shared Groundwater Aquifers in the Region

Table (3) summarizes the main features of the region's eight major shared aquifer systems.

Table (3): The main features of the region's eight major shared aquifer systems (ESCWA, 1998)

Aquifer	Regional extent and main features
a) *Eastern Mediterranean carbonate aquifer system*	part of the Eastern Mediterranean basin (48,000 km²). Jordan, Lebanon, Syria and the occupied territories. two major units: a lower Jurassic unit and an upper Cenomanian-Turonian unit
b) Jebel el-Arab basaltic aquifer system	part of the Horan and Arab Mountain (15,000 km²) extending through Jordan, Saudi Arabia and Syria. complex layering of basalt flows of different ages
c) *Jezira Tertiary limestone aquifer system*	Jezira area of Syria to Turkey
d) *Jezira Lower Fars-Upper Fars aquifer system*	extends over the vast Mesopotamian plain of the Lower Jezira of Syria and in Iraq
e) *Western Arabia sandstone aquifer system*	The Rum-Saq-Tabuk subsystem (northern Saudi Arabia to Jordan); Minjur subsystem (the middle of the Riyadh area); and the Wajid subsystem (southern Saudi Arabia and northern regions of Yemen). Four principal sandstone aquifers (Saq, Tabuk, Wajid and Minjur) ranging in age from cambrian to Triassic
f) *Central Arabia sandstone aquifer system*	comprises the Biyadh and Wasia sandstones in Saudi Arabia. Aquifer outcrops extend from W. Al-Dawasir in Saudi Arabia to Rutba in Iraq. Cretaceous age
g) *Eastern Arabia Tertiary carbonate aquifer system*	East Arab Peninsula basin covers a 1.6 million km² area extending through the Gulf states, Iraq, Jordan, Syria and Yemen (Umm er Radhuma, Dammam, Neogene sandstone, sandy marl and chalky limestone consists of a sedimentary complex of limestones and dolomites (FAO 1979).
h) Nubian sandstone aquifer system	Nubian sandstone basin (2.35 million km² area) extending through Egypt (0.85 million km²), Sudan (0.75 million km²), Libya (0.65 million km²) and Chad (0.10 million km²). (ESCWA 1992b and Fahmy 1993).

4.2 Past Cooperation On Shared Groundwater

Precedence in the ESCWA region with respect to bilateral or multi-lateral agreements on the use and management of shared aquifers is quite limited. The main reason being the states' classical view of groundwater as a sovereign resource. But another reason is probably the inadequate understanding of the issue of aquifer sharing on the part of decision makers and the less than adequate role on the part of professionals to improve this understanding. An additional handicap has been the weakness of the international water law with respect to groundwater. This weakness undermined the ability of the professionals in the water resources and in the legal fields to build strong arguments to pursue an enhanced cooperation track.

Nevertheless, significant joint efforts to delineate some shared aquifers and assess their potentials have been undertaken. In particular ESCWA, ACSAD, FAO, CEDARE and other regional and subregional institutions have sponsored the following activities:

- Investigations of the Basalt Aquifer System Shared by Jordan and Syria (ESCWA).
- Assessment of the Carbonate Aquifers of the Lower Tertiary (Paleogene) in the ESCWA Region (ESCWA)
- Hamad Basin Studies: involving Iraq, Jordan, Saudi Arabia and Syria (ACSAD).
- Shared Groundwater Resources Studies in the Gulf States (FAO).
- Assessment of the Nubian Sandstone Aquifer System (CEDARE).

5.0 INTERNATIONAL LAW AND SHARED GROUNDATER RESOURCES

Natural resources, in general, are broadly distinguished in international law into three categories:

- those that lie entirely within the confines of a single State and, thus, belong to that State and are subject to its national laws (e.g., a forest, lake, or mineral resource),
- those that are met with outside the territories of States and, thus, belong to the international community and are governed by international law (e.g., the Moon and the sea bed), and
- those that are shared between two or more States. They are of two kinds: *fluids* (liquids and gases) that transit from one State

territory to another or extend over the territories of several States and *animals* that migrate, or whose habitat lies across international frontiers.

Of concern to us, are resources in the last category: shared natural resources. By their very nature, shared natural resources cannot be partitioned between States simply by drawing a demarcation line. A borehole driven by one State into a shared gas deposit (or groundwater aquifer), for instance, may very well extract gas (or water) originating in the other State.

The immediate issue that follows is the extent of State's jurisdiction beneath its territory (i.e., whether or not there is a depth limit for State territory) and whether or not groundwater, considered in terms of depth, is located within the territory of a State.

For the first issue, the general rule in border treaties is that the border line extends vertically into the subsurface, unless otherwise provided. But the extent of the State's subsurface jurisdiction under its territory has been largely neglected in scholarly writings, possibly because of its little practical importance.

However, recent technological advancements have enabled States to reach greater depths in their marine territories and higher elevations in their air space. Hence, similar questions regarding the extent of State's jurisdiction over its continental shelf or air space have been addressed by legal scholars. It is likely that this question will continue acquiring more attention in the coming decades especially with the advent of new technologies to tap the subsurface energy, water, mineral and other resources (FAO, 1986). For now, however, four schools of thought are known. These set the limit of State territory at:

- the centre of the earth,
- the depth where the earth's crust ends and the lithosphere begins.
- the depth where it is technically possible to exploit it,
- the depth at which technology allows effective exploitation, irrespective of whether or not the State is actually able to apply that technology

For the issue of whether or not groundwater is located within the territory of a State, it is noted that there has been no systematic provision for groundwater in treaties and similar international instruments. Legal scholars explain this deficiency as either because States do not attach much importance to disputes that might arise over shared groundwaters or because States' practice in this regard has yielded satisfactory results, without having to embody into their conventions specific provisions regarding groundwater.

Nevertheless, groundwater basins or aquifers are distinguished into national and international, depending on the basin or aquifer configuration with respect to State's boundaries.

A national groundwater basin or aquifer is one which belongs to only one State and is under its exclusive jurisdiction, so it can be referred to as «State-owned aquifer». A «State-owned aquifer» falls entirely within the State's territory, including its recharge area, and it is not hydrologically linked with surface or groundwater in a neighboring State.

On the other hand, an international groundwater basin or aquifer does not belong to a single State because it forms part of an inter-state hydrologic system. Many groundwater basins or aquifers fall in this category. The various field situations or configurations which make a basin or an aquifer international are:

- The basin or aquifer may be traversed by an international boundary leaving parts of it in different States. The aquifer need not be linked hydrologically with other groundwater or surface water and, consequently, only the aquifer itself can be considered a shared resource. A confined aquifer traversed by an international boundary would fit this situation.

- The aquifer is entirely situated within the territory of one State but it is hydraulically connected to an international river. Here, distinction should be made between influent and effluent rivers.

- In the case of an influent river, the aquifer receives recharge from the river so that the use of river water by an upstream State may affect the aquifer recharge. In an effluent river, where the aquifer feeds the river, the excessive exploitation of the aquifer may decrease the flow in the river flow. In both cases, the aquifer, which is entirely within the territory of the State, will form part of an international hydrologic system only if its use affects the water in the system.

- The aquifer is entirely situated within the territory of one State but it is hydraulically connected, through a semi-permeable sandy or silty clay layer, to another aquifer in a neighboring State. In this case, groundwater will percolate from one aquifer to the other depending on the hydraulic head difference. Thus, an increase in the exploitation of one of the aquifers will modify the hydraulic heads and trigger increased groundwater movement towards the more exploited aquifer at the expense of the water reserves in the less exploited aquifer. Excessive exploitation of one aquifer can reverse directions of flow so that an aquifer which naturally feeds another aquifer will cease to do so.

- The aquifer is entirely situated in the territory of one State but its area of recharge is in another State. Such aquifer is often found in mountainous areas where the *water divide* of surface waters does not coincide with that of groundwaters. Modifications made by one State in the recharge area, such as changing its permeability, may effect exploitation of the aquifer by another State.

In the above examples, it is possible that activities affecting an aquifer or a connected river resources or recharge zone within the territory of one country may have an impact that extends beyond its frontiers. Over-pumping of an international aquifer on one side of the border may affect the part located on the other side. Changing a river regime may bring about a change in the water table level in another territory.

Thus, although shared natural resources come within the exclusive jurisdiction of the State in whose territory they happen to be, international law lays down certain norms that need to be respected by sharing States. Moreover, the similarity between legal rules governing the use of various shared natural resources of wildlife, gas, oil and atmosphere warrants the conclusion that there are certain general international law rules that apply to all sych resources (FAO, 1986).

Consequently, there is a "*need to have legal rules governing activities whose consequences may be, or indeed are, felt well beyond the territory of the State in which they are carried out*" (FAO 1986).

5.1 The Evolution of International Groundwater Law

Like surface water and many other natural resources, groundwater knows no political boundaries. An aquifer system can underlie a vast territory within the jurisdictions of several political entities, with discharge and recharge areas in differing jurisdictions and abstractions all throughout its areal extent. Such a physical situation invites contention, be it between states, municipalities or a city and a nearby rural community.

Until recently, however, the international legal regime on the use of shared water resources has been mainly focused on rivers and surface water. Matters relating to shared aquifers were relatively ignored. One reason for this negligence is the inadequate understanding on the part of decision makers and legislators of the physical interrelationship between surface and groundwater resources and of groundwater as an integral part of the hydrologic cycle. Today, most legislators and decision makers continue to regard groundwater sources as dissimilar from surface water with respect to ownership and usage, and omit this resource from the legal regime of international water law. Therefore, the first step in the evolution of the legal regime for groundwater was the acknowledgement of the interrelationship between surface and groundwaters.

Indeed, numerous international legal instruments (treaties, agreements, resolutions of international organizations as well as scientific bodies) recognize that groundwater is deemed to form part of one and the same cycle as surface water. This reciprocal dependence between surface and ground waters is recognized in provisions of many agreements and conventions. FAO (1986) reviewed several such agreements in which explicit catering is made for this reciprocal relationship as well as for the reverse hypothesis that the working of surface waters may affect groundwater.

State practice in using international groundwater is an important element in determining the juridicial regime, since it may provide the basis for developing general or particular customary rules (FAO, 1986). International organizations have in their turn adopted a series of recommendations which consider groundwater as an integral part of the hydrological cycle (e.g., the European Water Charter, 1967; the Declaration of Policy On the Rational Use of water, issued by the Economic Commission for Europe in 1984; the Draft Principles on the Use of Groundwater, prepared by the ECE committee in 1985).

Similarly, the ILA adopted similar resolutions which recognize the reciprocal influence at work between water and other natural resources.

Furthermore, several international treaties and many resolutions made recommendations to the international organizations and scientific bodies to also consider surface water and groundwater as forming part of one and the same cycle (FAO, 1986).

5.2 Particular Cases in International Groundwater Law

International groundwater law and treaty parctice are only at a beginning stage (TECLAFF-UTTON, 1981, pp. 189.). There are only few treaties and agreements that have provisions dealing with groundwater at various multinational (continent, region, catchment basin) and bilateral levels. Furthermore, so far, there has been no international ruling in groundwater. But there is the work being carried out by international bodies, such as the ILA which produced some very useful legal instruments (e.g., the Helsenki Rules and the Seoul Rules).

There are certain cases where shared aquifers are subjected to conventional juridical regimes by the States in whose territory they occur. Some treaties provide for a joint-use regime, others for a special regime.

a) Aquifers Under Joint Use

In international law it is necessary to distinguish between cases in which two States exercise joint sovereignty over a given territory and where two States exercise jointly only its use or its exploitation. The former situation is generally referred to as a «condominium», the second as an international «joint use».

In border treaties subscribed since the 18th century, one may find provisions dealing with groundwater situated along the boundary lines. To facilitate the use of such water by neighboring populations, it is usual to agree that the boundary line should pass through a spring or a fountain and that the two bordering States may use the water in common. One example of this situation is the Franco-British protocol of 1924 establishing the limits between French Equatorial Africa and the Anglo-Egyptian Sudan which provides for the boundary line to pass through several wells. These wells are declared to be of common use by the riparian tribes inhabiting either side of that line([1]).

Another example is the February 1888 agreement between France and Great Britain on the boundary in Somaliland, which establishes: *«les Protectorats exerces ou a exercer par la France et la Grande Bretagne seront separes par une ligne droite partant d'un point de la cote situe en face des puits d'Hadou et dirigee sur Abassouen en passant a travers les dits puits ... Il est expressement convenu que l'usage des puits d'Hadou sera common aux deux parties ...» ([2])*

In each example, the international boundary is clearly determined. Yet, there is also a water resource that is under joint use. This does not require bringing the territory under a condominium, for the community refers only to the use and development of groundwater, but each State continues to exercise jurisdiction within its borders for all other purposes. In case the aquifer dries up, the joint use would cease and the frontier line alone would continue to be enforceable.

b) Legal Regimes Stipulated by Convention

The best known regimes governing specific aquifers are those applying to the groundwater between Mexico and the United States and to the Genevois water table between France and Switzerland.

The question of groundwater between Mexico and the United States has been the subject of many technical and juridical studies ([3]).

The convention for the protection, use and recharge of the Genevois water table was signed on June 9, 1978, between the Canton of Geneva and the Prefecture of Haute-Savoie, and was confirmed by exchange of notes between France and Switzerland on July 19, 1978 and August 11, 1978 ([4]). The treaty creates a commission to supervise groundwater use. It is composed of six members, three appointed by each side, two of whom must be technicians specializing in water matters. The commission fulfills different functions, the main one being proposing an annual plan for the use of the aquifer. The commission also proposes measures designed to protect groundwater against pollution, and gives its technical approval for new withdrawal equipment and for change of the already installed equipment. It is also responsible for verifying building and operating costs for the pumping station that ensures the artificial recharge of the aquifer.

The commission keeps a complete inventory of public and private pumping installations in the two countries. Each installation has a metering device indicating the volume of water taken by each user. The artificial recharge station for the water table is provided by, and is the property of, the Canton of Geneva. France's contribution to defraying the recharge costs is assessed by reference to the amount of water taken by French users together with the contribution to the natural recharge of the aquifer made by French territory. The convention also provides for quality analysis of the water withdrawn and of the water injected in the recharge process.

The commission has at its disposal a system of control which allows it to know with certainty the intensity of use of the aquifer and thus plan withdrawals rationally with the needs of users in mind ([5]).

5.3 Contributions of Various International Organizations to the Evolution of International Groundwater Law

The evolution of international law on groundwater has been lagging behind, compared to surface water, for reasons pointed out earlier.

Historically, national laws have provided for absolute ownership of groundwater and efforts to modify this attitude have largely remained at the national levels (e.g., by declaring the resource a public property). At the international level, groundwater aquifers were considered sovereign resources and the use of international law to limit State's sovereignty over shared aquifers was not warranted. One reason is that decision-makers often find it difficult to recognize the inseparable relationship between surface and ground waters. The root of the problem, however, appears to lie in the way in which modern legal system develops, as a reactionary process to emerging situations rather than a proactive process to prevent predicaments.

In recent decades, the sharing of groundwater resources received the attention of international community. So, efforts to remedy the mishandling of groundwater in international law and integrate shared aquifers into international water law are very recent. These efforts have resulted in comparatively rapid advances in international groundwater law ([6]). The reform came through the work of international organizations which undertake the codification of international customary law pertaining to shared international waters. Most noteworthy of these organizations are the International Law Association (ILA) and the International Law Commission, whose works are summarized below.

a) Work of the International Law Association (ILA)

From the early 1950s, international controversies over water affected most regions of the world and prompted learned international bodies, such as the ILA, to begin studying the law applicable to these disputes. The work of the ILA began in 1954 and, except for seven years, continues to this day([7]).

One of the earliest explicit recognition of the interrelationship of surface and groundwater came in a statement of principles at the 48th Conference of the ILA in 1958 which provided that although international law heretofore focused predominantly on surface water sources, it is essential to give due regard to all of the interdependent hydrological features of a drainage basin.

In 1966, the ILA's early work culminated in the famous "Helsinki Rules on the Uses of International Waters of International Rivers", or the "Helsinki Rules" for short (see Box 1). The Helsinki articles represented one of the earliest attempts at codifying customary international law pertaining to shared international water resources.

Significantly, Article II of these Rules defines an international drainage basin, as a transboundary geographic area defined by the extent of the watershed, "including surface and groundwater."

The overarching general principle of the ILA's work on international water law is contained in Article IV of the Helsinki Rules which provides that the principle of equitable utilization governs the use of the waters of international drainage basins, which includes groundwater.

The Helsinki Rules have played an important role in the codification and progressive development of this branch of international law. States refer to these guidelines till now and some have recommended that elements of the Helsinki Rules be included in the UN's framework convention on watercourses.

Later, in 1986, the ILA adopted the Seoul Rules on International Groundwaters (see Box 2), which expand the Helsinki Rules as they relate to shared international groundwater resources. The Association thus felt that the topic was ripe for restatement, that is, unofficial codification. Paragraph 3 of Article 2 provides that states of a drainage basin must consider the interdependence of "groundwater and other waters, including any interconnections between aquifers . . . ." The inclusion of groundwater in the definition of drainage basin, and the obligation to give due regard to international groundwater resources, affirms the premise that groundwater is subject to contemporary international water law.

BOX 1 HIGHLIGHTS OF THE THE HELSINKI RULES

The ILA discussed the international river problems in its 47th and 48th conferences held, respectively in Dubrovnic in 1956 and New York in 1958 in an attempt to lay down rules to be applied on the utilization of international rivers. At its meeting of August 1966 in Helsinki, a set of articles was adopted. These articles, commonly known as the «Helsinki rules», founded a new concept of cooperation and understanding between riparian states. The following paragraphs highlight the main articles in the rules.

Article 1 points out that "the general rules of international law as set forth in these chapters are applicable to the use of the waters of an international drainage basin except as may be provided otherwise by convention, agreement or binding custom among the basin States."

Article 2 defines an international drainage basin "*a geographical area extending over two or more states determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus*".

Article 3 defines a basin state to be a state the territory of which includes a portion of an international drainage basin.

Article 4 states that "*each basin state is entitled to a reasonable and equitable share in the beneficial uses of the waters of an international drainage basin*". According to the ILA, this Article reflects the key principle of international law in this area, that every basin state in an international drainage basin has the right to a reasonable use of the waters of the drainage basin.

Article 5 laid down the criteria of a reasonable and equitable utilisation of the waters of an international drainage basin by stating that:

"1) What is a reasonable and equitable share within the meaning of article 4 iis to be determined in the light of all the relevant factors in each particular case.

2) Relevant factors which are to be considered include, but are not limited to:
   a) the geography of the basin, including in particular the extent of the drainage area in the territory of each basin state;
   b) the hydrology of the basin, including in particular the contribution of water by each basin state;
   c) the climate affecting the basin;
   d) the past utilisation of the waters of the basin, including in particular exiting utilisation;
   e) the economic and social needs of each basin state;
   f) the population dependent on the waters of the basin in each basin state;
   g) the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
   h) the availability of other ressources;
   i) the avoidance of unnecessary waste in the utilisation of waters in the basin;
   j) the practicability of compensation to one or more of the co-basin states as a means of adjusting conflicts among uses; and
   k) the degree to which the needs of a basin state may be satisfied, with out causing substantial injury to a co-basin state.

3) The weight to be given to each factor is to be determined by its importance in comparison with that of other relevant factors. In determining what is a reasonable and equitable share, all relevant factors are to be considered together and a conclusion reached on the basis of the whole».

BOX 2 THE SEOUL RULES ON INTERNATIONAL GROUNDWATERS

(Adopted by the International Law Association at the 62nd. Conference Held at Seoul in 1986)

Article I (The Waters of International Aquifers)

The waters of an aquifer that is intersected by the boundary between two or more States are international groundwaters if such an aquifer with its waters forms an international basin or part thereof. Those states are basin States within the meaning of the Helsinki Rules whether or not the aquifer and its waters form surface waters part of a hydraulic system flowing into a common terminus

Article II (Hydraulic Interdependence)

1. An aquifer that contributes water to, or receives water from, surfacewaters of an international basin constitutes part of an international basin for the purposes of the Helsinki Rules.

2. An aquifer intersected by the boundary between two or more States that does not contribute water to, or receive water from, surface waters of an international drainage basin constitutes an international drainage basin for the purposes of the Helsinki Rules.

3. Basin states, in exercising their rights and performing their duties under international law, shall take into account any interdependence of the groundwater and other waters including any interconnections between aquifers, and any leaching into aquifers caused by activities and areas under their jurisdiction.

Article III: Protection of Groundwater

1. Basin states shall prevent or abate the pollution of international groundwaters in accordance with international law applicable to existing, new, increased and highly dangerous pollution. Special consideration shall be given to the long-term effects of the pollution of groundwater.

2. Basin states shall consult and exchange relevant available information and data at the request of any one of them:

   a) for the purpose of preserving the groundwaters of the basin from degradation and protecting form impairment the geologic structure of the aquifers, including recharge areas;

   b) for the purpose of considering joint or parallel quality standards and environmental protection measures applicable to international groundwaters and their aquifers.

3. Basin states shall cooperate, at the request of any one of them, for the purpose of collecting and analyzing additional needed information and data pertinent to the international groundwaters or their aquifers.

Article IV (Groundwater Management and Surface Waters)

Basin states should consider the integrated management, including conjunctive use with surface waters, of their international groundwaters at the request of any one of them.

b) Work of the International Law Commission

As pointed out earlier, this UN body was entrusted with drafting of the UN Convention on the Non-navigational Uses of International Watercourses. It prepared the Draft Articles of the Convention as well as a Draft Resolution on « *Confined Transboundary Groundwater* » which lays down guidelines and general principles regarding these resources.

The Convention acknowledges the surface water- groundwater inter-relationship when it defines, in Article 2, a "watercourses," as "*a system of surface and ground- waters constituting by virtue of their physical relationship a unitary whole* . . . ." In recognizing that the two sources of water constitute a part of a unitary whole, the ILC acknowledged the fact that groundwater is governed by international water law. Moreover, as the Convention Articles are based on state practice, existing international agreements, and other potential sources, they are regarded as obligatory and operative insofar as they codify current customary international law. However, it is important to point out that the above definition of a watercourse creates some problems as to its applicability to groundwater. Several legal scholars have pointed out that the Convention applies only to non-confined aquifers.

The «*Confined Transboundary Groundwater*» resolution lays down guidelines and general principles regarding the confined transboundary aquifers. The text of the draft resolution is as follows:

" The International Law Commission,

Having completed its consideration of the topic «The law of the non-navigational uses of international watercourses»,

Having considered in that context groundwater which is related to an international watercourse,

Recognizing that confined groundwater, that is groundwater not related to an international watercourse, is also a natural resource of vital importance for sustaining life, health and the integrity of ecosystems,

Recognizing also the need for continuing efforts to elaborate rules pertaining to confined transboundary groundwater,

Considering its view that the principles contained in its draft articles on the law of non-navigational uses of international watercourses may be applied to transboundary confined groundwater,

1) Commends states to be guided by the principles contained in the draft articles on the law of non-navigational uses of international watercourses, where appropriate, in regulating transboundary groundwater;

2) Recommends states to consider entering into agreements with the other state or states in which the confined transboundary groundwater is located;

3) Recommends also that, in the event of any dispute involving transboundary confined groundwater, the states concerned should consider resolving such dispute in accordance with the provisions contained in article 33 of the draft articles, or in such other manner as may be agreed upon.

c) The 1989 Bellagio Draft Treaty

In view of the lack of internationally recognized legal and institutional norms for the utilization and management of shared aquifers, and the weakness of the existing institutions dealing with international aquifers, the need for a model or "blue-print" treaty became apparent. The Bellagio Draft Treaty was developed in response to this need. Specifically, it was developed:

- to be used as a blueprint for treaties regulating international groundwater resources,
- to facilitate cooperation, and
- to achieve optimum utilization of the resource.

The Draft Treaty was crafted by a multidisciplinary group of specialists which worked on it over a period of eight years. It provides mechanisms for international aquifers to be managed by mutual agreement rather than continuing to be subjected to unilateral taking. The Treaty addresses contamination, depletion, drought and transboundary transfers as well as withdrawal and recharge issues. The fundamental goal is to achieve joint, optimum utilization and avoidance or resolution of disputes over shared groundwaters.

The Bellagio Draft Treaty is yet another example of an international instrument which considers groundwater within the unitary whole of the hydrologic cycle.

The preamble to the Draft Treaty provides that the "conjunctive use of surface and groundwater" resources is the foremost means of achieving rational and efficient water use while simultaneously safeguarding those resources for the future. The Treaty created a theoretical commission and empowered it to declare shared conservation areas, protect water quality and establish comprehensive management plans for the rational use of waters in the shared area.

Unfortunately, the Bellagio Draft Treaty has not yet been adopted as an actual treaty, perhaps because it would significantly threaten the autonomy of nations sharing groundwater. In addition, it is not clear that the commission established by the treaty could effectively address the vast array of issues presented by various groundwater disputes.

d) Work of Other International Organizations

Many other international organizations carried out numerous works in which the surface water- groundwater inter-relationship and the need to follow an integrated approach when dealing with international watercourse systems were recognized. Examples of such works are those by the European Economic Community (EEC) and The United Nations Economic Commission for Europe (ECE).

The EEC issued several directives acknowledging that groundwater is subject to international water law. Directive 80/778, for instance, dealing with the Quality of Water Intended for Human Consumption, states in Article 2 that "water intended for human consumption,".... is any water used for that purpose, *regardless of its origin.*

The ECE, in a 1986 report on ground water legislation in the ECE region, acknowledged that "the interrelationships between surface and groundwater are various, frequently pervasive and of great practical significance." The Report endorsed that greater efficiency in use, storage and conservation, as well as improved overall administration of water resources could be achieved through an integrated approach towards these resources. In addition, the ECE Charter on Ground-Water Management asserts that groundwater protection policies should be included within the rubric of comprehensive environmental protection strategies.

5.5 Applicability of the UN Convention On Non-navigational Uses of International Watercourses to Shared Groundwater Aquifers

Recent legal works such as the Bellagio Treaty, the Seoul Rules, the ECU Charter on Groundwater Management indicate a shift to recognize the applicability of international law to groundwater resources equally and without distinction. This application is founded on the indissociable nature of and interdependency between the two water resources, such that they cannot be utilized or protected adequately or efficiently unless they are considered simultaneously under the same rubric of management and law. In this regard, legal scholars commonly refer to three principles of international water law which they consider equally applicable to shared ground and surface water resources. These are: the equitable and rational use, the no significant harm and the prior notification principles.

However, it is important to point out that the difficulties in applying these principles to groundwater aquifers are much more than applying them to surface water. Some of the difficulty lies in the complexity of delineating subsurface extensions and hydrogeologic properties of aquifers, so as to enable assessment of storage, allocations, and optimal pumping plans. Other difficulties arise when interconnections between surface and ground waters are considered, as detailed in the following section.

A close examination of the UN Convention reveals that its provisions promote a piecewise governance of water resources, by separating surface from groundwater resources. This is especially apparent in Articles 1 and 2.

While Article 1 limits application of the Convention only to "international watercourses," Article 2 defines "watercourse" as "*a system of surface waters and ground-waters constituting by virtue of their physical relationship a unitary whole and normally flowing to a common terminus*." Although this definition appears innocuous, it is important to point out what is not included in the definition.

Firstly, the *definition excludes water resources which are related but do not "flow to a common terminus."* Thus, for instance, water infiltrating from a stream to an underlying aquifer may, because of certain hydrogeologic characteristics, end up flowing towards different termini than the stream water. Under this condition, a use or management scheme which is developed for the stream would not be bound under the Convention to take into account concerns of those whose groundwater interests might be affected, quantity or quality-wise, by the scheme. Since almost every country in the world shares a groundwater aquifer with one or more countries, such a situation is extremely disturbing.

Secondly, and consequent to the first point, *the definition excludes water resources that are indirectly related.* For example, a third water resource directly related to the above mentioned aquifer but not to the stream would likewise be indirectly related to the stream. Thus, any use or management scheme developed for the stream would not have to consider the effects on the indirectly related water resources, again implicating the potential for disputes between states over the impacts of the scheme on water quality and quantity.

Finally, the Convention *excludes from the scope of "watercourse" aquifers unrelated to surface water*. In the context of hydrologic reality, this limitation ignores regions where surface water is sparse or nonexistent, such as arid and desert environments in which groundwater aquifers often traverse international boundaries.

This complex, and narrow, definition of a watercourse has caused misunderstandings and misuse of hydrogeologic terminology. The first such misuse occurred at the ILC, which drafted the Convention, when it misdefined groundwater that is not related to surface water to mean water in confined aquifers. Hydro-geologically, it is known that confined aquifers can be, and often are, related to surface water. So, in effect, this misuse of terminology has caused an unwarranted exclusion by the Convention of confined aquifers.

The ramifications of the misuse of terminology are two fold:

- Firstly, states may embark on strategies designed to use, regulate, or manage a particular water resource without regard to the consequences of such action on related but excluded water resources.

- Secondly, it permits the possibility that related water resources will be used or regulated under different systems that assert diversified and perhaps conflicting objectives.

For instance, an aquifer that is proven unrelated to any surface water resource in the region (and receives only negligible recharge through occasional rains and rare flash flood) will fail to fit under the UN Convention's definition of an international watercourse. Thus, as long as an aquifer neither forms part of a "*system of surface and groundwaters constituting ... a unitary whole*" nor flows to a "*common terminus*" with any other surface water, then any exploitation or management scheme of this aquifer by one or more of the nations sharing it would be exempt from abiding by the principles of the Convention, regardless of the potential or actual consequences to the quality or quantity of the water in the aquifer.

6.0 THE NEED, DRIVES AND POTENTIAL BENEFITS OF ENHANCED COOPERATION OVER SHARED WATER RESOURCES IN THE ESCWA REGION

In recent decades, the increased water stresses in many countries, resulting from growing water deficits, quality degradation and heightened tension between upstream and downstream states, has magnified the need for cooperation to protect shared river and aquifer resources. It has also improved the attitudes and resulted in better perception of issues and increased willingness of states to cooperate. There is now a wider recognition among countries of the need and benefits of cooperation to protect and sustain the use of shared water resources.

Evidence of this change may be found in the greater UN role in this regard and in the many cooperation agreements which have been reached with the assistance of various regional and international organizations. Examples my be drawn from the recent UN Convention on the Law of the Non-navigational Uses of International Watercourses and the EEC's charters on water quality protection and on groundwater management. It is argued that a similar mechanism for groundwater cooperation is much needed for the ESCWA region. The logical forum to develop and promote such a mechanism would be the Intergovernmental Committee on Water Resources (IGCWR) which was established in May 1995 by resolution of ESCWA's Ministerial Session.

The need of ESCWA countries to enhance cooperation on shared aquifers stems mainly from the growing water deficit, the increasing threats faced by downstream riparian states to the quantity and quality of water inflows from shared river, and the expected increase of groundwater abstractions to meet the water deficits. Groundwater is expected to play an increasingly important role, even in countries which traditionally depend on shared rivers. Often, the downstream states are nowadays challenged by the unprecedented ability of upstream riparian states to control or reduce the quantity or quality of downstream flow by building huge dams and discharging considerable volumes of liquid waste.

Therefore, for countries with significant fossil groundwater reserves stored in deep shared aquifers, it inevitable that increased abstractions from these sources will be sought and more attention will be given to shared groundwater management in general. Indeed, recent institutional reform in certain member countries (e.g., Egypt), through which greater attention was given to groundwater management, seem to support this anticipation.

A. The Drives and Potential Benefits of Cooperation Regarding Shared Aquifers

1. The Drives for Cooperation

Given that the present day recharge of most shared deep aquifers is much less than the anticipated abstractions, most of these aquifers will be essentially mined. Under this condition, it would be to the advantage of states to enter into dialogue to arrive at mechanisms to jointly utilize and manage such resources. Without equitable allocation of the resource, states can easily enter into a competition process which adversely affects the resource and can have a variety of political, socio-economic and environmental consequences. It these potential consequences which constitute the drives or motivations for dialogue and for the development of a cooperation mechanism over shared aquifers in the region.

a) Political Drives

The main political drive for initiating cooperation on shared aquifers is to avert disputes by eliminating or reducing potential tension over the shared groundwater.

Like surface water, groundwater knows no political boundaries. The mere fact that an aquifer system can underlie a vast territory, with discharge and recharge areas in differing jurisdictions and abstractions throughout its areal extent, invites conflict of interest, be it between states, municipalities or a city and its surrounding rural communities. At the international level, the need to avert potential disputes over such an aquifer is in the interest of all sharing states. The alternative would be to enter into uncontrolled exploitation of the aquifer, which could lead to irreversible aquifer damages and adverse impacts on the economies and relations between sharing states. On the other hand, ignoring the issue would neither make the problem disappear nor serve the management of the resource.

In the ESCWA region, where the demands are growing and considerable proportions of the supplies are often met from shared systems, the potential for disputes is quite high and a number of cases are already apparent at various bilateral and multilateral levels, and even at local levels (city vs. semi-urban regions).

b) Socio-economic Drives

Water importance for basic survival and for food and energy production as well as for numerous other fundamental needs and activities of the society gives this resource an extremely important role in socio-economic development. In the ESCWA region, this role is even more important in view of the growing water demands, increasing water scarcity and ambitious socio-economic development plans.

In essence, states would enter into legal arrangements for cooperation over the utilization and management of shared aquifers motivated by desire to achieve certain socio-economic gains. Most important gains that can be identified are:

i) *Meeting the Growing Demand:* As pointed out earlier, the water deficit in the ESCWA region is expected to grow to about 69 BCM by the year 2025. Since the potential for augmenting the surface water supplies is generally limited, besides being more vulnerable to external influences, it is likely that increased mining of fossil groundwater will be the most logical choice for many member states to cover the deficit, which is already happening in many states. It is, therefore, in the interest of sharing states to enter into proper legal arrangements to facilitate equitable exploitation of their shared aquifers to meet the demand.

Competition for shared groundwater without a joint management plan would likely lead to mutually damaging mining of the shared aquifer. In addition, joint management of the abstractions would help achieve a certain degree of resource sustainability.

ii) *Protecting the Interests of Sharing States:* Without cooperation, uncontrolled exploitation of a shared aquifer is likely to damage the medium and long term economic and social interests of states which are not presently tapping the resource at all or not utilizing it as extensively as other sharing states. In either case, this condition means that some sharing states will be deprived of their right in the future to an equitable share of the resource, which could lead to increased tension between concerned states.

Ideally, a legal regime for cooperation would contribute to safeguarding the interests of all sharing states, now and in the future.

iii) *Creating Opportunities for Broader Economic Cooperation:* Water cooperation can create opportunities for broader economic cooperation. This is especially true when the shared aquifers are developed in heavily populated border areas and where water is used in economic activities that have the potential to create economic interests for other sharing states. Conversely, if opportunities for water-related mutual benefits could be identified and pursued, they can also reinforce dialogue not only over the primary cooperation area of water but also beyond.

A legal regime for cooperation would include appropriate arrangements for encouraging water related economic activities, for cost sharing arrangements and for other aspects of broader economic activity.

c) Environmental Drives

Environmental drives for elaborating a legal regime to manage shared aquifers essentially stem from the adverse environmental impacts of competitive pumping. Competitive pumping can damage the aquifer mechanics, lead to water quality deterioration, cause excessive lowering of water levels, and potentially damage the related ecological systems. In many situations, these adverse impacts (or externalities) might make it impossible for individual states to set appropriate plans for resource use and management unless they enter into arrangements to establish equitable and reasonable allocation / optimal exploitation of the shared resource.

Specifically, the following environmental drives for enhanced cooperation might be identified:

i) Resources Conservation: a shared aquifer that is being utilized without user coordination can easily be abused, by overexploitation or quality degradition, as each party would seek to pump as much as it could before the other party. Hence, restraint and proper planning are necessary for managing a shared aquifer.

Uncontrolled competitive pumping or mining of shared aquifers can harm all parties involved by causing costly lowering of the piezometric/water levels and possible water quality degradation, if and when changing gradients induce inter-flow of low quality water. We stress her that all parties, not just the downstream riparians, could suffer. Indeed, unlike shared rivers where the upstream riparian state often has absolute and permanent leverage over downstream states, the leverage of an upstream state in a shared aquifers is often *limited* and *largely dependent on field hydro-dynamic conditions*, particularly when the regional hydraulic gradients are small and easy to manipulate and reverse. Firstly, this leverage is limited because an upstream state in a shared aquifer cannot entirely "cut-off" the flow to a downstream state. Secondly, the leverage depends on field conditions because an upstream state can find itself on the defensive when its excessive pumping from the aquifer reverses the hydraulic gradient and induces flow of polluted water from a downstream state. This vulnerability of both upstream and downstream states is yet another strong motive for sharing states to cooperate. Only through cooperation and an integrated approach towards shared aquifers will states be able to conserve and manage these resources effectively.

ii) Enhanced Resource Planning and Management: Cooperation contributes to improved planning and management of the shared resource. Delineation of the scale of groundwater development through agreement would eliminate uncertainty in the planning process. The objective is to avoid resource abuse, which could be detrimental to both the economy and the environment, and to maximize the benefits to all parties involved. The pre-requisite for this, of course, is good bilateral or multilateral relation.

2. The Potential Benefits of Cooperation

Water importance for basic survival and for numerous other fundamental needs and activities of the society makes it an exceptional resource in terms of the numerous opportunities it can create for cooperation and the many other potential benefits which such cooperation can generate. From the above discussion, the benefits that can be achieved by enhanced cooperation over shared aquifers can be summarize as follows:

- Averting potential disputes.
- Securing the growing water demands and protecting the water rights of parties involved.
- Creating new opportunities for broader socio-economic cooperation.
- Conserving the resource and reducing adverse mutual impacts.
- Reducing uncertainty in the planning of socio-economic activities which depend on the shared aquifer.
- Improving the management of the resource, and hence sustainability of the economic growth.

B. Constraints or Difficulties Hindering Cooperation

The difficulties of developing cooperation on shared rivers dwarf in front of those relating to shared aquifers. In general, these difficulties may be distinguished into technical, political, legal and institutional.

1) Technical Difficulties

Technical data are essential to develop an equitable allocation and use regime for a shared aquifer. Basically, data are needed to estimate the volume of water in the aquifer, plan the abstraction scheme, make allocations, design well- fields and manage the aquifer. More specifically, the requirement here is a thorough understanding of the aquifer's hydrogeology, its subsurface extensions, the direction and velocity of water flow, the storage volumes on both sides, the zones and quantities of recharge, the quality variations, the hydrogeologic properties and the long-term impact of abstractions across borders.

The technical difficulties lie in assessing and harmonizing the above parameters. Water professionals on both sides can often find themselves having data that contradict each other's argument.

2) Political Difficulties

Cooperation requires good political relations among sharing states. Strained relations in the region could slow water cooperation. However, it could also be argued that continuing water shortages can encourage dialogue and help restore relations, especially that water scarcity is becoming an important issue on the agendas of politicians in the region. The need to secure water supplies and maximize benefits from shared aquifers will facilitate building the required legal cooperation arrangements.

Another related problem, is the lack of political will and understanding by the decision makers and judicial community of the seriousness of the various legal, social, economic and scientific issues related to water resources and the need for enhanced management and enhanced cooperation on shared water resources. Adequate understanding is required in order to develop policies and laws that effectively address modern water problems. To educate these communities, the technical and scientific community must become more involved in the political, legislative and judicial process, and must be embraced by those communities so as to ensure compatibility between science and policies, regulations, and management and conservation schemes. This integrated approach is a must to enable states to use, manage, and protect their shared resources efficiently and effectively, for present needs and for future generations.

3) Legal Difficulties

The legal difficulties occur at the international and national levels. Internationally, states have traditionally considered groundwater as a sovereign resource. Laws emphasize a state's sovereign right to exercise control over its own resources. Hence, the international legal regime for management of shared aquifers is relatively much less developed or clearly defined than that for shared surface water resources. There is, however, an increasing recognition for the need for groundwater protection at the international level, but the law is not yet sufficient to control the exploitation of shared aquifers. Indeed, there is no internationally accepted legal regime for the exploitation of shared aquifers, although the Bellagio treaty might be a useful blue print or starting point in this regard.

At the national level, the difficulty lies in that the law has provided for absolute ownership of groundwater. In many member countries, there are still provisions which consider groundwater as part of the land . . . or as a commodity, susceptible of ownership through the act of capturing it by sinking a well. Modification of this approach is required so as to recognize the international dimension of this resource.

Another difficulty is that the development of the required legal regime might seem, to politicians and legislators, an anticipated rather than a manifested need. Even if the need may manifest itself before a crisis emerges, society as a whole rarely if ever comes to demand proactive legislation. Indeed, as some legal scholars would suggest, the creation or progressive development of law comes only as a direct reactionary response to the changing needs of the society (Eickstein, 1995). In essence, therefore, the call for a framework agreement on shared aquifers in the region might not receive the required response from the decision makers unless there is a manifested need.

4) Institutional Difficulties

Management of water resources at the regional level requires strong water institutions at the national levels as well as harmonized sector policies and objectives. Weak national institutions would inevitably hinder the implementation of joint management plans of shared aquifers.

The principle institutional difficulty with respect to shared aquifers is the weakness of the water management institutions at the national levels. Often, the organization and division of the various technical, institutional, managerial, legal and operational activities and responsibilities of water resources management among the many key actors in the sector in a given country is not clear. The fragmentation of the water interest over many different governmental and non- governmental bodies with little or no coordination among them is a common problem in ESCWA countries. Another common problem is the weak enforcement of regulatory policy (water legislation).

C. Basis and Requirements for Enhanced Cooperation

1) Basis for Enhanced Cooperation

When no agreement governs the relations of states sharing an international watercourse or basin, the basis for cooperation must be founded on internationally accepted legal norms. There are three key principles of international law that act to limit a state's sovereignty with respect to the development of shared aquifers.

- First, states are entitled to "a reasonable and equitable share of the beneficial uses of the waters."
- Second, states are obligated not to cause each other substantial injury with regards to water quantity or quality.
- Third, states have a duty to inform, consult, and participate in negotiations with each other regarding development plans and projects affecting shared water resources.

Any legal arrangements to augment and enhance cooperation among ESCWA member states regarding shared aquifers must be founded on these three principles.

2) Requirements for Enhanced Cooperation

A legal regime to enhance cooperation among ESCWA countries regarding shared aquifers is a necessary condition or requirement. In a broader approach, however, what the region needs is a *cooperation mechanism* on shared aquifers, of which the legal regime is a component. It is realized the process of developing such mechanism is to be steered by ESCWA Secretariat through the IGCWR.

It is worth pointing out that accomplishing this scheme would require essential inputs from numerous entities as well as some pre-conditions which would have to be met. Among these are:

Institutional reforms: the international dimension of shared water resources must be recognized to enable the building of strong institutions to guarantee the sustainable use of shared aquifers. States need to cooperate in creating the strong institutions which are empowered to regulate water use and which can proactively manage use and resolve disputes before crises develop. Currently, general principles of international law often govern groundwater disputes by default, but the adjudication of these disputes does not effectively address underlying problems. Groundwater disputes involve complicated scientific issues that judges may not be qualified to resolve, and adjudication creates an adversarial relationship which prevents future cooperation between the states involved.

The legal regime should provide an institution with the power to conduct scientific research, implement and construct water conservation projects, apportion and regulate the use of the groundwater, and adjudicate international groundwater disputes free of diplomatic constraints. Although granting these powers to an institution would threaten the autonomy of the subject states, the regime would benefit the economy and the environment of the states. Disputes would no longer be resolved on a case-by-case basis and sustainable use would be ensured.

It should be pointed out that the international community has many examples of transfer of sovereign powers from sharing states to a joint basin management authority (e.g., Senegal River). For the region, there is a good experience in establishing institutional arrangements for the development of another important natural resource: oil. In this regard, two types of arrangements are known in this sector; namely: the creation of the so called "neutral zones" and the straight concessions under what is called Production Sharing Agreements. It is worthwhile to investigate the legal feasibility of drawing upon these arrangements to develop appropriate arrangements for shared aquifers.

Legal reforms: where shared international water management and protection schemes are contemplated, an integrated approach must be undertaken. This requires cooperative efforts and communication among co-riparians based upon the principles previously discussed. It also requires legislative reforms in the national water laws, to recognize shared international aquifers and to enable establishing appropriate mechanisms for management of these resources.

Since the national legal regimes are often not prepared to deal with the many problems associated with equitable use of shared aquifers, a legal regime for cooperation must be developed. Because management will involve substantial investment of resources, states must recognize the long-term economic and environmental benefits of management and absorb the short-term costs. Thus, the regime should incorporate arrangements to share the substantial investments required to monitor, conserve and manage the resources effectively and efficiently.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

1. The ESCWA region will continue to face a growing water deficit, which is estimated to reach 69 BCM/ year by the year 2025, or about 35% of the estimated renewable plus non-conventional supplies, taking into account the expected increase in the utilization of non-conventional resources.

2. It is postulated that this water deficit will increase the pressure on fossil groundwater aquifers, which are mostly shared regional aquifers. Competition over these resources, which is likely to develop, could trigger or increase tensions, especially when no bilateral agreements exist to manage these shared aquifers.

3. To diffuse tensions and optimize the utilization and management of shared aquifers, the region needs to develop cooperation mechanisms over these important resources. Such a mechanism, which is to be developed in close coordination with ESCWA's Inter-governmental Committee on Water Resources (GCWR), can be referred to by member states to facilitate their cooperation.

4. The disadvantages of the lack of cooperation and potential benefits of cooperation far outweigh the possible constraints or difficulties in developing the needed cooperation regime. Therefore, it is in the interest of member states to pursue cooperation enhancement measures.

5. Notably, previous efforts by ESCWA and other regional organizations have resulted in a number of cases of good groundwater cooperation in the region. Examples include studies of the: Hamad Basin, the basalt aquifer between Jordan and Syria, the Paleogene carbonate aquifers, and the Nubian Sandstone Aquifer System (NSAS). These cases of cooperation must be assessed to draw lessons for developing the cooperation mechanism.

6. While the development of international law on shared aquifers has been lagging behind, compared with shared rivers, it is generally accepted that the same internationally recognized legal norms which apply to surface water could also be applied to groundwater. These rules are:

- First, states are entitled to "a reasonable and equitable share of the beneficial uses of the waters."
- Second, states are obligated not to cause each other substantial injury with regards to water quantity or quality.
- Third, states have a duty to inform, consult, and participate in negotiations with each other regarding development plans and projects affecting shared water resources.

Any legal arrangement to strengthen cooperation among ESCWA member states regarding shared aquifers must be founded on these three principles. However, additional efforts are needed at the national, regional and international levels to refine these rules to make them suitable for shared aquifers.

7. In essence, coordination to regulate abstractions and minimize mutual harms arising from competitive pumping of shared aquifers is needed, regardless of the magnitude of recharge to an aquifer, be it a deep confined aquifer in an arid zone where the recharge may be negligible or a shallow confined aquifer in a wet area with considerable direct or indirect recharge.

8. The need to enhance cooperation in the region regarding shared aquifers stems from political, socio-economic, and environmental drives. Political drives consist of dispute aversion and the need to elaborate agreeable dispute management procedures. Socio-economic drives comprise meeting the growing demand, protecting the interests of sharing states, and creating opportunities for broader economic cooperation. Environmental drives comprise resource conservation and enhanced resource planning and management.

9. The potential benefits of cooperation are: averting potential disputes, reducing uncertainty in the planning of socio-economic activities which depend on the shared aquifer, securing the growing water demands, protecting the water rights of parties involved, creating new opportunities for broader socio-economic cooperation, conserving the resource and reducing adverse mutual impacts, and improving the management of the resource and hence sustainability of the economic growth.

10. Technical, political, institutional and legal difficulties hinder the development of a cooperation regime. The technical difficulties are related to securing and harmonizing the data needed to properly assess the storage and develop an equitable allocation and use. Sometimes, political relations in the region could become a constraint on water cooperation. But it is arguable that water stresses, together with the opportunities which water cooperation can create, will encourage dialogues leading to favorable relations. Legal difficulties stem from the fact that states consider groundwater as a sovereign resource. Laws emphasize a state's sovereign right to exercise control over its own resources. The same treatment is sometimes reflected at the national level where the law grants absolute ownership of groundwater. Hence, legal reforms will be required to accommodate the international dimension of this resource.

The principle institutional difficulty is the weakness of the institutional arrangements for management of water resources at the national levels. However, over the past decade or so, the water sector in many ESCWA countries underwent extensive institutional and legal reforms to overcome the problem of fragmentation and many of the institutional weakness have been overcome.

7.2 Recommendations

Increasing utilization of shared water resources is a potential source of tension among states. It is argued, however, that the vital importance of these resources can often overcome the constraints on cooperation and lead to "equitable" sharing agreements. Not only that, but these resources can also become a medium for cooperation that goes beyond the mere allocation of water to build broader socio-economic interests among member states. Therefore:

1. Member states, are strongly encouraged to openly address their water sharing issues, assess their cooperation needs and develop the necessary policies in this regard, if none exist. The mandate of ESCWA's Inter-governmental Committee on Water Resources (IGCWR), which was established in 1995 by ESCWA's Ministerial Session, makes it the suitable forum for enhancing cooperation in this regard.

2. The region needs to have a cooperation mechanism on shared aquifers. The starting point in the process of initiating the proposed mechanism for cooperation on shared aquifers is to prepare a "*Framework for Enhanced Groundwater Cooperation*" to be presented to the IGCWR for ratification. ESCWA can provide the

support needed for the development of the desired cooperation mechanism. Member States are encouraged to join this process.

3. Water professionals and managers are encouraged to assume a proactive role to raise awareness among decision makers in member states of the need for and benefits of cooperation and to highlight the necessity of a cooperation mechanism to achieve the optimum sustained yield of a shared aquifer. More importantly, water professionals must become involved in legislative efforts whenever water issues arise, both in the domestic as well as the international context.

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Sustainable Planning of Water Resources Using Two-Stage Stochastic Programming Approach

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SUSTAINABLE PLANNING OF WATER RESOURCES USING TWO-STAGE STOCHASTIC PROGRAMMING APPROACH

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ABSTRACT

Scarcity of natural water resources in many parts of the world has prompted the water specialists to seek sustainable and integrated water policies. This philosophy has been the focus and call of many international water organizations over the last two decades. Economic, social, and environmental aspects are among the main factors to be considered in planning various water programs. In addition, sustainability requires accounting for the participatory approach and the conflicting interests of different consumers, in all planning stages. The problem becomes more sophisticated when recognizing the variability and uncertainty present in hydrological and economic terms

This paper addresses the issue of sustainable planning and management in water resources by incorporating various groups of considerations into one mathematical problem that accounts for the future uncertainties. A two-stage stochastic programming formulation is selected to satisfy these requirements. A regional water supply problem is used as an application example to demonstrate the current approach. The problem seeks the optimal design capacities of recharge facilities, water treatment, and secondary and tertiary wastewater treatment plants while meeting the future demands of different consumers. The first stage of this formulation represents the design criteria at the present time when a decision must be made. The second stage represents the system response to the design where other actions (recourse decisions) are to be made after observing the future random input. The Regularized Stochastic Decomposition (RSD) algorithm is employed to solve the problem found in different forms and scenarios. Results are shown for different levels of uncertainties and for linear and nonlinear first-stage objective functions.

Key words: sustainability - water resources - planning - uncertainty - two stage stochastic programming.

INTRODUCTION

Scarcity of water resources in addition to their quality degradation in many circumstances prompted many regional and world organizations to react and declare the problem as alarming. United Nations, World Bank, Asian Development Bank, and the Inter- American Development Bank are among many world organizations heavily involved in water policies.

In 1977, the United Nations Water Conference of Mar del Plata made the following appeal: "All people, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of quality equal to their basic needs". The Action Plan adopted by the conference resulted in launching the international Drinking Water Supply and Sanitation Decade in 1981 which brought water and sanitation services to hundreds of millions of the world's poorest people. In January 1992, five hundred participants, including government-designated experts from a hundred countries and representatives of eighty international, intergovernmental and non-governmental organizations, attended the international conference on Water and the Environment (ICWE) in Dublin, Ireland. At the closing session of the conference, they adopted the Dublin statement and the conference report that set out recommendations for action at local, national, and international levels based on four guiding principles as follows:

Principle No.1: Fresh water is finite and vulnerable resource, essential to sustain life, development and the environment.

Principle No.2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.

Principle No.3: Women play a central part in the provision, management and safeguarding of water.

Principle No.4: Water has an economic value in all its competing uses and should be recognized as an economic good. The statement made by the participants, known by Dublin Statement, had highlighted many world water problems describing them of being not speculative in nature; nor are they likely to affect our planet only in the distant future. They are here and they affect humanity now. The future survival of many millions of people demands immediate and effective action. The world and international efforts and attention being paid in that regard represents a solid evidence of the problem seriousness and sends an alarming message to all countries in general, and to the developing countries in particular.

In 1992, the United Nations held a conference on Environment and Development in Rio de Janiro. The conference resulted in a very comprehensive report addressing the issues of sustainable development, named Agenda 21, referring to the approaching twenty first Century. Chapter 18 of the Agenda addresses the protection of the quality and supply of freshwater resources and application of integrated approaches to the development, management and use of water resources. It proposed seven program areas as follows:

[1] Integrated water resources development and management

[2] Water resources assessment

[3] Protection of water resources, water quality, and aquatic ecosystems

[4] Drinking-water supply and sanitation

[5] Water and sustainable urban development

[6] Water for sustainable food production and rural development, and

[7] Impacts of climate change on water resources.

The topics and concepts introduced in chapter 18 of Agenda 21 cover many issues related to sustainable development of water resources. However, the report has many items presented in an abstract way and need further elaboration and illustrations. In particular, it lacks detailed procedures required to fulfill many objectives during the planning and designing phases. The design aspects inherent in these programs imply that the engineers and designers of such projects are able to incorporate and account for the principles included in the report into their designs. It is important for the designers and/or specialists in the field of water resources to have documented procedures describing in minute details the required approach to achieve the listed objectives. Numerical examples and/or case studies elaborating on the identified objectives can favorably help in this regard. More efforts are generally needed in this respect to demonstrate the design and planning terminology accounting for all considerations reported in the agenda. This can be achieved via introducing new technical materials; such as textbooks and/or publications having the flavor of integrated and participatory approach outlined in the objectives.

The term sustainable water resources is being widely used in many publications and reports issued by world organizations. Most of these reports haven't defined the term in an explicit way. Based on the 20/20 initiative conceived in 1994 by UNDP, UNESCO, UNFP A, UNICEF, and WHO, the water supply system is considered sustainable when it:

[1] provides a continuous, efficient, and reliable service, at a level which is desired

[2] can be financed or co-financed by the users

[3] can be maintained with limited but feasible external support and technical assistance

[4] is used in an efficient way, without negatively affecting the environment, conserving it for the generations to come.

In another meeting (Helmer 1997), it was reported that water management within a sustainable development framework should address quantity and quality concerns through an integrated approach, integrally link land use management with sustainable water management, recognize freshwater, coastal and marine environments as a management continuum, recognize water as an economic and social good and promote cost-effective interventions, support innovative and participatory approaches, and focus on actions that improve the lives of people and the quality of their environment. A more comprehensive coverage of the world perspectives of the sustainable planning of water resources can be found elsewhere (Elshorbagy et al. 1999).

A major and important aspect of the sustainable planning of water resources is to incorporate the different forms of future uncertainties in the detailed planning procedure. One way to account for these uncertainties in mathematical programming models in design is to use a probabilistic representation instead of the best estimates of the uncertain coefficients. Some versions of this type of models were introduced in the late 1950's by Dantzig (1961) and Charnes and Cooper (1959) through the chance constrained programming that is widely used in engineering applications. This study considers one of the most recently developed algorithms to solve two-stage stochastic linear programs with recourse. The Regularized Stochastic Decomposition (RSD) has been applied to solve simple engineering applications under limiting conditions. The present work employs this approach and modifies it so that it can be applied to a wider and more practical range of applications. The next section presents a summary of the main features of the modified algorithm.

TWO-STAGE STOCHASTIC PROGRAMMING WITH RECOURSE

Two-stage stochastic linear programs (LP) with-recourse problems have a first-stage set of decision variables that must be made at present and a set of second-stage variables to be determined in the future based on the uncertain future conditions and satisfying restrictions resulting from the first-stage decisions. A general formulation of the problem is:

$$Min\, f(x) = cx + E_{\bar{w}}\,[Q(x,\varpi)] \qquad (1)$$

$$s.t. \quad x \in X \subseteq R^{nl} \qquad (2)$$

$$where \quad Q(x,\bar{\omega}) = \text{Min}\; qy \qquad (3)$$

$$s.t. \quad Wy = \bar{\omega} - Tx \qquad (4)$$

The problem consists of the following components: [I] a first-stage objective function, cx, associated with n1 first-stage decision variables, x, and m1 first-stage constraints, and [2] a second stage objective function Q(x, ϖ), with second-stage solution y of n2 variables, and m2 second-stage constraints based on some observation ϖ. The random vector, ϖ, is defined on a probability space (Ů,A,P) where Ů is a compact set. The distribution probability function, E ϖ, is associated with ϖ, and E ϖ [ ] is the mathematical expectation with respect to ϖ. The set of feasible first-stage decisions, x, is assumed to be convex and bounded. With these conditions, the total objective function will be a piecewise linear convex function of x. The stochastic program is said to have complete recourse property if the second-stage is feasible for all values of xåX.

This type of problem is very common in many practical applications. Due to its simple formulation, many algorithms have been developed for its solution. Higle and Sen (1991) introduced a Stochastic Decomposition (SD) approach that combines many of the strengths of the decomposition-based algorithms and the stochastic gradient methods. A major problem with the algorithm is the progressively increasing size of the master program as a result of the new cut (constraint) added at each iteration after solving the subproblem. Yakowitz (1994) later introduced a quadratic term in the master program that restraints the movement of the solutions so that the function estimates are adequate. The size of the master program is limited by introducing a cut-dropping scheme similar to that given in Miftlin (1977) and Kiweil (1985). For more details about theoretical developments and/or proofs of the RSD algorithm, the reader can consult other references (Higle and Sen, 1991 and Yakowitz, 1994).

REGULARIZED STOCHASTIC DECOMPOSITION (RSD)

To briefly summarize the RSD algorithm (Yakowitz, 1994), a random realization ϖ, is generated at each iteration k and a master program is solved at the current solution x_{k-1}, called the current incumbent, producing a direction d_k. Adding d_k to the current incumbent x_{k-1} results in a new point z_k, called the candidate solution ($z_k = x_{k-1}+d_k$). The total objective function is computed at z_k, x_{k-1}, and other points to check if the current incumbent solution should be replaced by the candidate or to stay as it was. Termination criteria are then checked to decide whether to stop or to proceed with new random generations. The master program "M^k" is formulated as:

$$M^k: \qquad \mathrm{Min}[0.5\left|d_k^2\right| + \nu_k(d_k)] \qquad (5)$$

$$s.t. \qquad x_{k-1} + d_k \in X \qquad (6)$$

subject to: $\nu_k(d_k) = \max\{f_k^j(x_{k-1} + d_k)\} \qquad \forall\, j \in J^k \qquad (7)$

The function f^j_k is a linear approximation of the objective function given in (1) at (x_{k-1}) and known as a cut or support. The superscript j defines the iteration at which the cut was first developed while the subscript k defines the iteration at which the cut was last updated, usually the current iteration. The set J^k is redefined at each iteration according to a cut-dropping scheme that acts to limit the size of the master program. More detailed description of the algorithm and its termination criteria can be found elsewhere (Elshorbagy et al., 1997). The algorithm was coded in Fortran in a way that allows one to solve any two-stage stochastic problem. GRG2 (Lasdon, 1985), a nonlinear programming model, was used to solve the master problem at each iteration. GRG2 applies the generalized reduced gradient method as a basis for solving the NLP. A small subroutine linked to GRG2 is required to describe the first-stage objective function and constraints of the investigated problem.

Nonlinear first-stage objective function

The RSD approach, to date, is limited to solving linear two-stage problems with uncertainty only in the RHS of the second-stage constraints. Since many engineering problems behave in a nonlinear manner, the algorithm was modified to handle the nonlinearity of the first-stage objective function. The assumption of convexity of the overall problem is violated, in this case, especially with problems in which the first-stage objective function is non-convex. Therefore, global optimality of the optimal solution is no longer guaranteed. However, local optimal solutions are often adequate in engineering practice. Prudent selection of the initial point can potentially improve the solution and bring it closer to the global optimal solution.

The nonlinearity in the first-stage objective is introduced by including this nonlinear function, $g(x_k)$, in the objective of the master program. The cuts identified with this objective will only approximate the second-stage stochastic function. The new objective, equation (8), replaces equation (5) and the cut expression is also modified as of equation (9). All other definitions and equations remain the same.

$$Min[0.5|d_k|^2 + g(x) + \upsilon_k (d_{k)})] \quad (8)$$

$$f_k^j (x_k) = \alpha_k^j + \beta_k^j * x_k \quad (9)$$

Stochastic coefficients of the second-stage objective function

Both the SD (Higle and Sen, 1991) and the RSD (Yakowitz, 1994) algorithms were originally developed for the case of stochastic right hand sides of the second-stage constraints. In many applications, the coefficients of the second-stage objective function include future revenues and/or prices that might be subject to a great deal of uncertainty. Therefore, it was necessary to modify the algorithm to handle the stochasticities of the second-stage objective function. Although the modification was successfully developed, computational problems during implementation pointed out the difficulty in practical usage of the algorithm in certain situations. To consider the uncertainty of the second-stage objective function, the subproblem and its dual must be redefined for the case of deterministic RHS and stochastic objective coefficients. The subproblem, S_k. is:

$$Q(z_k, \overline{q_k}) = \text{Min } (\overline{q_k})y \quad (10)$$

$$s.t.\ Wy = H - T z_k \quad (11)$$

And its dual, DS^k, is: $Q(z_k, \overline{q_k}) = \text{Max } \pi(H - T z_k)$ (12)

$$s.t.\ \pi \in \Pi = \{\pi : \pi W - \overline{q_k}\} \quad (13)$$

Recall that the set II in the case of random RHS was independent of the random realization ω_k. This observation made it possible to select any π_t that corresponds to ω_t for t=1,2,....,k-1 using a simple argmax operation. In the present case, Π is no longer independent of the random observation ω_k and the argmax operation alone does not guarantee the feasibility of the selected π. Another approach to determine the correct multipliers is suggested.

Since $(H\text{-}Tz_k)$ is independent of q_k at each iteration, the multipliers which were identified in V^k can be arranged in descending order according to the value of $\pi(H\text{- }Tz_k.)$. For each q_t, t=1,...., k-1, the corresponding π_t is selected by testing the feasibility of the sorted multipliers in V^k one by one until equation (13) is satisfied. This multiplier, π_t, is selected to be the one which corresponds to the current q_t. This sorting-testing scheme should perform well if the number of multipliers in V^k is finite and small.

APPLICATION PROBLEM: REGIONAL WATER SUPPLY

Consider a region that has two communities. Each community has demands for both potable water "P_i" for municipal use and reused water "U_i" for irrigation and other purposes. The goal is to design water supply facilities required to satisfy the community demands over a 20-year period of time. The demands of potable water can be met from direct supply from the aquifer "Q" and/or treated water from the water treatment plant "W" which is supplied from a surface source "V" (Figure 1). The demands of reused water can be also met from direct supply from the aquifer or from a tertiary treatment plant "T" which is supplied from a secondary wastewater treatment plant "S". The aquifer is recharged through a basin system "R" with water from the river or the wastewater treatment plant after secondary treatment.

The planning problem is to determine the design capacities of the recharge basin, water treatment plant, secondary wastewater treatment plant, and tertiary treatment facility. These decisions represent the first-stage decision variables in the two-stage formulation. The second-stage variables represent the water allocations (in million gallons per day, mgd) from the supply facilities to different users during different time periods. The variables y_1 to y_{17}, shown on the system (Figure I) are the second-stage operation variables for the first period. The total number of the second-stage variables for the two periods is 34.

The first-stage objective function represents the present construction cost of the four supply facilities. These costs were first assumed to be linear functions of the design capacities with linear cost coefficients given in Table 1. The second-stage objective represents the expected value of the uncertain operation cost during the future time periods. The operation costs include treatment costs and pumping costs. These costs were assumed to be linear functions of the treated and delivered amounts of water, respectively. The linear coefficients of these costs are given in \$/million gallons per day and listed in Table 2.

The time value of each period was considered through the use of equivalent present worth of the operation cost during the period. It was assumed that the operation cost is uniformly distributed along each individual period with constant average annual value. This annual value was obtained by multiplying the allocation variable (mgd) by 365 days/year by the corresponding average operation cost coefficient. The present worth of each period k (P_k), given at the beginning of the period, is then calculated using a discounting factor of 6.145 corresponding to n= 10 years and using a 10% discount rate. A second discount factor of 0.386 is required for the second period operation variables to present cost. The structure of the water supply planning problem, given in the two-stage formulation, can be written:

$$\underset{\{x,y\}}{Min} \sum_{l=1}^{4} c_l * x_l + 6.145*365*E[\sum_{r=1}^{17} q_r^1 * y_r^1 + 0.386*\sum_{r=18}^{r=34} q_r^2 * y_r^2]$$

$$+q_e * \left[\sum_{\xi=1}^{2} [eq^{\xi} + \sum_{v=1}^{2} (ep_v^{\xi} + eu_v^{\xi}) \right] \qquad (14)$$

Subject to

First-stage constraints

$$x_l > 0 \qquad l \in \{1,4\} \qquad (15)$$

Second-stage constraints (For ξ=1,2)

[1] Canal capacity

$$\sum_{\to x_l} y^{\xi} \leq x_l \qquad l \in \{1,4\} \qquad (16)$$

[2] Water Availability

$$\sum_{\to V} y^{\xi} \leq AV^{\xi} \qquad (17)$$

[3] Potable and Reuse Demands

$$\sum_{\to P} y^{k} + ep_v^{\xi} \to DP_v^{\xi} \qquad v = 1,2 \qquad (18)$$

$$\sum_{\to U} y^{\xi} + ep_v^{\xi} \to DU_v^{\xi} \qquad v = 1,2 \qquad (19)$$

[4] Aquifer Storage

$$QI^{\xi} + \sum_{\to Q} y^{\xi} - \sum_{-Q} y^{\xi} + eq^{\xi} \geq QS^{\xi} \qquad (20)$$

[5] Quality of Reuse Demands

$$y^{\xi}_{Q\rightarrow U_v} \geq PCU * DU^{\xi}_v \qquad v=1,2 \tag{21}$$

[6] Quality of Potable Demands

$$y^{\xi}_{W\rightarrow P_v} \geq PCP * DP^{\xi}_v \qquad v=1,2 \tag{22}$$

[7] Temporal Continuity

$$QI^{\xi} + \sum_{\rightarrow V} y^{\xi} + \sum_{v} (ep^{\xi}_v + eu^{\xi}_v) + eq^{\xi} \geq (1+loss_{avg}) * \sum_{v} DP^{\xi}_v + DU^{\xi}_v \tag{23}$$

[8] Mass Continuity

$$(1 - loss_j) * \sum_{j\ \rightarrow j} y^{\xi} = \sum_{j\rightarrow j} y^{\xi} \qquad j \in \{R, W, S, T, P1, P2\} \tag{24}$$

where x_i is the design capacity of the supply units with x_1, x_2, x_3, and x_4 being capacities of the recharge basin, water, secondary, and tertiary treatment plants, respectively. q_r^1 is an objective function coefficient related to the allocation, y_r^1 (the superscript 1 refers to the first period), and depends on its treatment and pumping costs. q_e is a unit price of the penalty water used to maintain feasibility as explained later. The first-stage constraints are only simple bounds to maintain non-negative values of the capacities. The subscript of y on the second-stage constraints identifies the allocated water. For example, Y> U_i, means all y's entering the unit U, and $Y_{Q>}U_1$ refers to the allocated water from unit Q to unit U_1 and so on. The second-stage constraints are divided into eight groups and explained as follows:

[1] Capacity constraints insure that the total delivered amount of water to any unit during any time period, ξ, will be less than the capacity of the unit.

[2] River Availability constraints insure that the available water in the river 'AV' exceeds the amount diverted to the system during any time period, ξ. The average amount of available water during the two periods was assumed to be 120 mgd.

[3] Demand constraints guarantee that the potable demands, DP, and the reuse demands, DU, are satisfied for the two communities during any period, ξ. ep_v and eu_v are external penalty water required to maintain feasibility during random generated constraints

which may cause the demand to exceed the supply. Table 3 lists the values of the demands used in this application.

[4] Aquifer Storage Constraints assure that the amount of water stored in the aquifer at the end of each period is greater than a pre-specified reserve amount, QS. The amount of stored water equals the initial storage, QI, plus the entering and the external penalty waters minus the withdrawn water.

[5] Reuse Quality Constraints maintain a pre-specified ratio of the total reuse demands 'PCR' to be direct supply from the aquifer.

[6] Potable Quality Constraints maintain a pre-specified ratio of the total potable demands 'PCP' to be delivered from the water treatment plant.

[7] Temporal Continuity Constraints insure that all demands and losses are met using true sources of water. If these constraints are not present, a situation might result in which the model constraints are all satisfied although the true supplies from the river or the initial storage of the aquifer during advanced periods are not sufficient to satisfy the demands.

[8] Mass Balances Constraints preserve the mass balances at different nodes and accounting of their losses. The nodes of concern are the supplying units and the two nodes of potable demands (P).

The total number of second-stage constraints is forty two. The stochastic parameters at the right hand side (RHS) of the second-stage constraints are AV, DP, and DU. The number of independent random parameters considered in this case is 10. Stochasticity in the treatment costs of the four supplying units along with the pumping costs are also considered and represent eight independent random parameters. Continuous normal distributions with a coefficient of variation of 0.25 were assumed for all random parameters.

RESULTS AND DISCUSSION

The application problem was solved using the RSD model for the following three cases:

[1] Linear first-stage objective function and stochastic RHS

[2] Non-linear first-stage objective function and stochastic RHS, and

[3] Linear first-stage objective function and stochastic second-stage objective function.

Demands, available water, and treatment costs with its related pumping costs were considered random parameters in different cases. To assess the improvement in the objective function using the stochastic design (using the RSD model), the objective function was evaluated using the optimal deterministic design with the mean values of the corresponding uncertain parameters. In case 1, the design capacities using the stochastic approach were obtained after 15.75 hours. The four capacities obtained usthis design were larger than those of the deterministic design with about 5% improvement in the total objective function. In case 2, a power form for the first-stage objective function was assumed. Two separate designs were examined using different values of the power function exponent. Table 4 lists the stochastic and deterministic designs for these two cases along with the total function improvement obtained when the stochastic design was used instead of the deterministic one. Results show that the stochastic design in both linear and concave non-linear first-stage objective (power coeff.= 0.80) enlarged the facility capacities while it reduced the capacities in case of convex non-linear case (power coeff. = 1.50). The solution in the third case with stochastic objective function coefficients was exactly the same as that obtained from the deterministic model (given in Table 4, case of linear first-objective function). This solution was reported on the results of the algorithm after large number of iterations. This indicates that the variability in the objective coefficients for this particular setting of the problem had no effect on the first-stage decisions.

A major problem related to the execution time was encountered in solving case #3. The number of vertices generated at each iteration was growing monotonically with the number of iterations. That resulted in significant delay on the progress of the algorithm. The termination of the algorithm is justified by the fact that the multipliers found during the later iterations do not affect the last solution. This condition can be reached after a reasonable execution time, potentially in cases of small problems having few discretized random variables. The model was stopped after four days of execution with 1500 iterations yielding very close solution values to the final solution but without satisfying all of the termination criteria.

CONCLUSIONS AND RECOMMENDATIONS

The regularized stochastic decomposition (RSD) algorithm was coded to solve two-stage stochastic linear programs. An application system that seeks the design capacities of four water supply plants to different users with different demands was solved. The algorithm was modified to consider a nonlinear first-stage objective function and was successfully applied to the application problem. Another modification to consider the stochasticity of the second-stage objective function coefficients was implemented. Although that modification was successfully programmed, the computations showed that the algorithm cannot be efficiently applied due to long execution time required to handle the infinite number of dual multipliers generated from the subproblem. Another approach is therefore needed to deal with the stochasticity of the objective coefficients in a more efficient way. The results of the application system show significant improvements obtained when using the RSD algorithm with maximum improvement in case of convex nonlinear objective function.

The algorithm presented in this paper and its application represent an illustrative approach to address the sustainable planning of water resources stressed by many world water organizations. The approach basically transforms the relevant information related to the planning problem into simple constraints then incorporate them into one mathematical formulation accounts for future variability and uncertainty. The desired sustainability aspects can always be strengthened in the presented approach by introducing more relations capable of describing the important social, environmental, and economical factors in addition to the technical ones in an integrated and comprehensive style.

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Table 1. Construction cost coefficients for the first-sta~e decision variables

Unit	Recharge	Water Treat.	Wastewater Treat.	Tertiary
Coefficient	2,650	80,000	40,000	15,900

Table 2. Cost Coefficients for the second-stage objective function ($/mgd)

Treatment Cost Coefficients

Unit	Recharge	Water Treat.	Wastewater Treat.	Tertiary
Coef. In Period I	0.026	2.643	1.586	0.264
Coef. In Period II	0.032	3.171	1.718	0.317

Piping and pumping Cost Coefficients

Route	V-R	V-W	R-Q	W-P	P-S	T-U	S-T	Q-U	Q-P	S-R	S-V	T-V
Period 1	1.32	0.00	5.30	5.30	5.30	1.32	13.21	7.93	2.64	5.30	0.00	0.00
Period 2	1.60	0.00	5.80	5.80	5.80	1.50	14.50	9.25	3.20	5.80	0.00	0.00

** The route V-R means from the component V (river) to the component R (recharge)

Table 3. Demands for different users in million gallons per day (mgd)

User	P1	P2	U1	U2
Period 1	150.0	190.0	114.0	132.0
Period 2	190.0	227.0	150.0	170.0

Table 4. Results for thecase of Stochastic RHS

Unit	'R' (mgd)	'W' (mgd)	'S' (mgd)	'T' (mgd)	'Obj. Fn.' (10^6 dollars)	NK[1]	NV[2]	KP[3]	Time (hrs)
Case of Linear First-Objective Function									
Det. Soltn	612.36	146.89	333.03	181.22	83.511				
Stoch. Soltn	824.90	160.44	363.53	190.41	79.497	2719	198	100	5.75
Improvement in Obj. Fn. = 4.014 (million $) = 5.05%									
Case of Nonlinear First-Objective Function with Power Coeff. = 0.80									
Det. Soltn	587.50	146.89	332.99	236.99	68.514				
Stoch. Soltn	937.94	177.13	401.52	255.53	60.888	1284	139	50	2.50
Improvement in Obj. Fn. = 7.627 (million $) = 11.13 %									
Case of Nonlinear First-Objective Function with Power Coeff. = 1.50									
Det. Soltn	609.91	146.89	332.99	42.57	285.324				
Stoch. Soltn	586.78	75.68	189.20	0.00	217.122	954	39	50	2.33
Improvement in Obj. Fn. = 68.20 (million $) = 23.90%									

[1] Number of iterations [2] Number of Vertices [3] Number of iterations required by termination criteria #1

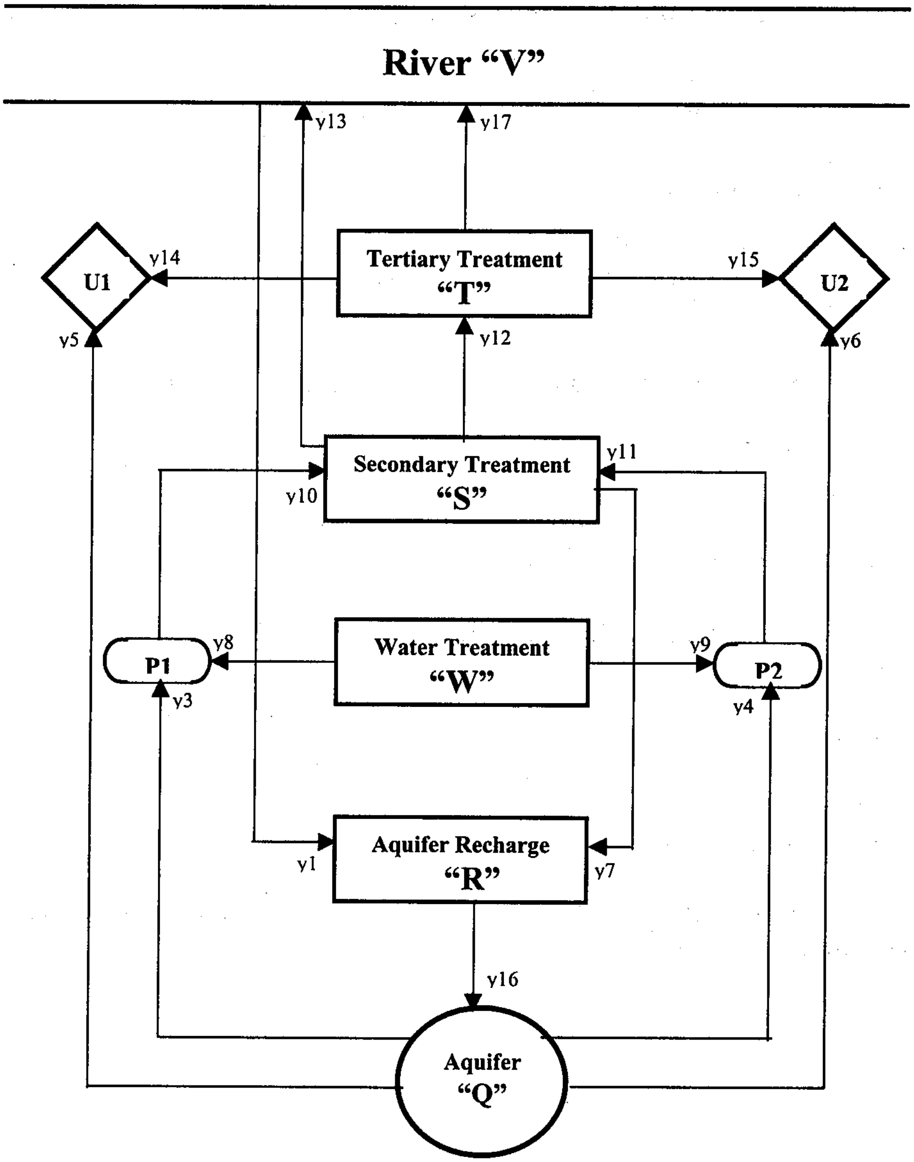

Figure 1. Water supply application problem

Sustainable Water Management For The Kingdom of Saudi Arabia

A.S. Al-Turbak and K.H. Al-Dhowalia

SUSTAINABLE WATER MANAGEMENT FOR THE KINGDOM OF SAUDI ARABIA

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ABSTRACT

In spite of the efforts made by the government of Saudi Arabia to develop its water supplies, the consumption of water has reached alarming levels. Total demand for water in all sectors has increased many folds during the last few decades. The main causes are expansion of the agricultural sector, increase of population and the rise in the standard of living.

Management of water resources is an essential part of any development plan. Scarcity of water in Saudi Arabia makes it essential to manage water resources properly. This work is directed toward seeking sustainable management for water resources in the Kingdom. The first step was to review changes in supply and demand for water during the last two decades. Future supplies and demands (for all sectors) up to the year 2025 were also estimated. This was carried out using different scenarios and assumptions. The last part of the study presents major future problems facing the water sector in the country and suggests possible solutions.

Key words : Sustainability, water management, water supply, water demand, Saudi Arabia, future demands, future water problems.

INTRODUCTION

The Kingdom of Saudi Arabia has seen tremendous changes in its social and economic spheres in the last few decades. Wealth from oil revenues made it possible for the government to develop all sectors of the economy. One major sector which has seen tremendous growth is the agricultural sector. It has grown so fast during this period causing huge withdrawals from the country's limited deep groundwater reserves. The growth of cities, increase in the population and the rise in the standards of living caused domestic and industrial water consumption to increase many folds.

The constant pressures on the country's water resources made it necessary to develop both the conventional water resources (surface and groundwater) and the unconventional ones (desalination of sea water and treated wastewater). More than 200 dams for different purposes were constructed to utilize surface water which is available in some regions of the country. The Kingdom's huge aquifers were also extensively studied and utilized for different uses. With respect to desalination of sea water, many stations were built on the Red Sea and the Gulf. Saudi Arabia is currently the world's largest producer of desalinized sea water. Desalination plants produce water for coastal urban centers and for many cities in the interior of the country including the capital city of Riyadh. Wastewater treatment plants were also constructed in many urban areas. Utilization of treated wastewater, however, is still limited.

In spite of the tremendous efforts made by the government to develop the water supplies in the country, the consumption of water in Saudi Arabia has reached alarming levels as shown by studies like Abu Rizaiza and Allam (1989), Al-Ibrahim (1990) and Al-Turbak and Al-Dhowalia (1996). The objective of this paper is to seek sustainable management for water resources in the Kingdom of Saudi Arabia through the following:

1. Review charges in supply and demand for water during the last few decades.

2. Predict future supplies and reserves as well as demands (for all sectors) up to the year 2025. This was done using different scenarios and assumptions.

3. Discuss major future problems facing water resources management in the country and suggest possible solutions to meet these problems.

PAST WATER SUPPLIES AND DEMANDS

Available Water Resources

Water resources in Saudi Arabia can be classified into four types: Surface water, groundwater, desalinized water and treated wastewater.

Except for the mountainous area, in the southwestern part of Saudi Arabia, precipitation is very low and infrequent with extreme variation from one year to the next. The average rainfall for the whole country is about 90 mm per year. In Saudi Arabia, surface runoff occasionally occurs during the rainy seasons when there are rain storms. Estimates of the amount of runoff water range between 2,000 and 2,400 MCM (Ministry of Planning, 1985) per year. Most of the runoff occurs in the coastal areas and highlands of the southwest, where rainfall is relatively abundant and regular. The Ministry of Agriculture and Water (MAW) has constructed about 200 dams throughout the country to utilize the surface-runoff water. While these dams store runoff water and increase infiltration for recharging groundwater resources, they also prevent flash floods. It is expected that the efficient use of dams provided a potential surface-water supply of up to 900 MCM/year for the Kingdom in 1985 (Ministry of Planning, 1985). Since 1985, more surface water has been utilized especially after the completion of King Fahad Dam in Bishah (capacity 325 MCM), but surface water resources in Saudi Arabia are very limited and are important only in the southwestern region of the country.

Al-Ibrahim (1990) presented the most concise summary of groundwater resources. He stated that groundwater is the most important source of water in Saudi Arabia. It comes from two types of aquifer: renewable and nonrenewable. The first type, shallow aquifers, contains a renewable water supply charged by infiltration from rainfall and surface-runoff. The renewable groundwater is estimated at around 950 MCM/year. The other type, deep aquifers, contains a reservoir of water formed thousands of years ago when water was trapped in sedimentary rocks such as limestone and sandstone. These deep aquifers receive negligible or no recharge and therefore store nonrenewable and depletable groundwater resources. The depth of these aquifers ranges between 100 and 500 m and may exceed 1,000 m in some areas. Nonrenewable groundwater reserves were estimated at 500,000 MCM of which 67% is stored in seven major aquifers, while a series of secondary aquifers holds the rest (Ministry of Planning, 1985). The renewable groundwater resources are utilized mainly for agricultural purposes in small farms located adjacent to wadis (dry water courses) in many areas of the country. The nonrenewable groundwater has been used extensively especially since 1980 at alarming rates to provide water for irrigation in the extensive areas put under cultivation outside the traditional agricultural oases. It was estimated by Al-Turbak and Al-Dhowalia (1996) that about 35% of the nonrenewable groundwater resource (500,000 MCM) has been used by 1995.

Due to scarcity of fresh water resources in Saudi Arabia, desalinized sea water is extensively used as an additional source for domestic water supplies. Saudi Arabia is the largest producer of desalinated seawater in the world. The Saline Water Conversion Corporation (SWCC), which is the authority incharge of desalination, presently operates 25 desalination plants, with a total daily production capacity of about 2 MCM. Seawater desalination is an expensive operation that requires a large amount of money to construct, operate, and maintain. In addition, the TDS level in the Red Sea and Arabian Gulf (which varies between 40,000 and 60,000 ppm) is much higher than that of other seas and oceans (Wojcik, 1981). For this reason, water desalination in Saudi Arabia is more expensive than in other countries using the same methods of desalination. Moreover, considering the fact that the operational life of a desalination plant is in the range of 15-25 years, Saudi Arabia will require large amounts of expenditure to replace worn-out plants. This will impose a heavy burden on the country's financial resources.

In an arid country where natural water resources are limited, reclaimed wastewater can be an important potential source of water supply. In addition, the treated wastewater has several advantages over other sources of water. It is cheaper than seawater desalination; it minimizes pollution; and it is a good nutrient source for landscape and farm irrigation. The total amount of collected wastewater in all urban centers of the Kingdom was estimated to be 10MCM in 1995 (Al-Turbak and Al-Dhowalia, 1996). Out of this amount, 418 MCM were treated using secondary treatment or better. This is expected to grow rapidly as more sewer network and more treatment plants are constructed in the future.

Water Demand

Water demands in different sectors are met from either traditional sources (surface and ground- water) or from non-traditional ones (desalination and treated wastewater) depending on the type of use. The agricultural sector uses mostly non renewable groundwater with some of its demands met by surfacewater, renewable groundwater and treated wastewater. Water for domestic use comes mainly from desalination or groundwater. Industrial sector demand comes mainly from deep nonrenewable groundwater.

Figure 1 shows the increases in demands for water from 1980 up to 1995. Demand for water in the agricultural sector has grown at a very alarming rates since 1980. In that year, it was estimated at 2000 MCM. In 1985, it reached a level of 7430 MCM. The average annual growth rate for water consumption was 60%, four times greater than what was anticipated by the Third Development Plan (Ministry of Planning, 1980). By the year 1990, this demand reached 14580 MCM/year and in 1995 it was estimated at about 17814 MCM.

Municipal water demands has also increased during the same period due to increase in population, rising standard of living and the immense growth of urban centers. In 1995, municipal water requirements were put at 1356 MCM. Industrial and other demands were estimated for 1995 to be 550 MCM.

FUTURE WATER SUPPLY AND DEMAND

Prediction of Future Water Resources

It is expected that utilized surface water resources will increase to about 2000 MCM by the year 2025. This will be mainly due to the construction of more dams throughout the country.

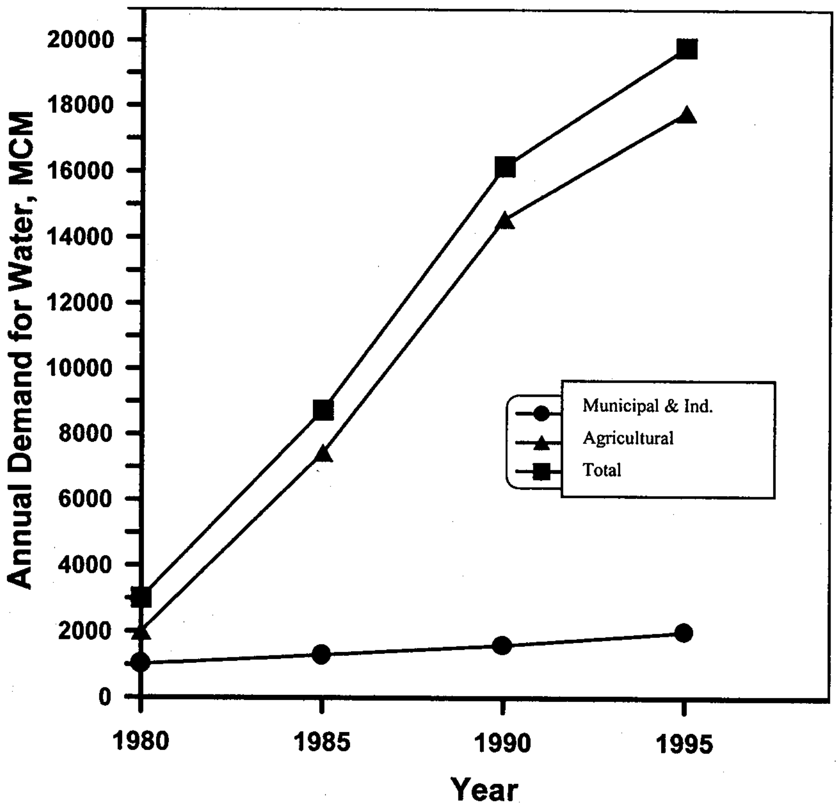

Figure 1. Demand for water in different sectors

Renewable groundwater resources that are utilized are also expected to increase due to developments taking place in the areas where they are available. It is expected that by the end of the study period, about 1500 MCM of renewable groundwater will be available. Available nonrenewable groundwater resources will continue to decline as more water is pumped from major aquifers. The amounts withdrawn upto the year 2025 will highly depend on different scenarios of future development especially in the agricultural sector.

Desalinized seawater is expected to increase at about 3% annually. This estimate was based on the last few years increases and on the number of desalinization projects planned during the next development plan (2000–2005). This resource will be about 1366 MCM by the year 2025 and will exclusively be used for domestic purposes.

Treated wastewater will continue to be available at increasing amounts as more treatment plants are constructed and as more parts of different cities are connected to sewage networks. It is anticipated that the amounts of this important resource will increase from about 30% of domestic water supply to almost 70% by the end of the study period.

Future Water Demand

Tables 1-3 show the estimated demands for the years 1995-2025 for all the sectors and using three different alternatives. In all of these alternatives, the population of the country was taking from the census of 1992 and the growth rate was assumed to be 3.78 annually as suggested by the General Statistics Department. The industrial sector demand was also assumed the same in all of these alternatives. This was mainly due to the growth rates in that sector that are fixed in the government plans.

Table 1 shows the results using the first alternative (A1) in which the agricultural sector demand is assumed constant at the 1995 level (17814 MCM). The municipal water demand was based on 300 liters per capita per day. The second alternative (A2) results are presented in Table 2. In that alternative, the agricultural demand is assumed to decrease by 20% (1995–2005), 10% (2005-2015) and 5% (2015–2025). Municipal demands were calculated using 200 liters/person/day. Table 3 gives the results for the third alternative (A3). To obtain these results, the demand in the agricultural sector was assumed to drop by 40% (1995–2005), 20% (2005–2015) and 10% (2015 – 2025). The domestic water demand in (A3) was calculated using 150 liters/person/day.

Table 1 Estimated Annual Water Demand (A1) in MCM

Year	Agricultural	Municipal	Ind. & Other	Total
1995	17814	1356	550	19720
2000	17814	2186	715	20715
2005	17814	2531	880	21225
2010	17814	2947	990	21751
2015	17814	3448	1100	22362
2020	17814	4050	1155	23019
2025	17814	4776	1210	23800

Table 2 Estimated Annual Water Demand (A2) in MCM

Year	Agricultural	Municipal	Ind. & Other	Total
1995	17814	1356	550	19720
2000	16033	1639	715	18387
2005	14251	1898	880	17029
2010	13361	2210	990	16561
2015	12470	2586	1100	16156
2020	12024	3038	1155	16217
2025	11579	3482	1210	16371

Table 3 Estimated Annual Water Demand (A3) in MCM

Year	Agricultural	Municipal	Ind. & Other	Total
1995	17814	1356	550	19720
2000	14251	1093	715	18387
2005	10688	1266	880	17029
2010	8906	1473	990	16561
2015	7126	1724	1100	16156
2020	6235	2025	1155	16217
2025	5344	2388	1210	16371

Comparison of Alternatives

To meet future demands in different sectors, the following was assumed (in all alternatives):

1. Demand for agriculture is met by all renewable surface and groundwater and 90% of treated wastewater. The rest is met by pumping from nonrenewable groundwater.

2. Municipal water supplies will come from desalinization and from well fields drilled in deep aquifer.

3. Industrial and other uses will be met by 10% of treated wastewater with the balance coming from deep groundwater.

Alternative (A1) makes the assumption that agricultural water demand will stay the same for the whole period of prediction. This is not realistic since the government, realizing the danger of depletion of groundwater, has introduced few measures to slow excessive pumping. The municipal consumption in (A1) was also predicted using 300 L/capita/day which is very high. The average demand in 1995 was about 226 L/person/day in spite of the wastes in many large urban areas. If (A1) is followed as a plan, although unlikely, deep groundwater reserves will be exhausted in about two decades.

The second alternative (A2) assumes a municipal water demand that is about the present one. The agricultural water demand is reduced by the year 2025 to about 65% of its 1995 level. This alternative will also result in the depletion of deep groundwater resources but at some delayed time from (A1); perhaps one decade more. The third alternative (A3) requires the reduction of agricultural sector consumption by the end of the study period to 30% of its 1995 level. It will also require reducing domestic uses to 150 liters/person/day. This last alternative is the best among the three. It will be possible to have sustainable water resources for the next few decades and beyond. It will result in conserving part of the groundwater reserves beyond the year 2025. If this alternative is followed, 95% of the agricultural water demand will come from renewable resources by the end of the study period. This will not only result in the conservation of deep groundwater resources but also will allow the country to have a sustainable agricultural production.

MAJOR PROBLEMS FACING WATER SECTOR IN SAUDI ARABIA

Water supplies and demands in any developing country face many difficulties and problems. Saudi Arabia provided the water supplies with its utmost attention. However, certain problems continued to bother planners and there will be probably worse in the future if no solutions are introduced. The most serious problems are:

1. Demand for water in the agricultural sector has grown to a level much higher than the renewable resources of the country. This meant that major aquifers were mined at a very fast rate. If this trend continues in the future, nonrenewable groundwater resources will be depleted soon. The government, however, has introduced some measures to reduce to some extent the excessive pumping from groundwater reserves.

2. Desalinized sea water is currently used to meet part of the even growing demands. The government has spent billions of dollars in construction, operation and maintenance of desalination plants. But with the increase of population in urban centers, decreasing groundwater supplies and lack of conservation, domestic water supplies will be in danger in the future.

3. Treated wastewater represents a very important source to be utilized for many purposes in Saudi Arabia. However, the amounts actually used now are small. This is mainly due to slowness in wastewater treatment plants construction and in providing necessary facilities to transport treated wastewater to areas where it can be efficiently used.

4. Surface water and renewable groundwater represents the most important natural water resources for the future. In spite of this, they have not been developed properly in some parts of the country. They also suffer from neglect and inefficiencies in the areas close to wadis and in old oases.

SUGGESTED SOLUTIONS TO MEET FUTURE WATER SHORTAGES

Shortages of water in arid areas are normal and expected. However, severe shortages of water will have serious social and economic effects. They will also cause severe health problems and may result in economic collapse. To avoid the problems that will be faced by the water sector in Saudi Arabia, or at least reduce their effects, it is necessary to concentrate actions in the following areas:

1. Reduce, in a gradual manner, the consumption in the agricultural sector, to a safe level. That level should be no more than the sum of renewable surface and groundwater resources and treated wastewater. Alternative (A3) or similar plan should be adopted.

2. Conservation of water use in arid regions is of a paramount importance. Although some conservation efforts (public awareness programs, television and other public media messages etc.) were made in the past, there is urgent need to do more. Actions needed include the use of drip irrigation, increase prices for water and require drainage water recycling.

3. Give priority in government spending to wastewater treatment plants construction and to distribution and pumping facilities for transporting treated wastewater. This will result in more treated wastewater being available for different uses. Hence, some of the demands for agriculture and industry can be met from this resource.

4. Due to possible future shortages of domestic water supplies, it is necessary to reserve parts of the areas covered by major aquifers for future domestic use. MAW has made an effort in designating few protected areas for that purpose. However, there is need to do more in this regard. The reserved areas should be large enough especially close to major urban centers with at least 1 KM^2 of protected surface area per 1000 people.

5. Increase production of desalination sea water and carry on more research in the area of desalination especially on methods and materials that will help to reduce costs.

6. Develop water resources in areas adjacent to wadis and use the renewable surface and groundwater in old oases in an efficient manner.

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Possible Impacts of Climate Change on Water Security in Qatar

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POSSIBLE IMPACTS OF CLIMATIC CHANGE ON WATER SECURITY IN QATAR

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ABSTRACT

Efficient utilization and management of water resources is an important aspect in an arid environment like the Arabian Gulf. A comprehensive assessment of the available water and its use is a prerequisite for an integrated development and management of water resources. Sharp variations in the climatic conditions of a place or a region has a bearing on water availability and consumption. In the present study, an attempt has been made to analyse all the climatic parameters that have influence on water resource sector. Observed surface air temperature, wind speed, evaporation and rainfall and computed values of evapo-transpiration and water balance of Doha have been subjected to linear trend analysis. Significant warming trend in the surface air temperature of Doha has been found. This has obviously resulted in significant rising trend in the evaporation and evapo-transpiration. The trend in the annual rainfall series is however found to be insignificant. The increasing water loss due to significant rise in temperature/evapo-transpiration could not be offset by the less significant rainfall trend. As a result, there is a significant declining trend in the water balance in Qatar. In other words, stress in soil moisture conditions is constantly increasing. The population of Qatar has increased by about 4.3 times since 1971. However, the water consumption of Qatar has raised by 10 times since then. This indicates the significant rise in the per capita water consumption of Qatar. With increased water losses due to climatic warming and constant increase in the per capita water consumption, the water security of Qatar may be affected adversely, if sufficient planning is not done. The northern half of the peninsula has good groundwater potential and it is worthwhile to take up construction of artificial recharge works in identified areas.

Key words: water security in the Gulf, Qatar, climatic change, water balance, water resources

INTRODUCTION

The role of water in any national economy needs no emphasis. Water is a prerequisite for every developmental activity and its demand is ever increasing. Along with domestic needs, the industrial requirements are also increasing at a faster rate with population and economic growth. It is quite essential to make reliable estimates of future water needs keeping various growing activities in mind. In making such projections, it is important to know the climatic variations of the region that may affect the hydrological regime.

In arid and semi-arid regions, relatively small climatic changes could produce large water resource problems. Irrespective of the causes of changes in climatic conditions, whether natural or man made, their impacts on water security need to be assessed for addressing possible remedial measures. The most important climatic parameter in water resource sector is the rainfall, but unfortunately, it is not predictable with reasonable skill, more so in an arid region like Qatar.

Hydrologists have been studying the potential consequences of changing climatic conditions in various regions/countries. These studies have been based on different methods that may broadly be grouped in to the following four categories.

1. Analysis of long-term variations in the meteorological elements and run-off data

2. Use of water balance methods over a long-period of time

3. Use of atmospheric General Circulation Models (GCM's) for predicting future climatic trends and thereby hydrologic characteristics.

4. Application of deterministic hydrologic models to study rainfall-runoff relations using climatological data sets, GCM outputs etc.

In the present study, an attempt has been made to present long-term changes in the observed climatic elements of surface air temperature, wind speed, evaporation and rainfall and computed values of evapo-transpiration and water balance at Doha. It is hoped that the results of the study shall provide useful information about the implications of climatic changes on water security in Qatar.

DATA AND ANALYSIS

1. Data

As per the procedures outlined in a technical note of the World Meteorological Organization (WMO, 1966) the sample size of the time series should be as long as possible for climate change studies. Keeping this in mind all the available data in respect of Doha have been utilized. For stations other than Doha, the data period is not long enough to perform any trend analysis. The list of parameters along with the period of data considered is given in Table 1.

Table 1: List of climatic parameters whose data were used in the study

S No.	Parameter	Data Period	Number of years
1	Monthly mean surface air temperature (°C)	1962-1999	38
2	Monthly total rainfall (mm)	1962-1999	38
3	Mean monthly and annual wind speed (knots)	1974-1999	26
4	Monthly pan evaporation (mm)	1976-1999	24
5	Monthly total evapotranspiration (mm)	1976-1999	24
6	Monthly water balance (mm)	1976-1999	24

The annual time series for trend analysis have been obtained from the monthly observed/derived data by simple averaging or totaling. There were no missing observations in the data set.

2. Analysis

The parameters at serial number 1 to 4 in the above table are observed ones, whereas 5 & 6 are the derived parameters. The procedure followed in deriving these two series is briefly given below.

Experimental work by Van Bavel (1966) in Arizona demonstrated the basic validity of Penman's equation when applied to evapo-transpiration, but at the same time showed the need for a modification in the aerodynamic term under severe advective conditions. This is based on the recommendation of a working group set up by the Food and Agricultural Organization (FAO) in 1972 and published in FAO Irrigation and Drainage Paper No. 24 by

Doorenbos and Pruitt (1975). The procedure consists of computing potential evapo-transpiration by Penman's method with an appropriate albedo values. This value is then modified to take in to account the variation of day and night wind speed and correction factors based on prevailing regime of temperature, wind and humidity to provide the modified potential evapo-transpiration. The procedure has been clearly outlined in WMO (1976) which has been adopted in the present study for computing monthly evapo-transpiration values at Doha.

Water balance is expressed simply as the algebraic difference between rainfall and evapo-transpiration without consideration of runoff, as there are no river systems in the region of study.

In order to estimate the trends in the series, simple regression analysis with time as the independent variable was used. For testing the statistical significance of linear trends, the most widely used Mann Kendall rank statistic has been adopted (Mann, 1945; Kendall, 1948; Kendall and Stuart, 1961). The statistic T is computed by the equation:

$$T = \{ 4P/N(N-1)\} - 1$$

N- length of the time series

The statistic $P = \sum ni$

It is obtained as follows. Compare the value of the first term of the series X_1 (or its rank K_1) with the values of all later terms in the series, from 2nd to nth. Count up the number of later terms whose values exceeded X_1 (or K_1) and denote this number by n_1. Continue this procedure for each term of the series ending X_{N-1} (or K_{N-1}) and its corresponding number n_{N-1}.

In as much as T is distributed very nearly as a Gaussian normal distribution for all N larger than 10, and has an expected value of zero and variance equal to (4N+10)/9N(N-1), it can be used as a basis of significance test by comparing with the values

$$T(t) = 0 \pm tg \{(4N+10)/ 9N(N-1)\}^{1/2}$$

Where tg is the desired probability point of Gaussian normal distribution appropriate to a two tailed test. The above method has been used for testing the significance of trends, for all the parameters excepting rainfall. For rainfall data, especially over arid zones like middle east which are seldom Gaussian (normally) distributed, Kendall's (1970) suggested appropriate method (Sneyers, 1990; Denhard and Schonniese, 1992) was used.

The standardized test quantity

$$Q = S/[1/18\{N(N-1)(2N+5)-b_1(b_1-1)(2b_1+5)\}]^{1/2}$$

Where S is the standard deviation of the series and b_1 is the number of identical data values in the series. When the values of Q is greater than 2, the trend is significant at 95% confidence level (< 5% error probability) and if Q >3, it implies significance at 99% confidence level (<1% error probability).

3. Results

Table 2 summarises the results of the trend analysis of various parameters considered in the study, along with the means and standard deviations. It may be seen that highly significant (99% level) increasing trends are observed in the annual surface air temperature, evaporation and evapo-transpiration (Figs. 1, 2 and 3). In the case of mean wind speed and water balance, very significant (99% level) declining trends are observed (Figs. 4 & 5).

Table 2: Results of trend analysis of different parameters.

S. No.	Parameter	Mean	S.D.	Mann Kendall T	Significance value	
					95%CL	99%CL
1	Surface air temperature, °C	26.8	0.52	+0.272**	±0.222	±0.263
2	Annual rainfall, mm	83.4	70.9	Q=0.891	Q>2	Q>3
3	Mean wind speed, kts	8.4	0.99	-0.772**	±0.273	±0.325
4	Annual evaporation, mm	3221.5	232.9	+0.413**	±0.286	±0.339
5	Annual evapotranspiration, mm	2372.2	167.9	+0.391**	±0.286	±0.339
6	Annual water balance, mm	-2282.9	180.8	-0.355**	±0.286	±0.339

Despite considerable decreasing tendency in the wind speed, there is a significant increasing trend in the measured Pan A evaporation and computed evapo-transpiration. This indicates the strong influence of climatic warming over the region. With regard to rainfall, no notable trend is observed (Fig. 6). The systematic and significant decreasing trend in the computed water balance due to large increasing trend in the eavpo-transpiration and very little rising tendency in the rainfall. The monthly water balance was also worked out for the period 1976-1999. Of the total 288 months in the period of study, only two months had slight positive water balance. They are December, 1995 (10.3 mm) and November,1997 (3.0 mm). These are due to rainfall amounts exceeding evapo-transpiration values in these months. The observed rainfall amounts in these months were 80.5 mm (Dec., 1995) and 110.5 mm (Nov., 1997). The month-wise mean climatological water balance may be seen in Fig. 7. From this, it may be seen that water stress conditions are severe in the months of May, June and July. Water deficits on an average, are low in winter months of December, January and February. The month of May experiences the highest water stress with -313.74 mm followed by June with -299.0 mm and the water deficit is lowest in December (-77.32 mm). We may therefore say that water requirements for horticulture and agriculture is less in December and highest in May and June.

The evapo-transpiration and water balance figures given above may be said to be theoretical since there is no water /soil moisture really available. This is also referred as climatic water balance. For computing actual evapo-transpiration, Turc (1954 and 1955) and Pike (1964) have developed an equation commonly referred as Turc-Pike relationship. This can be written as:

$$AET = P.\ PET/(P^2+PET^2)^{1/2}$$

Where:

AET = actual evapotranspiration
P = precipitation
PET = potential evapotranspiration

The above relationship is valid only on annual scale, particularly in dry regions where many months will have zero rainfall. Utilizing the above relationship actual evapo-transpiration and the actual water balance for the period 1976-99 have been computed and plotted. Fig. 8 depicts both the climatological water balance and true water balance series. Climatologically large water deficits are seen at Doha and with increased values over the time period. In the case of true water balance, it is almost zero or no water is left from the precipitation input in all the years.

Taking into account the standard deviation of the annual rainfall, there have been five excess rainfall years (annual rainfall> mean + SD) and only three deficit years (annual rainfall < mean + SD). The excess years were 1964 (302.8 mm), 1976 (193.4 mm), 1982 (167.3), 1995 (260.9 mm) and 1997 (240.2 mm); and the deficit years were 1962 (0.4 mm), 1970 (12.2 mm) and 1985 (9.7 mm). The climatological and true water balance values in these years along with evapo-transpiration (climatological and true) figures are given in the following table (Table 3).

Table 3: Evapotranspiration and water balance values in excess and deficit rainfall years at Doha, Qatar

	Excess rainfall years					Deficit rainfall years		
Parameter\year	**1964**	**1976**	**1982**	**1995**	**1997**	**1962**	**1970**	**1985**
Climatic evapo-transpiration (mm)	NA	2143	2441	2537	2479	NA	NA	2527
Actual evapo-transpiration (mm)	NA	193	167	260	239	NA	NA	10
Climatic water balance (mm)	NA	-1950	-2274	-2276	-2239	NA	NA	-2518
True water balance (mm)	NA	0.78	0.39	1.37	1.12	NA	NA	0.0

NA: Data not available (Pan Evaporation data for Doha are available only from 1976.)

4. Concluding remarks

The linear trends found in different climatic parameters of Doha, Qatar have strong implications on water resource sector. The highly significant increasing trend in the surface air temperature has obviously resulted in very significant rising trend in the observed evaporation and computed evapo-transpiration. Although there is a significant decline in the mean wind speed but had not influenced much on evaporation/ evapo-transpiration. This clearly shows the dominant role played by the climatic warming observed at Doha. The significant declining trend in the water balance explains the effect of the increasing trend of evaporation/evapo-transpiration and a very little offset potential due to dismal increase in the rainfall amounts.

From the analysis of linear trends in the study, it is found that there is an increase of 23.4 mm/year in the evapo-transpiration and decrease of 28 mm/year in the water balance. These are 1.0% and 1.25% of their annual totals respectively. Whereas, the trend in the annual rainfall is only 0.32 mm/year, which is about 0.38% of the mean annual rainfall. If it is expressed in terms of volume, hypothetically, there is an increase of 267.6 million cubic meters of water loss per year from the whole of Qatar due to rising trend in the evapo-transpiration. The marginal rising trend in the rainfall accounts for 3.7 million cubic meters of water in a year from the whole of Qatar. This is only 1.37% of excess climatological evapo-transpiration due to observed climatic warming.

As a result of rapid increase in the income, the living standards of people of Qatar have risen and thereby increased domestic water consumption. Most of the population in Qatar have running water in their homes. As per the GCC Economic Data books (GCC, 1996 and 1998), the total consumption of water has increased from 1742 million gallons in 1971 to 16,986 million gallons in 1993. There has been therefore a ten-fold increase in water consumption in the 23-year period. If we see the population growth, the population of Qatar in 1971 was 122,000 and rose to 526,000 in 1994. This increase in 24 years is about 4.3 times. Thus it is evident that per capita water consumption has been increasing quite fast and the trend seems to be continuing. With the increased water loss due to climatic warming and due to ever-increasing per capita consumption rates, the water security in Qatar may be affected adversely, if no remedial measures are taken.

The findings of the FAO (1981) report indicate that the northern half of the peninsula has a reasonable potential for groundwater. It was estimated that northern groundwater province contains approximately 2500 Mm^3 of fresh water within two aquifer systems. The safe yield of these two systems alone is worked out to be 27 $Mm^3/_{yr}$, as compared to the total safe yield of 40 $Mm^3/_{annum}$ in the whole of Qatar. As per their estimates, a total area of about 6500 km^2 is available for groundwater recharge in Qatar (FAO, 1974). Infiltration of about 10-15% of the storm rainfall to the aquifers in the northern parts is possible (FAO, 1981). It is therefore worthwhile to take up construction of artificial recharge works in combination with flood protection works in the recommended areas. This will help in enhancing the groundwater potential in Qatar.

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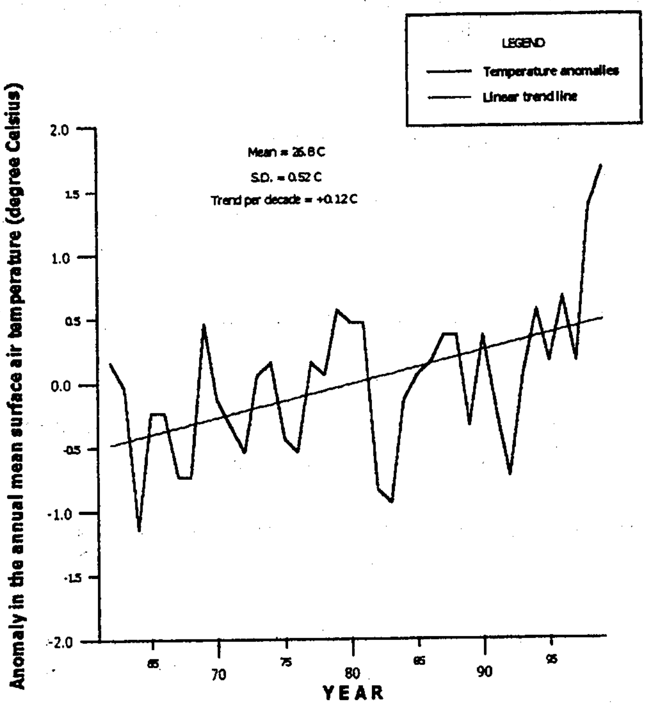

Fig.1 : Variation of annual surface air temperature during 1962-99 at Doha along with trend line.

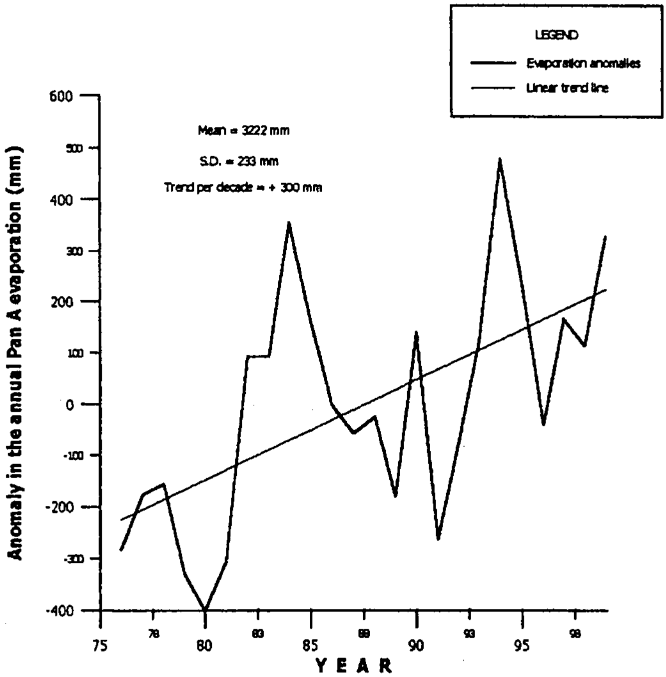

Fig.2 : Variation of annual evaporation along with trend line during 1976-99 at Doha

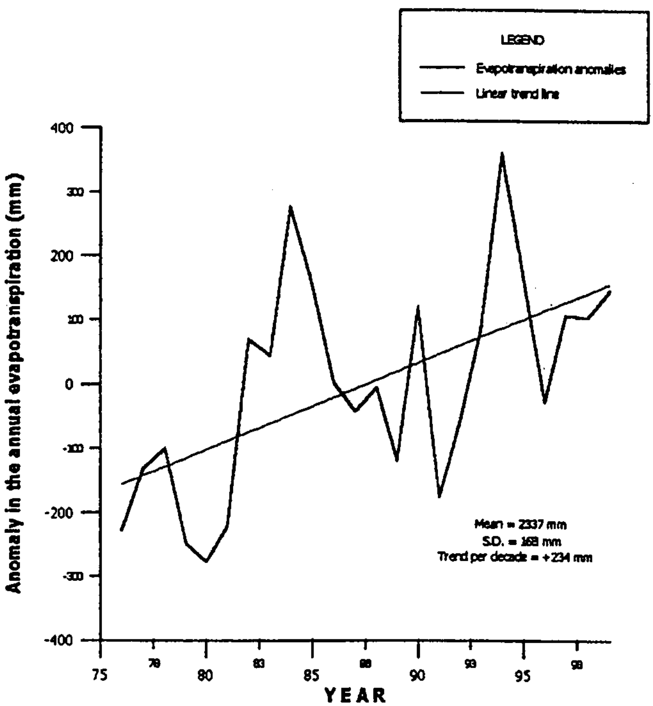

Fig.3 : Variation of annual evapotranspiration during 1976-99 at Doha along with trend line

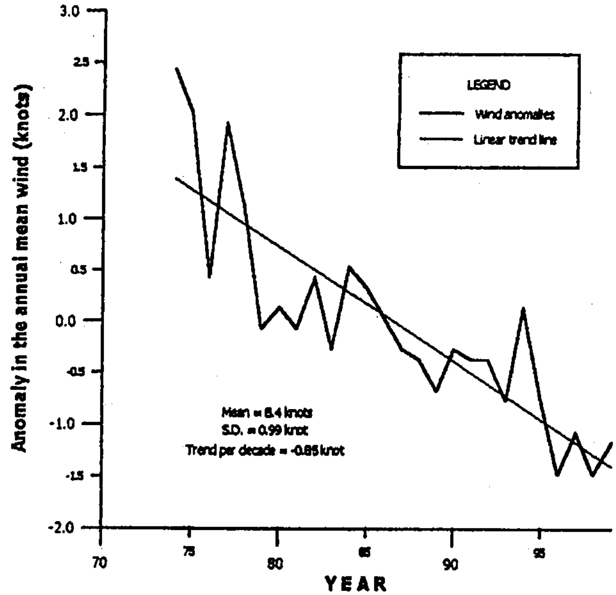

Fig.4 : Variation of annual wind speed during 1974-99 at Doha along with trend line

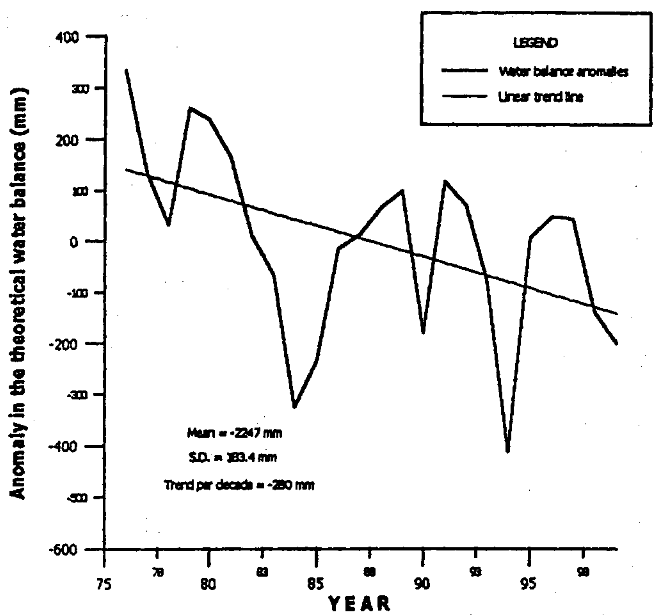

Fig.5 : Variation in the annual theoretical water balance during 1976-99 at Doha along with trend line

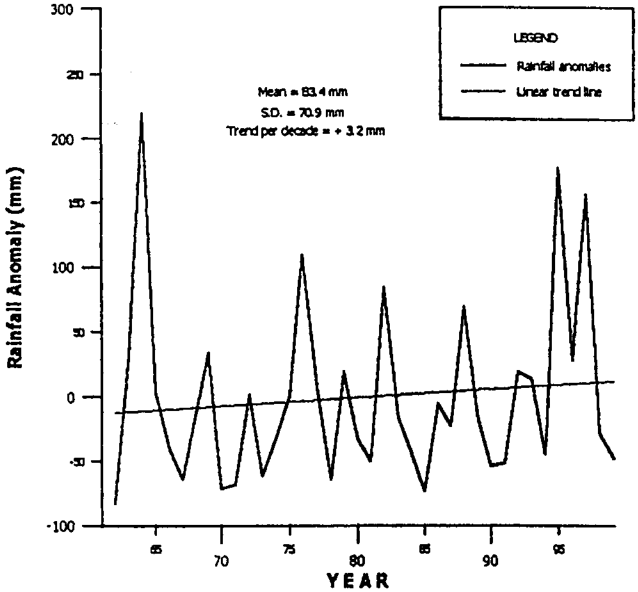

Fig.6 : Variation of annual rainfall during 1962-99 at Doha along with trend line

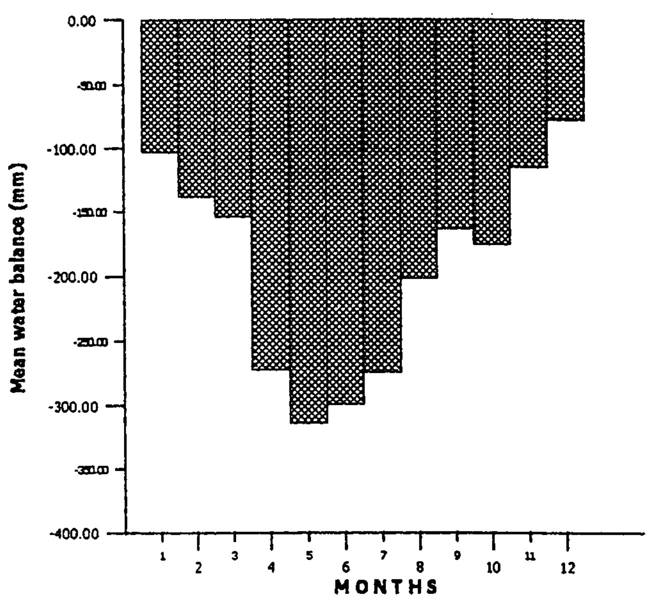

Fig.7 : Theoretical mean monthly water balance (mm) at Doha

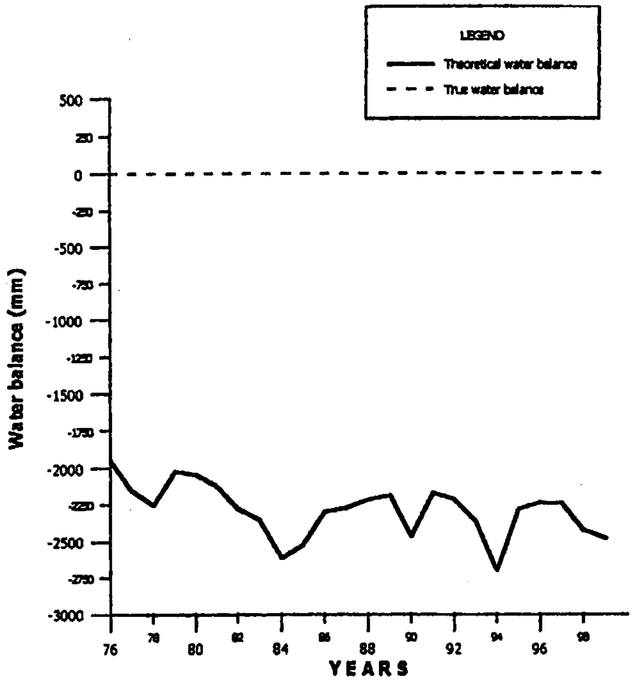

Fig.8 : Theoretical and true water balance (mm) at Doha during 1976-99

Oman Water Resources: Management and Measures to Conserve Water for Domestic and Agricultural Use

Ahmed S. Al-Marshudi

OMAN WATER RESOURCES : MANAGEMENT AND MEASURES TO CONSERVE WATER FOR DOMESTIC AND AGRICULTURAL USE

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ABSTRACT

Agriculture in the Sultanate of Oman depends on irrigation. Remarkable public and private investment have been draw into water and land resources development and into the modernization of the farming techniques in order to strengthen the contribution of agriculture to the national economy.

Rapid agricultural expansion has triggered significant groundwater depletion and saline water intrusion in the major coastal aquifers, showing that the nation's limited water resources can't sustain the level of the current agricultural development

A comprehensive water program has been undertaken by the government to conserve water through efficient use. Measures included modern irrigation system, dams construction, *Aflaj* system improvement and water policy legislation.

This paper explores these measures in order to suggest ways for better water allocation. Specific actions are recommended to improve the use and distribution of *aflaj* water resources. Careful consideration, however, must be given to prevailing social rules and habits governing *aflaj* management.

Key words: Water Resources, *Aflaj*, Irrigation, Tradition, Conservation.

INTRODUCTION

With water becoming an increasingly scare commodity in the Sultanate of Oman, it has now a big potential of becoming a limiting factor for agricultural, and even for industrial development. Many authors who dealt with water resources in Oman stated (Al-Zubari, 1997; Hayder & Adel-Magid, 1993) ' the greatest challenge the Sultanate of Oman facing is the provision of fresh water supply to meet the domestic, agricultural and industrial sectors demands. With groundwater resources, over-exploitation and desalination plants limited capacity, planners are continuously searching for additional sources of water which can be used economically and effectively to promote further development.

With growing concern about water scarcity and inefficient allocation and use of water resources, increasing attention is being given to market base allocation. It provides one of most promising institutional arrangements for allocating surface and groundwater irrigation, particularly for securing water supplies for high value uses in urban area and agricultural firms, as an alternative to development of costly new sources of supply which often entails environmental damage. (Mahmood Ahmed, 1996).

Irrigation performance has been an important issue in water management and conservation policy in Oman. Increasing the productivity and the efficiency of water resources is a significant objective in the agricultural development strategy (JICA, 1990). With agriculture's present use of 80% to 90% of the nation's fresh water, water conservation in the agricultural sector has now become priority for the government (George 1996; Hayder & Adel-Magid, 1993). Measures are presently being sought by which irrigation water can be used more efficiently. Particular attention has been given to the improvement of "traditional", on farm surface irrigation, since this method is employed in the majority of farms with water wells and within all *aflaj* systems.

The present study focused on the issues of water resources management measures. What measures has been taken in order to conserve groundwater and to improve the existing traditional *aflaj* system. The main objective was to develop recommendation for improved water use efficiency.

COUNTRY PROFILE

The Sultanate of Oman occupies the southeastern corner of the Arabian Peninsula and has a total area of 312,500 sq. km. According to official estimates the land area is composed of varying topographic features: valleys and desert areas account for 82 percent of the landmass: mountain ranges, 15 percent, and the coastal plain, 3 percent.

Northern Oman has a mountain chain with heights up to 3,000m above sea level. The Jabel Al Quara in Dhofar in the South divides the coastal plain of Salalah from the interior plains of the Najid.

Climate

With the exception of Dhofar region, which has a light monsoon climate and receives cool winds from the Indian Ocean, the climate of Oman is extremely hot and dry most of the year. Thus, Oman climate is characterized by high summer temperatures, scanty and irregular rainfall, and high rate of evaporation, high relative humidity and persistent winds from all direction. As can be clearly seem in fig 1 that there are significant seasonal variations in the average monthly temperature. The hottest months are July and August with temperature touching 45°C while December, January and February are the coolest averaging 17°C.

Precipitation on the coast and on the interior plains ranges from twenty to 100 mm a year and fall during mid- and late winter. Rainfall in the mountains is much higher and may reach 700 mm. Because some parts of the plateau and mountainous areas are composed of porous limestone, rainfall seeps quickly through to replenish underground aquifers. Thus, a huge reservoir under the plateau provides springs for low-lying areas. In addition, a numerous wadis channel water to these valleys, making water available through traditional *Aflaj* system.

Agriculture

By far the most important agricultural areas in Oman are the Batinah and the Interior. Both regions sustain almost 80 percent of all agricultural production and have witnessed vigorous development in recent years. Crop production depends entirely on irrigation, the main crops being dates, alfalfa, wheat and fruits and vegetables crops.

The most important problems of agriculture in Oman can be summarized as follows:

1. Limited water resources for irrigation. This problem is already clear in the decision-maker policy. A Sultan decree no. 88/82 was imposed on 12 November 1988 (Oman Official newspaper, 1988) to consider water resources reserves as national resources; their use is subject to permission. Another decree no. 89/72 on 23 July 1989 imposed modern irrigation net in Batinah region because of increased salinization of soil.

2. Because of scarcity of water, crop production has little economic return in general, except for vegetable and fruits.

3. During the last decades, there has been a clear migration from the countryside to the cities. Besides, the expertise for modern agriculture is lacking.

4. Capital investment in agriculture is limited in Oman.

5. Agricultural sector has been affected by rural-urban migration, in which the labor force has been attracted to the high wages of industry.

6. Agriculture and fishing sectors have declined in relative sectoral importance. For example, in 1967 the two sectors together contributed about 34 percent of GNP; by 1990 they accounted for 3.8 percent (Statistical Yearbooks, 1975, 1991)

However, the government encourages farming by distributing land, giving advice on new production techniques in particular modern irrigation methods. Consequently, the area under cultivation has increased, with an accompanying rise in production. Nevertheless, agricultural activity has also depleted freshwater reserves and underground aquifers and has increased salinity in both soil and water.

WATER RESOURCES

Agricultural production in Oman is particularly dependent on water resources since most crops grown are irrigated and they consume more than 94% of total water use (Zaibet and Omezzine, 1997). This may lead us to say Oman is characterized by an arid climate and limited water resources, which preclude the potential for substantial horizontal expansion of cropped area. Efforts, therefore, are being directed to vertical expansion, i.e., increase in water productivity and water use efficiency (MAF, 1995).

Oman has perfected the art of exploiting available water resources over centuries. This has led to the creation of two main systems. The objective of such systems is to bring available groundwater for agricultural and domestic use. Authors have classified these systems as (Dig-wells system and *Aflaj* system) which are use groundwater (Wilkinson, 1977; Hayder and Omezzine, 1996). However, a newly developed technique to explore water from the sea is through the desalination process. Currently desalinated water amounts to 52 MCM/year 48MCM/year in the capital area (see fig 1), and is expected to reach 140 MCM/year in 2020 (Zaibet and Omezzine, 1997). Desalinized water is meant for domestic use but would save water that would otherwise be pumped from water wells (Hayder and Adel-Magid, 1993).

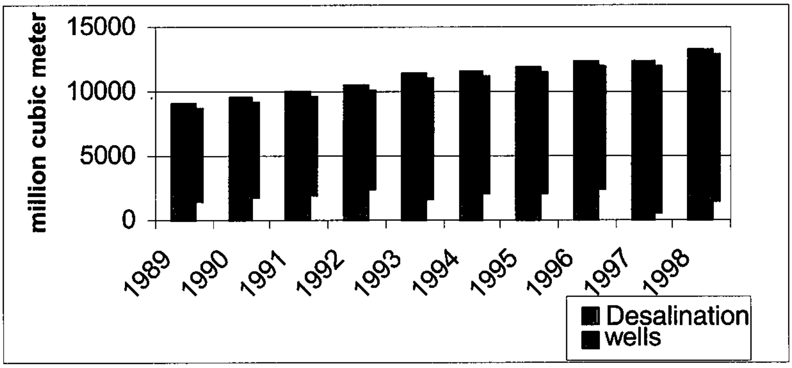

Fig.1. The two main sources of domestic water in the capital area
Source: Statistic Yearbook, 1998

Dig-Wells System

This system uses modern methods of extracting underground sources of water. Diesel and electrical pumps have replaced animal power as a means of raising water from wells since 1960. According to the recent well inventory carried out in 1992 by the Ministry of Water Resources, there are 176,000 wells owned by citizens, of which 50% is concentrated in the Batinah region. In addition, the FAO Review report (1997) pointed out that 47% of the total number of 62,411 households, the well system, is their main source of water.

In recent years the introduction of modern techniques, electric or diesel pumps, extracting water from these wells, have led to higher extraction rate compared with traditional methods. Another cause is the increase in agricultural productivity. As a result of this the following problems occur: At present groundwater depletion already takes place, especially in the coastal areas, leading to sea water intrusion and deterioration in water quality. The assessment of seawater interaction on the Batinah coast has been examined through several studies. The most important of these so far is the production of the series of maps comparing the extent of saline water interaction and falls in groundwater levels during the period 1983 to 1991. (Ministry of Water Resources, 1997).

The latest FAO report, (1997) about agricultural production in Oman, stated that only 2.7% of the total cultivated land have benefited from the sprinkler irrigation system and 3.4% from micro-irrigation techniques. The report goes on pointing out the Ministry of Agriculture and Fisheries effort.

"Although the MAF is making efforts to introduce modern irrigation techniques, the traditional flood system (*Aflaj*) remains the most common irrigation technique".

The Aflaj System

Irrigation in Oman has its roots in antiquity. Sutton (1984) stated that "the ganat of *aflaj* systems of Oman have provided communities with water for irrigation and domestic purposes for 1,500-2,000 years". She went on to say, "many of the systems at present in operation are over a thousand years old, and owe their continued existence to the well established social and financial structures which have evolved over the years and which take care of administration and maintenance".

Aflaj (sing. *aflaj*) are the main source of irrigation water in Oman beside wells. They are utilized in agriculture as well as for domestic use since ancient times. Water distribution is complicated but rather efficient to ensure fair and adequate water supply for all farming lands. Water is mainly distributed to the contributors (owners) and their share is inherited, while others may buy a share from the owners or through rental (from regular auctions) according to the farmer's need of the water.

According to the Ministry of Water Resources, the number of *aflaj* in Oman is estimated to be 11,000, among which 4,000 major ones flowing constantly.

The *aflaj* maintenance was the responsibility of every individual in the society. The preoccupation with distribution of water rights is reinforced by the fact that *aflaj* produced isolated communities. Each of these communities tends to form a self-sufficient society whose members cooperate in water matters. The social structure that has grown up in each settlement was based on the need to organize the water supply, and fund both regular and sporadic and urgent *aflaj* maintenance.

MEASURES TO CONSERVE WATER RESOURCES

Recent years have seen a significant expansion in the cultivated area - most notably, areas irrigated from wells. With agriculture's present use of 80-90 percentage of the nation's fresh water, water conservation in the agricultural sector has now become a priority for the government (George, 1996; Hayder and Adel-Magid, 1993).

Government efforts to rationalize the use of water resources as a component of national food self-sufficiency strategies have been substantial. First, extensive programs have been implemented to introduce subsidized new irrigation systems in order to improve the management of water in agriculture (Zaibet and Omezzine, 1997). Second, over farming and attendant water problems caused the government to establish the Ministry of Water Resources in 1990 (FAO, 1997).

Measures are presently being sought by which irrigation water can be used more efficiently (Norman, 1997). These can be summarized as follows.

1. Modern Irrigation Systems

Most crops producing areas in the Sultanate of Oman receive only 100-200 mm of rainfall annually. Virtually all crop production is therefore dependent on irrigation (Norman, 1997). About half of the 62,000 ha cultivated in the Sultanate are irrigated from wells, while the rest are irrigated by traditional *aflaj* system. Almost all of the land using wells water applies one or more of the better-known irrigation methods. However, a number of newly irrigation methods, namely sprinkler irrigation, drop irrigation and central pivot, have been introduced in the Sultanate.

For the past 25 years government subsidies used to provide technology to the farmer and train him in modern methods used in agriculture. Subsidies were also approved for modern irrigation projects. However, in recent years, basic subsidies in the input costs, such as machinery, seeds, fertilizer etc, have been removed. Nevertheless, in order to encourage farmers to use modern irrigation methods, Ministry of Agriculture and Fisheries has approved a financial subsidy. This subsidy varying between 75% for small-scale schemes (4.2 ha), 50% for medium-scale schemes and 25% for large-scale schemes (21 ha) (Oman,1999).

Adoption of modern irrigation systems is potentially the most significant method in water conservation practices and saving could be as much as 50% above traditional surface irrigation methods (Hayder and Adel-Magid, 1993). Therefore, this could reduce the problem of ground water depletion, especially in the coastal areas. Another benefit can be obtained by large commercial farmers who can save tremendous amount of input cost.

It is true that modern irrigation methods save water, but the initial cost incurred is very high. In addition, a careful balance must be made between the crop water requirements and water needed to control salinity. In other words, meeting only the evapotraspiration requirements would lead to salt buildup in the root zone.

2. Recharge Dam

Groundwater is the main source, harvested by well or *aflaj*. The wadis, usually dry riverbeds, suddenly fill with floods when rainfall occurs. Some of the floods infiltrate soil naturally, but in many years there are losses to the sea or desert of millions of cubic of water.

Recharge dams represent one of the few practical tools available for surface water management under Oman's conditions. Although their impact on the Sultanate's total fresh water availability is modest, they enable recharge to be directed to key locations of water deficit or of development potential, and they make beneficial use of sizable flood flows otherwise lost to the sea or desert (Al-khazane, 1997)

From 1985 – 1996, Oman has built 20 major dams, of which there are 16 recharge dams and 4 flood control dams. Table 1 gives sites and specification for recharge dams already constructed.

DAM	1	2	3	4	5	6	7	8	9	10
W Al-kod	1985	110	1674	14.0	5100	8.0	5.0	53.0	2.60	11.55
Salahi (Sohar)	1986	126	554	8.8	9062	4.5	3.0	27.0	2.50	0.500
W.Quryat (Bahla)	1986	131	427	8.5	1630	5.3	3.0	32.0	0.18	0.125
W.Jizz (Sohar)	1989	128	812	6.6	1234	20.4	6.0	129.	1.25	5.400
Tanuf	1989	160	157	5.0	135	14.8	3.0	36.0	0.12	0.700
Al-Hamra	1989	164	173	4.8	415	7.6	4.0	45.0	0.16	0.450
Ibri	1991	148	753	8.3	2635	5.9	6.0	59.0	0.70	0.500
W. Maawil (Barka)	1991	120	566	7.5	7500	8.3	6.0	38.0	2.50	10.00
Sur	1991	141	680	2.2	530	7.0	4.0	29.5	0.19	0.700

Table 1.Groundwater recharge dams-Oman

Source: Hayder and Adel-Magid, 1993

1. Year of construction of dam.
2. Average yearly rainfall (mm)
3. Dam water surface area (sq. km.)
4. Dam water capabilities (million cubic meter)
5. Length of dam (million cubic meter)
6. Height of dam (m)
7. Top width of dam
8. Max bottom width. (m)
9. Dam Lake Area (sq. km.)
10. Dam year's storage capacity

It is clear from Table 1 that Al-Khod recharge dam has the highest storage capacities (11.55 million cubic meters) followed by Wadi Maawil (10 million cubic meters), in spite of both receiving the low average rainfall. On the other hand, Wadi Sur has the lowest storage capacities (6.4 million cubic meters) but receives the highest average rainfall.

Recharge dams are meant to collect part of the 120 million cubic meters of rainfall lost yearly to the sea and desert. Lack of monitoring systems in most of the recharge dams makes their assessment and evaluation rather difficult. Visual surveys, however, have suggested that, on the average, the dams do catch sizable amounts of runoff. One concern is that the dams have deprived the coastal plains of the fertile silt and fine materials the stream used to carry down the valley.

3. Water resources policies and legislation

The Ministry of Water Resources is in charge of water resources assessment, whereas the Ministry of Agriculture and Fisheries (MAF) is in charge of irrigation. In 1988, Royal degree No. 83/88 declared the water resources of Oman a national resource. This is the most far-reaching and important piece of legislation on water resources. Oman has several laws on water resources. These have included the following:

1. No wells may be constructed within 3.5 km of the mother well of the *aflaj*.

2. Permits are require for the construction of new wells, for deepening existing wells, for changes in use and for installing a pump.

3. All drilling and well digging contractors are required to register with MWR on a yearly basis.

A freeze on new wells was imposed in addition to delimiting several "no drill zones" in areas where groundwater supplies are low.

Aflaj systems improvement strategies

The *Aflaj* system requires tremendous expenditure of labor for maintenance as well as for construction. *Aflaj* repair and maintenance is a priority task for the Ministry of Water Resources because the system, as mentioned in section of *aflaj* system provide more than 50% of the water resources in the country.

The Ministry of Water Resources '*Aflaj* section has a strategy for repair of *aflaj* nationally and has supervised the technical specifications and allocated available resources to repair 47 *aflaj* in 1997 (Oman, 1999).

A number of problems have been identified in the *aflaj* system. They fall into two categories. Problems due to physical structures of the *aflaj* system and problems which resulted from the administrative management of the system.

The physical structure problems can be summarized as follows:

1. Water conveyance of some *aflaj* over a wide gravid or earth bed has resulted in losses due to seepage and evaporation.

2. Water losses could be also attributed to breakage, poor grading of channels, and disorderly patterns of distribution.

3. The structures of Land and present water rights fragmentation have increased in channel losses.

4. The nature of the watering cycle that can go as long as 16 days, does not allow cultivation of high value vegetable crops and could lead to water stress during the dry and hot days.

Problems, which result from social management focus on the socially accepted competitive conditions, are not solved when water rights are in the hands of a few large owners selling to few small waterless landlords. Also there is evidence of some market power leading to speculation and, therefore, to unacceptable higher water costs for small landowners.

To sum up, low demand, lack of free inter-community mobility and absence of new water collection and distribution system too often result in over-irrigation and waste of water during wet years and in regions with surplus water supply.

Agrarian reform of the *aflaj* system in Oman is, therefore, of great importance. Hayder and Omezzine (1996) have forwarded a number of recommendations. A summary of these is as follows:

1. Improvement of the operation of the water tradable system through some form of public regulation.

2. Sustainable use of *aflaj* water can be made more flexible by the introduction of new engineering and irrigation techniques such as consolidated farming and the construction of artificial pools to collect and use water more efficiently to meet the needs of more diversified cropping systems.

3. Specific actions for *aflaj* water sustainability which may include:

i. Increasing efficiency of the present *aflaj* irrigation to combine the best features of the *aflaj* systems with the benefits of modern irrigation systems.
ii. Cultivation of high value crops to give an incentive to farmers to maintain their *aflaj*.
iii. *Aflaj* maintenance through channel lining and provision of improved dams and cisterns.
iv. More rational water distribution and modification of water rotation to suit crop water requirement.
v. Installing water measuring devices and basing shares on time and discharge.

CONCLUSION

The overall picture drawn from measurements taken in order to conserve Oman's water resources reveals the important of water management tools. Thus, the recommendations of this paper may help to find solutions to some high priority problems. However, attempts to undertake these actions require careful consideration of prevailing social rules and habits. It is well recognized that any suggested changes of an existing system may bring problems of greater complexity.

The recommendation adopted by the United Nations Conference on Environment and development held in Rio de Janerio in 1992 and the Oman Vision 2020 Conference guide the objectives of Ministry of Water Resources. These objectives focus on improvement of water use efficiency through water demand management and appropriate water resources development. The principal instrument to date has been the issuance of regulations and legislation. Water wells construction and *aflaj* maintenance regulations were issued in 1990. For example, requests for construction and deepening of wells within the Sultanate are assessed according to these regulations take into account the water situation in the area. (Oman, 1999)

The Sultanate has limited land and water suitable for agricultural production. Of these two resources, water is the most limiting factor in production of agronomic crops. Therefore, the available water (from rainfall) must be conserved when and where possible. Given that the water resources within the Sultanate are limited, the main issues and strategies that the government should address in the coming years are:

1. Creating and cultivating water conservation awareness among the public.

2. Matching water use to water availability

3. Establishing an integrated program for the conservation and management of the resources at catchment basin level

4. Controlling saline intrusion by reducing abstraction below the long-term rate of recharge

5. Adopting improved irrigation techniques and selecting appropriate crops to reduce agricultural water use.

6. Controlling urban water losses

7. Increasing the use of treated wastewater and desalinated water

8. Protecting the quality of groundwater resources as well as quantity.

9. Careful and appropriate siting of new groundwater recharge dams to take into account the problems experienced with existing dams.

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Water Security Key to Sustainable Development

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WATER SECURITY KEY TO SUSTAINABLE DEVELOPMENT

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ABSTRACT

Qatar and most of the Middle East countries have an arid climate where the total evaporation exceeds the amount of precipitation. In general fresh water resource has been scarce in the region. Therefore earlier people were nearly starving for water.

Due to the oil wealth the development in all spheres of life has been very rapid, including the water supply sector. Water is being used in palaces, large villas with large size gardens and multi bathrooms, swimming pools, daily washing of cars, golf course, industries and construction. Population growth and continuing urbanization, higher standards of personal cleanliness and industrial development coupled with plentiful subsidized water supply have resulted into high water consumption.

The objective of this paper is to critically examine the current status of water resources and propose ways and means to achieve water security. Necessary actions have to be taken considering the cultural, social, religious, institutional, technical and political aspects to sustain the development process.

INTRODUCTION

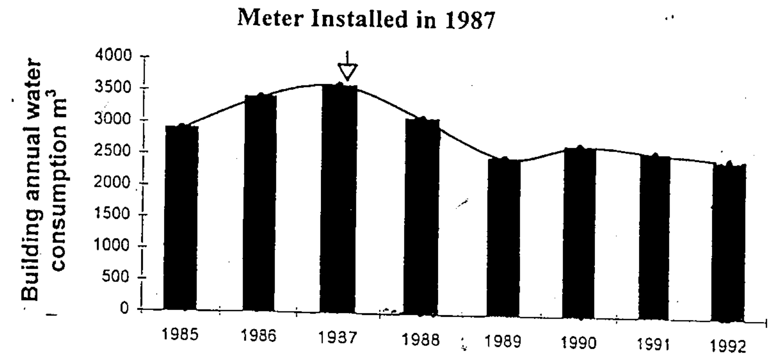
Water resources in Qatar are as follows:

- Underground fresh water generally found in the northern part of the country is mostly used in agriculture.
- Seawater is desalinated and used for domestic, public, commercial and industrial purposes.
- Brackish underground water is used to produce water for a small community in Abu Samrah, bottled water and water for sand washing.
- Treated municipal wastewater is used to irrigate landscape and roadside plants, and a farm growing animal fodder.

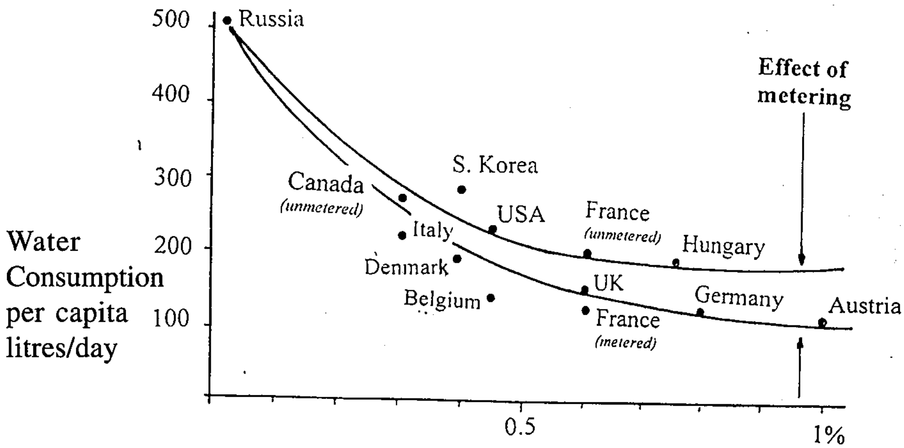
Water is now considered a key to the sustainable development, i.e. for the continuity of the development process. The region including Qatar has enormous oil and gas wealth but lacks fresh water resources. The excess money at the disposal of these countries resulted into the rapid development in the last three decades. Little attention was given to the sustainability of development including the development in water sector.

Property type	Description	Demand (L/day)
A1	Domestic – Flat	648
A2A	Domestic – villa – European Compound	1704
A2B	Domestic – Villa – Old Arabic Style	738
A2C	Domestic – Villa – Junior Housing	2447
A2D	Domestic – villa – intermediate Housing	4136
A2E	Domestic – Villa – Large	10000
A3A	Domestic – Palace in small compound	20000
A3B	Domestic – Palace in large compound	35000
A4	Domestic – Labour Camp	26360
A5	Domestic – Staff Housing	23955
B01	Non – Domestic – Shop	700
B02A	Non – Domestic – Mosque – Small	2000
B02B	Non – Domestic – Mosque – Medium	3500
B02C	Non – Domestic – Mosque – Large	5000

Table 1. Property demand in Doha (ASCO)



a) Meters installed in 32 apartment building in France
Water consumption is reduced by 34%



Water price as % of disposable income
b) Relationship between water price and consumption

Figure 1 : Effect of metering and price on water consumption

The property demand given in Table 1, based on the study made by ASCO consultant shows that water consumption is quite high in Doha. This is because of luxurious life, high standards of personal cleanliness, palaces and large villas with huge gardens, multi bathrooms, swimming pools and daily washing of cars. The same is true in other countries in the region (Akkad 1990). Water supply is subsidized for the citizens in the Gulf countries. Population growth and continuing urbanization are also contributing to high water demand.

Water demands have begun to slow in many industrialized countries due to the use of water saving plumbing fixtures, public awareness, modifying production processes in the industry, reuse, recycling, metering, leakage control, water pricing and realistic water policy. Because of water conservation measures, estimated water withdrawals for all purposes actually declined in the USA by almost 9 percent between 1980 and 1995 (Konig, 2000; Manzione, et. al. 1991; Ogoshi, et al 2000; Ploesers, et. al. 1992; Vickers, 1990). Even countries like UK and Japan where the precipitation is high, water conservation methods have been implemented as a means to manage the water resources in a sustainable way (Ogoshi, et.al. 2000). In Fig. 1 the effect of metering and price on water consumption in some countries is shown (Roseberg 1994). The water consumption is highest in Russia where it is subsidized. It reduces when consumers have to pay based on the consumption.

STATUS OF WATER RESOURCES

Qatar receives 54.76 million cum of recharge/year from rainfall, while the net recharge has been estimated as 113.06 million cum. It has been estimated that in 1998/99 the water withdrawal was 307.435 million cum with a subsurface outflow of 18 million cum (Nair, 2000). These estimates indicate that the water withdrawn far exceeds the recharge value. Consequently the underground fresh water is depleting. Most of the precious underground water is used in agricultural farms producing low value crops. However it is a matter of national pride to grow crops even though the economics do not go in favour of growing crops.

7.3 million liters per day (ML/d) of water is supplied in some rural areas in the northern and central Qatar by well fields. At present 354 ML/d of desalinated water using multistage flashed distillation process is produced. Desalinated seawater is supplied to cities for residential, public, commercial and industrial uses. Potable water is also used for irrigating lawns, parks, gardens, and the golf course. A minimum of three-day strategic storage is provided in Doha, the capital of Qatar.

Reverse Osmosis plants produce 0.7 ML/d and 1.2 ML/d of potable water at Abu Samra and at North camp respectively. Bottled water is produced from brackish underground water using membrane technology. A sand washing plant uses reverse osmosis process to desalinate the brackish water.

The data in Table 2 indicate that the water supply system has expanded very rapidly during the last three decades. As a result there is much to be desired in the construction, operation and maintenance of the water supply system. Some new water mains got corroded in a very short period and had to be replaced.

Cars are washed on a regular basis with the help of a pressure hose resulting into wastage of water. All this consume large quantity of water. Unaccounted for water is significant which adds to the total water use. However leak detection survey has been done is some parts of the city. Gradually this activity needs to be extended throughout the system.

There is no incentive to reduce the water consumption because water is subsidized. In general people do not realize the importance of water and therefore conservation of water is not yet a priority.

PROPOSED MEASURES

Water problem has social, cultural, religious, institutional, technical and political dimensions. Considering all these aspects the following innovative approach should be adopted to reduce water consumption, improve water supply system, satisfy consumers, optimize the capital investment and ensure water security.

- A public awareness compaign through media, display of placards at strategic locations, and popular lectures may go a long way in creating public awareness regarding wastage and excessive use of water. Imams of the mosques should be taken into confidence in this regard. The water professional should meet and discuss with Imams the water problems in the society and the possible solutions. As an example the value of water should be brought into focus during Friday prayers in the mosque by quoting relevant verses from the Holy Koran: "Allah loveth not the waste through excessive use". Women and children must also be targeted to bring home the importance of water savings.

- Conservation measures should be implemented by various customers through behavior, technology, and management. The details of conservation measures are presented in Table 3. Water efficient household plumbing fixtures, landscape vegetation that blends with the surrounding, industrial and agricultural conservation measures, metering of water consumption, water pricing will ensure water security. The society cannot sustain in the long run subsidized water supply system.

- The utility planner should incorporate water conservation component in the master plan (Macy 1991). A reduction in demand will eliminate or postpone future capital investment and reduce operating costs. However conservation may not completely replace the need for additional supplies but it may supplement the need.

	1971	1999
Water demand (million cubic meter)	8	134
Storage capacity (million liters)	45.4	1062.4
Primary and Secondary distribution mains (80 to 1400 mm dia) Km	390	3500
Number of consumers receiving pipe water supply	9500	136,500

Table 2 : Growth of water supply system in Doha

Customer	Hardware/Technology	Behavior/Management
Water Utility	Leakage detection and repair hydrant capping, pressure reduction	Maintain and replace production and customer meters, service and adjust equipment and valves
Residential	Low-volume toilets, showerheads and faucets, efficient clothes and dishwashers, leak repair, pool cover	Wash full loads only; shut off unused faucets and hoses
Commercial, Industrial, Institutional	Recirculated cooling towers, process water reuse, efficient fixtures and appliances, leak repair	Shut off unused valves, service and adjust equipment and valves, wash full loads only, meter large usages
Agricultural	Low Energy Precision Application (LEPA) sprinkler, and drip irrigation, canal lining, level contouring, surface mulches	Improved tillage practices, irrigation scheduling, on-farm metering
Landscape	Native and drought-tolerant turf and plant species, drip irrigation, cisterns, hand watering, control and valves, matched sprinkler heads, automatic shut-off hoses	Xeriscape design and management, irrigation scheduling (frequency and time of day)

Table 3 : Examples of conservation measures

- Monitoring the integrity of water reservoirs and water mains should form part of the operation and maintenance program. Management has to be proactive rather than reactive. Water mains inspection through closed circuit television cameras may be employed. This will show the internal condition of the water mains and appurtenances that will help in making the repairs or replacement atthe right time, saving capital and inconvenience to consumers.

- Leak detection survey of the pipe network and the reservoirs must be carried out on a continuous basis. This will reduce the unaccounted for water considerably. The water saved in this way may be supplied to the new consumers.

- Construction must be carried out as per specifications. A strict supervisory control during construction is required. The quality of bedding material and outside plastic tape wrapping must be carefully inspected and supervised.

Until recently the water industry was entirely managed by the governments in most of the countries. Gradually this trend is changing and the water industry is being privatized. Qatar has taken a bold step in this direction and recently converted the Ministry of Electricity and Water into a Corporation, i.e. now the industry is semi privatized. The implementation of the measures proposed herein will make the water industry achieve water security.

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Water Resources Scarcity and Solution

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WATER RESOURCES SCARCITY AND SOLUTION

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ABSTRACT

A review is given on the water availability in the Middle East region.

The increase of the population together with the industrialisation of the region has resulted in a dramatic rise in water needs in the region. Water is becoming a rare resource taking into account the dramatic decline of ground water tables. Water resource management therefore requires great technical and management skills to ensure long time sustainable use of these scarce resources.

Option for water conservation or re-use of increasing urban wastewater flows may contribute to better water resources management in arid and semi-arid regions of the world.

Key words: Water scarcity

1. INTRODUCTION

Water is vital for the existence of mankind; without water there would be no life on earth. The body of a human person consists of 65 per cent water. Apart from the domestic water consumption, water is needed for irrigation, power generation, recreation, industrial production and disposal of wastewater.

There is an enormous amount of water on our planet, around 1.4 -1.5 x 10^9 Km^3 in the form of oceans, seas, rivers, lakes, ground water or ice. However, only 3-5 percent of the total quantity of water on earth is available in the form of fresh water in the rivers, lakes and ground water. Fresh water is limited but the needs for fresh water are increasing, due to the increase of the world's population, increased irrigation practices and industrialisation.

According to the United Nations Population Reference Bureau, 2000 years ago the world population was about 300 million. At the end of the 17th century it was 600 million. By 1850, it grew to about 1200 million people, by 1945 to about 2400 millions and by 1969 to about 3500 million people. It took 1680 years for the population to double after the birth of Christ. After that it doubled in only 170 years, and then again in 95 years. It may take only 45 years to double the 1945 population, i.e. by the end of the century it may reach 6000 million, the result is obvious; the per capita as well as the total water needs are increasing.

During the early 60s the total fresh water consumption in Germany was 150 liter per capita per day. At present it is about 350 lpcd. By the year 2000 it may reach up to 400 lpcd (1) assuming the industrial water requirement increases at an average rate of 3 percent per year. A similar situation exists in USA. In 1965 the total per capita consumption was 460 lpcd (the industrial requirement was 35 % of it). Estimation is that these will increase by the year 2000 up to 500 lpcd and 170 lpcd respectively with an overall annual rate of increase being taken as 0.3 to 0.4 percent

In developing countries like Yemen the existing per capita consumption is lower. In Sana'a domestic consumption may range between 50 to 80 lpcd but the rate of increase is much higher (it is estimated to annually increase by 3-5 % for the coming decade). With this prospect, water has to be regarded as a scarce resource and proper care should be taken to prevent the non-sustainable exploitation of these resources resulting to serious ground water depletion in the near future.

In this paper the problems of water shortage and the potential (but all partial) solutions are highlighted. Among these solution reuse can be a valuable instrument.

Location	Surface Area (Km2)	Water Volume (Km')	Percentage of Total water
Surface water Fresh water lakes Saline lakes Stream channels	 855,100 699,700 ———-	 125,100 104,300 1,300	 0.009 0.008 0.000
Subsurface water Ground water (less than 4/5 mi deep) Ground water (more than 4/5 mi deep) Soil moisture, etc.	 129,565,000 129,565,000 129,565,000	 4,171,400 4,171,400 66,700	 0.307 0.307 0.005
Icecaps and Glaciers Atmosphere (at sea level) Oceans	17,880,000 510,486,000 361,486,000	29,199,700 12,900 1,322,330,600	2.147 0.000 97.217
Approximate total		1,360,183,400	100.00

Source: Adapted from R.L.Nace, "water of the world", Natur. Hist., vol. 73, No. 1, January 1964

Figure 1 General distribution of the worlds estimated water resources.

Adapted from R.L.Nace, "water of the world", Natur. Hist., vol. 73, No. 1, January 1964

2. WATER AVAILABILITY

Water resources

Attempts have been made to estimate the total amount of water in the hydrosphere and the quantities involved in the general circulation of water on earth. *Figure* 1 intends to give only a global indication of the available water quantity [2].

Practically all of this water (estimates vary between 93 to 97 percent) is contained in the oceans and salt seas. Of the fresh water resources of the earth (i.e. about 4 of the total), the proportion stored in the form of snow and ice or permafrost - and thus not readily available for the use has been estimated as about three quarters of the total fresh water. About half of this frozen water is in the polar ice caps.

Consequently, only about one percent of the water in the hydrosphere is in a form that can easily and economically be exploited by the present available technologies. Of this available water, 99% is in the form of ground water (about half of which may be more than 1000m. below surface) and only about one percent is in the form of surface water (lakes and rivers).

The total amount of water vapour in the atmosphere has been estimated at about equal to that stored in the surface waters namely about one- fifth of the one percent of all the fresh water. The remaining form of water resources is the water contained in the biomass or biosphere, which can be set at around 0.1% of the total fresh water resources. Though the estimate amounts of water in the biosphere and atmosphere are relatively insignificant, they play a key role in the movement of water through the hydrological cycle.

Water in arid and semi arid region

The world of today is facing a complicated problem of water shortage. The problem is most difficult especially in the semi-arid and arid regions. The world's sand deserts appear to be enlarged and droughts are contributing to the economic devastation of whole nations. The south western part of the United States, for example, faces declining water tables and increasing ground water salinity.

Nevertheless arid regions are still under exploiting their agricultural potentials. Therefore increased water demands may be expected for irrigation. Unless water saving technologies, concepts and methods specifically suited to the dry regions are applied the overexploitation of water resources may indeed become severe. Water practices developed for temperature climates may not always work as well in the arid regions for technological, environmental, economical, and cultural reasons.

The water distribution in some of the Middle East countries, is compared with some of the wet countries in Figure 3. Some factors to be taken are:

1. Climatic condition
2. Water Resources Management (including water supply, irrigation practices and water conservation strategies)

This paper will focus on water supply. A condensed review on water resources for water supplies as well as the methods of water conservation. The last is to be seen as an integrated part of the total water resources management.

Country	Area	Popula-tion	Water availability (rain- evaporation)		Availability river water		Use per capita
		(million)	In $m^3 x 10^6$	m^3 per cap	$(x10^6 m^3)$ input	Output	(in m^3)
Jordan	88,930	4.3	700	160	400	-	173
Syria	184,060	12.5	7,600	610	27,900	30,000	449
Lebanon	10,230	3.0	4,800	1,620	——	860	217
Iraq	237,730	18.9	34,000	1,800	66,000	——	4,575
Egypt	995,450	54.1	1,800	30	56,500	——	1,202
Turkey	769,630	55.6	196,000	3,520	7,000	69,000	317
Nether-lands	33,920	14.8	10,000	680	80,000	——	1,004

***Figure* # 3 Water availability and shortages in the Middle East (World Resources, 1990-1991, Oxford 1990)**

3. WATER SUPPLY

Agriculture is by far the world's largest user of water. There are many possibilities for affecting the water demands that could bring benefits to larger areas of arid lands. A major opportunity to save water is by applying water saving irrigation technologies. This is true for the areas with old irrigation methods as well as the large, capital intensive modern water management systems.

Conventional agricultural systems are not the major topic of this paper. However, the following points may be worth to be mentioned.

1. Improvement of the existing irrigation system may be the greatest opportunity for making more effective use of water. Replacement of the old canals with closed conduits or the application of the drip irrigation will reduce the evaporation while canal linings will reduce seepage loses.

2. Farm management can save significant amounts of water. A deficiency in the design of on-water distribution and drainage may result in the sub-optimal water use; mismanagement of a scarce resource.

3. Balanced use of ground water and surface water should be considered in combination for optimal use of total water resources available.

4. Farmers universally practice excess irrigation when water is available. This can lead to the problem of water logging and leaching of fertility. Sometimes excess irrigation may be needed to remove accumulating salts; recent studies indicate that the amount required to combat soil salinization may be much lower than was formerly believed.

5. Conventional irrigation is neither cheap nor simple; complexities in the design, construction and efficient operation of standard irrigation projects are frequently oversimplified or overlooked. Fields are often inadequately leveled because of the high cost involved with the consequence of wastage; even a small irrigation system can waste large amounts of water.

To enhance water supplies, the following technologies may be worth mentioning:

Rainwater Collection

Collection of rain water from the hill slopes and man-made catchment areas can furnish low cost supplies for arid and semi arid lands.

Infrequent rainfall may still comprise considerable amounts of water (10 mm of rainfall equals to 1 00,000 liters of water per hectare). Collection of rain water can provide water for the regions where other sources are too costly to be exploited. Rainwater collection is particularly suited to supplying water to small rural residential areas or individual units as schools, gardens, and livestock. Pollution risk bas to be given proper attention. At present ways of increasing water runoff by modifying the runoff of the soil are being studied.

Rainwater collection is possible in areas with as little as 50-80 mm average annual rainfall. Runoffs can sometimes be collected from an untouched catchment; one way is dig ponds in small depression where they can collect runoff. Most of the time catchment areas for such purposes need to be modified.

This modification maybe done by increasing the soil impermeability. Conditioning the soil as catchment areas for making it suitable for rainfall collection can be through the chemical treatment.

Sodium salts, which cause the clay to break down into small particles sealing the soil pores and cracks can be used to increase runoff of many clay containing soils. Other methods to increase runoff are silicon, latexes, asphalt and wax. The most promising material is asphalt because of its low cost and easy application. Water collection methods are site specific. Characteristics of soil in terms of water holding capacity, erodability and runoff, the topography and the climate are to known.

As the rainfall in the arid regions is intermittent, storage must be an integral part of any rainwater collection. When the water collection techniques are used for runoff farming, water is stored in the cultivated soil.

Rainwater collected from the slopes can be used in agriculture. The combination is defined as runoff agriculture, which was developed almost 4000 years ago in the Middle East to permit crop production on terraced lands receiving as little rain as 100mm average annual rainfall. The farmers cleared the hill sides to increase runoff water and built rock walls along the contours to collect the water and by ditches conveyed it to lower fields. Also in Yemen this is a traditional practice.

It would be better if floods can be diverted to areas where water is needed or can be stored. The flood water can be diverted from its natural courses and spread over adjacent floodplains or detained valleys to promote infiltration. These areas must be selected with full consideration to topography, soil type and vegetation.

Microcatchment farming

Some plants can grow in a region with too little rainfall for its survival because a rainwater catchment exists around its roots. Microcatchment may range from 10 to 1000 in each surrounded by a dirt wall 15 - 20 cm high. At the lowest point within the catchment area a basin is dug about 40 cm deep and a tree can be planted in it.

The size of the basin is to be matched to the expected amount of water needed. Microcatchment are more efficient than the large scale water collection schemes because convenance loses are minimized. In the areas of light rain they provide runoff water when others will not. They are cheaper to construct as they do not need channels and terrace walls. They can be built at any slope, including almost level plains.

Contour catchment farming

Contour catchment farming makes use of a series of terraces that shed water on to a neighboring strip of productive soil. They are often located on a hill slopes. Highway edges often illustrate the principle of such a method. The road acts as a catchment, roadside vegetation on the lower side is greater and denser. It has been even proposed that water storage tanks be built besides roadside pavement at the foot of suitable hill slopes to collect water.

Runoff agriculture requires a deep soil that has the ability to store water between rains. It is fitted for deep-rooted crops, such as trees and shrubs, which can draw stored water and are not in need of frequent rainfall.

The following environmental requirements may be considered:

1. 80 mm of rainfall per rainy season is essential (more than 80 mm if it occurs during summer)

2. Topsoil must be impermeable to enhance water runoff.

3. Cultivated soil should have high storage capacity.

4. Soil salinity should not be more than 2- 3 %

5. Soil depth should be at least 1.5- 2 m.

Runoff water must be distributed evenly over the cultivated area to prevent ponding, excess irrigation, or percolation "losses". Runoff agriculture has been shown to be technically sound for modern use. Some microcatchment farming occurs today in several arid countries like Mexico, India, Pakistan, and Australia. In Afghanistan, the microcatchment method is used to grow wheat and fruit trees over 70,000 ha area.

Irrigation with saline water

Most of the deserts have underneath saline water. Also surface waters (estuaries, coastal ponds and irrigation return flows) may contain large amounts of salts. The use of saline water may solve the water problems in agriculture as well as in domestic water supplies without the need for desalination. However, WHO recommends in their guidelines that for drinking water TDS should not exceed 2000mg/1. agricultural restrictions are less severe. New knowledge of plant physiology and soil science and recent irrigation techniques all combined into operational management, increased the potential use of saline water to grow variety of crops.

The salt tolerances of the crops are to be known in order to select suitable crops to be used for known saline waters. Although only a few crops such as cotton, barley, wheat, sugarbeets, grass, Bermuda grass are known to be salt resistant, these are important in developing countries as they form the basis of agricultural production. Date, palm, olive, pogerana and pistachio can tolerate salt to higher degree.

Water with total dissolved solids (TDS) below 450 mg/l may be used on almost any crop. When adequate drainage is practiced water up to 2000mg TDS/l can be used nearly to all crops except to those crops with high sensitivity to salts. Water with above 2000mg/l can be used for salt tolerant crops.

When saline water is used, the basic premise is that proper irrigation and drainage management should be practiced to prevent salt build up in the soil. Leaching is necessary so more irrigation water is needed than the plant requires. The extra water transport the salts down below the root zone (for saline water with 5,000 mg TDS/L or more leaching requirements may be more than 25 % extra water to bring the salts below the root zone). Trickling irrigation improves crop yield irrigated with saline water better as compared to furrow irrigation.

Irrigation with saline water does not promise the conversion of vast stretches of arid lands into cultivated fields. Salinity of ground water will increase by irrigation with saline water; this may make it unsuitable for other purposes. The project may have a short useful life as the soil can irreversibly be damaged by saline water irrigation.

Some plants are sensitive to salts through some stages of their growing life like sugar beets plants. Also one must alert when applying test results from temperate regions to tropical region. The same plant can tolerate salts more under humid conditions than under arid region. Ambient temperatures may affect a plant's salt tolerance.

Research in the field of how to use saline water in agriculture is needed. Adequate management is essential to minimize water needs and optimize sustainable crop production by use of saline water. Attention may be given to:

1. The physiological stress of plant and its growth performance,
2. Alleviation of plant stress by irrigation, fertilisation, soil aeration, and leaching practices, chemical and physical treatment etc.
3. Practical field knowledge on breeding and selection of plants that can be grown on saline water.

4. Water Reuse

The overall water demand can greatly be reduced by reuse of water. Reuse of wastewater can be used for many purposes such as in agriculture, industry or for recharge of groundwater. In USA wastewater has been treated to an extend that its effluent can be reused for municipal water supply. However, quality criteria are strict and it required extensive and expansive treatment.

At present and in the near future water reuse will take a great part in meeting the water requirements in many parts of the world. Environmental regulations, water scarcity and economic factors are expected to accelerate wastewater reuse especially in the agriculture and industries. Other benefits of reuse include improved surface water quality, preservation of high quality water for potable consumption and recreational opportunities.

Reuse can be direct or indirect. In direct reuse wastewater is treated and piped directly to the user point without any intervention (for example municipal wastewater plant directly connected to an irrigation system). Indirect use involves an intermediate step between the generation of reclaimed water and its reuse. This may include discharge, retention and mixing with another water source before reuse. Recycling means the reuse in the same generating plant.

The most readily available source of wastewater for reuse is municipal wastewater.

The wastewater from municipalities can be available for reuse in number of ways with treatment ranging from none to most advanced system available, depending on the end use of water. Wastewater can be used for irrigation of different crops, for ground water recharge, recreational impoundments or pasture for dairy animals.

Wastewater from industries are highly specific in composition and May limit the reuse option available for that wastewater due to presence of specific pollutants. Manufacturing operations can contribute heavily to the total amount and composition of the wastewater generated.

Irrigation return flow are in potential a reusable resource. However these waters are often highly contaminated with salts leached out of the soil. Treatment is needed before reuse can be practiced. This may include desalination.

The following reuse option can be considered: municipal reuse, industrial reuse and agricultural reuse.

Municipal reuse

Wastewater can be reused for municipal purposes. Advanced (tertiary) treatment is required for direct reuse of wastewater in order to meet strict water quality criteria if the water is to be used for drinking or domestic purposes. In some countries, like Japan a dual water distribution system exists (in Tokyo for example); treated wastewater is used for toilet flushing and landscaping irrigation. Effluent criteria for ammonia, nitrates, phosphates and micropollutants can be met by advanced technologies at considerable cost. To produce water of high quality it needs large investments in capital and equipment. However the cost must be compared with those of the regeneration of water from other sources. Indirect reuse of wastewater is the reuse of treated municipal wastewater after it has entered and become a part of a natural surface or groundwater resource. Any person located in an area where surface water is used for domestic supplies at a point downstream from the discharge of the municipal treatment plant indirectly reuses wastewater. This practice has been used in nearly all countries with only minor concern of public health objections.

After recharging groundwater aquifer with wastewater, the reuse of such groundwater is considered as indirect reuse of wastewater. Recharging of aquifer can be carried out either by deep well injection or by shallow surface spreading with subsequent percolation of ground water. These latter practice benefits from the extra purification provided through soil filtration during the long travelling time through the soil.

However the reuse of water without causing environmental disaster calls for good management and good understanding of user's requirements. Mismanagement of reuse systems may cause serious health risks or create irreversible harm to the environment.

Industrial reuse

Recycling of water in the industry is the result of scarcity of water resources, environmental constraints, and economic factors. These practices include: (a) treating some or all process wastewater to make suitable for plant processes, make up or cooling water. (b) recycling the water within the same line of production before final discharge with final treatment and (c) sequential use of effluent from one process input into another with or without essential treatment.

Treated municipal water is sometimes used for cooling, or separation that do not have severe water quality requirements. The degree and kind of treatment depend on the demand and economics of application. For example, for pulp and paper production, wastewater effluent can be reused after limited advanced treatment.

Irrigation reuse

When considering the reuse of reclaimed water the first option will be for irrigation. Wastewater contains large variety of valuable nutrients, which are absorbed and taken up by the plants for their growth. As for example, it is estimated that reuse of wastewater in Saudi Arabia will by the year 2000 supply more than 10% of the agricultural water demand of the country.

	Demand, million m^3/year		
	1978	1990	2000
Urban water supplies	198	1,028	1,807
Agriculture	3,171	3,684	5,119
Others	131	163	315
Total	**3,500**	**4,875**	**7,241**
Usable, reclaimed wastewater	35	368	674
Quantity of available wastewater as percentage of the agricultural demand	1.1%	10	13.1 %

Figure 5 **The existing and anticipated water requirements of Saudi Arabia.**

The use of municipal wastewater for irrigation is especially attractive where fertile agricultural land is located near the urban cities. Some biological treatment should take place prior to its application, but for many crops the degree of wastewater treatment required is so low that little technology and capital investment is required. For example, in Mexico City large amounts of untreated sewage is used for irrigation. Where irrigation system is already in use, connecting them to the municipal system is fairly simple, though institutional arrangements may prove difficult.

Since the Environment Protection Agency (EPA) in USA encourages the direct irrigation with wastewater, irrigation by such wastewater has become more wide spread as an «innovative and alternative» wastewater treatment technology. Both can be accomplished at the same time, yielding in saving of energy and in cost of wastewater treatment. Additional benefits include augmenting groundwater supplies, utilisation of the nutrients in the wastewater as fertiliser, and preservation of the quality of the surface waters.

Indirect use for irrigation is quite common, either or from rivers down streams of a wastewater discharge where the river water is withdrawn for irrigation. Many countries in the Middle East are practicing the irrigation with treated or untreated municipal wastewater.

Storm water reuse

Where storm water is collected by a separate sewerage system in urban areas, a source of reusable water is provided to the city that, with a certain amount of treatment, is acceptable for number of uses. Usually storm water is low in organic pollution (BOD), but high in suspended solids as compared to raw domestic wastewater. As the storm water is high in suspended solids only some physical treatment may be necessary to avoid soil clogging during reuse.

Recreational use

Wastewater after advanced treatment (tertiary) treatment can be used for recreational purposes such as boating, fishing and even swimming. Reclaimed wastewater is also being used successfully for irrigation of golf courses or public greens. However, serious attention has to be given to the contamination of the effluents with pathogenic bacteria. Indicators that have to be monitored closely include feacal coliforms and helminth eggs.

5. OTHER SOURCES OF WATER

Groundwater mining

Large quantifies of water are stored in many productive aquifers in arid regions of the world. Aquifers of this type are wide spread beneath the desert in Northern Mexico, Southwestern USA, North Africa, Eastern Saudi Arabia, Sinai and many other places of the world. The water of aquifers is not naturally replaced once it is withdrawn. It must be considered a «wasting asset» like any other mineral commodity. The development of such source of water must be known to be depleting with few decades and the capital investments must be amortized within that time. Under some conditions these aquifers may provide interim supplies to generate capital to underwrite expansive system that bring in more permanent supply of water from outside the region. Development of such aquifers is now proceeding in several countries such as Algeria, Libya, Egypt, Saudi Arabia, Mexico, and USA.

Desalination

Over the past few decades many proposal to build huge distillation plants to produce water for agriculture have been widely advertised and intensively promoted. Although new improved methods of using membranes and ion exchange have been developed no methods can yet produce low cost fresh water. Current promises of cost reduction for distillation plants are based on the assumption that the cost of the cost of the production decreases as the size of the plant increases. But a practical limit also exists to the cost reduction achieved by this means. Also, there are problems in disposing of huge quantifies of brine, pumping and conveying desalted water to the point of use, and storing it until needed. Also, desalting plants need large amounts of energy for construction and proper operation. At present desalination cost will be prohibitive for agricultural application.

Solar distillation

This process uses the same principles that keep a green house warm during the winter. The sun's rays pass through the glass roof without losing significant energy. A black surface on the bottom of the still absorbs the energy and the energy is transferred to the water. The temperature of the water increases and the water evaporate. The glass top of the still is cooler than the vapor, and when the vapor contacts the glass it condenses and flows to the collection trough.

Solar distillation needs more research to develop it into an inexpensive way of water production that serves many developing countries. In Australia, solar distillation is now used in many small commercial communities.

Artificial rain

The addition of ice, frozen carbon-dioxide, and silver iodide promotes the condensation of super cooled water caused formation of rain. This is known as cloud seeding. Seeding procedures are difficult to predict; due to the imperfect knowledge of the physical processes causing precipitation and of the difficulties in getting seeds into clouds in optimum amounts it is difficult to plan it at the right time and place.

Iceberg harvesting

Icebergs can be transferred to semi arid or arid regions. According to the experts, "the idea appears both technically feasible and economically attractive and merits serious consideration". Exploitation proposals and critical technology assessments must precede any decision that iceberg harvesting is a realistic and desirable alternative.

6. WATER CONSERVATION

Water conservation is an integral part of water resources management. methods of water conservation are:

1. Reduction of evaporation from water surfaces.
2. Reduction of seepage loses.
3. Reducing evaporation from the soil surfaces.
4. Methods of irrigation.
5. Reducing cropland percolation loses.
6. Reducing transpiration.
7. Selecting and managing crops to use water more efficiently.
8. Controlled environment agriculture (closed or partially open environment agriculture)
9. Artificial Recharging of Underground Reservoir.

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Sustainability of Water Resources in Kuwait through Harmonized Management

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SUSTAINABILITY OF WATER RESOURCES IN KUWAIT THROUGH HARMONIZED MANAGEMENT

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ABSTRACT

Both economical and social development are highly dependent on the availability of sustainable water resources. Each water resource has specific demand areas. Some of the demand areas can be covered by more than one water resource. Located in an arid region, Kuwait suffers from the limitation of its water resources, especially the natural resources. Ground water and rainfall are the only natural water resources in Kuwait, both are limited. Ground water is limited in quantity and quality, where most of it is brackish to saline with isolated fresh water lenses in northern Kuwait. Due to the increasing demand on ground water, water table is generally depleting, especially in the farming areas of Al-Abdali and Al-Wafra. Rain water is scarce and not systematic; the yearly average is around 120 mm, while the yearly average potential evapotranspiration is more than 4000 mm. Other water resources like desalinated seawater and treated wastewater; both are expensive and vulnerable to stoppage due to various reasons.

This paper discusses the implementation of harmonization management on the available resources, obstacles expected to accompany this implementation, proposed results from implementation of this management and finally recommendation that would help the decision makers on how best to apply harmonization management in Kuwait water resources.

INTRODUCTION

The classical definition of Integrated Water Resources Management (IWRM) is as follows "Group of procedures undertaken for water resources utilization and control for the benefits of the society". The IWRM takes into consideration these procedures to communicate between the following dimensions:

- Natural Dimension (such as water and land),
- Economic Dimension (such as privatization of water sectors),
- Social Dimension (society interaction),
- Cultural Dimension (religious and heritage).

In other words, IWRM aims to comprehensively assess the available water resources and needs, and to establish a balance between the resources and needs with proper planning and monitoring of water resources quality and quantity. To obtain the ultimate goal of sustainable development, communication between the above mentioned dimensions should be maintained (Saad, 1997).

Historical Background

The term IWRM is not an entirely new water management concept. Originally, it was used for river management. The UN Economic Commission for Asia and the Far East published the first manual of "Multi-Purpose River Basin Management" in 1955. After that many reports were published on river integrated management. However, the first time the word "Integrated" was used in a UN- sponsored study published on "Integrated Development of the Varad/Axios River Basin" in Yugoslavia/ Greece in the 1970's (Kindler, 2000).

The international society expressed, for the first time, the importance of the IWRM during the Earth Summit in Rio de Janeiro, Brazil in 1992. The Earth Summit gave IWRM priority within the program of water resources protection, as detailed in chapter 18 of the 21st Century Agenda (United Nations, 1992a). The Summit recommended all countries to develop national action programs for optimum and sustainable utilization of water resources. These programs should be applied through the establishment of structural foundations and laws by the year 2000. All the objectives of the programs should be met the year 2025. Since the Earth Summit, IWRM has been discussed in many conferences and meetings.

Objectives of IWRM

The objectives of the IWRM were set by the Earth Summit following a dynamic, active, sustainable and multi-sectorial approach to manage water resources as follows:

1. Identification and protection of potential sources of fresh water supply that integrates technological, socio-economic, environmental and human health consideration.

2. Sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy.

3. Design, evaluation and implementation of projects and programs that are economically efficient and socially appropriate within clearly defined strategies, based on full public participation.

4. Strengthening, in particular in developing countries, of the appropriate institutional, legal and financial mechanisms.

IMPLEMENTATION OF IWRM IN KUWAIT

Water is the most limited and strategic resource in Kuwait. Aridity and squandering of water resources – both exert more pressure on the already limited water resources in Kuwait. Additionally, towards the end of last century strong public awareness emerged for greenery enhancement and landscaping in both governmental and private sectors. Therefore, new and huge water demand area was developed requiring irrigation water. Likewise, a very significant and abnormal increase has been developed in per capita consumption of fresh water especially during the last ten years. These circumstances heightened the need for best utilization of the existing water resources through an integrated management scheme.

Natural Water Resources

Kuwait located in the heart of the arid region and as part of the Arabian Peninsula, suffers from a harsh, dry and hot climate for most of the year. Natural water resources are represented, practically, by ground water, which is mostly brackish to saline, with limited and isolated fresh ground water lenses in northern Kuwait. Rainfall is around 120 mm/year occurs in the form of heavy rainstorms with wide range of intensity. Rainfall in Kuwait usually received in unpredictable scattered thunderstorms, with wide range of intensity (22-232 mm/y) averaging to 120 mm/y both annually and seasonally. High evaporation rates reaching 4000 mm/year (Al-Rashed, 1993) hinder any form of natural recharge to the ground water resources.

Ground Water

Ground water in Kuwait produced from both Kuwait Group and Dammam Formation aquifers through single and dual aquifer wells distributed within various water fields in Kuwait. The quality of the produced water is mostly brackish, with an average TDS of 5000 mg/l except the northern fresh water fields of Rawdhatain and Umm Al-Aish fields. The total production capacity of the brackish ground water can reach 120 MGPD (0.55 MM^3PD), the current production rate equals to 65.7 MGPD (0.3 MM^3PD). Ground water in Kuwait is distributed to domestic consumers through a special network. Irrigation, mixing with distilled seawater in a ratio of 10%, industry and cattle drinking are the main consumers of ground water (MEW, 2000).

Non-conventional Water Resources

Desalinated water and treated wastewater are the main non-conventional water resources in Kuwait.

Desalinated Seawater

The limited natural water resources in Kuwait led to full dependence on desalinated seawater as the only source for potable water. Kuwait comes in the third place of desalination capacity in the world after Saudi Arabia and UAE. Desalinated seawater is the main source for the urban sector, which includes residential, governmental and commercial consumers. Also, part of the industrial and agricultural sectors demands are met by the expensive desalinated water. A recent study indicated that around 88% (Mukhopadhyay et al., 2000) of the desalinated water is consumed by the urban sector. Kuwait was the first country in the world to apply the Multi-Stage Flash (MSF) method for seawater desalination on commercial bases since the late 1950's. Total installed capacity of the desalination plants in Kuwait is 283.2 MGPD (1.29 MM^3PD), while the maximum daily consumption is 268.7 MGPD (1.22 MM^3PD). The latest average per capita consumption was 488 l/d (MEW, 2000). In addition the seawater desalination there are some Reverse Osmosis (RO) units used for ground water desalination in specific sites around Kuwait, with a total production capacity of 8.25 MGPD (37,500 m^3/d).

Desalination plants are mainly built in few arid countries around the globe where renewable water resources are very scarce. Over 90% of the total world desalinated water is produced form the GCC countries. The water demands in most of the developed and western countries are met by natural water resources. Therefore, normally developed countries do not invest in the development of new technologies, that are not critically need, to reduce the costs and enhance the efficiency of the desalination plants. Due to the severe shortage of natural water resources, Kuwait has devoted much attention to develop, enhance and reduce the costs of the desalination plants. The first lab in the GCC countries to apply and develop lower cost desalination technologies was established in Kuwait in 1979 in collaboration between MEW, KISR and Germany. One promising techniques that has been developed is the reverse osmosis (RO) which has been applied in some of the GCC countries as in Saudi Arabia and Bahrain and in a pilot scale in Kuwait.

The following challenges faces the seawater desalination in Kuwait:

- The high capital and operational costs of desalination processes.
- The international experiences and innovated investigations to develop low cost desalination plants are quite limited.
- Seawater desalination plants are vulnerable to pollution and sabotage activities.

However, seawater desalination in Kuwait has the following opportunities:

- Current desalination techniques can be modified and/or hybrid with other new techniques, also new techniques can be developed within the GCC countries to overcome the high cost of desalination.
- The cost of desalinated water should be taken into consideration when imposing new slides tariff system for the consumers.

Treated Wastewater

As the only increasing resource of water, treated wastewater would play a major role in meeting the ever-increasing demand on water for the different sectors. Possible uses for treated wastewater vary, according to the effluent quality, from irrigation of specific crops to almost potable uses. Treatment complexity should be according to the proposed usage of the effluent as recommended by the UN Economic Council (Peavy et al., 1985): "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade". Relation between ground water and treated wastewater should be strengthened as wastewater should be one of the major sources of artificially recharging ground water aquifers or as a hydrostatic barrier from salt water intrusion.

Wastewater in Kuwait is treated to the tertiary level within three main treatment plants; namely Ardhiya, Riqa and Jahra. Around 80% of potable water in Kuwait reach these plants as wastewater. The produced treated wastewater from Ardhiya and Jahra plants is transported to the Data Monitoring Center (DMC), where it is tested biologically and chemically before being transferred to specific farms nearby the DMC. Treated wastewater produced from the Riqa plant is used for landscape irrigation of the nearby highways and roads (MPW, 1995). The Ardhiya, Riqa and Jahra plants produced 54 MGPD (246,000 m^3/d), 25 MGPD (114,000 m^3/d) and 11MGPD (50,000 m^3/d), respectively. The total production of tertiary treated wastewater equals to around 90 MGPD (410,000 m^3/d), from which only 30 MGPD is being utilized mainly in landscaping and fodder production projects (Al-Khaldi, 2000). Huge amounts of treated wastewater are still discharged to the sea. High storage capacity for this valuable water is the ground water aquifers. The concept of recharging treated wastewater in aquifers was practiced since early 70's in several developed countries. Treated wastewater can be stored in aquifers using two main methods; one is directly recharging the aquifers through injection wells, and secondly indirectly recharging the aquifers through artificial bonds and dry wells (wells screened in the unsaturated zone). The indirect recharge of treated wastewater is also a mean to treat the wastewater through infiltration. This method was applied in Kuwait and gave very promising results (Viswanathan et al., 1999).

The following challenges faces the treated wastewater as a main toll in the water resources management in Kuwait:

- The stigma usually associated with the reuse of treated wastewater.

- As the future main resource of water in arid countries, treated wastewater should be optimally utilized.

- Expanding the uses of treated wastewater needs more complex and, therefore, higher cost treatment plants and techniques.

However, treated wastewater in Kuwait has the following opportunities:

- The only increasing resource of water that is increasing with population and time.

- Development of treatment techniques is being practiced worldwide, which means more opportunities will be there to reduce treatment cost.

- The general believes shared by the public and the government that treated wastewater should be more effectively utilized.

- Wastewater after simple treatment can be utilized for unrestricted irrigation and landscaping, which represent a major consumer of treated waste water in Kuwait.

Future Expanding Projects of the Water Resources

Two new desalination plants are due to open during the next couple of years. The first plant will in south Al-Zoor with a total capacity of 96 to 111 MGPD (436,400- 457,780 m^3/d) in three phases. The second will be in Sabbiya with a total capacity of 24-29 MGPD (109,100-131,830 m^3/d) in one phase (MEW, 1999). This will rise the current production capacity by around 50%.

The production of the Jahra wastewater treatment plant will be increased from 11 to 13-20 MGPD (59,100-90,920 m^3/d). Also the Riqa treatment plant will be increased to reach 40 MGPD (181,840 m^3/d). By the year 2001 a new treatment plant will be established with a production capacity of 27 MGPD (122,740 m^3/d) (Al-Khaldi, 2000). The proposed developments of the wastewater treatment plants will almost double the current production capacity.

Five ground water fields are either under construction or planned to be developed. The total proposed capacity of these fields will reach about 100 MGPD (0.45 MM^3PD).

Demand Sectors

The demand sectors in Kuwait can be classified into five sectors as follows:

- Residential sector (houses),
- Investment buildings (flats),
- Commercial sector,
- Industrial sector, and
- Government sector.

The trend of consumption with increment of time for both fresh desalinated water and brackish ground water (MEW fields only) is the same. The main consumer of water in Kuwait is the residential sector as can be seen in

Figures 1 and 2. As clear from the figures, the number of consumers of fresh water in the residential sector represent 88% of the total number of all sectors' consumers. While for the brackish water (MEW fields only), the number of consumers reaches 98% of the total number of all sectors' consumers. This raise the issue of conservation and optimum utilization of water in the residential sector which should be implemented through various means, taking into consideration the consumers' views and suggestions.

Worldwide agriculture is the main consumer of water followed by domestic and industrial sectors. As listed earlier, agriculture was not from the sectors listed because water consumption in the farming areas is not controlled by meters or other effective method. However, an average consumption of 40-45 MIGPD was estimated for the farming areas (Al-Sulaimi et al., 1994).

Current Status of Water Resources Management

Water resources in Kuwait are under the domain of two ministries; MEW and MPW. All aspects of ground water and desalinated water are within the MEW responsibilities, while the treated wastewater is under the domain of MPW.

Other authorities are involved in the utilization of these resources. The Public Authority of Agriculture and Fisheries Affairs (PAAFA) control the utilization of ground water in the farming areas and the utilization of treated wastewater in greenery and landscaping governmental projects.

Kuwait Institute for Scientific Research (KISR) represents the Research and Development arm for all concerned authorities aiming to develop the water resources in Kuwait through scientific research. Research is conducted in four main areas: water resources management, ground water, wastewater treatment and utilization and water desalination. The Environment Protection Authority (EPA) of Kuwait responsible for monitoring the environmental impacts of water resources production, treatment and utilization.

The Council of Ministers, usually, take the initiative to resolve major water-related issues that involve more than one ministry or/and authority. The private sector, mostly involved in some production, treatment and utilization aspects of water resources.

Factually, there is a kind of harmonization between the water-related authorities. However, such harmonization should be strengthened and developed into a formal IWRM scheme that would emphasis on the optimum, harmonious and effective utilization of all the water resources with a clear understanding of the real needs of all the sectors.

Proposed Scheme of IWRM in Kuwait

Although generally it is agreed that the IWRM is the best management approach to cope with complexities of contemporary water resources management, several comments have been raised indicating that the IWRM concept cannot be implemented in a dogmatic way. One should benefit from others experience and choose what is appropriate for our local dimensions listed earlier. For example, in The Netherlands, the integrated management is mainly a policy at the strategic level and the gap between integration at the strategic level and other operational level is still very large (Kuijpers, 1993). This example shows that IWRM approach cannot be implemented in a fragmented institutional setup of largely autonomous and poorly coordinated administrative bodies. However, fragmented and shared responsibilities are a reality and are always likely to exist. Thus, one should stress on "effective coordination" between administrative bodies, than to concentrate on the degree of fragmentation. Indeed, there are many examples of merged agencies, but in reality nothing has been changed; on the other hand, there are several examples of major problems that have been solved through effective coordination mechanism.

To obtain most of the IWRM objectives in Kuwait, it is necessary to implement a number of basic steps. The more we implement of these steps the more we will be close to the optimum IWRM.

The first basic step is to establish a higher committee representing all authorities related to water resources through which a national action plan should be prepared along with investment programs with set costs and goals. The following steps should be carried out by the committee through the authorities it represents:

1. Harmonization between the authorities with regard to protection arrangements of water resources through effective coordination.
2. Development of water resources databases, and forecasting, economic planning and water resources management and planning models and environmental impact studies.
3. Implementation and/or development of the optimum privatization schemes for water resources, which would consider the socio-economic aspects of the country. This can be done through managing the demand instead of managing the resources, as being done now, and considering new effective tariff system.
4. Enhancement, updating and development of public awareness programs towards conservation of water consumption, especially for the residential sector.

5. Development and enhancement of local, regional and international cooperation towards sustainable water resources for everybody.

6. Manpower development of the concerned authorities in the field of water resources and support of scientific research centers.

7. Harmonization and cooperation between research and development centers within the GCC countries, in order to be more effective and to get the ultimate benefit from the specialized manpower and facilities available in the GCC countries.

Opportunities of Implementation

The following are the opportunities that would back IWRM in Kuwait:

1. *Water Resources Assessment:* There are already several studies with regard to the assessment of water resources, especially for ground water, available in MEW and KISR.

2. *Water Resources Policy*: The current policy concentrates on two main concerns: *(1)* to develop means and procedures of conservation and optimum utilization of the costly desalinated water, depending on two main factors. Firstly, the Islamic rules that encourage the conservation and forbidden the squander of water. Secondly, the loyalty to the country. *(2)* to supplement the costly desalinated water, whenever possible with alternatives such as brackish ground water and treated wastewater

3. *Research and Development:* Kuwait is one of the leading countries in the Middle East in the research and development, especially in the field of water. This will provide the decision maker with the basic needs for implementation of well prepared and applicable IWRM scheme. Among one of the main research areas that would serve the IWRM is the compatibility and preliminary studies of aquifer storage and recovery (ASR). Previous research in KISR proved the technical and economic viability of the ASR technique in Kuwait by utilizing both excess desalinated water and treated wastewater as recharge water and ground water aquifers as hosts.

4. *Recognition of the Wastewater Importance: There* is a general recognition during the last few years among the public and the government for optimum utilization of the, mostly wasted, treated wastewater.

5. *Current Water-Related Foundations:* There are relatively, limited number of water-related authorities in Kuwait (mainly MEW and MPW). This will pave the way for smooth implementation of IWRM.

RECOMMENDATIONS

1. Conventional and non-conventional water resources should be assessed continuously and the assessment methods should be developed using the most updated techniques and practices.

2. A clear and applicable water policy should be prepared through the involvement of all water-related parties, including the consumers of each sector, with a clear schedule of review and development according to the upcoming issues.

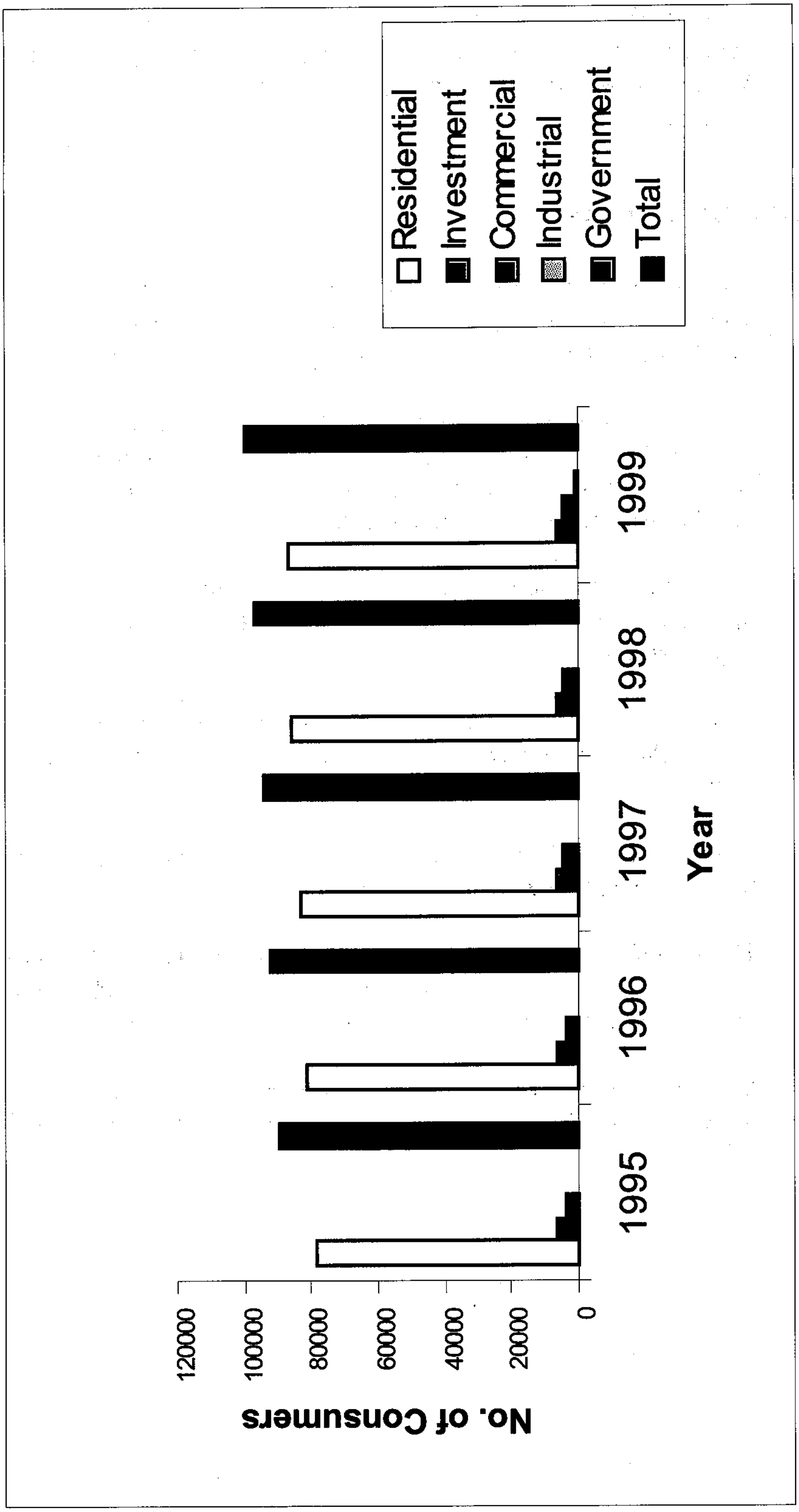
3. Secure the necessary factors for full implementation, such as funding, well prepared manpower and the authority for implementation.

4. Reduce the overlap between the responsibilities of the different water-related authorities, and develop the harmonization between them.

5. Development of the water resources manpower, especially, in the water resources management issues.

6. The effectiveness of implementation of practical IWRM depends on continuous and concentrated monitoring and data updating of different water resources quality, quantity, facilities and needs.

7. Involvement of research and development in all stages of preparation, implementation, monitoring and updating of the IWRM scheme.


Residential
Investment
Commercial
Industrial
Government
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No. of Consumers
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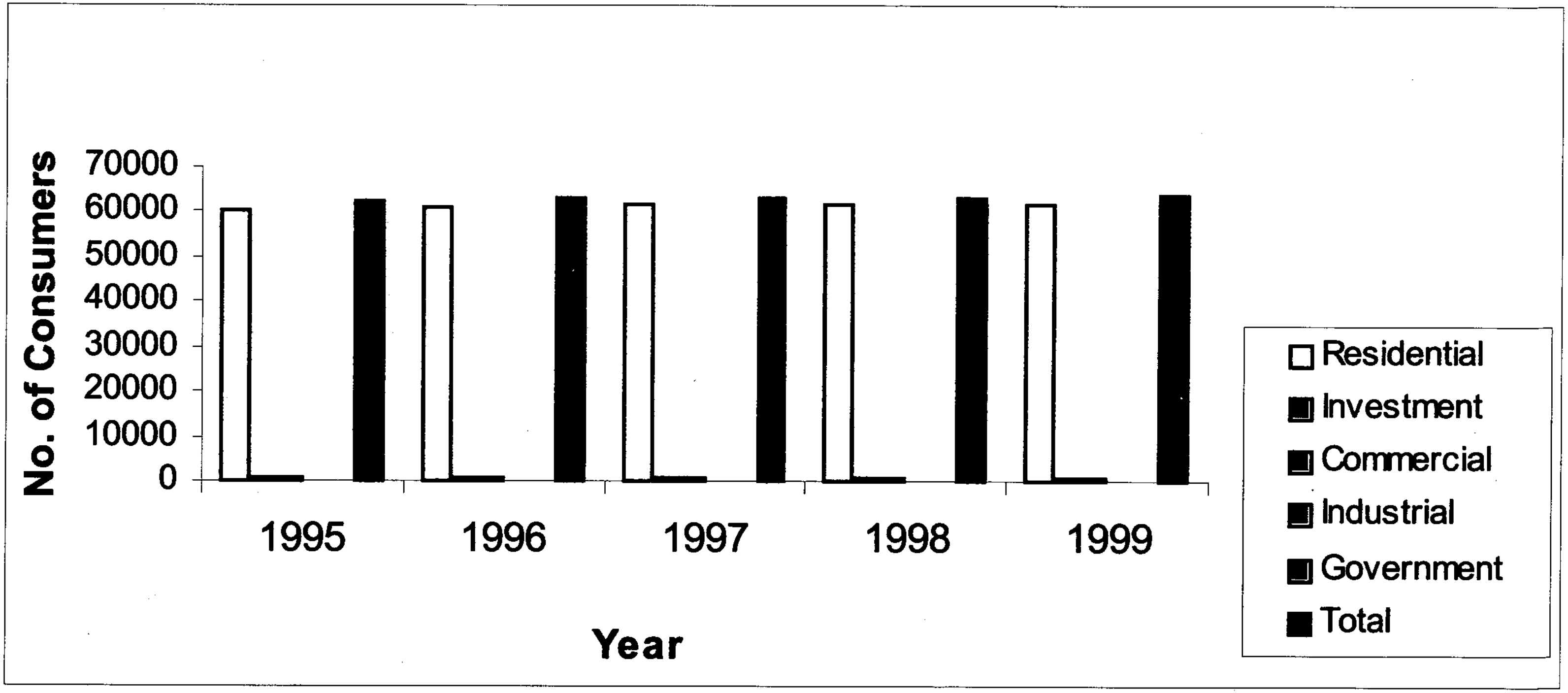
No. of Consumers
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10000
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1995
1996
1997
1998
1999
Year
Residential
Investment
Commercial
Industrial
Government
Total

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Oil and Water do Mix in the Case of Saudi Arabia

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OIL AND WATER DO MIX IN THE CASE OF SAUDI ARABIA

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ABSTRACT

The goals of attaining economic development and social wellbeing must go together in national socio-economic planning. The two are to be linked together by means of appropriate relations. Among the many items of life-fulfilling needs in such a complementary perspective of socio-economic development is water resource. Because of its critical importance appropriate water-resource policies are to be implemented for sustaining an affordable water rate for all levels of use. Yet this should not put undue burden of government expenditure on the public purse. The balance between the provisioning of water resource as a basic need and sustainable government expenditure on it can be attained through a general equilibrium model of production in relation to water subsidy. Such a problem is examined in this paper for the case of Saudi Arabia, where petroleum production model, revenue and water rate are interlinked through appropriate subsidy policies.

Key words: water resource, oil production, general equilibrium economic modeling.

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INTRODUCTION

The study of economic development cannot be complete without addressing the deep social issues of needs (Streeten, 1981). Among the many issues in this area is the central one of social wellbeing. Such a wellbeing objective is realized through distribution, security and entitlement of the basic needs of life. Various instruments of economic development are directed in attaining economic security to ensure that the citizens have sufficient means for fulfilling their essential needs (Levine, 1988). Such kinds of economic security should be guaranteed intergenerational.

Water resource plays a central role within the context of socio-economic development and wellbeing. A nation that guarantees this basic need adopts an important moral command with respect to preserving life and progeny within a healthy environment. Thus there appear linkages between economic development, in which water plays so central a role as a factor of production, and the role of water as a basic need for human wellbeing (Hussaini, 1971).

The Sixth Development Plan of Saudi Arabia gives special emphasis on water resource development and management so as "to provide sufficient quantities of good quality water to meet the needs of the population, the producing sectors and other public services in a more efficient manner." (Ministry of Planning, 1995). On the side of maintaining efficiency and productivity of production and use of water resources, the Sixth Development Plan aims at conserving water resources, particularly of non-renewable water resources and to sustain supply to meet future demand for water. In meeting these objectives the Saudi Government aims at increasing its extensive desalination efforts (Al-Sahlawi, 1999).

In a modern society the provision of water for all purposes (consumption, irrigation and industrial use) must appear as a sustained input in the aggregate production function (Coucri, 1998). In a general equilibrium perspective of the relationship between water resource and socio-economic development, water must establish a critical linkage in the production process across sectors, including the household as the important sector for studying wellbeing.

In this paper we will show that the provision of water resource when guaranteed by subsidy derived from petroleum revenue implies a social usage of oil. In the case of Saudi Arabia, we will show that such a social function of petroleum revenue in subsidizing a sustained fair price for water has contributed to the social wellbeing component of economic development. This is why we claim that in the context of social and developmental relationship, oil and water *do mix* in the case of Saudi Arabia.

In the first part of this paper, we will conceptualize the interactive model involving an aggregate petroleum production function, revenue equation and water subsidy linkage with production. The formal model is thereby of the general equilibrium type. Such a model will explain the pricing policy of water resource as a critical factor in economic development and social wellbeing. In the second part of the paper we will explain the nature of demand and supply curves of water in the presence of targeted subsidy rates arising from petroleum revenue. We argue that such a sustainable flow of subsidy would be required for maintaining the water rate for end users. In the third part of the paper we will provide limited empirical perspectives pertaining to some of the general equilibrium relations taken up in the conceptual part of the paper. The fourth section is a conclusion summarizing the results pertaining to our limited empirical observations in the light of Saudi Arabia's pricing policy on water in view of the general equilibrium model.

THE GENERAL EQUILIBRIUM MODEL: OIL PRODUCTION, OIL REVENUE AND SUBSIDIZING WATER RESOURCE

Oil producing sector

The general equilibrium framework of the formal model comprises a two-sector model with linkages between them. In sector 1 crude oil production generates revenues. In sector 2 the petroleum revenue is injected into a pricing model for water input. The general equilibrium model comprising oil production and revenue, water subsidy and water rate is then closed up by linking the reverse flow of subsidized water resource into the petroleum production and revenue generation capability in sector 1.

The general equilibrium model with three equations explains in a simple way the sectoral linkages that should be encouraged for a balanced functioning of an economy in the light of sustaining both its socio-economic development and social wellbeing objectives. In the absence of such a balance, subsidizing water resource by sheer government expenditure can put pressure on government spending to the detriment of price stability and economic efficiency. Cost inefficiency can then be caused by such an unsustainable provisioning of water resource, albeit that water would still be a basic need but a costly one to provision. Now sustainability of social wellbeing under subsidy inefficiency in the absence of a balanced sectoral linkage between the petroleum production and revenue model and the derived input of water in this production specification is lost.

The formal model

Let, $Q = F(K,L,W)$ .... (1)

be the aggregate petroleum production function

The cost and revenue equations respectively are,

$C(Q) = r.K + w.L + p_w.W;$ .... (2)

$R(Q) = p_{oil} \cdot F(K,L,W).$ .... (3)

The following symbols are defined in the above equations.

Q denotes aggregate output of crude oil.
R(Q) denotes oil revenue.
C(Q) denotes cost of crude oil production as a function of output level.
K denotes the capital stock required in petroleum production.
L denotes the stock of labour required in petroleum production.
W denotes the volume of water resource required in petroleum production.
r denotes the price of capital.
w denotes the wage rate.
p_w denotes the water rate in the demand and supply of water.
p_{oil} denotes spot price of oil (e.g. Arabian Light).

In the above equations, p_w and p_{oil} are set exogenously. Thus through the revenue and subsidy relationship to be shown below, these price variables act as policies and play important role in socio-economic development. Consequently the ratio, (p_w / p_{oil}) is a policy parameter.

Since the profit function is not usual to consider in the case of petroleum production because of its public ownership in Saudi Arabia, therefore we will treat the alternative ratio,

$[R(Q)/C(Q)] = p_{oil} \cdot F(K,L,W) / [r.K + w.L + p_w.W] = a.$ .... (4)

'a' is a sustainability ratio for petroleum production in view of the need to sustain the levels of socio-economic development and social wellbeing. The 'a'- ratio must therefore be importantly maintained at a stable level.

We now have, $F(K,L,W) =$
$a. [(r/p_{oil}).K + (w/ p_{oil}).L + (p_w/p_{oil}).W]$ ....(5)

Several forms of the aggregate production function can be specified. In our case of treating complementarity between the goals of socio-economic development and social wellbeing, it is important to consider such complementarity among the factors of production. Contrarily, the existence of marginal substitution among the factors, K, L, W, adversely affects one or the other factors by making them compete with each other. The result then is an inequitable utilization of factors, resources and distribution of factor incomes.

In our complementary type production function the objective is to attain economic efficiency and profitability simultaneously along with distributive equity. Underlying this perspective of socio-economic planning is an appropriate kind of technological change. In this technological choice productive factors interrelate in establishing equitable distribution of resources among all of them. A sharing of resources for attaining overall economic efficiency and distributive equity is thus put into effect by appropriate choices and policy variables.

To address the above kinds of conditions we choose the Cobb-Douglas Production Function with increasing returns to scale (Henderson & Quandt, 1958).

In reference to the Cobb-Douglas Production Function with increasing returns to scale we re-write expression (5) as,

$$K\alpha L\beta W\gamma = a. \; [(r/p_{oil}).K + (w/\,p_{oil}).L + (p_w/p_{oil}).W]. \qquad \ldots\ldots\; (6).$$

Here, $\alpha > 0$, $\beta > 0$, $\gamma > 0$, are the factor elasticity coefficients of output, with $\alpha + \beta + \gamma > 1$, indicating increasing returns to scale in oil production.

We interpret this equation as follows: The value of total petroleum output is proportionately distributed in a sustainable way among factor inputs according to their real prices measured relative to petroleum price. Thus, petroleum price plays an important exogenous role in determining payments. For complementarity among factors to exist their respective prices must move in the same direction together. Hence the real factor prices, including importantly the price of water as shown, must remain fairly stable and monotonic in the same direction among the factors at given oil prices.

The coefficient 'a' must be stable or be increasing on a time trend because it plays an important role in the measurement of revenue impact relative to cost of production. Stability of the coefficient 'a' will imply that revenue impact among factors remains sustainable and equitable in the given production function.

For factor complementarity and sustainability property of 'a'-ratio to exist the coefficients of the Cobb-Douglas production function must satisfy the relationship,

$$\alpha + \beta + \gamma > 1, \alpha > 0, \beta > 0, \gamma > 0.$$

Water subsidy and oil revenue

A portion of the oil revenue, say 'b', is directed as subsidy, S, for maintaining a stable water price (water rate), p_w. That is,

$$S = b.R(Q); \qquad \ldots\ldots. (7)$$

$$p_w = f(S) = f(b.R(Q)) = f(b.p_{oil} \, . \, F(K,L,W)) \qquad \ldots\ldots. (8)$$

It is noted from expression (8) that petroleum output, Q, and price, p_{oil}, should move in a way that maintains a healthy flow of oil revenue, $R(Q) = p_{oil} \, . \, F(K,L,W)$.

Consequently, S remains a sustainable amount of subsidy. Furthermore, let,

$$p_w = f(S),$$

be in the linear form with a negative coefficient for S in relation to p_w.

The following results are obtained:

1. $dp_w/dS < 0$, but if S itself remains steady, then $dp_w \approx 0$........ (9)

2. After logarithmic differentiation of the expression,

$$S = b.p_{oil} \, . \, F(K,L,W) = b. \, p_{oil} \, . \, K\alpha L\beta W\gamma,$$

We obtain, $g(S) = g(p_{oil}) + \alpha.g(K) + \beta.g(L) + \gamma.g(W)$. .... (10)

g(.) denotes the percentage rate of change of the variables inside (.). Expression (10) points out that a given amount of subsidy would be needed to sustain the complementary use of productive factors in the aggregate oil production function. This is attainable by a stable flow of oil revenue relative to the cost of oil production, as shown above.

Consequently, in expression (10) it is $g(p_{oil})$ that would determine the critical relationship for this revenue-subsidy sustainable relationship in reference to socio-economic development.

3. Furthermore, on writing, $p_w' = p_w - A = B. \, p_{oil} \, . \, K\alpha L\beta W\gamma$, where A and B are coefficients, we obtain,

$$g(p_w') = g(p_{oil}) + \alpha.g(K) + \beta.g(L) + \gamma.g(W) \qquad \ldots\ldots. (11).$$

Clearly then, $g(p_w') = g(S)$. This means that the water rate and subsidy are inversely related up to a given amount of the subsidy. That is, such a subsidy level sustains a stable water rate. This result points out that stability of the subsidy level must be sustained in order to maintain a given scheme of water rate.

Closing up the petroleum production, revenue and water subsidy model: reverse flow of subsidized water as a factor input in the aggregate oil production function

Expression (8), $p_w = f(S) = f(b.R(Q)) = f(b.p_{oil} . F(K,L,W))$, helps to close the model between water pricing, the subsidy on it, oil revenue and oil production. From the stability of $R(Q)/C(Q) =$ 'a', it is clear that $p_w = f(S) = f(b.a.C(Q))$. That is, $S = a'.C(Q)$, where, $a' = a.b > 0$. Thus, $S = a'[r.K + w.L + p_w.W]$. This means that a proportion of the payments to factor payments in the oil production function is maintained by the use of water subsidy. This is due to the fact that since subsidy in water returns the stabilizing effect of water rate to the aggregate oil production function, therefore, by the effect of complementarity among the productive factors, all the factor payments benefit from this reverse input of water resource in production. The resulting cost stabilization now contributes to the stable 'a'-ratio, for $R(Q)/C(Q) = a$.

We now have a circular interrelationship among oil production, oil revenue, water subsidy and water rate. Into this interrelationship is introduced the socio-economic developmental effect of complementarity among the productive factors, including the reverse flow of subsidized water resource as a factor of production. The social wellbeing aspect of this developmental impact is reflected in the stable water rate that is made possible by a steady flow of oil revenue relative to the cost of oil production and by the channeling of some of this revenue into water subsidy. Finally, complementarity among productive factors contributes to cost stabilization by maintaining stable complementary factor prices for given levels of cost of production. This in turn sustains $R(Q)/C(Q) = a$.

DIAGRAMATIC EXPLANATION OF THE CLOSED CIRCULAR MODEL

The closed model of aggregate oil production and revenue, water pricing and subsidy is required to establish the feedback relations that exist between the social and developmental consequences of water subsidy and its sustainability in the Saudi case. This means that the revenue generating capability relative to cost of crude oil production must be sustained in order to sustain the subsidy derived from oil revenue. The circularly closed general equilibrium model is explained by means of figure 1.

The systemic feedback loops shown in figure 1 are self-explanatory. One notes that the stable levels of oil production and revenue flow in relation to the cost of crude oil production make the sustained water subsidy possible. This supports steady water rates. Thus we have the pair, (S,P), as shown.

Next these parameters enter the goals of economic development by supporting the complementary relations among (K,L,W) in the increasing returns to scale Cobb-Douglas production function. The stable water prices caused by water subsidy adds to social wellbeing, water being a basic need in all aspects of life. The developmental and social wellbeing effects thus become interactive in the general equilibrium feedback.

Finally, the reappearance of water, and hence its subsidized prices in the petroleum production function, regenerates the system of feedback loops. This closes the model in a circular fashion between production and subsidized water resource with complementarity among the factors of production, including subsidized water resource.

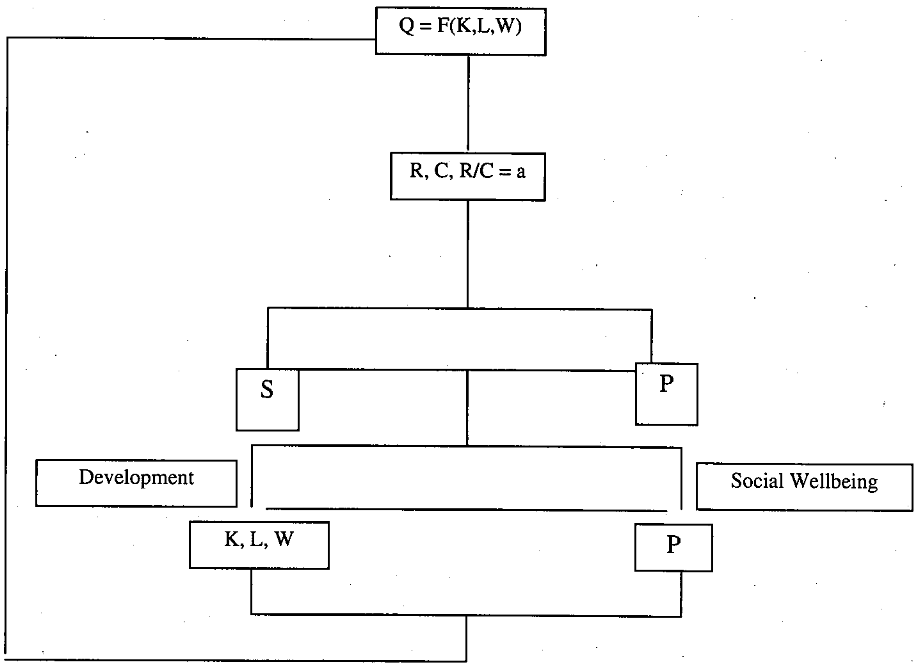
The circular use of water resource in boosting up the productivity of economic production in Saudi Arabia has been emphasized in the Sixth Development (1995). The aim is "to raise labour productivity in the water sector and to train Saudi manpower to adapt to the continuous development in water technologies." In our conceptual framework of the general equilibrium model we have shown that water resource when appropriately subidized to maintain its price level supports a stable cost of production in the petroleum sector. This in turn favours other factors of production, leading to stability in the revenue/cost-ratio.

The most critical parameters for such sustainability in the closed and circular feedback are the stability of the revenue-cost ratio, 'a', and the complementary nature of the production function, Q = F(K,L,W), among the productive factors. For policy variables we must also examine the relative movements in water and oil prices, (p_w/p_{oil}). These effects in principle provide first, the effect of sustainable oil in maintaining water subsidy. Secondly, by establishing factor complementarity, water subsidy becomes an important element of social wellbeing. Thirdly, they provide policy directions by using the policy parameter, (p_w/p_{oil}).

The developmental and social wellbeing effects are thereby realized by the complementary nature of factors in the production function. In this case, increasing returns to scale in oil production are indicated by the case of

$\alpha + \beta + \gamma > 1$, with $\alpha > 0$, $\beta > 0$, $\gamma > 0$. Increasing returns in turn are reinforced by the stabilization of production cost through complementarity among factors. These effects cause the revenue/cost ratio to remain stable. Cycles of circular causation are thus established in such a development-wellbeing interrelationship between oil production, revenue and water subsidy.

Figure 1: Circularly closed feedback in petroleum production, revenue generation and water subsidy model in the light of development and social wellbeing impact.



DETERMINING SUBSIDIZED WATER RATE IN THE GENERAL EQUILIBRIUM MODEL

From the negative relationship of water rate to subsidy as a matter of social policy, we note that there is a limit to the extent that water rates can be subsidized. This follows the need in our oil production model to maintain the revenue/cost ratio and stabilize the cost of oil production. The pricing schedule for water under different impacts of subsidy in the overall production and revenue system, as shown in figure 1, now becomes a critical element. This is explained by means of figure 2.

In the case of water demand shown by (p_w,W)-relations, we contend that there will be shifting kinked demand curves, such as D_1D_1 to D_2D_2, with kinks a_1 shifting to a_2. This is the result of injecting subsidy in support of a socially acceptable water pricing policy (MacDonald et al, 1999). These kinks convey social decisions that must be taken up periodically to set appropriate subsidy and water rates. By our result in the case of Saudi Arabia the water subsidy must have remained constant over periods of time, since water prices have remained unchanged for the periods 1986-1994, when the water rate was on average SR3 per cubic meter, and for the period 1994-2000, when the water rate was SR5 per cubic meter.

The subsidy effect in the shifting kinked demand curves for water impacts upon the petroleum productivity curves, Q_1 and Q_2. This causes the productivity curves to shift upwards, as shown by b_1 shifting to b_2.The revenue effect of such productivity shifts is shown by R_1 and R_2 under the petroleum demand curves in the (p_{oil},Q)-quadrant.

Since the revenue/cost ratio must be stable in our model, therefore, the petroleum demand curves must shift outwards, as shown, along with the shifts in the petroleum productivity curve of water.

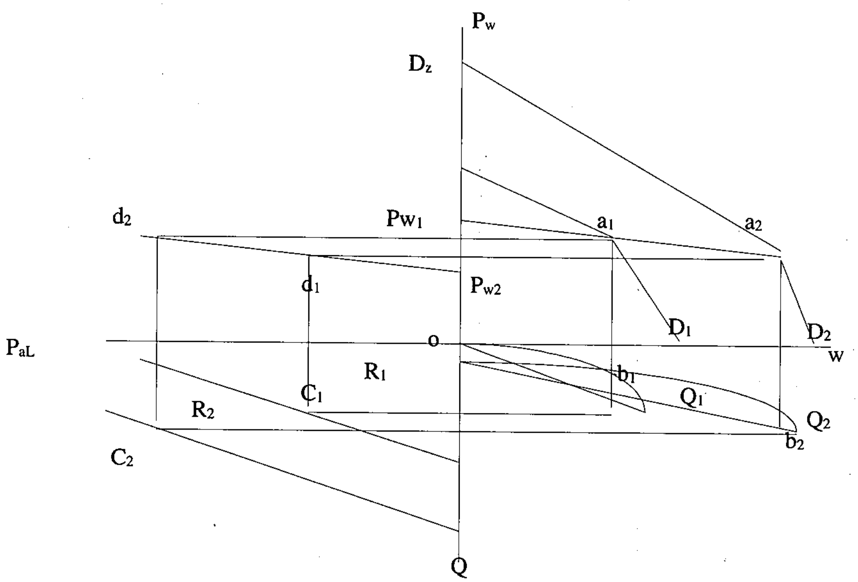
The circular feedback model is completed by recycling the effect of oil prices (i.e. revenues) on the setting of water rates in terms of water subsidy. The effect of sustained oil prices on stable water rate is shown in the (p_w, p_{oil})-quadrant by the points d_1 moving to d_2. The near flat relationship between p_w and p_{oil} indicates a fairly stable water rate on a time trend related with increasing oil prices.

The points in the respective quadrants, (a_1, a_2), (b_1, b_2), (c_1,c_2), (d_1,d_2), are interrelated, as shown. Such points are policy-induced on the basis of three important effects. These are namely, maintaining revenue/cost stability, the effect of this on sustaining water pricing subsidy and water rate, the resulting complementarity among the productive factors (K,L,W), and the stability in the policy parameter, (p_w/p_{oil}). These effects in turn stabilize production costs and the revenue/cost ratio. Thus once again the circularly closed relationship of the petroleum production, revenue and water subsidy model of economic development and social wellbeing is established.

It is precisely because of this nature of policy-induction of the mentioned geometrical points that methodologically we cannot consider an output-maximization objective criterion function for the oil production model. Instead, we find that a simulation model was inherently present in our general equilibrium model. In this regard, expressions (6) and (8) show that assigned values of p_w relative to p_{oil} must be continuously fed into these equations to generate, petroleum output, and thereby, revenue/cost stability, level of subsidy and water pricing. The simulative nature of the General Equilibrium Model was brought out in figure 1.

We now infer from the almost fixed nature of the points (a_1, a_2) in figure 2, that water rates administered by social policy under a subsidy derived from oil revenue becomes an elastic supply curve. Thus water can be seen as an economic necessity in the supply function. This supply function is shown by the curve SS in (p_w,W)-quadrant. Its elastic but slightly negative slope indicates the existence of increasing returns to scale in the aggregate oil production function. This is also a condition required to maintain sustainability between production, revenue/cost ratio, subsidy and water pricing.

Figure 2: Subsidized water pricing in the petroleum production, revenue and water subsidy model of development and social wellbeing.



EMPIRICAL SUPPORT FOR THE OIL REVENUE AND WATER PRICING-SUBSIDY RELATIONS

In order to support our conceptual formalism on the relationship among oil production, revenue and water pricing model vis a vis subsidy, we need to study the following critical conditions by means of data in table 1. The principal indicators to observe for stability are the R(Q)/C(Q) = a-ratio. If this ratio remains fairly constant on a time trend then our inferences on stable crude oil output and revenue, stabilized cost and sustained oil prices will follow, and vice versa, in view of circular causation in the general equilibrium model. The level of water subsidy as percentage of oil revenue is an inferred result from the stability of other relations. Thus, in the absence of such estimates the stability of the 'a'-ratio, water rate and oil price will be used to infer the social and developmental effects of subsidy derived from sustained flows of oil revenue. The analysis is explained in figure 2.

Empirical results on stability relations in oil production and water pricing in Saudi Arabia

Table 1 gives the secondary data on the basis of which table 2 is calculated and estimation results are interpreted.

Table 1: Petroleum and pricing data: water and oil

Time	Petroleum Output,[1] Q	Spot Price Arabian Light,[2] p_{oil}	Petroleum Revenue, R(Q)	Cost of Production (Gross Capital Formation)[3] C(Q)	Avg. Water Rate, p_w/Cub.metr (200-300+ Cub.metr)
	('000b/d)	($/SR)	(Millions SR)	(Millions SR)	(SR)
1990	5674	20.82	118,142	—	3.00
1991	6670	17.43	116,266	—	3.00
1992	7083	17.94	127,077	—	3.00
1993	6758	15.68	105,976	—	3.00
1994	8045	15.39	95,505	8,084	5.00
1995	8023	16.73	105,728	14,768	5.00
1996	8102	19.85	135,982	8,536	5.00
1997	8329	18.80	159,985	9,088	5.00
1998	8033	12.24	79,998	9,231	5.00

Sources: various issues of **OPEC Bulletin** and **Annual Report of Saudi Arabian Monetary Agency**, 1999. Water rates are obtained from the Department of Water and Sewage, Ministry of Agriculture, Riyadh.

1. Output is measured in thousands of barrels of crude oil.
2. These denote spot prices of Arabian Light.
3. Gross capital formation is treated as a proxy for cost of crude oil production.
4. The values of oil production for the period 1990-94 has been estimated by Revenue/price of Arabian Light.
5. The water rate for 1994 is kept at the 1995 level of SR5.00 per cubic meters of water.
6. Revenue for 1991 is estimated from a linear estimated equation (Rev = 116,395 - 64.2882.t.

Table 2: Computed revenue/cost and price ratios

Year	1994	1995	1996	1997	1998
a = R(Q)/C(Q)	11.81	7.16	15.93	17.60	8.67
Average a = 12.23					

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998
p_w/p_{oil}	0.1441	0.1721	0.1768	0.1913	0.1949	0.2989	0.2519	0.2660	0.4098
Average = 0.3									

Computed from Table 1.

Estimated time-trend equation for 'a'-ratio (Y):

$$Y = 10.9860 + 0.4160.t$$

(2.367) (0.2558)

level of significance 81.5%

$R^2 = 0.0213$; DW = 2.323

Estimated time-trend equation for (p_w /p_{oil})-ratio(Y):

$$Y = 0.100453 + 0.0267050xt$$

(3.31073) (4.95286)

Sign.Levels(%) 98.7 99.8

$R^2 = 0.7780$; DW = 2.16588

Some interesting results can be read off table 2 with respect to our theoretical inferences. In both cases we note that there is a fair degree of stability of the estimated ratios ('a'-ratio and price-ratio, (p_w/p_{oil})). Our theoretical inferences on the stability of revenue flows in support of maintaining a regular flow of subsidy for water and its linkage in the general equilibrium production model, is established. The short time period of available data on the required variables, particularly for the cost of production series (gross capital formation) makes the corresponding results only illustrative in our study.

The estimated time-trend equation for 'a'-ratio shows that about 41.60 per cent of the change in 'a'-ratio is explained by time trend. This is reliable at the 81.50 percentage level of significance according to t-statistic. Hence, the estimated value of the 'a'-ratio is close to 11.00 on a trend. Because of the short period of time, 1994-1998, the estimated equation shows low goodness of fit by the R^2 value. The value of DW-statistic shows no serious autocorrelation in this estimated equation.

With regards to the time-trend on water price relative to oil price we note that only 2.67 per cent is estimated to be due to change in this ratio over time. Thus the price relative policy parameter, (p_w/p_{oil}), is found to be stable around 0.100453 in the long-run (between 1990-1998). The time-trend estimate is reliable at the 99.8 percentage significance level according to t-statistic. There appears to be no time-series errors due to autocorrelation of the error terms. The R^2 value of 0.7786 indicates a fairly good linear fit for the estimated equation over the long-run.

In summary, the empirical results for the period 1994-98 for which consistent data are available indicate a fairly stable trend for the a-ratio (=R(Q)/C(Q)). The (p_w/p_{oil})-policy parameter is also stable and low. Thus increasing oil prices on a trend subsidize water rate to a stable level, while the stable 'a'-ratio is causally related with factor complementarity and reverse flow of water resource in the aggregate oil production function.

Policy Conclusion

The formulation and theoretical analysis of a General Equilibrium Model in oil production and revenue and the sustained effect on water subsidy and rates establishes a complementary framework among factors. One of these factors is the reverse flow of subsidized water. This along with factor complementarity stabilizes the cost of production. Such a stabilization of cost versus revenue is both theoretically and empirically proven in our General Equilibrium Model. The circular flow of resources among factors in the aggregate production function of oil establishes the innovative specification model of a type that is not of the neoclassical genre. Here extensive complementarity prevails causing cost reduction through factor price stabilization (Choudhury, 1996).

The empirical section of the paper establishes many of the complementary, sustainable and wellbeing implications of our General Equilibrium Model. Of particular importance to note here is the nature of kinked demand curves for water resource. This phenomenon was explained by means of the policy nature of water rate based on oil price movements. In actual case for Saudi Arabia we find that between the years 1986 and 2000, there were two major re-setting of water rates. Between 1986 and 1993 water rate remained at the average of SR3.00 per cubic meter between 200-300 cubic meters of usage. Between 1994 and 2000 the new water rate was set at SR5.00 per cubic meter for the same usage level. The policy effects of such rate setting are explained by the kinks on the oligopoly type demand curves for water and by the slightly positive shape of the (p_w/p_{oil})-curve in quadrant 2 of figure 2 (Mansfield, 1985). In this way, both p_{oil} and p_w can be considered as policy variables, and their ratio, (p_w/p_{oil}), can be seen as a policy parameter.

The last point mentioned above accords strongly with the aim of the Sixth Development Plan of Saudi Arabia with respect to the use of water resource for the sustenance of wellbeing in all sectors of the economy. This aim is a long-term sustained goal of the Saudi Government. The Sixth Development Plan mentions the following directions along which the water resource policy will be pursued (1995):

In the area of general wellbeing while treating water as a basic need the Plan says, "Water should be considered as the most basic and valuable resource, and as an important factor in measuring the economic efficiency of public and private sector projects."

To keep up with the supply of water resource to all end-users the Saudi Government aims at attaining the following measures (Sixth Development Plan, 1995 p. 191): "The water studies program will be resumed to update the hydrological information on water aquifers, and the water potential studies for some areas." "Rules will be established for the operation and maintenance of existing water resources in order to preserve their productive efficiency." "The implementation of water projects will be continued, while giving priority to the population's need for potable water." "Expanded use will be made of reclaimed waste for agricultural and recreational purposes, and its potential use for industrial purposes will be studied."

On the issue of productivity and efficiency of productive factors being utilized in the water resource development sector the Sixth Development Plan points out the following directions: "Suitable training programs will be prepared for the manpower working in this sector." In terms of the closure of the General Equilibrium Model by reverse flow of subsidized water we note here the expected effectiveness on stabilization of cost of production and a stable supply of water that can be generated by the implementation of such a program. Consequently, the cost stabilization effect of the resulting sustained supply of water and of factor productivity on cost control can be transmitted to the petroleum aggregate production function. Thereby, the $R(Q)/C(Q) = a$-ratio can be maintained at a long-term stable level.

On the matter of a step-wise need to re-set water rates periodically so as to contain unwanted excessive pressure on Government expenditure in water resources, the Sixth Development Plan points out the following measures: "Regulations and legislation with respect to the organization of water consumption for all purposes and on an economic basis will continue to be issued, in order to promote the conservation of water resources." "A revenue collection program will be developed according to a system of water consumption tariffs for various consumer categories to provide financial resources that are sufficient to cover the operating expenses of water production and distribution." These points are consistent with the inferences derived from our General Equilibrium Model.

The social wellbeing connection between water and oil in Saudi Arabia is thus found to be a sustainable relationship over time albeit periodic re-setting of water rate in relation to the movement of oil prices and revenues. Subsidy on water in Saudi Arabia is thus closely related with the flow of oil revenue, *ceteris paribus*, within the bounds of economic efficiency, productivity and social wellbeing, jointly required to sustain water supply at adequate levels. Thus we claim that *Water does mix with oil* in Saudi Arabia in the General Equilibrium Model of causality among productive relations, economic productivity and social wellbeing, as formalized in this paper.

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Surface and Groundwater Resources

Environmental Impacts on the Ground Water Quality in El-Tur, South Sinal, Egypt

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ENVIRONMENTAL IMPACTS ON THE GROUND WATER QUALITY IN EL-TUR AREA, SOUTH SINAI, EGYPT

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ABSTRACT

The, hug thick, renewable Quaternary aquifer in El-Tur area is the only source for drinking water supply to the residential areas (El-Tur and Sharm El-Sheikh cities). It is of vital importance to keep this groundwater out of the different sources of pollution. In this study, sixteen water samples have been collected from eight wells. These water samples have been analyzed for each of the major and trace elements. The distribution of the concentrations of Chloride ions increased towards the inland zone. The chloride which is driven from sea water was differentiated from that of anthropogenic sources by comparing the ratios of Bromide/Chloride. All the water samples manifested slightly increase in the values of Chemical Oxygen Demand. This proves the contribution of surfacial anthropogenic sources pollution of the groundwater. Three irrigation wells show alternatively an increase in the values of TDS, Ca, Mg, Na, $S0_4$, NH_4, Mn, Cu, AL and COD above the standard values which are laid down by different organizations. Fortunately, these wells are not used for drinking purposes. The other five wells which used for drinking purposes are free from different pollutants except two of them. One well shows a slight increase in Mn content and the others contain minor amounts of P04. This paper proved that the increase in the chloride concentrations is a contribution from surface sources and not from sea water. It is recommended that the water of these wells should be treated before being used for drinking. An appropriate schedule for monitoring the water quality of drinking water should be carried out.

INTRODUCTION

In general, Sinai Peninsula is suffering from water deficit, which are required for different development purposes like urbanization, agriculture, industry mining and tourism This water scarcity is due to the location of Sinai within the arid and semiarid zone. Land use is primarily urban with scattered small agricultural areas. Associated with the urban setting is the potential for contamination. Before 1986, the domestic effluent has been disposed through septic tanks. This has resulted in increasing problems of soils and groundwater contamination. During 1986, the sewer system and the treatment station have been established. Sewage treatment results in the formation of semisolid sludge containing sediment, organic waste, bacteria and metals. This is also another sources of pollution.

Groundwater pollution is of great concern, it may take many years for contaminated water to be flushed from a system because of the slow rate of movement. However groundwater contamination is usually a local rather than a regional problem. Polluted water moving through soil and rock may be attenuated to some degree. Attenuation processes include dilution and dispersion, mechanical filtration, chemical reaction, membrane filtration and radioactive decay. In our study 16 water samples were collected from selected well. Each well is represented by two samples, one acidic and the other not acidic. These water samples have been analyzed for each of the major ions as well as the trace elements. The main objective of this paper is to high light the different sources of pollutants in the study area.

LOCATION OF THE STUDY AREA

Fig. (1) shows the location map of the study area. It is bounded from the north by latitude 28' 30-, from the south by latitude 28' 05-, from the east by longitude 33' 45-, and from the west by the gulf of Suez and longitude 33' 30-.

HYDROGEOLOGY

The area of study is occupying a portion of El-Qaa plain which is characterized by the occurrence of surface thermal spring (Hmmam Sidna Musa). El-Qaa plain basin is bounded from the eastern side by crystalline mountains and sedimentary ridges, which are acting as the main watershed areas. Beneath the surface of the study area a huge thick of the Quaternary rocks. As shown in fig (2) three aquifer systems are identified. The first aquifer system occurs in a limited area along the down stream of wadi El-Awag near El Tur and wadi village. It composed of gravel, sand and silt. The second aquifer system composed mainly of gravel and sand with interbeds of clay lenses. It is considered the most promising aquifer in the area of study. The third aquifer system composed of intercalation of sand and clay beds. The values of the different hydraulic parameters in the second and third aquifer systems are printed in table (1).

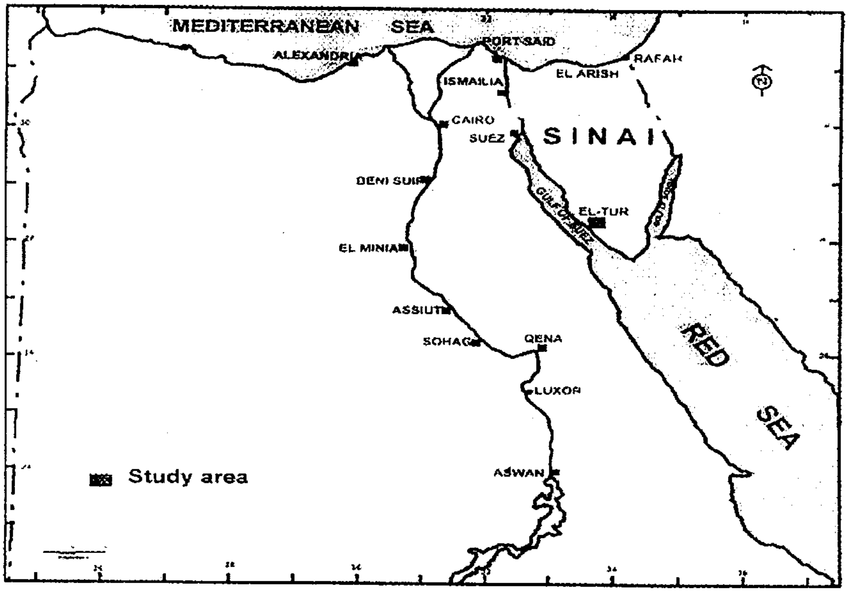

Fig. (1) Location of the Stud Area

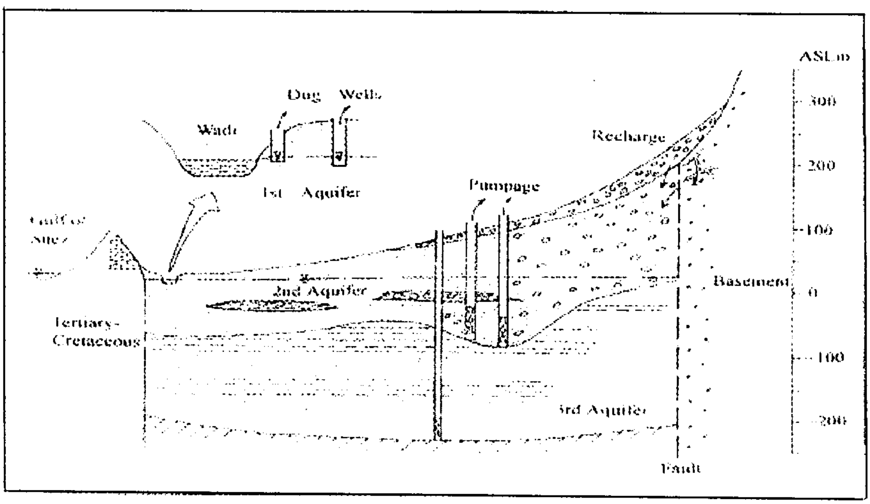

Fig. (2) Schematic Cross Section of El-Tur Area (WRRI & JICA, 1999)

Table 1 :Hydraulic parameters of the Quaternary Aquifer systems:

Aquifer Systems	Yield (m3/h)	Specific capacity (L/s/m)	Transmissivity (m2/day)	Hydraulic conductivity (m/day)
First Aquifer	10 - 80	-	-	
Second Aquifer	20 - 115	0.33 - 6.11	106 - 2150	
Third Aquifer	20 - 52	0.08 - 1.07	9 - 52	0.28 - 5.23

The groundwater is flowing from the north-east towards south-west direction. The Quaternary aquifer in the area of study is under water table conditions (unconfined aquifer). This makes the aquifer susceptible to contamination from surfacial anthropogenic sources.

RESULTS AND DISCUSSION

The collected water samples on February, 2000 have been analyzed chemically and biologically in the Drainage Research Institute. The results of the chemical analysis including EC, pH, TDS, the major elements, metals, non metals and COD are printed in an internal report. To evaluate the groundwater quality in the area of study, the following topics will be discussed:

- Use of Bromide and Chloride Ratios to Differentiate Potential Sources of Chloride

Dissolved chloride is common in shallow groundwater, but concentrations resulting from natural sources are generally low (Hem, 1992). The unconfined Quaternary aquifer in El-Tur area is susceptible to chloride contamination not only from Suez Bay (WRRI and JICA, 1999) but also from surfacial contamination from anthropogenic sources. The surfacial contamination from anthropogenic sources represented by marine aerosols (Cl,Br), septic tanks, leaky sewer lines and fertilizers ($CINO_3$) and pesticides (Cl,Br).

The average chloride and bromide concentrations in sea water are 19,000 and 65 mg/1 respectively (Hem, 1992). The calculated bromide concentrations in the water samples range between 0.06 and 0. 1 mg/1. These low values of bromide show that, the primary natural sources of bromide are precipitation and marine aerosols (David C. Andreasen et.al., 1997). Minor amount of bromide can be introduced into the groundwater from additional sources like pesticides and automobile emission.

According to (Hem, 1992) the Br/CI ratio of sea water must be equal 3.4 x 1 0-3. The Br/CI ratios in the water samples range between 5.88 10-5 and 7.67 10-'4. These values are lower than that of sea water. To determine the sources of chloride in groundwater four factors will be taken into consideration. These factors are:

1. Nitrogen and COD concentrations; N-Nitrate concentration range between 1.98 and 3.96 mg/1, where the concentrations of COD range between 70 and 95 mg/1. These values prove the presence of surface contamination from anthropogenic sources.

2. Well screen position: The theoretical depth to fresh water and sea water interface was estimated by use the Ghybeen-Herzberg relation. According to this relation the depth to the fresh water/ sea water interface is approximately 40 times the height of the water table above the sea level. In this study the well screen of the sampled wells are located above the estimated fresh water and sea water interface.

3. Groundwater balance: (WRRI and JICA, 1999) have been estimated the amount of recharge by 5.9 106 m^3 /year and the total abstraction by 3.44 106 m^3 /year. This indicates that, the groundwater in the study aquifer is out of stress and it is capable for additional development.

4. Water table gradient: Water table slopes generally towards the Gulf of Suez where the lowest measured water table is about 5.0m.

The above mentioned four factors and the dissimilarity between Br/CI ratios of sea water and that of groundwater samples proved the presence of surfacial anthropogenic sources of chloride. These sources within the study area that may contribute chloride to the groundwater include septic tank effluent, leaky public sewer lines and slug of sewage treatment station.

EVALUATION OF GROUNDWATER QUALITY

The quality of water is its suitability for a specific use. It is a consequence of the natural physical and chemical state and such alteration as may have occurred through the actions of humans. Any solute that enters the hydrology cycle through human action is a contaminant; if it renders the water unfit for use, it is a pollutant. In the following the water quality criteria for drinking water supply will be discussed:

Drinking Water Supply

To evaluate the groundwater samples in the area of study the results of the chemical analysis have been compared with that which laid down by (WHO, 1971), (ECAFE and UNESCO, 1963) and (Middlebrooks, 1982).

Hydrogen Ion Activity (pH)

In the area of study the values of pH range between 6.8 and 7.4. These values are suitable for drinking water supply.

Total Salinity (TDS)

Fig. (3) shows the distribution of TDS in the area of study where it ranges between 492 and 3991 mg/ l. According to the Permissible limit for potable water (1500 mg/1), the water samples of wells w3, w4, w5, w6 and w7 are suitable for drinking purposes. Wells wl, w2 and w8 are not suitable for drinking purposes.

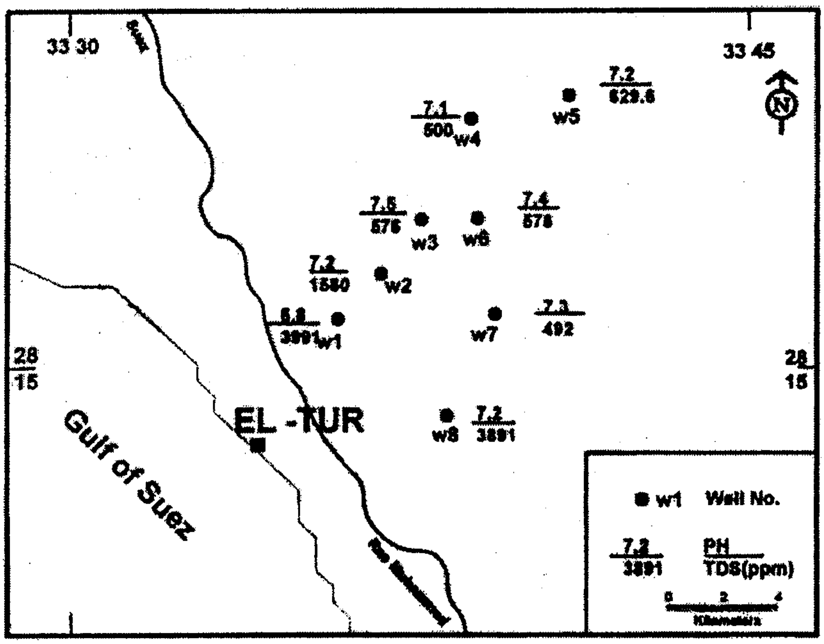

Fig. (3) Distribution of pH and TDS of the Quatenary Aquifer in El-Tur Area

Major Elements

Fig. (4-a) shows the distribution of Ca, Mg, Na, K, while Fig. (4-b) shows the distribution of HCO3, S04 and CI. The water samples of wells w3, w4, w5, w6 and w7 are less than the permissible limit for drinking water supply. Well wl shows an increase the concentrations of Ca, Mg, Na, S04 and CI. Well w2 shows an increase in the concentrations of Na and S04 while well w8 shows an increase in the concentrations of Ca,Na, S04 and CI.

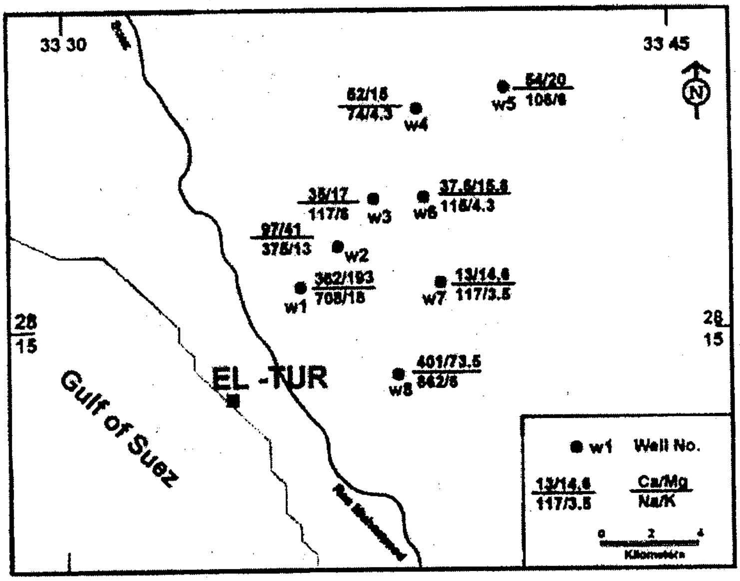

Fig. (4-a) Distribution of Major Cations of the Quaternary Aquifer system in El-Tur city

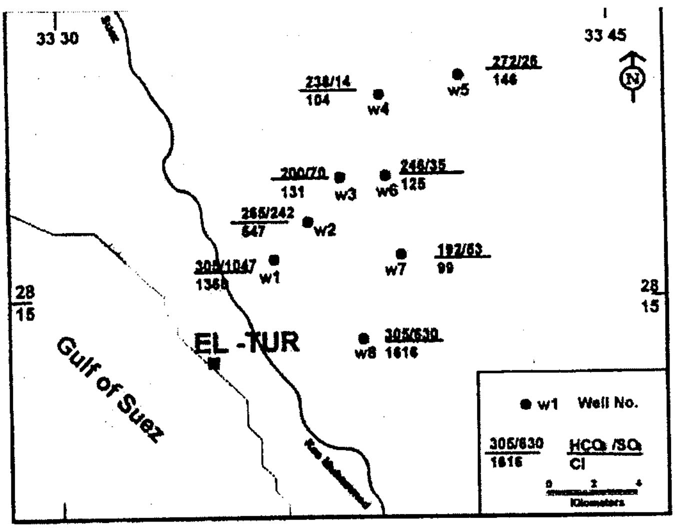

Fig. (4-b) Distribution of Major Anions of the Quaternary Aquifer in the El-Tur Area

Heavy Metals

Fig. (5) shows the distribution of Mn, Cu, Fe, Zn, AI and Pb in the area of study. The reported values of heavy metals show that, the water samples of wells wl, w2, w3, w4, w5 and w6 have concentrations less than the standard values except its content of Mn, Cu and Fe. This increase in the concentrations of the heavy metals is most probably attributed to the dissolution of some minerals in the sediments of the aquifer rich in these elements. Manganese can be taken in concentrations of 5 to 10 times those of the standard value (0.05 mg/1) (Stanley N. Davis et. al., 1966). Fortunately, the lead is not detected in all the water samples.

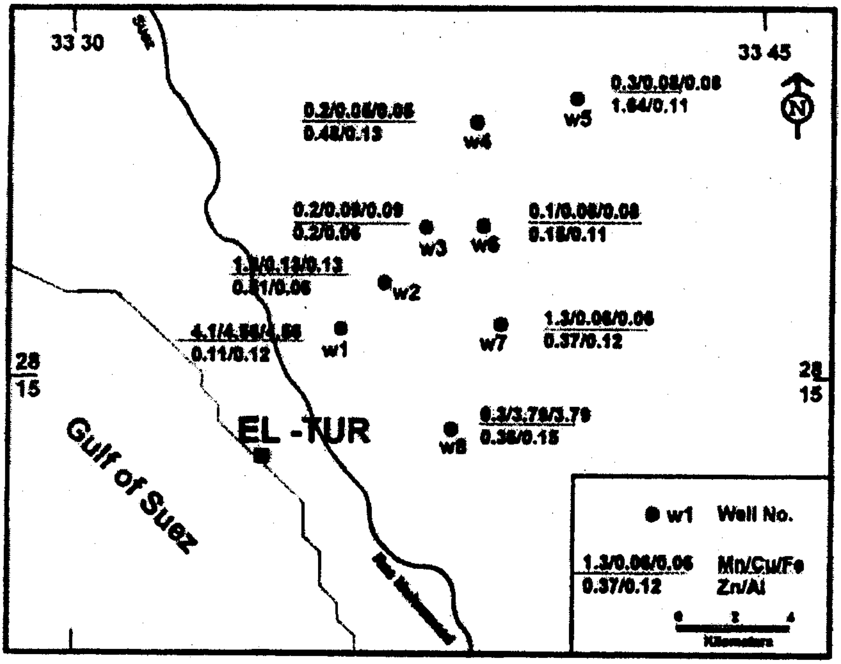

Fig. (5) Distribution of the Heavy Metals of the Quaternary Aquifer in the El-Tur Area

Nutrients

Fig. (6) shows the distribution of the NH_4, NO_3 and PO_4 in the water samples of the study area. The concentrations of NH_4 and NO_3 in all wells are lower than that of the standard values for drinking purposes except well w2 where it shows slightly increase in the concentration of NH_4. This indicates the presence of some source of pollution at this site.

Phosphate in most water samples is not detected. In wells w4 and w8 phosphate concentrations are lower than the standard permissible limits for drinking water.

Chemical Oxygen Demand (COD)

Fig. (6) Shows that, the groundwater in the area of study have concentrations range between 59.0 mg/l and 184.0 mg/l. Because the COD should be absent in potable water, this is an indication on the presence of surfacial source of pollution.

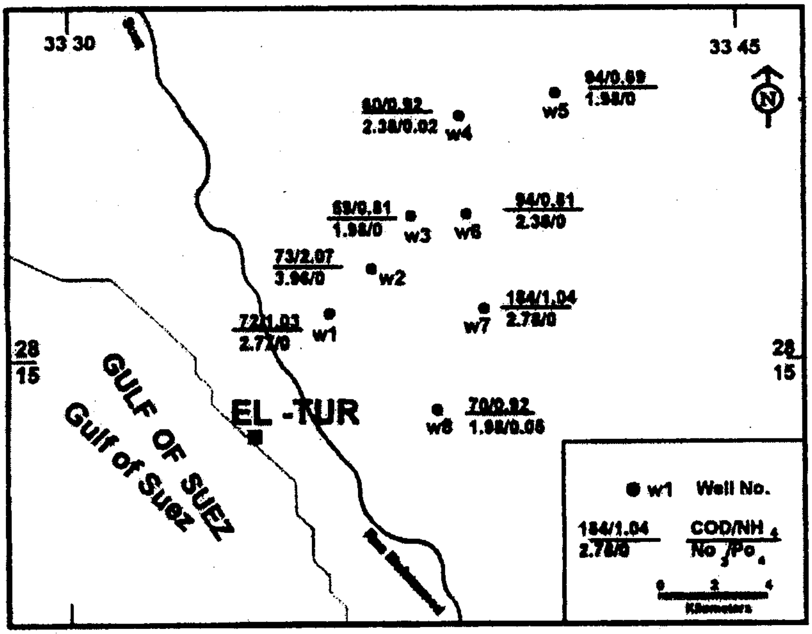

Fig. (6) Distribution of Nutrients and COD of The Quaternary Aquifer in El-Tur Area

CONCLUSION

Chloride in groundwater from salt water intrusion can be differentiated from chloride of anthropogenic sources by comparing the distinctive Br-:Cl- ratio in sea water to Br-:Cl ratios in groundwater samples. Dissimilar ratios indicate that chloride has entered the groundwater from anthropogenic sources. This method was effective for groundwater samples with chloride concentrations greater than 30 mg/l (David C. A. et.al., 1997).

All the groundwater samples indicate slightly increase in the concentrations of COD, this is probably from anthropogenic sources contribute pollutants to the groundwater. Among these sampled wells, three wells used for irrigation purposes and five used for drinking purposes. The irrigation wells show distinctive increase in the concentrations of TDS, Ca, Mg, Na, SO_4, NH_4, Mn, Cu, Al and COD above the standard values for drinking purposes. These wells which have been used for drinking purposes contain low concentrations of different elements except two wells, one shows slight increase in its content of Mn and the other shows slight increase in the content Of $P0_4$.

RECOMMENDATIONS

1. The Quaternary aquifer in El-Tur area not stressed and is capable for development.

2. Because this aquifer under unconfined conditions and susceptible for contamination from surfacial sources of pollution, an appropriate program for monitoring the water quality fluctuations should be carried out.

3. Drilling new wells must be carried out towards the inland area.

4. Adequate treatment technique must be applied to the pumped water wells before using it in drinking purposes.

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The Use of Telemetry in Water Resources Monitoring Networks in the Sultanate of Oman

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THE USE OF TELEMETRY IN WATER RESOURCES MONITORING NETWORKS IN THE SULTANATE OF OMAN

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ABSTRACT

The Ministry of Water Resources has the responsibility to assess and manage the water resources of the Sultanate of Oman. To provide the assessment of the Sultanate's water resources, a network of hydrological and meteorological stations have been established to monitor wadi flow, rainfall climate, aflaj and groundwater. Utilizing the data obtained from the stations, various analyses can be made to assist in the planning and design of recharge dams, the modification and improvement of wadi channels to reduce flooding, the design of road structures that cross the wadi drainage, and the planning of structures in developing areas.

The main objective of using the telemetry system is to provide a direct communication link between the remote field stations and the Ministry offices on which real-time data could be obtained. Two telemetry stations have been installed as a pilot study of the system. Both stations were fitted with rainfall gauges, one had also wadi bubble gauge and the other had a borehole water level sensor. The data is transmitted using GSM modem.

The result is that it was possible to obtain real-time data, more frequent data, to reduce site visit's and to detect equipment failure at the main office. It is recommended that further investigations be done on the communication links such as Meteoburst and Meteosat. The installation of the system on selected remote monitoring stations, selected wadi stations, and some of the recharge dams for the purpose of monitoring and securing the safety of the recharge dams.

Key words: Telemetry, Monitoring, Water Resources, Real-time data

1. INTRODUCTION

The Ministry of Water Resources has the responsibility to assess and manage the water resources of the Sultanate of Oman. To provide the assessment of the Sultanate's water resources, a network of hydrologic and meteorological stations have been established to monitor wadi flow, rainfall climate, aflaj and groundwater. By collecting data over an extended period of tune at these stations, rainstorms, floods, droughts, and other hydrologic events can be monitored. Utilizing the data obtained from the stations, various analysis can be made to assist in the p and design of recharge dams, the modification and improvement of wadi channels to reduce flooding, the design of road structures that cross the wadi drainage, and the planning of structures in developing areas.

In order to improve the performance of the network in terms of better quality and cost effectiveness, a telemetry system was introduced. This paper illustrates the pilot telemetry stations installed at two locations in the Sultanate of Oman namely, Nizwa and AI Khawdh. The purpose of using the system is to provide a direct communication link between the head office at the Ministry of Water Resources and remote field stations that would permit obtaining real-time data.

The advantage of having Telemetry stations is the ability to make water management decisions on the basis of the most current or real time data. This will become more visible in the future as the Ministry of Water Resources addresses the increasing demand for conserving and utilising the Sultanate's limited supply of fresh water. From an operational perspective, telemetry will provide information that will improve the efficiency and effectiveness of the staff by greater selectivity in scheduling field trips to respond to flood and to correct problems in more timely fashion when gauges malfunction. In the office, data can be downloaded on computers for quicker processing to meet requests for data from the MWR staff, other Ministries and planning authorities.

2. BACKGROUND

In 1991, the MWR reviewed the types of telemetry systems available and its use throughout the world to recommend the best type of system to be implemented in Oman (MWR, 1992). Four main methods of telemetering environmental data were identified. These were by telephone Fine, by UHF/ VHF radio, by satellite and by meteor burst. The telephone line and the radio were restricted to urban areas and can not be used in remote areas. Both meteor burst and satellite were well suited for Omani conditions, and meteor-burst telemetry system was recommended based on the advantages of long-term costs (Strangeways, 1991).

Due to technical and economical factors, it was decided that the project should not continue. In 1997, MWR decided to try 2 stations using GSM modems. Thanks to the new technology, this option was round to be more economical and technically feasible. As a result, two stations as a pilot project were selected one at AI Khawdh and the other at Mudeyfi near Nizwa (see **Figure 1.**).

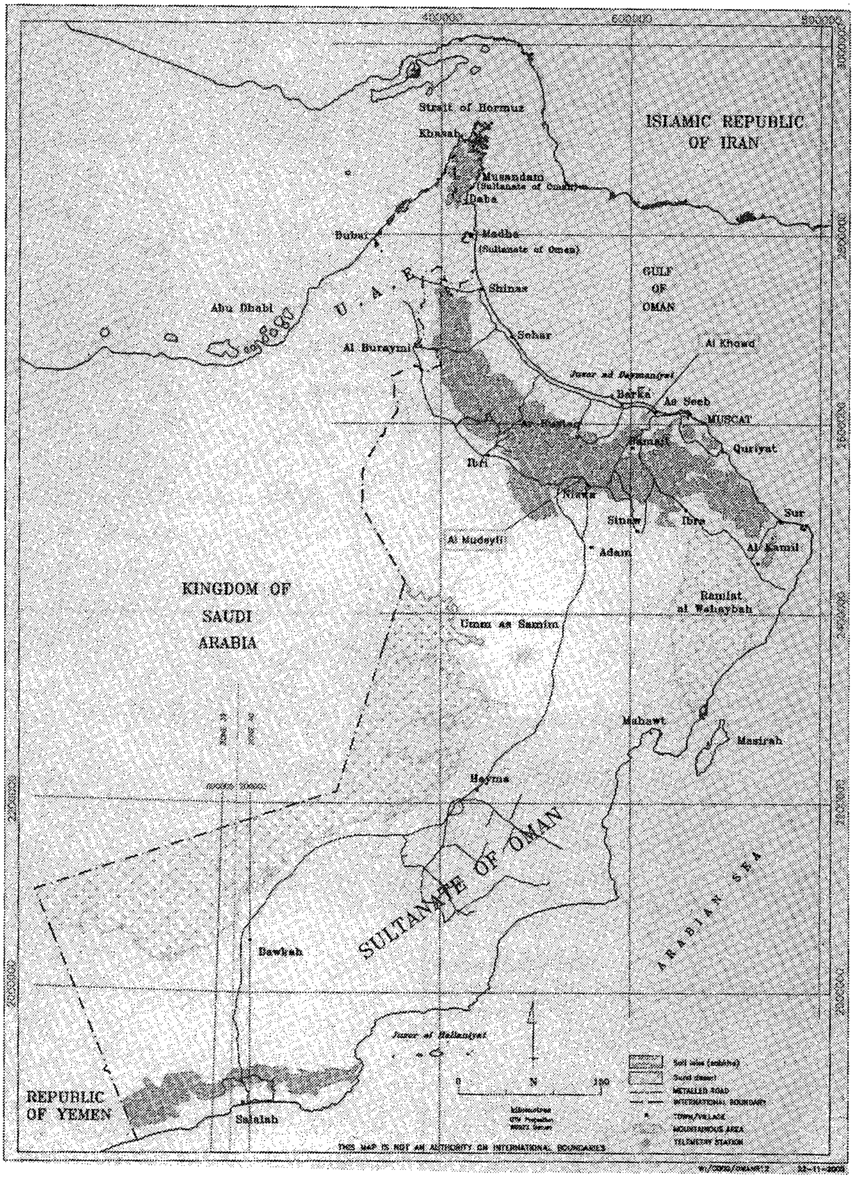

Figure 1: Location of the two Telemetry Stations

3. EXECUTION OF THE PILOT PROJECT

The two telemetry stations were installed in September 1998. Training on the installation and operation of the stations was given to the MWR staff. AI Khawdh was installed into the original large shelter. There is ample room for all the elements in the shelter, and the solar cell and rain gauge were installed on the roof of the shelter. This installation works well, is easy to carry out, and can be used again if needed in a different station (see **Figure 2).**

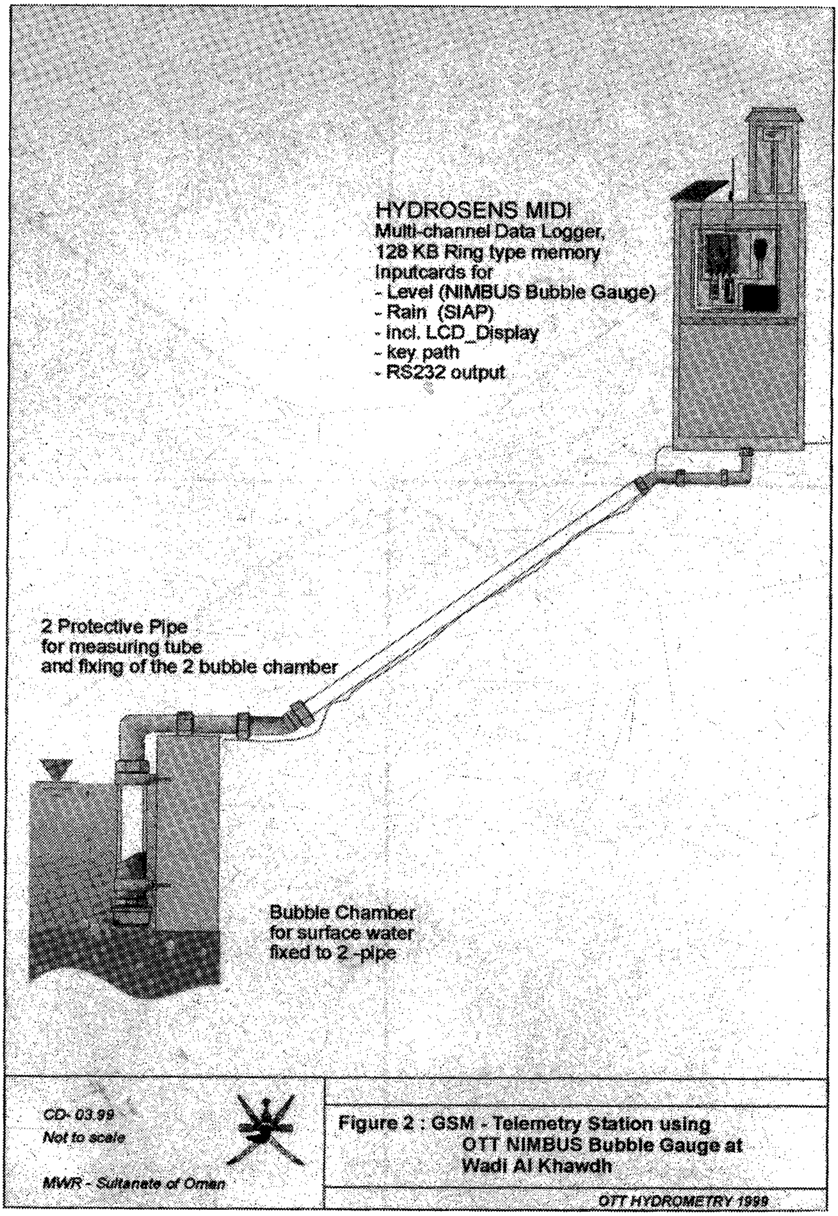

Figure 2 : GSM - Telemetry Station using OTT NIMBUS Bubble Gauge at Wadi Al Khawdh

At Mudeyfi, the rain gauge was installer on the normal pedestal and at the standard height. The logger and ancillaries were installer in a weather-proof shelter, which also houses the battery, and the solar cell was installed on an adjacent pole higher than and about one metre away from the pole that carries the shelter. The wiring from the well and the rain gauge is protected within pipes and brought into the shelter through cable glands. This is a tidy and effective installation and could be used at all new stations (See **Figure 3).**

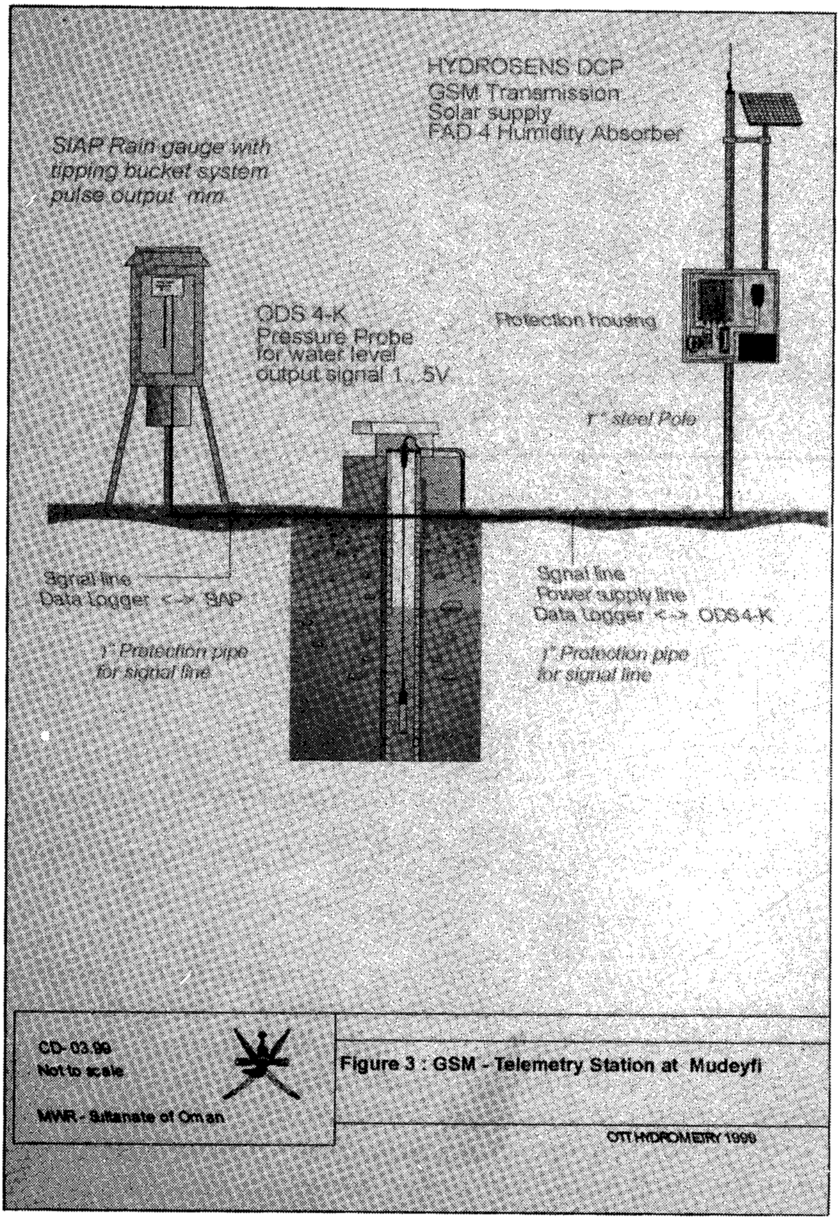

Figure 3 : GSM - Telemetry Station at Mudeyfi

The generalised configuration of logger, modem battery and connection to solar panel is shown in **Figure 4.**

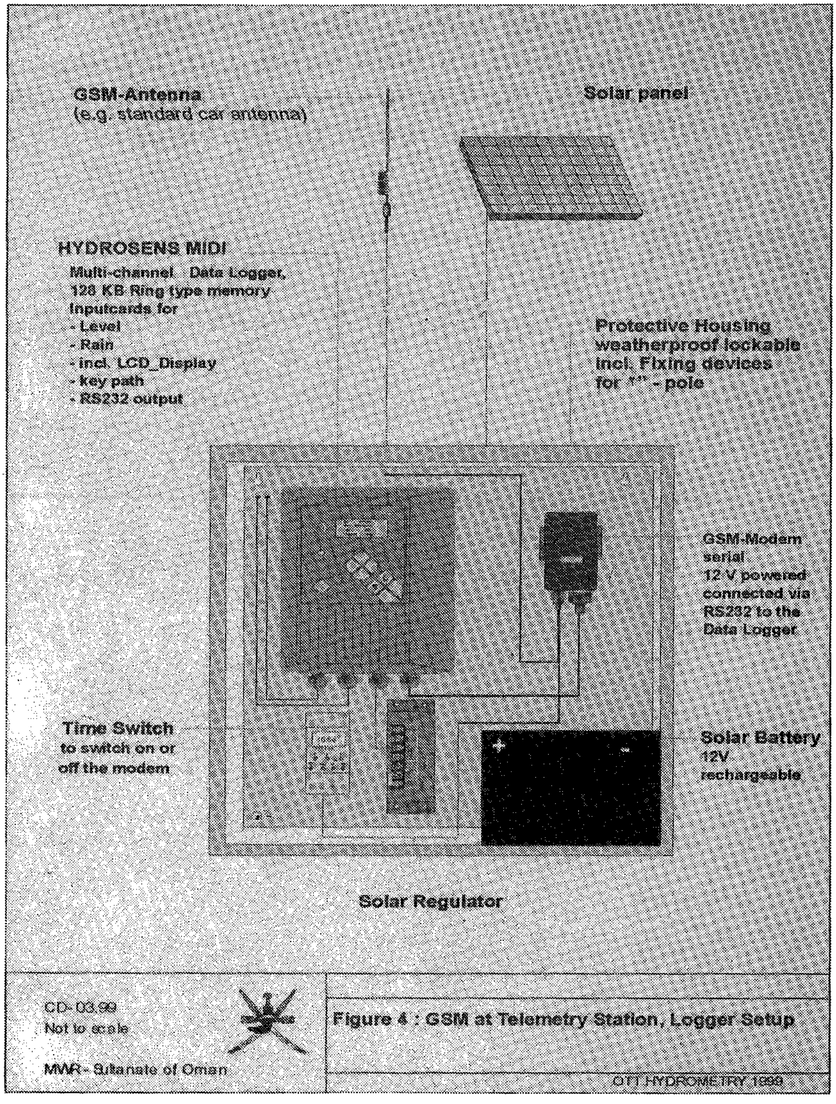

Figure 4 : GSM at Telemetry Station, Logger Setup

Since the stations were installed, field visits have been done on a monthly basis for the purpose of inspection and making sure that the equipment is working smoothly. While at the office, the stations are contacted twice a week to check if the equipment is operational and whenever the staff at the department need data for the purpose of downloading. The stations are also contacted whenever sign for rain or wadi flow are anticipated. With the exceptions of minor technical problems, the telemetry stations have been performing very well.

4. RESULTS OF THE PROJECT

Since the installation of the telemetry station in September 1998, the system has proved to be very beneficial and the way forward for monitoring stations which are in remote areas. Figure 5 shows the data collected from the AI Khawdh Telemetry station white Figure 6 represents the Mudeyfi station.

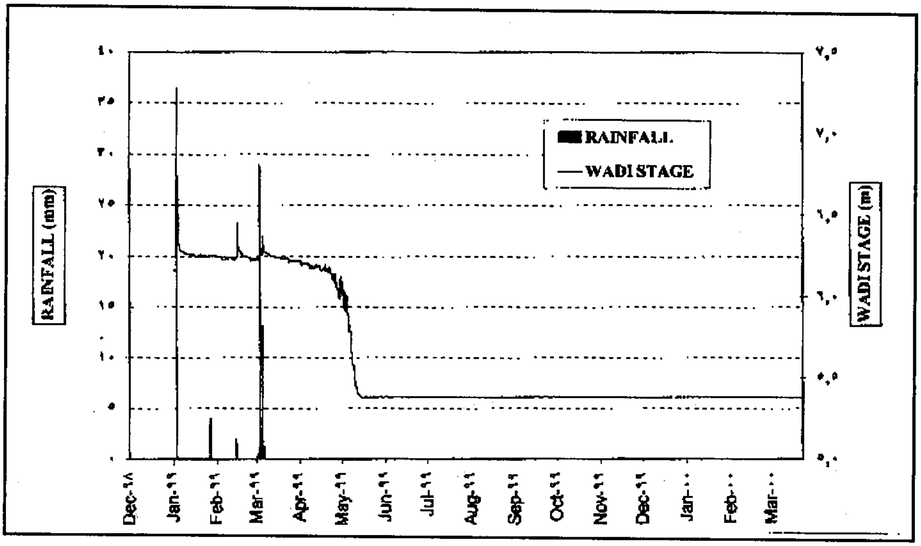

Figure 5: Wadi Al Kha Wdh Station

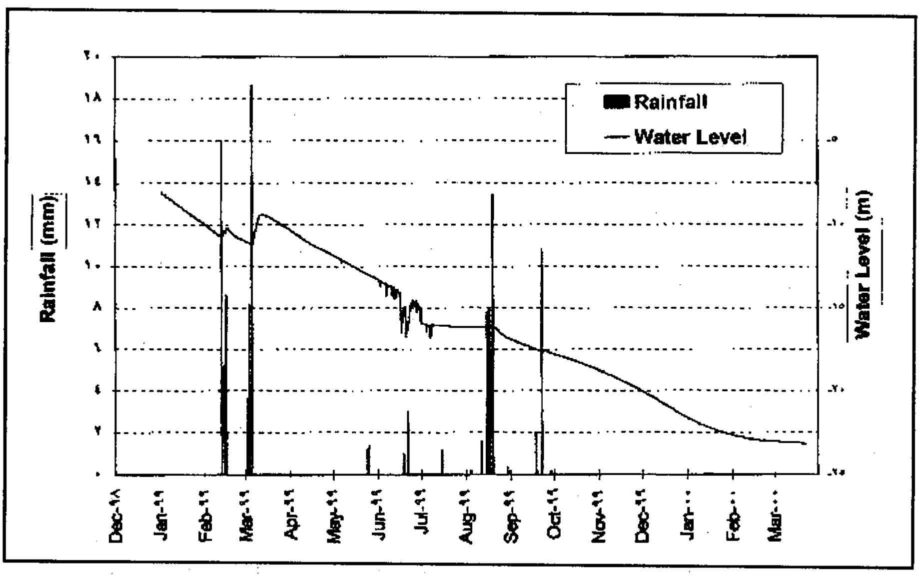

Figure 6: Mudeyfi Station

5. FUTURE SITE SELECTION

As criteria for the selection of further sites for expanding the network of telemetry stations, the following points might be considered:

- Important station from which real-time data acquisition is imperative.
- Station to be used for flood warning purposes.
- Station with very difficult access (e.g. rain gauges in the Jabal).
- Well station for monitoring abstraction.
- Falaj station for monitoring water distribution.
- Reservoir station for monitoring inflow rate, abstraction and/or infiltration rate.

The cost of a Telemetry station will depend on the type of data logger, sensor and the type of the GSM modem used at the station. It will also depend on the number of sensor needed at the station, for example for both Mudeyfi and AI Khawdh stations two sensors were connected to a data logger. On an existing station with a data logger that has RS 232 interface built in, the only cost for the Telemetry would be GSM Modern, Solar Panel and Batteries.

6. RECOMMENDATIONS

As data are required in "real time", for example in flood forecasting, telemetry is of course essential. However, telemetry also allows data to be collected more quickly and cheaply from remote sites. These sites may be difficult to reach simply due to their distance or due to their difficulty of access, such as the rain gauges which can presently only be reached by helicopter. As seen above, Telemetry also gives an early warning of equipment failure, which can go undetected for long periods at logging sites, and consequently with much loss of data.

In view of the above it is recommended that the following is considered:

- Installation of Telemetry Systems on the High Altitude Rain Gauges after ensuring the GSM coverage. The access to these stations is very difficult, the only way to get to these stations is by a helicopter. It is dangerous and risky, several problems have been reported.

- Installation of Telemetry Systems on selected Wadi Gauging stations. These could be selected for the purpose of determining the volume of water which could be expected on a given recharge dam before even the wadi gets into the reservoir.

- Installation of Telemetry systems on selected recharge dams. This will give an early warning to the engineers at the Ministry to instruct the technician when to open the culverts. Therefore, the optimal operation of these culverts for recharge will be assured.

Some of the benefits noticed during the operational period can be summarised as follows:

- It has been possible to obtain a real time data within a minute without physically going to the site.

- Whenever the station was not working it was possible to either solve the problem at the office by doing the calibrations instants or by sending the technician. Without telemetry this would not have been noticed until the next month visit.

- Because the stations are contacted at the department and not monitored by a technician who has to enter it into a computer and then send the data through diskette, the data is safe and correct. If any missing of data is noticed, the station can be contacted again instants.

In addition to the above there are also advantages of Telemetry System for future monitoring and can be summarised as follows:

- A Telemetry system with remote stations at key locations throughout the country will give the MWR the ability to determine which regions are receiving rainfall and experiencing wadi flows day or night. The system would give the MWR the ability to obtain data from remote stations as the storms occur.

- The system would give the MWR the ability to check if remote stations are operating, without actually going to the sites.

- Site inspections can be reduced to routine schedules to change data storage modules, change batteries or perform preventive maintenance.

- A Telemetry system can be used for flood warning purposes

- Data transmissions are secure and the range will depend on the GSM coverage.

- In comparison to the other previously proposed systems the GSM is considered to be the cheapest option.

Some of the limitations of the Telemetry system for future monitoring could then be summarised as follows:

- The GSM coverage could be a problem for some of the remote stations, but hopefully this will be improved in the near future.

- Some sites are too confined within canyon walls or blocked by jebel ridges to be easily converted to a telemetry system.

- Some sites may be located near to some significant electrical interference where communication between the head office and site could be difficult.

- Installation of Telemetry systems on selected key boreholes for the purpose of monitoring of response of groundwater levels to recharge on the alluvial fans after a heavy rainfall event upstream.

- It is also worth considering installation of Telemetry systems on selected remote stations as these could be monitored cheaper by telemetry than by sending technicians.

- Finally, it is recommended that further investigations be done on the communication links such as Meteoburst and Meteosat.

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Groundwater Quality Management at Ras Laffan Industrial City

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GROUNDWATER QUALITY MONITORING AT RAS LAFFAN INDUSTRIAL CITY

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ABSTRACT

The newly established Ras Laffan Industrial City, situated in the northeast of Qatar along the Arabian Gulf, has total area of 106 km^2. The City has two operating LNG plants, and more gas-based industries are planned in the near future. Industrial developments in the area have potential to impact groundwater resource. To determine the extent of these potential impacts, and to provide immediate corrective action, a study to determine the groundwater quality was conducted. The study aimed at providing background characteristics of the groundwater quality and determining potential sources of contamination. It included installation of ten monitoring wells, strategically located to detect changes in groundwater quality. The monitoring involved the measuring and recording of static water level, purging of wells, and the determination of the physical and chemical characteristics of the groundwater.

Key words : Groundwater, Hydrogeology, Arabian Gulf, Coastal zone, and Industrial Development

INTRODUCTION

Industrial developments have potential impact on natural resources like groundwater. Domestic and industrial activities, if not managed properly, could alter the groundwater quality either by point source or indirect discharges. Contaminants in the groundwater could spread far beyond the site of release. In order to assess the effectiveness of prevailing regulations, a study was carried out to establish a baseline database to determine any future changes in the groundwater quality.

OBJECTIVE

A study was planned to :

- Determine the background water quality characteristics and indicator trends of groundwater
- Identify any possible source of contamination as a basis for corrective measures
- Gather hydrological information for future studies
- Safeguard and preserve groundwater resources for future use

THE STUDY AREA

Ras Laffan Industrial City (RLC) is situated approximately 80 km north of Doha. The City covers a total of 106 km^2. The construction of the city resulted from the ratification of the Strategic Plan for Natural Gas Utilization in Qatar (1). At present , there are two LNG plants operating in the City and more gas-based industries are planned in the future. Figure 1 shows the location map of the City; groundwater-monitoring wells are marked from numbers 1 to 10.

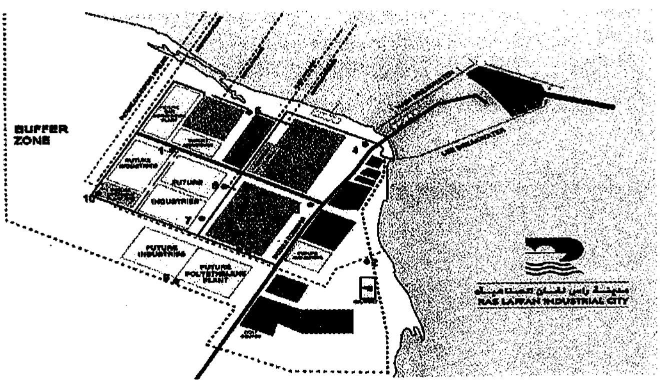

Figure 1 : Location map of groundwater monitoring wells

REGIONAL TOPOGRAPHY AND GEOLOGY

The State of Qatar covers an area of 11, 437 square kilometers and has a flat, eroded landscape of low to moderate relief and is classified as desert or semi-desert. The peninsula may be divided into sabkhas, sand dunes and stony desert. Geologically, the Qatar peninsula is a part of the Arabian Gulf basin. The basement extends between the Arabian shield to the west of Saudi Arabia and the Zagro belt of Iran to the east. Qatar's geological structure comprised of a central arch or done which runs approximately north-south through the center of the peninsula. The subsequent erosion and uplift of the core of the central dome has resulted in the exposure of the Rus formation. The most important structural element is the Simsima Arch, which branches off the main central arch extending under Ras Laffan.

LOCAL GEOLOGY AND HYDROGEOLOGY

The surface geology of Ras Laffan is dominated by cretaceous, tertiary, and quaternary sediments. These are main shallow marine limestone with minor shales and some evaporites. Weathered simsima limestone with surficial sands and aeolian deposits occurring in the lower-lying portions underlis majority of the area. The majority of the site has hard pan cover as part of the prepared surface. The Simsima limestone is underlain by the run formation and contains significant groundwater resource[(2)].

In this area, groundwater is present in two aquifers. The upper aquifer is located in the Rus formation and the lower, exploitable aquifer is located in the upper Um Er Raduma (UER) formation.

The absence of surface water in the City limits the natural recharge source from rain. Qatar experiences rain during the months of January, February and December to an average of 75mm per year. It is estimated that about 12% of the rainfall reaches the Rus formation. It is good to note that groundwater is not used for domestic and/ or industrial purposes within the City. In other parts of the country, groundwater pumping exceeds the estimated recharge rate. Excessive pumping leads to the lowering of groundwater level and the deterioration of groundwater quality in Qatar.

SCOPE OF THE PROGRAM

RLC has set guidelines and/ or parameters to preserve the groundwater resource for future use and to establish groundwater baseline data. In compliance with the City regulation, a groundwater quality monitoring program was developed to asses the impact of present industrial activities on groundwater resource[3]. The variable physical characteristics of the groundwater are measured monthly through a network of monitoring wells. The monitoring wells of the physco-chemical characteristics of the groundwater enabled assessment of groundwater quality and record seasonal variations. Groundwater analysis is undertaken to gauge background characteristics and to determine any potential sources of contamination. The recorded data shall be used as a basis for future studies.

APPROACH

The program started with the installation of ten monitoring wells within the City. The location of the boreholes are indicated in Figure 1, positioned at different locations that aims to provide maximum coverage of the area and to permit the future investigation of contaminant migration. Boreholes were drilled between the period of December 1996 to July 1997, details of which presented in Table 1. Well depth varied from 5.58 m (Well no. 5) to 11.42 m (Well no. 9). A 3 mm-thick PVC casing of 150 mm internal diameter was installed to line the wells, perforated with 25 slit openings (30mm x 3mm) covered with a 4 m of geotextile glass fabric. A 45 cm length of pipe was left protruding above the ground. On the surface, the wells were sealed by a well mouth cover and protected by concrete foundation. Wash out process was repeatedly done to remove any residual oil and grease remaining from the drilling operation.

The Groundwater Quality Monitoring Program is carried out on a monthly basis. The monitoring involved water level measurement, purging, in-situ or field determination of variable physical parameters and sample collection and data reporting/ interpretation.

METHODOLOGY

Various accepted and applicable procedures [4,5] for groundwater monitoring are compiled and studied to come up with a comprehensive procedure: RLC-DP-REE-007 (Groundwater Monitoring). The following text discusses the procedure(s) in brief :

Water level measurement and Purging

Static water level is measured and recorded before and after the purging of a monitoring well [5]. Water level is measured using an electronic contact gauge. The recorded water level is used as a basis in determining the purging time. A minimum of three well volumes is purged from each well. A submersible positive displacement pump was used for this purpose.

In-situ measurement

Immediately after the purging, field measurements are performed using pre-calibrated portable water quality loggers comprising of built-in sensors, a lanyard to provide direct reading from the well and a data acquisition system. Field results are automatically stored in the instrument's data acquisition.

MONITORING RESULTS AND DISCUSSION

Water Level

The fluctuation of the water table at a groundwater site is caused by several phenomena. These include recharge to the aquifer, withdrawal of water to aquifer, and evapotranspiration. As mentioned earlier, groundwater in the City is not exploited for use but the sabkha areas could act as a natural discharge zone [2], causing significant lowering of the water level. On the other hand, there is no surface water in the City and elsewhere in Qatar, limiting the natural source of recharge to rain. Heavy rainfall could result in ponding in low-lying areas, eventually reaching the aquifer. Additionally, tidal fluctuations may (at a minimum) occur in the wells near the coast.

In the study area, groundwater was encountered between 1.949 m and 6.697 m elevation with static water levels between +0.87 m and -0.6 m. Groundwater level fluctuations for 1999 are illustrated in Figure 3. Heavy rains during the first quarter of the year increased the water levels in the moderately permeable sand, gravel, and limestone strata. The highest recorded rainfall (local) for that year is 58 mm recorded in February, which results in ponding in the permeable sabkha areas. Evaporation did, however, rapidly reduce the areas of these pools of surface water. The general trend for water level fluctuation is decreasing towards the summer because evapotranspiration causes diurnal fluctuation of the shallow groundwater[4]. Water tables in unconfined aquifers that are a few meters below the land surface response to thermal gradient between mean air and groundwater temperature. The recorded monitoring data showed that water level continuously declined since there is no source of recharge. Water level is lowest during the month of November; wells near the sabkha areas with more pronounced variations.

Salinity and Conductivity

Groundwater in the study area is highly saline. Electrical conductivity varied from 7,500 ms/ cm to 100,000 ms/ cm, equivalent to 10 ppt and 70 ppt of salinity. Monitoring Well no. 9, located far inland has the lowest Total Dissolved Solids (TDS), ranged from 3,750 to 8,400 PPM. Unlike Well no. 5 (less that a kilometer from the shore), saltwater intrusion in this Well is minimal based on the recorded data. The general trend for groundwater conductivity is increasing towards the summer.

The increased evaporation rates towards the summer and the natural groundwater level lowering though the sabkha resulted to significant increase in groundwater conductivity. Mainly because evapotranspiration concentrates major ions in the monitoring wells, greatly influenced are Wells in the coastal areas. In some boreholes, conductivity is even higher than the recorded seawater values. The pattern indicates that aside from mineral dissolution from bedrock and soil, saltwater intrudes into the shallow aquifer. The monitoring data is illustrated in Figure 4. Comparison of the conductivity values of monitoring Wells 9 and 5 are shown in Figure 5. Well no. 9 is located at the southern boundary of RLC, deepest borehole and the farthest from the sea. On the other hand, Well no. 5 is approximately 1 km away from the sea and shallow. Because of this characteristic, direct utilization of the groundwater resource is not feasible.

Dissolved Oxygen

The dissolved oxygen ranged from 0.7 to 6.5. Monitoring wells far off the coast showed a stable and higher dissolved oxygen levels as compared to wells near shore. The trend could be attributed to the solubility characteristics of oxygen in water containing high percentage of salt. Extreme salinity and elevated temperature will decrease the rate of solubility of oxygen in this well. In Figure 6, the dissolved oxygen levels of two wells at different locations are compared and interpolated with salinity and temperature to show the relationship.

Table 1: RLC Groundwater Monitoring Wells Information

	Well No.									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Location –N[1]	461732	458383	459679	461980	463199	460517	459091	458027	456447	459795
Location -E[1]	230679	235640	234418	235639	232453	232049	231290	232357	231641	228366
Date Installed	7/1/97	29/12/96	20/12/96	8/1/97	5/1/97	25/12/96	27/12/96	23/12/96	26/12/96	4/1/97
Casing Type	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Casing Elevation[2]	61 cm	61 cm	61 cm	61 cm	61 cm	61 cm	61 cm	61 cm	61 cm	61 cm
Screen Height	4 m	4 m	4 m	4 m	4 m	4 m	4 m	4 m	4 m	4 m
Well Depth [2]	8.55 m	6.74 m	8.65 m	8.75 m	5.58 m	10.69 m	8.59 m	8.57 m	11.42 m	5.62 m
Elevation[3]	4.135	2.542	3.999	3.466	1.949	6.697	3.004	3.554	6.050	1.667

Notes:
1- Qatar National Grid System
2- in meters from ground level
3- readings according to Qatar National Height Datum (QNHD)

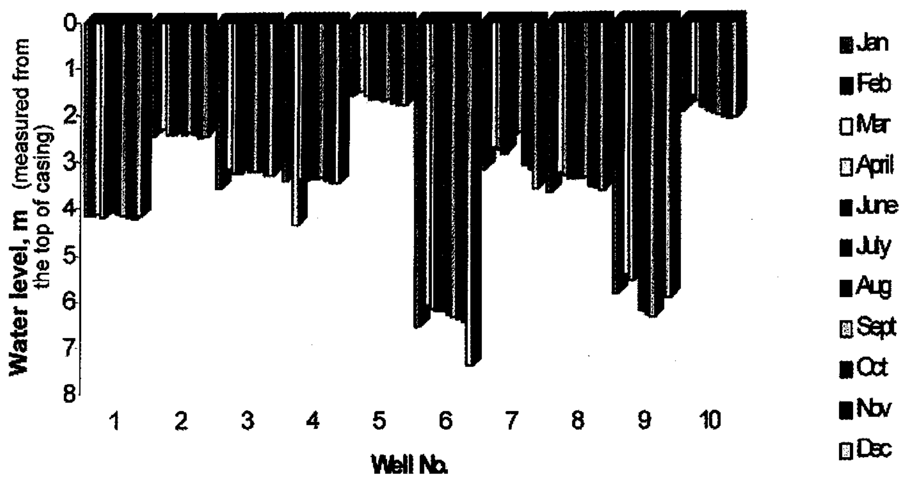

Figure 2 : Fluctuations in Water Level measured from the top of the casing

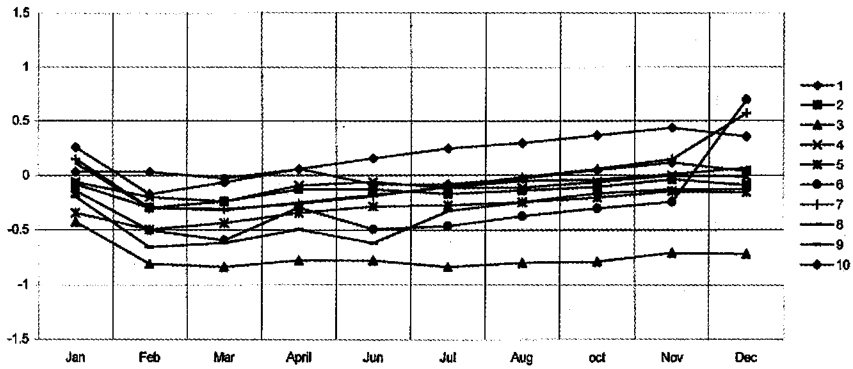

Figure 3 : Groundwater elevation (QNHD)

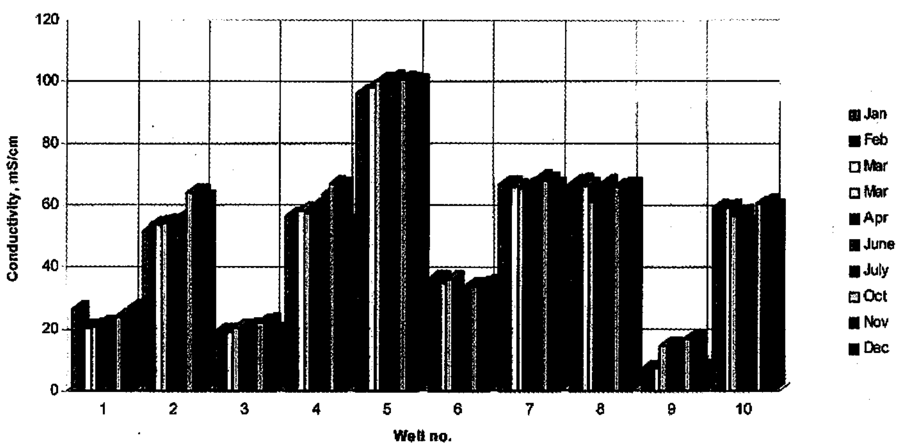

Figure 4 : Conductivity Variations in Monitoring Wells

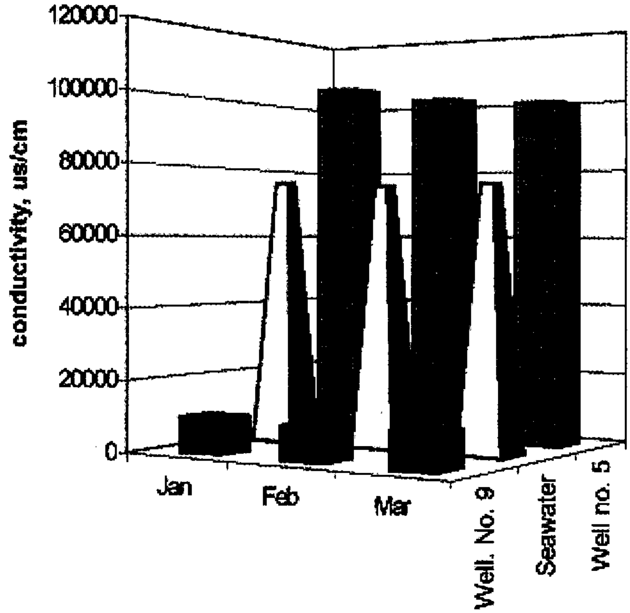

Figure 5 : Comparison of conductivity levels at three stations

Ammonium and Ammonia

Earlier studies suggest that the groundwater in the area is nutrient-poor [6]. The results of the monitoring confirm these findings with ammonia ranged from 0 PPM to 0.02 PPM.

pH and Temperature

The groundwater pH is ranged between 7.5 to 8.6 pH units. The good agreement between each well during each month indicated that the variation in pH levels was relatively due to the change in water temperature ranging from 25°C to 31°C. The temperature is obviously related to seasonal variations. Air temperatures in Qatar are highest in July and August. Figure 7 illustrates the results : the line graph corresponds to the temperature whilst the bar graph to pH.

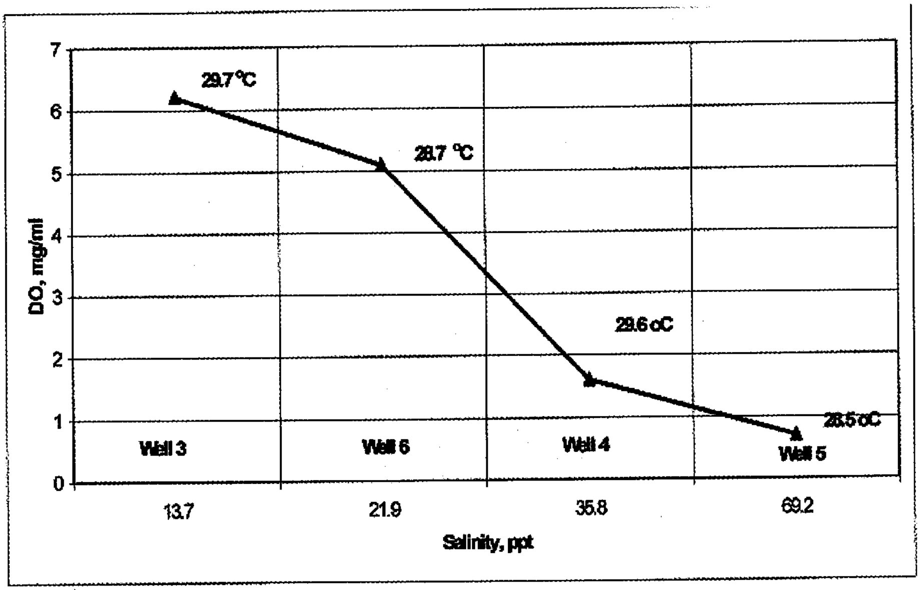

Figure 6 : Effect of Salinity and Temperature on Dissolved Oxygen

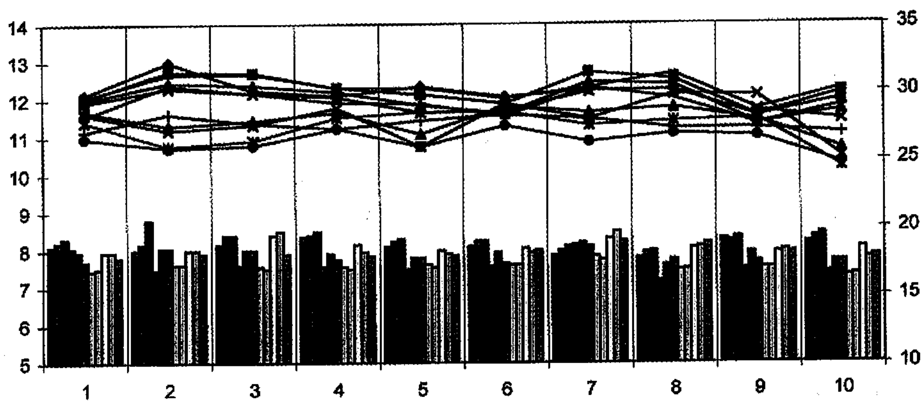

Figure 7 : pH and Temperature Variations

CONCLUSIONS

Based on the results of the monitoring, the following conclusions can be drawn :

- The fluctuation in groundwater level is mainly due to the seasonal variation and tidal intrusion at a minimum. There is no known source of recharge except the occasional rains in the cooler months

- The elevated salinity and conductivity values of groundwater wells are more pronounced in the near-shore wells. This characteristic limits its use in the future unless pre-treatment is made

- The variations in the groundwater quality in the area are influenced by the meteorological variations and its' topographical setting and not as a result (direct or indirect) of the industrial developments

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Estimation of an Unconfined Aquifer Recharge Potential During Storm Events in a Watershed in Oman

Dr. Abulbasher M. Shahalam, Dr. Alan El-Zawahry and Aisha Al-Qurashi

ESTIMATION OF AN UNCONFINED AQUIFER RECHARGE POTENTIAL DURING STORM EVENTS IN A WATERSHED IN OMAN

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ABSTRACT

The weather factors such as temperature, vapor pressure, wind, precipitation, infiltration, evapotranspiration and inter-storm time-gap directly affect the potential volume of water available from surface and underground reservoirs.

In this study a mass balance model with a principal component of aquifer re recharge has been formulated and tested in an arid watershed holding an unconfined aquifer. Precipitation data are analyzed to determine distribution of inter storm time-gap.

A calibrated evapotranspiration model was used to predict the evapotranspiration. The performance of the model was tested with observed data. The model appears to be effective in reproducing observed evapotranspiration utilizing climatic data. From water budget, recharge potentials were determined. Recharge potential is significantly related to dry days prior to a storm.

Key Words : Aquifer, Recharge, Evaporation, Storm

INTRODUCTION

In a watershed, the weather parameters such as temperature, vapor pressure, wind, precipitation, infiltration, evapotranspiration and inter-storm time-gap, watershed topography and geology directly affect the water transport and storage in the watershed. In a specified region, the effects of surface topography and geology can remain more or less fixed. Therefore, in a regional hydrologic cycle, the weather factors that are monitored in weather and hydrology stations commonly define watershed water conditions.

Aspects related to water management in an area depend on potentials of local water storage and loss. For the purpose of water management, a predictive model capable of generating reliable information on storage and loss is thus essential for engineers and scientists involved in water resources management.

The basic surface and groundwater hydrology usually starts with the aspects of water storage and losses. Water experts attempt to generalize the relationships among weather factors, such as evaporation, transpiration, infiltration, surface and in-ground storage. Rational and empirical relationships are developed. Water mass balance remains as the most important tool to calibrate, verify and test such schemes. Final forms of such relationships vary from one region to another.

Weather and water conditions in a watershed in Oman have been studied. A mass balance model has been defined for the watershed. Weather conditions in the area have been combined to components of a conventional mass balance model. The model has been used to determine potential recharge of watershed aquifer system.The output of the model were utilized to establish a relationship between recharge potential of a storm to the dry-days prior to the storm.

MASS BALANCE

The following mass balance scheme has been applied with specific characteristics of a watershed in an arid-zone. Water runoff from such watersheds are usually negligible. Mass balance[3] of water in a watershed may be define as:

$$\Delta S = P + Q_i + Q_g - Q_{os} - Q_{og} - T - I - E \qquad [1]$$

Where:

ΔS = change in surface water storage in watershed,
P = Precipitation input,

Q_i = Surface water input,
Q_g = Groundwater input,
Q_{os} = Surface runoff exit,
Q_{og} = Groundwater exit,
T = Transpiration.
I = Infiltration.
E = Evaporation.

The above expression may be simplified for an unconfined shallow aquifer with negligible input flow ($Q_g = 0$). Such an idealization is feasible if the a aquifer is too large in dimensions or is confined at the bottom and sides by relatively non-permeable boundaries. In an independent watershed $Q_i = 0$. In highly permeable soils of an arid region where evaporation and infiltration rates supersede precipitation, the surface runoff is usually temporary and occasional. For the aquifer defined above, $Q_{og} = 0$. Expressing combined effect of evaporation and transpiration as E_T and assuming R to be the net infiltration or recharge, the expression [1] becomes equation [2].

$$R = P - E_T - Q_{os} \qquad [2]$$

Where:

R = Aquifer recharge
E_T = Evapotranspiration

The expression output as well as the inputs are functions of same set of climatic factors. The watershed and the associated aquifer behave as a non-linear system.

The simplified model [2] is tested adopting an evapotranspiration expression[4] as shown in equation [3].

$$E_T = C\,(e_o - e_a)\,[1 + w/10] \qquad [3]$$

Where:

e_o = Saturated vapor pressure at water surface temperature (inch, Hg)*
e_a = Vapor Pressure of the air, (inch,Hg)*
w = Wind Velocity (mph*) at 25 ft above water surface/ Saturated ground level.
C = Coefficient.

It is noted that the expression was originally introduced for lake and reservoir waters. The model is chosen for its simplicity. The value of C determined from real data, however, transforms the mode of evaporation measurements into field conditions. The additional purpose of adopting the model is to demonstrate the intricate relationships of the climatic data to evapotranspiration. The factors e_o and e_a are directly related to temperature, relative humidity and vapor pressure. In order to verify the model, records of climatic conditions within a watershed are necessary.

* 2.54 cm = 1 inch
1 mile = 1.6 km

DATA ANALYSIS AND DISCUSSION

Wadi Al-Khod watershed near Mascat, Oman (Figure 1) was selected to test the model. Seven rainfall stations collects data within the watershed. The aquifer underneath is an unconfined aquifer that receives recharge water. A recharge dam has been constructed to retain the water as much as possible within the aquifer system. Records[5] of pen evaporation, air temperature, relative humidity, vapor pressure and surface wind were available for years from 1979 to 1994. Table 1 contains the minimum, mean and maximum of the data.

Table 1 . Evaporation, Temperature, Relative humidity, Vapor Pressure and Surface wind in the watershed area. (Records 1979 /94)

	Jan.	Feb.	March	April	May	June
Evaporation (Piche, mm/day)						
Min	3(1.6)*	2.8(1.4)	3.4(1.7)	5(1.8)	6.4(1.4)	5.8(0.9)
Max	12.8(3.6)	13.8(3.9)	18.8(4.8)	24.8(5)	27.2(4.1)	25.4(3.9)
Mean	6.6(1.2)	7.1(1.3)	8.9(1.7)	13.7(3.2)	16.6(2.8)	14.4(2.3)
Temperature , °C						
Min	13.9(1.1)	14.2(1.5)	16.5(1.2)	20.1(1.5)	24.4(1.8)	27.2(1.2)
Max	30.4(1.6)	32(2.4)	36.9(2.5)	41.4(1.5)	45.2(1.3)	46.4(1.6)
Mean	21.3(0.6)	21.9(0.8)	25(1.1)	29.7(1.6)	34.1(1.2)	35.3(0.9)
Vapor Pressure, inch Hg						
Mean	0.48(0.04)	0.49(0.05)	0.5(0.04)	0.6(0.05)	0.62(0.07)	0.8(0.08)
Surface wind. Mile/hr						
Mean	16.9(6.2)	13(8.9)	12.6(11)	14.4(11)	10.3(9.7)	6.3(7)
Max	20.16(8.4)	18.8(9.2)	18(5.9)	19.7(7.2)	18.2(6.8)	14.3(8.1)
	July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Evaporation (Piche, mm/day)						
Min	4.6(0.8)	3.6(1)	4(1)	5.4(1.4)	4.2(1.1)	3.3(1.1)
Max	26.3(6.7)	17.2(6.7)	19.6(4.9)	18.9(3.9)	3.7(3.3)	11.2(2.2)
Mean	10.8(2.3)	7.8(2.4)	9(1.9)	10(1.6)	7.9(1.3)	6.3(0.7)
Temperature, °C						
Min	27.2(1.2)	25.4(1)	24.4(1)	21(1.8)	17.2(1.7)	15.7(1.5)
Max	45.1(2)	42.7(2.5)	41.7(1.6)	39.9(1.3)	34.6(1.5)	30.9(1.2)
Mean	34.2(1.2)	31.9(1)	31.4(0.7)	29.5(1)	25.7(0.8)	22.7(0.8)
Vapor Pressure, inch Hg						
Mean	0.91(0.06)	0.92(0.04)	0.82(0.06)	0.67(0.04)	0.6(0.03)	0.5(0.04)
Surface Wind, mile/hr.						
Mean	5.2(1.2)	4.8(1.1)	5.2(1.2)	11(10.5)	7.1(7.9)	14.4(9.3)
Max	15(5.9)	4.9(1.2)	11.3(9)	11.6(8.8)	16.8(6.6)	14.7(10.8)

* Standard deviation in bracket.

The coefficient C in equation [3] were estimated for each month of a year utilizing mean values of climatic data of Table 1. The coefficient values appear in Table 2.

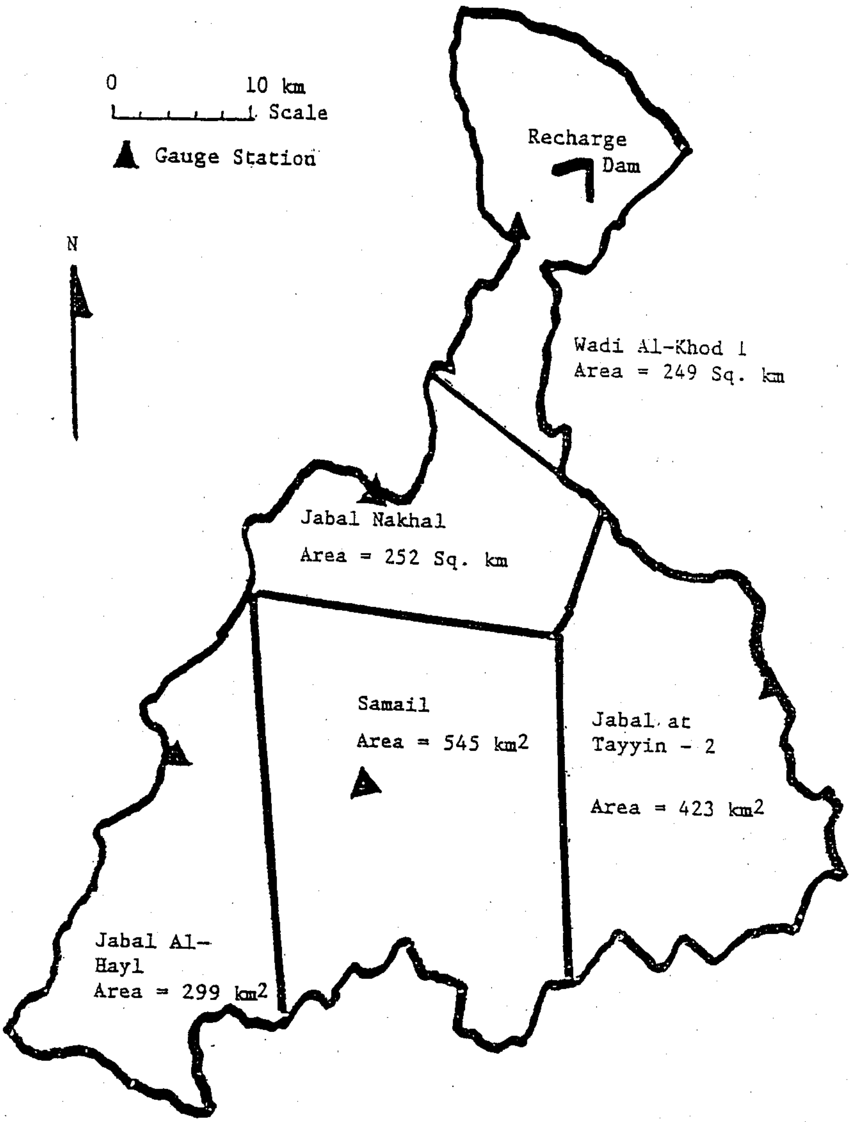

Figure 1. Al-Khod Catchment (Al-Khod, Muscat, Oman)

Table 2. Mean monthly values of evaporation coefficient

Jan	Feb	Mar.	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0.36	0.42	0.35	0.35	0.33	0.38	0.40	0.44	0.43	0.33	0.47	0.31

Average value of C is 0.38 with a standard deviation of 0.051. The calibrated evapotranspiration equation for the specific watershed is shown in equation [4].

$$E_T = 0.38\,(e_o - e_a)\,[\,1 + W/10]\qquad [4]$$

From available rainfall and watershed discharge data 6,7 at the downstream side of the recharge dam (Figure 1), five separate storm incidences were selected. Table 3 contains data related to the storm events. Four of five events are in winter months (Nov-April).

The value of C appears to be reasonable. Its value reported elsewhere varies from 0.36 to 0.5. The higher value tends to be in shallow puddles and wet soils. The concerned watershed condition falls in the category of wet soils. The model appears to generate observed evapotranspiration very closely.

Table 3 . Sample Storm events

EVENT	Time	Total Precipitation, mm	Surface water Discharge, m^3	Days Water on Surface	Dry days Preceding Wet Precipitation
1	Feb - April, 87	76	11×10^6	120	74
2	Dec – Feb, 89/90	134	10×10^6	120	216
3	Feb - April, 92	45	1.6×10^6	120	15
4	Sept, 90	10	0.5×10^6	30	30
5	Dec - April, 91 / 92	80	2×10^6	151	144

Evapotranspiration rates during the wadi (watershed runoff channel) runoff period were estimated utilizing mean climatic conditions (Table 1) of the event period (Table 3). Evapotranspiration rates appear in Table 4.

Table 4. Evapotranspiration rates during five specific wadi runoff periods.

Events	Evapotranspiration rate mm / day
1	12.7
2	7.6
3	12.7
4	8.4
5	9.4

Equation [2] has been balanced to determine the amounts of recharge during five sample events. The estimated values of various components appear in Table 5. It is noted that such a balance is possible because of the high permeable soil of the watershed. Surface water is evident only during storm events and short periods following the events. Due to recharge dam, the water upstream remains in wadies (depressed area of flow). The length of Al-Khod wadi is about 64 km with an average width of 0.5 km. In the calculation of total evaporation and recharge, an effective surface area of 32 km^2 was used.

Total watershed area is about 1802 km^2. For calculation of precipitation volume, the precipitation was assumed to be uniform over total watershed.

Table 5. Recharge, Total Precipitation, Evapotranspiration and Surface Water Discharge for Five Storm Events.

Event	Total Precipitation $\times 10^6\ m^3$	Surface Discharge $\times 10^6\ m^3$	Evapotrans-piration $\times 10^6\ m^3$	Potential of G.Water $\times 10^6\ m^3$	Fraction Recharge Precipitation
1	137	11	49	77	0.56
2	241	10	29	202	0.84
3	81	1.6	49	30	0.37
4	18	0.5	8	10	0.55
5	144	2	45	97	0.67

Recharge potential (Table 5) as a fraction of total precipitation appear against total dry days (Table 3) preceding storm events in Figure 2.

From the figure, as expected it is evident that the recharge potential increased as the dry days preceding a storm increased. It is mainly due to sandy surface soil and prevailing extreme temperature condition throughout the year. Evapotranspiration rate does not change significantly during the year. Mean temperature even during winter months remains above 20°C.

The derived relationship between ratio of recharge to precipitation and dry days preceding a storm is shown in expressions [5] and [6].

$$y = 0.1846\ x^{0.2807} \qquad R^2 = 0.9201 \qquad [5]$$

$$y = 0.1629\ \mathrm{Ln}\ (x) - 0.0604 \qquad R^2 = 0.9241 \qquad [6]$$

Where:

y = (Recharge Potential / Precipitation)
x = Number of dry days before a storm.
R^2 = Correlation coefficients.

The two expressions [5], and [6] appear to be meaningful up to maximum 411, and 671 dry days, respectively, preceding a storm.

CONCLUSION

Based on watershed water budget of concerned watershed and its associated aquifer recharge potential, the following conclusions might be drawn.

1. Climatic data combined with hydrologic records provide useful information towards determining the potential recharge of a shallow unconfined aquifer in extremely arid watersheds.

2. Evapotranspiration is a significant factor in the loss of precipitation water in a watershed where water is temporarily stored upstream of a recharge dam.

3. Recharge potential of Precipitation water is significantly dependent on number of dry-days preceding a storm.

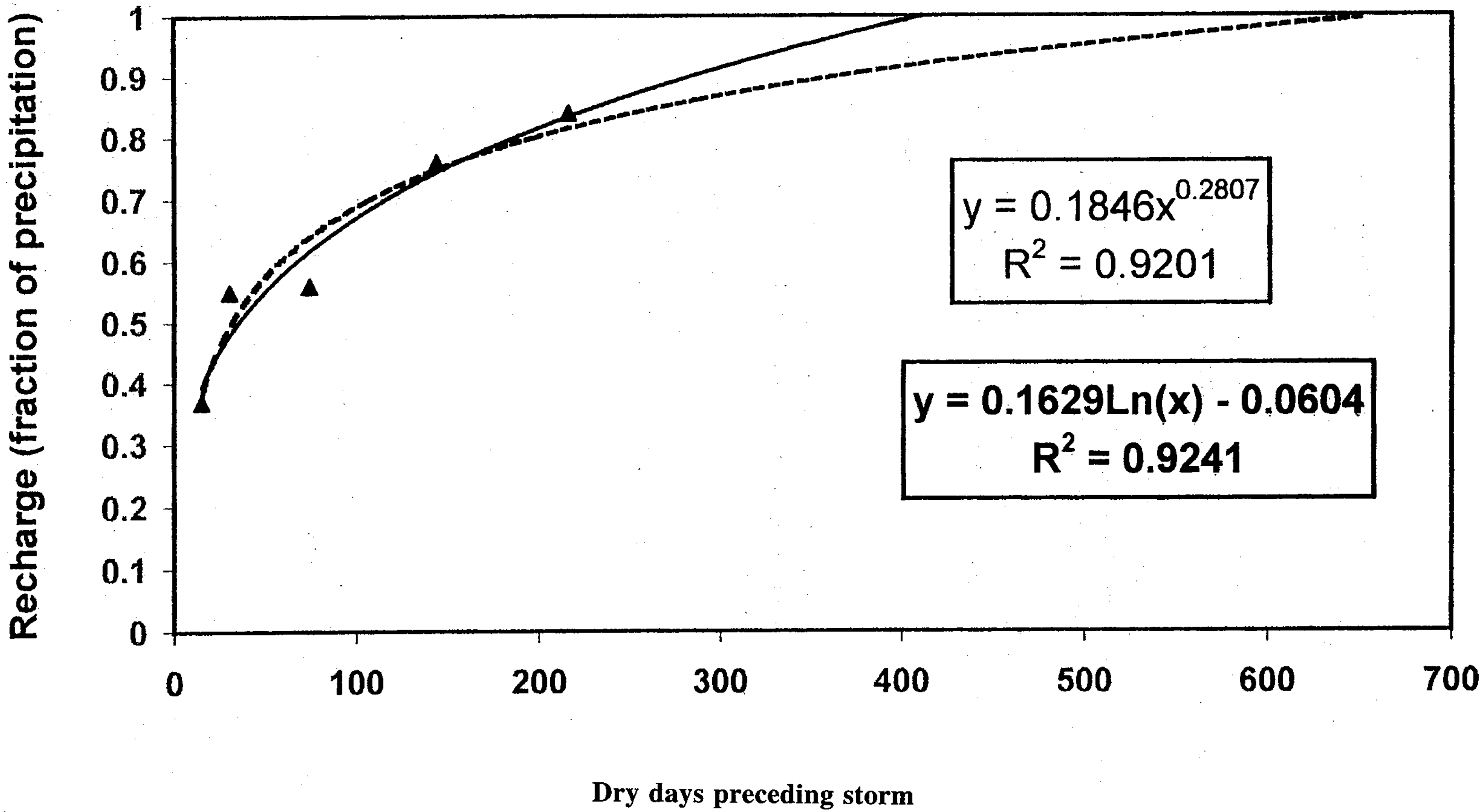

Figure 2 Recharge (fraction of precipitation) Vs. dry days preceding storm event

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New Insights into the RUS-UER Aquifer System - The Oily Water Injection and Ras Abu Jarjur Wells Abstraction

Shawqi Al-Mannai and Simplicio T. Polinar

NEW INSIGHTS INTO THE RUS-UER AQUIFER SYSTEM - THE OILY WATER INJECTION AND RAS ABU JARJUR WELLS ABSTRACTION

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ABSTRACT

The Rus-UER Aquifer System (C) supplies 34 million cubic meters (MCM) per year, of raw water with Total Dissolved Solids (TDS) of 13000 ppm for the Ras Abu Jarjur desalination plant (RAJDP). Meanwhile, the oil industry injects water having an average of 230 PPM of oil and 8000PPM of TDS into the C currently at 7 MCM/ year or a total of 280 MCM from 1963 to 2000. At the C, natural salinity from existing wells varies from 6000 to 60000 ppm. Past studies suggested the idea that it is limited and recharged only within the Bahrain pericline, which appears inconsistent with the present manifestations. The average salinity level of RAJDP wells has remained stable since the start of the operation, contrary to past predictions. The most-feared oil increase in the RAJDP wells remains to be seen, although it was encountered at one drilling site. This paper mainly evaluates the immediate and long-term impacts of oily water injection, considering the groundwater withdrawal for the RAJDP. In the process, it presents alternative concepts of aquifer geometry, and indicates qualitatively the salinity and oil migration mechanism, giving better tools for the rational and scientific management of groundwater. For instance, low salinity wells can deliberately be constructed. Finally, it is found that C is not the traditional aquifer, as initially assumed. Its several layers are actually aquifuge or aquitards. The sub-aquifers in the C occur or are being developed in the narrow but highly productive depositional contacts of varying pressures and salinity, which extend beyond international boundaries.

INTRODUCTION

A state in the Arabian Gulf of the Middle East, Bahrain sits over a dome-shaped underground structure. Within the domain of the currently-used water bearing zones under Bahrain and Eastern Saudi Arabia, the lithological sequence has been traditionally classified, from top to bottom, in the following order: Neogene, Alat, Orange Marl (OML), Khobar, Shark Tooth Shale (STS), Rus, Umm Err Rahduma (UER) and Aruma. Alat or "A", Khobar or "B" and Rus-UER or "C", which are considered homogeneous aquifers, are being used as water sources for domestic, municipal, agricultural, and industrial needs. Total withdrawal from the three identified aquifers is estimated at 256 MCM/ yr.

The major stresses in C are the injection of oily water at the tank batteries of the oil industry and the abstraction of brine water to serve as raw water for the Ras Abu Jarjur desalination plant (RAJDP) of the Ministry of Electricity and Water (MEW). Figure 1 shows the location of the tank batteries and the RAJDP wells. There are 15 existing production wells and another four are being considered for its expansion program. The RAJDP wells are screened at Rus, 40 to 98 meters below ground surface (mbgs), and opened (without casing) at the upper portion of UER or at the depths of 98 to 170 mbgs (Figure 13).

Figure 2 shows the location map of the observation wells (OW) of the C.

JUSTIFICATION

Specifically, the Rus-UER aquifer system or the C supplies the raw water, having Total Dissolved Solids (TDS) of 13 g/ l, for the State's main reverse osmosis (RO) desalination plant — the Ras Abu Jar Jur Desalination Plant (RAJDP). For the said plant and other users, abstraction from the C is estimated at 34 million cubic meters per year (MCM/ yr).

Moreover, as shown in Table 1, the Rus-UER aquifer system has received a total of about 280 million cubic meters of injected water by the oil industry from 1960 to 2000. The injection is in progress at 18,700 cubic meters per day, which is an average TDS of 8000 ppm. The injected water carries an average oil content of 230 ppm which poses a great peril to the RAJDP RO process in the future. Varying in depth, the injection wells are opened at different zones in the C.

When a zone or group of layers is classified as one aquifer, they should not differ so much in salinity, top to bottom. But this is not true in the C, just as in the upper Dammam systems, A & B.

Therefore, the existing classification and related assumptions cannot support the manifested salt water mechanism in the aquifer systems.

A & B were assumed homogenous aquifers and identified to be replenished from recharge areas in Saudi Arabia. On the other hand, though the UER geologic formation extends to Saudi Arabia and other countries in the Gulf, the UER water in Bahrain has been considered and consequently modeled to exist only within the Bahrain pericline. Continuity to Saudi Arabia and other countries was discounted. Thus, past investigators worked on the basis of this worst case scenario, painting a picture where the C has very limited use [5]. Therefore, using old assumptions and the corresponding assessment results tend to give unfounded alarms to the country and have blurred efforts for rational and scientific water resource development and management, generating negative thrusts to the national economy.

Moreover, the present method of designing production and observation wells are pictured as the main cause of groundwater wastage and/ or increase in salinity. With this study, the proper method of water well design and construction can be prescribed.

By studying the C system further, particularly its water quality parameters, it may open to a new assumption that it has large aerial extent and is presumably replenished from lands beyond international boundaries, similar to A & B aquifers. It looks closer at the hypothesis that Bahrain is likened to a "big well" in the very large Rus-UER multi-layer and confined aquifer system instead.

The discovery of more appropriate concepts will have a strong impact on the economic development of Bahrain.

OBJECTIVE

This paper is primarily prepared to get some insights into the RAJDP well field and the injection of oily water by the oil industry into the C aquifer, among others.

Hopefully, this study creates a stronger hypothesis or more reliable concept regarding the salt water intrusion mechanism of C so that more rational and realistic data collection programs can be drawn, out of current ones, adding new approaches and disregarding unworkable procedures.

Nevertheless, the behavior of the well field has to be viewed with respect to a wider and deeper perspective of C. Therefore, in effect, this study also reassesses the prevailing concepts of the geometry and salinization of C under the Bahrain Island. It tries to ask, and deduces the answers to the following questions: Is C one homogeneous aquifer? Or does it have several sub-aquifers?

With the mentioned conditions, well-founded groundwater models shall be prepared and will optimistically yield practical results.

SCOPE & LIMITATION

Although it may make some reference to the three aquifers, this report revolves mainly around the C.

It focuses primarily on the short-term and long-term effects of the injection of water with high oil content by the oil industry with respect to the withdrawal of upper C water as an input to the RAJDP.

With the review of past assumptions of the C's geometry and the formulation of new logical assumptions, well logs, geophysical data and major water quality parameters as functions of depth and time were analyzed.

With the limited equipment and resources available during the preparation of this paper, the findings and recommendations may be considered as preliminary, subject to confirmation with the collection and corresponding analysis of more field data, particularly with highly sophisticated and computer-supported geophysical data, coupled with the more thorough and comprehensive analysis of data from old bore holes.

THE OLD TRADITIONAL ASSUMPTION

Figure 3 gives the existing perception of C. This figure and other documents indicate the following assumptions:

1. Rus-UER Aquifer System or C is practically homogeneous;
2. It is only getting recharge at Bahrain's Rus outcrop and has no regional horizontal flow and thus, replenishment comes from natural rainfall and oily water injection by the oil industry;
3. It is modelled like a box which is opened at the top, closed at the bottom and in all its vertical sides; and

4. Low salinity water is assumed floating over high saline zone.

The old concept was based on the logic that the STS at the top of Rus and the Aruma at the bottom of UER are the only impermeable or semi-permeable layers confining the Rus and UER layers which were all considered to be aquifers or permeable.

FINDINGS/ OBSERVATIONS

Figure 4 is a typical conductivity and temperature log of boreholes at C. If the C were one homogeous aquifer, the electric conductivity curves should have been roughly straight line or would have a uniform slope. On the contrary, all the curves have sudden increases or decreases of slopes, giving a strong signal that waters of varying salinity come from different sub-aquifers of the C. Per isolated section data, Tables 2 to 4, the deeper part of the UER has lowest pressure, absorbing more of any injected water and relatively good groundwater from highly pressurized zones [1].

At the start of this research, the conductivity values of the observation well WRD 1125 in the Sitrah Island were measured as a function of depth, considering two conditions: discharging and non-discharging. When the abstraction was zero, TDS was at 7000 ppm, and, when it was pumped at 5 liters per second (l/ s), TDS increased to 15000 ppm. Again, this manifestation supports the hypothesis that C must have sub-aquifers of varying salinity and pressure.

Figure 5 presents the TDS and other water quality parameters of the RAJDP wells. Beyond expectation, TDS and most water quality parameters remain constant for more than fifteen years from the start of the operation. Oil content is still less than 0.1 ppm.

RAJDP production wells drilled only till a depth of 170 mbgs, fully opened at Rus and partially at UER. UER in this area, therefore, would be till 300 mbgs. About 130 meters of UER strata were not included or penetrated by RAJDP wells, where brine water at 30000 to 60000 ppm is present[3]. If the old assumptions were right, the RAJDP would have increased salinity only after few days of pumping.

Figure 6 summarizes observation results at Saar, where three UER and two Khobar observation wells are being maintained. This case shows that as boreholes are pumped at similar abstraction rates, salinity depends on where or within what zone the well is opened within the Rus and/ or UER.

New and old data of most C and B observation wells reveal that hydrogen sulfide is confined only at some zones, say at the middle of UER and also at the lower Khobar. At the UER, Tables 2 & 3 were results of an isolated section test from the 1980s, supporting this contention[1]. With the old assumption of aquifer geometry, H_2S gas should have been present in the entire aquifer, more at the top and lesser at bottom of the aquifer. Therefore, this phenomenon disproves the old assumption and adds more credibility to the new concept that water occurs at sub-aquifers which are the geological contacts of formations within Rus and/ or UER. If H_2S is confined, water must also be so.

In Figure 7, high resistive zones are seen at the Rus. In the Khobar aquifer, this type of high resistive zones contain low salinity water (Orange Marl and Khobar Dolomite contacts). At the upper part of the UER, high resistive zones were also noted in almost all of the RAJDP wells and UER observation wells [(1), (2), (3) & (4)].

Figure 8 & 9 give the underground statigraphy of the Ras Abu Jarjur production wells. In most of the wells, highly fissured zones can be correlated horizontally. Moreover, the presence of high gamma above and/ or below suspected geological contacts or highly fissured layers in the UER, generally indicates confining controls or conditions in addition to the hydraulic impenetrability of most limestone layers[3].

Furthermore, analysis of water level data supports the hypothesis that the C waters come from various sub-aquifers. It is observed in Figure 10 that the water level at 1126 is lower than at the eastern portion. If the old assumption were true that the UER is one and homogeneous, WRD 1126 which is situated west must be higher than that at east because the usage of UER in the west is much lesser than at the east. Moreover, C in the west is nearer to the probable recharge areas.

In reference to Figure 1 illustrating the location of the tank batteries where the injection wells are, Figure 11 presents the wells within each tank battery, indicating their depths, and their cased and open holes. It is observed that the disposal system is designed to use most of the whole span of C, judging upon how the wells are opened.

To summarize the preceeding details, this old traditional concept cannot anymore stand amidst the following manifestations:

1. Sudden changes in the Electric Conductivity (EC) Curve as function of well depth; salinity and pressure do not gradually increase with depth,

2. Considerable variation of ECs (with depth) at non-discharging and discharging conditions,

3. Constant TDS and other parameters with time at the fifteen RAJDP wells,

4. Dependence of salinity on where or what zone the well is opened at the C and other aquifers in Bahrain.

5. Presence or confinement of Hydrogen Sulfide at the middle UER and also at the Lower Khobar and the absence or minimal presence in other zones.

6. Indication of the presence of geological contacts of low saline water in Rus, say in C2, C3, in the upper UER on the basis of resistivity logs, similar to the Orange-Marl and Khobar-Dolomite contact which is the proven highly productive and low saline zone in Khobar.

7. Presence of high gamma above and/ or below suspected geological contacts or highly fissured layers in the UER, which generally indicates confining conditions in addition to the hydraulic impenetrability of most limestone layers.

8. Indication from long term piezometric levels, that UER is not one aquifer, and

9. Inconsistency of the old assumption with actual salinity distribution.

CONCLUSIONS

From the mentioned findings, an alternative aquifer conceptual model is presented in Figure 13. The aquifers under Bahrain are actually in narrow but highly productive bands which have been developed within the influence of depositional contacts, whose salinities and hydraulic pressures vary considerably from one to the other. The system initially at the an early geologic time was generally impervious. With the thrust of the Arabian plate towards the Gulf and/ or Zagros mountains, like in the case of plywood, the boundaries between formations break up and form fissures which are being opened up further with the flow of water. These bands or boundaries of formation which are now called sub-aquifers in this report are about 3 to 5 meters in thickness, spanning the most part of the Gulf and Gulf countries.

Seventeen (17) possible bands or depositional contacts or aquifers in Bahrain are deduced, nine of which possibly are at the C, four in B, two in A, and two at Neogene. Some depositional contacts may be tight or absent in some areas, but in general would extend beyond international boundaries. Therefore, C is not a traditional homogeneous aquifer, as initially assumed. This would mean that the identified layers within C, B, A, Neogene, etc. are actually not the aquifers but aquifuges or aquitards. To reiterate, C is not one as the system is composed of several sub-aquifers.

On the basis of the mentioned findings, the inter-relationship between the RAJDP well field and injection wells of the oil industry are governed by the following parameters:

(1) Design of Ras Abu Jarjur Wells (Opened and Screened Depths),

(2) Design of Injection Wells (Opened Hole Depths),

(3) Rate of Abstraction at the RAJDP well field,

(4) Rate of Injection at the Tank Batteries (TB).

The said parameters would considerably influence the migration of oily water to the RAJDP well field from the TB Injection wells. The presence of deep injection wells within each TB has by chance saved Ras Abu Jarjur wells and its huge desalination plant.

The RAJDP wells are drilled up to a depth of 170 mbgs. At the nearest TB, this depth is equivalent to 130 mbgs. Therefore, ideally, all injection wells must be cased upto a minimum of 130 mgbs and opened from 130 to 280 mbgs, where the zones of lowest pressure and high salinity groundwater (greater than sea water) are found.

The rates of injection at the TB and abstractions at the RAJDP well field will influence the migration of oily water within the abstraction zone of Ras Abu Jarjur if the mentioned ideal design criteria are not met.

Of the six tank batteries, TB1, TB3 and TB4 are the most likely sets that would pollute the Ras Abu Jarjur desalination plant with oil.

From Figure 11, the following flow mechanisms can be deduced at each TB:

(1) At TB1, Wells W5, W11, W24, W38 and W26 are available to inject oily water into the Rus-UER system. These wells function as one integrated hydraulic system because they are constructed near each other. The injected oily waters at W5, W11, W24 and W38 tend to pass through W26 in their way to the deeper zones with lower pressure.

(2) At TB3, the injected water at W4 will either go to W32 and W20. However, since the depths of W32 and W20 do not reach the zones of the least pressure, the wells in this tank battery need immediate attention as they have the greater potential of polluting the RADJP wells.

(3) TB4 has W27, W16, W31, W1, W37 and W29 disposal wells, which definitely function as one hydraulic system. The presence of deep wells W27 & W31 prevents the early migration of oil to the RADJP well field. Since they have the least possible continuity to the deeper wells, W16 and W1 pose the greatest threat to the RAJDP well field.

(4) At TB6, the presence of two deep wells, W28 and W34, both of which approximately reach the zone of lowest pressure, prevent any injection at W6, a shallow injection well, from migration to Ras Abu Jarjur.

(5) At TB2, W30 absorbs most of the injection at the other wells, W22, W36 and W39. Any injection at W3 will threaten the Ras Abu Jarjur wells.

(6) At TB5, W21 deep injection well minimizes the migration of oil water towards the Ras Abu Jarjur well field. However, W21 is not deep enough to give any long-term assurance. Any injection at W2 will move fast towards the RAJDP wells.

In the micro level, the wells at each TB of varying depths will act as one integrated system; with the deeper wells acting as paths towards the lower pressured geological contacts at the bottom of UER and/ or at the top of Aruma. Morever in the macro level, hopefully, the well system in all of the tank batteries will also act as one integrated system, compensating the TBs without very deep wells.

It is concluded that by reasons of the construction of the injection wells and their proximity to Ras Abu Jarjur well field, Tank Battery No. 3 (TB3) poses the highest risk. The wells at TB5 are next on the danger list.

The negative impact of the injection wells will be minimized if close attention is intially focussed on TB3 and TB5 by deepening one of the wells or constructing another, deeper well.

The contiuning injection of water with an average of 230 PPM of oil and an average TDS of 8 grams/ liter by BANOCO into UER and Aruma is seen as more of a liability rather than an asset in the long-run, in respect to the abstraction at the RAJDP well field. The injection can only benefit the said well field if the oil content is reduced and perhaps other hazardous chemicals are removed. Recent drilling at the Bahrain International Gulf Course has demonstrated migration of oily water from the TB.

Most of the existing UER observation wells are opened at contacts C6 or C7 to C8 or C9 and have continously falling water levels. The lowering phenomenon does not mean the depletion of UER, it only shows that these observation wells are opened at most of the nine C sub-aquifers of varying salinities. It is more of the result of readjustment, mixing of low and high-saline waters and the flow of water from high-pressured sub-aquifers to the low-pressured ones, rather than depletion or overabstraction in the Bahrain Island.

The best and most convincing indicator that geological contacts at Rus and Top UER, C1 to C7 are not in immediate danger is the stable TDS at the Ras Abu Jarjur production boreholes for more than ten years. This indicates that the semi-confining layers within and between the above mentioned contacts, and the lower UER, contacts C8 & C9, are until now sufficient to control the upward flow of high density saline water.

Finally, there is a need to re-design the observation network covering the C under the State of Bahrain and even in neighboring countries, where similar hydrogeological cases are present.

RECOMMENDATION

There are two scenarios which can be presented to stop an unseen but certain environmental disaster in the Rus-UER aquifer, considering the mentioned two major stresses on the system. Firstly, in the future, the oil content and other harmful chemicals in the injected water will be reduced, while the cleaner water shall be injected on the horizon where the RAJDP abstraction wells are opened. Secondly for immediate action, the existing rejected water having an oil content of about 230 ppm must be injected into the zones at UER and Aruma where pressures are low and salinity levels are high.

In line with the second scenario, immediately at TB3 and TB5, two deep injection wells must be constructed (one for each TB). These wells must be cased till 130 mbgs and opened till 280 to 300 mbgs.

The following injection wells must be plugged immediately with sulfate resistant cement from top to bottom: (1) Well No.16 at TB4, (2) Well No. 1 at TB4, (3) Well No. 2 at TB5, (4) Well No. 3 at TB2

In the medium term, deep injection wells cased until 130 mbgs and opened until 280 mbgs must be constructed at TB1 and TB2, thus having at least one deep disposal well in each tank battery.

In the long-term, injection wells which are opened above 130 mbgs must be phased out. Only injection wells which meet the specifications as indicated in the report will be kept active in all of the tank batteries and other injection points of the BANOCO. Considering it from the technical point of view, waste water injection wells maybe allowed but must be opened only at the lower UER. Before phasing or plugging any injection well, remedial action by pumping and retrieving the oil content must be undertaken.

Considering the present salinity level, ultimately, all injection of oily water within the UER zone should be stopped. Otherwise, the oil content must be lowered to an acceptable level, which must be less than what is acceptable with the Ras Abu Jarjur reverse osmosis desalination plant (< 10 ppm). Remediation efforts which include the recovery of oil now stored at the horizon which is being used by the the RAJDP wells must be undertaken.

It is seen that Bahrain is likened to a big well in a vast and huge Rus-UER aquifer system. After the appropriate observation networks are adjusted and operationalized and the the problems related to the injection of oily water by the oil industry are resolved, additional abstraction through carefully designed wells maybe undertaken with the Rus-UER system. Initially, 50 percent of the existing withdrawal maybe added, while changes of quality parameters are closely monitored. Future additions will depend upon future re-evaluation of various parameters.

High abstraction users may be required to construct their observation wells, in accordance with the herewith mentioned recommended policy.

Further development of UER should adopt a policy that one well shall be opened only in one sub-aquifer. Furthermore, wells in a particular sub-aquifer should be spaced appropriately. The drilling of four production boreholes to augment the raw water supply for the RAJDP is recommended, while careful monitoring of the RUS-UER system must be updated and maintained. The design of the additional production boreholes (Figure 13) shall substantially be the same as the existing ones. However, their depths maybe reduced. ***It is strongly recommended that the first and/ or second well is drilled only to a depth of 145 mbgs, instead of 170 mbgs***. Thereafter, the first and/ or second well should be tested. The depths of the remaining two wells will depend upon the results of the tests with the first two wells. If this is implemented, salinity maybe reduced.

Most of the observation wells may have to be re-designed and renovated. Some wells in the Ras Abu-jarjur well field may be partially plugged so that they will be in harmony with the production wells, opened only at upper and middle UER. The construction of some special sets of observation wells opened only to each sub-aquifer will have to be undertaken in the future. Inactive and fully-penetrating wells around the area like the WRD observations wells are certainly channels of highly saline water to possibly pollute the better aquifer strips. These wells must either be fully or partially plugged to a maximum depth of 145 mbgs.

A facility to measure water levels and collect water samples must be provided in all of the proposed production wells. If possible, it must also be incorporated in the existing fifteen production wells, possibly gradually during each shut down for maintainance.

During the drilling process of additional boreholes using C or a part of it, drillers must be required to conduct geophysical logging.

The upgrade and/ or purchase of computer-supported geophysical logging systems are recommended to support any Ras Abu Jarjur project and also the continuing program to observe and monitor the groundwater system in the State of Bahrain.

As initially mentioned, this study is an analysis of old data, limited amount of new data and newer concepts of the Rus-UER aquifer system. It is rather broad in the treatment of some components. Therefore, there is a need to update or continue this study as soon as possible.

The updated study must be supported by intensive geophysical logging. With the geophysical logging, construction of test boreholes along with the undertaking of isolated section tests must also be done. The data shall be organized with the now-available Windows-based Geo-Graphics Information System (GIS). Finally, a groundwater model to predict changes in piezometry and water quality, mainly salinity or TDS, which considers also the density of water in its flow mechanism will also be needed.

An international or joint commission involving countries with common aquifer systems should be organized in order to coordinate the rational and scientific development and management of groundwater resources.

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Table 1: The Oily Water Injection					
Tank	Oil Content	Water		Barrels of Water	Estimated Oil
Battery		Barrels/day	Barrels/Annum	(1960-2000)	(1960-2000)
TB#1	208	26,706	9754366.50	399929026.50	83,185.24
TB#2	241	31,170	11384842.50	466778542.50	112,493.63
TB#3	267	17,863	6524460.75	267502890.75	71,423.27
TB#4	268	14,669	5357852.25	219671942.25	58,872.08
TB#5	216	15,369	5613527.00	230154607.00	49,713.4
TB#6	181	11,640	4251510.00	174311910.00	31,550.46
Average	230	117,417			
Average Cubic Meters					
Total for the Six Tank Batteries/Annum			42886559.00	,758,348,919	407,238.07
Total for the Six Tank Batteries (M3)/Annum			6818429.68	279,555,616.87	64,745.79

Table 2: Well Head Water Quality Data/Result, Isolated Section Test, WRD 1116, 1982					
Interval Tested	Date	Time	EC at 25°C (us/cm)	Temperature (°C)	H²S (mg/l)
24-96	29/9/82	20.30	14,200	31.0	
92-110	15/11/82	14.00	16,300		
126-144	16/11/82	20.00	17,200	29.0	Little
168-186	17/11/82	12.00	22,600	30.0	Abundant
205-223	17/11/82	21.00	34,300	30.5	Abundant
281-299	30/11/82	18.00	73,000	33.5	
318-394	8/12/82	12.00	116,400	34.8	Abundant
94-220	2/11/82	10.40	17,200	30.5	

Table 3: Pumping Test Data/Result, Isolated Section Test, WRD 116, 1982				
Depth Interval Tested	Water Level Below GL	Discharge (l/s)	Drawdown (m)	EC (us/cm)
24-96	23.83	7	0.13	13,000
92-110	23.62	10	1.59	16,400
126-144	23.68	8.8	1.46	16,500
168-186	23.94	5.5	16.53	21,200
205-223	24.66	8.7	2.26	33,200
281-299	35.63	3.4	12.04	107,600
318-394	35.71	5.7	7.01	108,500

Table 4: Piezometric Pressure Data, Isolated Section Test, WRD 116, 1982			
Depth Interval (m)	Aquifer	Date	Measured Peizometric Level (m BNLD)
24-96	Rus	29/9/82	+4.96
92-110	UER	15/11/82	+5.17
126-144	UER	16/11/82	+5.11
168-186	UER	17/11/82	+4.85
205-223	UER	17/11/82	+4.13
281-299	UER	3011/82	-6.84
318-394	Aruma	8/12/82	-6.84

Figure 1: Location of Tbs and RAJDP Wells

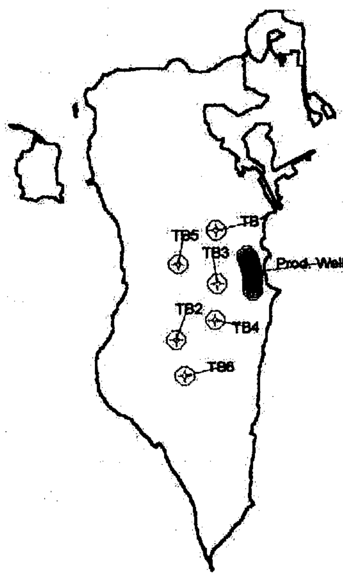

Figure 2: Location of C Observation Wells

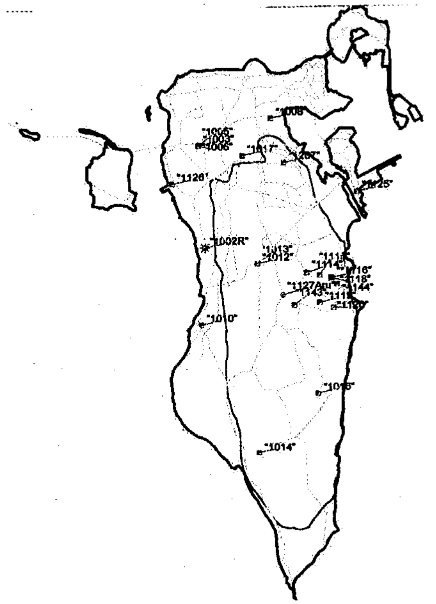

Figure 3: C's Old Concept

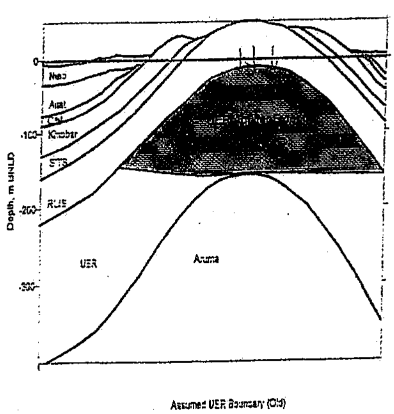

Figure 4: Typical Temp-Cond Log

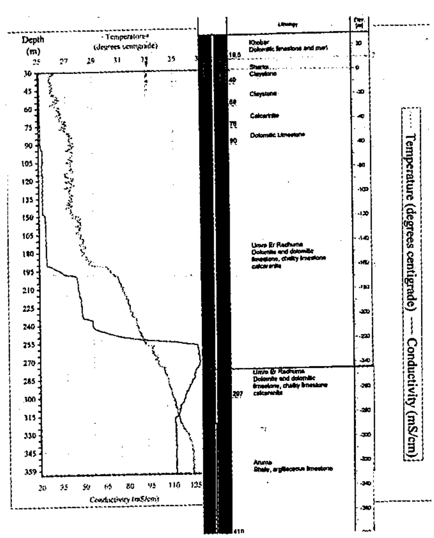

Figure 5: RAJDP Water Quality

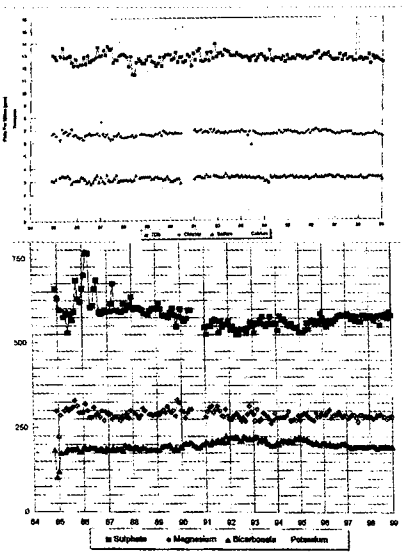

Figure 6: Saar EC & Pumping Tests' Results

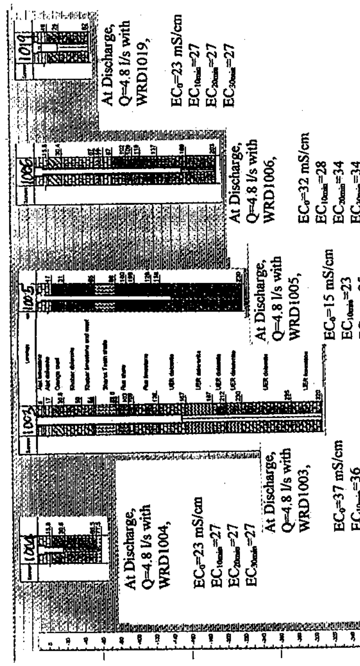

Figure 7: Typical Gamma & Electric Log, 1003

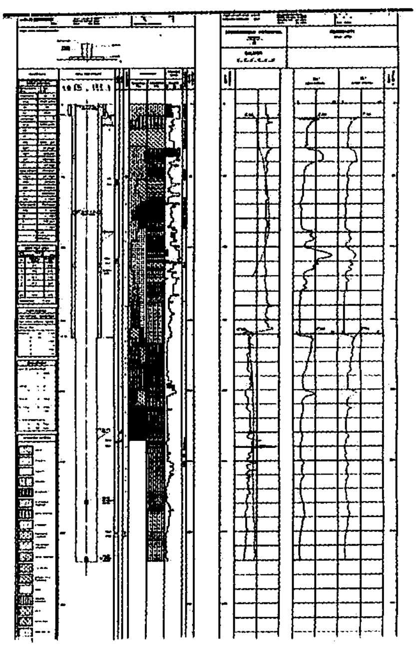

Figure 8: RAJDP Fissures & High Gamma

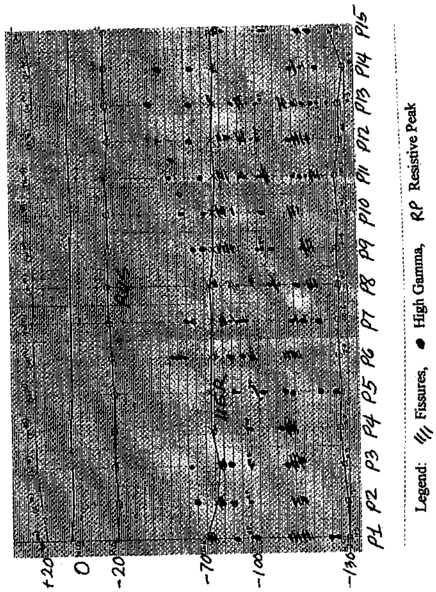

Figure 9: RAJDP Correlated Sub-Aquifers

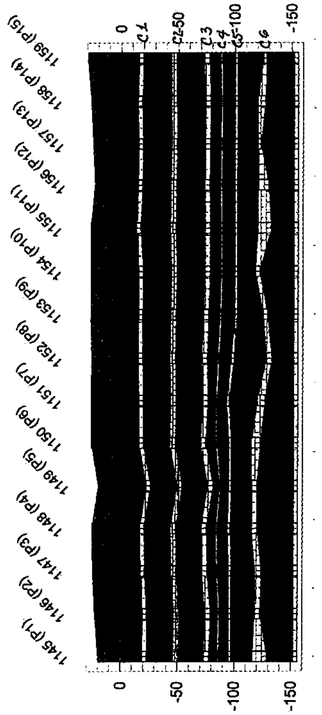

Figure 10: Piezometric Levels at C's OWs

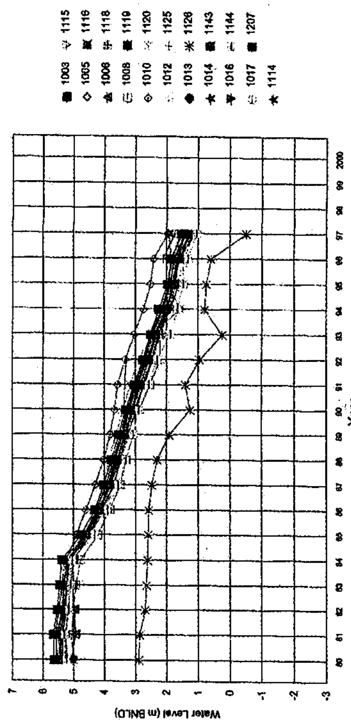

Figure 11: TB Injection Wells

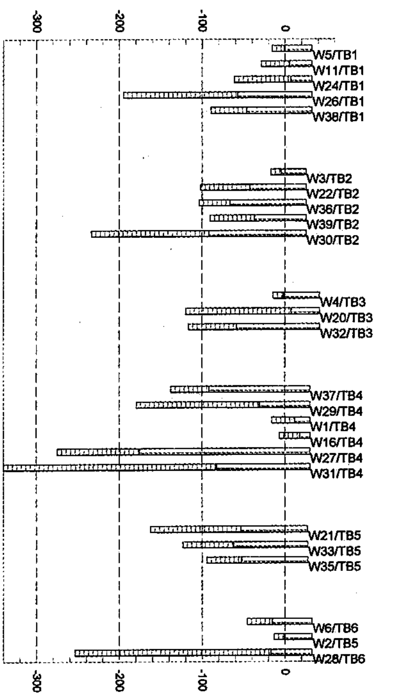

Figure 12: Common Design of RAJDP Wells

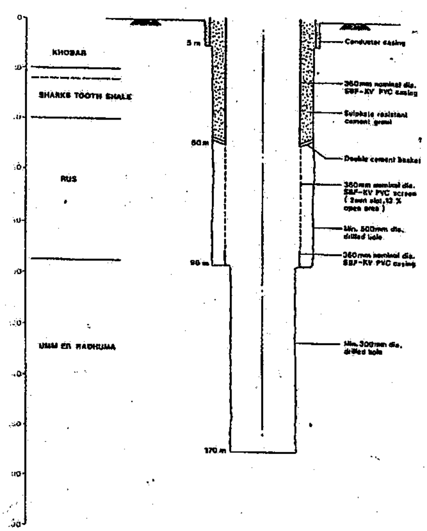

Figure 13: Conceptual Model - Bahrain Aquifers (3)				
Member/ Past Assumptions	**Layers or Sub-Aquifers**	**Sub-Aquifer Code**	**Layer Type**	**Remarks**
Sea				
Neogene (Confining Layer or CL)	**Neogene Marl**		CO	
		N1	FH	Source of Sea Springs; Sea Intrusion
	Neogene		CO	Thin or absent in some area,
		N2	FH	Sea Intrusion ???
	Neogene Marl		CO	
Alat or "A"		**A1**	FH	Low Salinity (< 3 g/l)
	A_Limestone		SC/CO	
		A2	SH	High Salinity
Orange Marl (CL)	**Orange Marl**		CO	
Khobar or "B"		**B1**	FH	Low Salinity, 2 to 3 g/l
	Khobar Dolomite		SC/CO	
		B2	CO	High Salinity
	Khobar Marl		SC/CO	
		B3	SH	Low Salinity, >B1 and <B2
	Alveolina		SC/CO	
		B4	SH	High Salinity
ST Shale (CL)	**Shark Tooth Shale**		CO	
Rus (Part of Aquifer C)		**C1**	FH	TDS at 7-8 g/l
	Rus_1		SC/CO	
		C2	FH	Probably of TDS less than C1????
	Rus_2		SC/CO	
		C3	SH	TDS of 11 g/l
UER (Main Part of Aquifer C)	**UER_1**		SC/CO	
		C4	SH	Low to Medium TDS, 11 g/l
	UER_2		SC/CO	
		C 5	FH	Resistive Peaks; probably very low TDS
	UER_3		SC/CO	
		C6	SH	TDS 14 g/l
	UER_4		SC/CO	
		C7	SH	Bottom of Ras Abu Jarjur Wells, 14 g/l
	UER_5		SC/CO	
		C8	NH	High Salinity, 25 g/l, & Low Pressure
	UER_6		SC/CO	
		C9	NH	High Salinity, 60 g/l, & Low Pressure
Aruma	**Aruma**		CO	

LEGEND:	**FH**=Full Hydrologic **SH**=Semi-hydrologic **NH**=Connate	**SC/CO**=Semi-confining/ Confining **CO**=Confining

Study on Ground Water Quality of Aligarh

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STUDY ON GROUND WATER QUALITY OF ALIGARH

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ABSTRACT

Water is rarely pure in a chemical sense. Impurities are added throughout the hydrological cycle as water comes into contact with minerals, on the surface or beneath the ground. Human activities further pollute the water. Man's health may be affected by the ingestion of contaminated water either directly or through food. Well and pump water are two major sources of drinking water in rural India particularly where a municipal water supply is not available. But due to non-availability of sewerage systems this water gets contaminated due to the seepage of sewage into ground water which is subsequently contaminated with pathogenic, carcinogenic and mutagenic compounds. The problem is further accentuated due to the fact that, little or no treatment is carried out to the hand pump or well water supply. In view of this, a study was carried out to evaluate the status of ground water in Aligarh city, where a part of the population receives municipal ground water and a part gets ground water through hand pumps, wells and tube-wells for daily use. The water samples from 55 sites collected from different parts of Aligarh city and the villages around the city were tested for various water quality parameters. Bacteriological tests were also carried on the water samples for determination of E-Coli. It turns out from the present study that at most places the ground water is safe for drinking and other purposes. 75% of samples tested were completely safe for drinking. The ground water at all places was colorless and odourless, with regard to pH, alkalinity, total solids and fluoride. The water at the majority of places was found to be excellent for almost all purposes. At some places such as Mamu Bhanja, Chawk Madar Gate, Bibi Sahey and Upper Fort the ground water was found to be hard and could not be used with soap.

Key words : 1. Seepage, 2. Sewage, 3. Ground Water, 4. E-Coli, 5. Contaminated

INTRODUCTION

Water that is free of disease causing microorganisms and chemical substances deleterious to health is called 'potable water'. The pathogens most frequently transmitted through water are those which cause infections to the intestinal tract. Natural and treated waters vary in microbiological quality. Ideally, potable water should not contain any microorganisms known to be pathogenic. It should also be free from bacteria indicative of pollution by excreta. To ensure that a supply of potable water satisfies the guidelines of bacterial quality, it is important that samples should be examined regularly for indicators of fecal pollution. There are other coliform groups that flourish outside the intestinal tract of animals. These organisms, native to the soil and decaying vegetation are often found in water. Because the life cycle of some pathogens may include periods in the soil, these groups of coliform organisms also serve as an indicator of pathogens.

In view of the important problem to assess the ground water quality considering physical, chemical and biological parameters, a literature review has been made [(1-12)]. During the latter part of the nineteenth century, before bacteriological examination became accepted, the safety of water was evaluated by chemical methods. The relative concentrations of ammonia, nitrogen, nitrates, nitrites and albuminoid nitrogen were used to indicate the presence and amount of pollution. Water was considered to be safe when the predominant amount of nitrogenous matter was in the oxidized forms. The use of each chemical test was made to evaluate the bacteriological safety of water to prevent outbreaks of waterborne disease. Generally, water contains chemical such as iron, calcium, magnesium, manganese, silica, fluoride, nitrate, phosphates, sulphates, and chlorides. When the quantities of these chemicals increases then they affect body systems and cause the destruction of health [(14)].

A guideline value represents the level of a constituent that ensures aesthetically pleasing water that does not result in any significant risk to the health of a consumer. The quality of water defined by the guideline values is such that, it is suitable for human consumption and for all usual domestic purposes, including personal hygiene. When the guideline value is exceeded the cause should be investigated with a view to taking corrective measures.

High level of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and exert a significant chlorine demand. The recommended guideline value is 5 NTU or 5 NTU but the level should preferably be less than 1 NTU. Colour in drinking water may be due to the presence of coloured organic matter e.g. humic substance metals or highly coloured industrial wastes. It is desirable, therefore, that drinking water should be colourless. The guideline value is 15 true colour units (TCU). Most people can detect levels of colour above 15 TCU in a glass of water. Water odour is mainly due to the presence of organic substances. Some odours are indicative of increased biological activity, others may originate from industrial pollution.

The problem associated with the chemical constituent arises primarily from their ability to cause adverse effects after prolonged periods of exposure; of particular concern are cumulative poisons and carcinogens. There is either direct or indirect evidence that all of the substances for which guideline values have been recommended can cause harmful effects and are known to occur in water. It must remain a basic tenet of public health protection that exposure to toxic substances should be as low as possible. The guideline values (Tables 1 to 3) indicate a tolerable concentration, but they must not be interpreted as defining targets for water quality [14]. Any judgment associated with the use of bacteriological guidelines must however, take into account the precision, validity, and appropriateness of the sampling procedure.

EXPERIMENTAL INVESTIGATION

The water samples from 55 sites collected from different parts of Aligarh city and the villages around the city as marked in Figure 1 were tested for various water quality parameters. Bacteriological tests were also carried on the water samples for determination of E-Coli. The samples were collected in the precleaned bottles which were immediately stoppered. Stagnant water from hand pumps were flushed by operating them for a few minutes. The sources of the samples are the hand pumps installed by Jal Nigam, Aligarh; these hand pumps draw water from more than a hundred feet depth; some samples were collected from private hand pumps also.

METHODOLOGY

The parameters for defining water quality are : pH value, turbidity, alkalinity, toatl hardness, chlorides, fluorides, conductivity, heavy metals and suspended and total dissolved solids. The methods to be employed for the determination of the values of these parameters are given in Table 4.

RESULTS AND DISCUSSION

Table 5 shows the results of water samples collected from 55 sites. These water samples were analyzed to ascertain the ground water quality of

Aligarh. The pH values of water samples collected were almost neutral for all samples. The average pH values of the samples was 7.3. At few places, namely Kowarsi, Maheshpur, Dhorra, Sootmill and Bannadevi, the pH values were between 8 to 8.5. But in all the samples the pH values were within the prescribed limit laid by Indian standards. The pH values of 11% samples were below 7.

The average alkalinity of water samples tested was found to be 41.47 mg/ l. There was not much variation in the alkalinity of the samples. The highest alkalinity of 81.5 mg/ l was observed for the sample taken from ordinary hand pumps at Sir Syed houses. In most of the samples the alkalinity was found in the range of 30 mg/ l to 45 mg/ l.

The average chloride concentration in samples was found to be 129.02 mg/ l. There was much variation in chloride concentration from place to place. 16% of the samples tested were found to have chloride concentrations exceeding the maximum desirable limit of 200mg/ l, but in none of the samples was the chloride concentration more than maximum permissible limit of 600mg/ l.

The fluoride concentration was below the maximum safe limit of 1.0mg/ l for the entire samples. All samples analyzed have fluoride concentration of not more than 1mg/ l, which is the maximum desirable limit set by Indian standards. The groundwater of Sir Syed Nagar and Jamalpur were found to have the highest fluoride concentrations of 1mg/ l among the entire samples tested.

The water at many places was found to have moderate turbidity. But for none of the samples was it higher than the prescribed limit of 5NTU. For 20% of the samples, the ground water was found to have turbidity more than 5 NTU. The highest turbidity of 8 NTU was found for the water sample of Raghuvirpuri. Turbidity of water from the hand pump of Police Chowki Bhamola had a turbidity of 7 NTU.

At a few places, the groundwater was observed to be hard, the maximum hardness of the sample being 864.70mg/ l at Mamu Bhanja in the city area. The total hardness in the ground water sample of Chowk Madar Gate was also fairly high and was found to be 853mg/ l. The average hardness of all the samples tested was 332mg/ l with the minimum value of 145mg/ l at the village of Maheshpur.

All the samples were tested for heavy metal (Chromium and Nickel) contamination. Only the ground water samples at two places tested positive for heavy metals. In the water of Rasalganj, the chromium was found to be 1.5 PPM and Nickel 0.1 PPM. The sample collected from Maheshpur (a small village on the by-pass of Annupshahar Road, Aligarh) was reported to have 2.9 and 1.1mg/ l of Chromium and Nickel respectively.

About 25 % of water samples tested were found to have E-Coli more than the prescribed limit, making water unfit for drinking purposes. However, it was noticed, that most of the samples having high E-Coli concentration were collected from ordinary hand pumps. The ordinary hand pumps draw water from the upper strata, which is more vulnerable to such contamination. The highest E-Coli count of 70 per hundred ml was found in the groundwater of Mallah Ka Nagla.

It may be observed from Table 6 that the ground water is unsafe for drinking purposes at 5 places which are highlighted in Figure 1. Most of the water samples tested were found to be colourless, odourless and of low solid concentration.

CONCLUSIONS

It may be concluded from the present study that at most places the ground water is safe for drinking and other purposes. 75% of the samples tested were completely safe for drinking. The ground water at all places was colorless and odourless, with regard to pH, alkalinity, total solid and fluoride. The water in a majority of places was found to be excellent for almost all purposes. At some places such as Mamu Bhanja, Chawk Madar Gate, Bibi Sahey and Upper Fort, the ground water was found to be hard and could not be used with soap. 25% of the samples were observed to have E-Coli counts of more than 3, namely Mallah Ka Nagla (Ward 43), Aslam Market (Ward 49), Pathar Bazar (Ward 59) and Marris Road (Ward 44) making it unfit for drinking. It may however be noted that the majority of the samples analyzed were from hand pumps of Jal Nigam, which draw water from a depth of more than hundred feet. Only 30% of samples analyzed were from ordinary hand pumps drawing water from depth of less than a hundred feet. All the groundwater samples reported to have higher E-Coli counts were found to be from the ordinary hand pumps. However, E-Coli was not detected in any samples collected from Jal Nigam hand pumps. Although the chloride concentration was not found to be higher than the maximum permissible limit of 600 mg/ l in any of the samples, in 16 % of the samples the chloride concentration was higher than the desired limit. The chromium concentration was observed to be high at two places, Rasalganj and Maheshpur and the values were 1.5 PPM and 2.9 PPM respectively, which are higher than the prescribed limit of 0.05 PPM.

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Table 1: Organic Constituents of Health Significance (9)

S.No.	Constituents	Guideline Values (mg/l)
1.	Aldrin and diealdrin	0.03
2.	Benzine	10.00
3.	Benzopyrine	0.01
4.	Carbon Tetra Chloride	3.00
5.	Chlordane	0.30
6.	Chloroform	30.00
7.	DDT	1.00
8.	1,2 - dichloroethane	10.00
9.	1,1 - dichloroethane	0.30
10.	Hexachlorobenzine	0.01
11.	Gamma HCH (Lidone)	3.00
12.	Methoxychlor	30.00
13.	Pentachlorophenol	10.00
14.	Tetrachloroethane	10.00

Table 2: Aesthetic Quality (9)

S.No.	Constituent or Characteristic	Unit	Guideline Value
1.	Aluminum	mg/l	0.20
2.	Chloride	mg/l	250.00
3.	Colour	TCU	15.00
4.	Copper	mg/l	1.00
5.	Hardness	mg/l	500.00
6.	Iron	mg/l	0.30
7.	Mangnese	mg/l	0.10
8.	pH	-	6.5 - 8.5
9.	Sodium	mg/l	200.00
10.	Total dissolved Solids	mg/l	1000.00
11.	Sulfate	mg/l	400.00
12.	Turbidity	NTU	5.00
13.	Zinc	mg/l	5.00
14.	Suspended Solids	mg/l	Nil
15.	Fluoride	mg/l	1.0
16.	Calcium	mg/l	60
17.	Magnesium	mg/l	40
18.	Chromium	mg/l	0.05
19.	Nickel	mg/l	Not Required

Table 3: Guideline Values for Bacteriological Quality (9)

Organism	Guideline Value*	Remarks
A Piped Water Supply A1 Treated water entering the distribution system Faecal Coliforms	0	Turbidity < 1 NTU for disinfection with chlorine pH, preferably < 8.0, free chlorine residual 0.2 - 0.5 ppm.
Coliform Organisms	0	
A2 Untreated water entering the distribution system Faecal Coliforms	0	In 98% of the samples examined throughout the year, in the case of large supplies, sufficient samples are examined.
Coliform Organism	3	In an occasional sample but not in consecutive sample.
A3 Water in the distribution system Faecal Coliforms	0	In 95% of the samples examined throughout the year, in the case of large supplies, sufficient samples are examined.
Coliform Organism	3	In an occasional sample but not in consecutive sample.
B Unpiped Water Supply Faecal Coliforms	0	Should not accure repeatedly if occurrence is frequent and if saulary protection cannot be improved an alternative source must be found if possible.
Coliform Organisms	10	
C Bottled Drinking Water Faecal Coliforms	0	Source should be free from faecal contamination.
Coliform Organisms	0	
D Emergency Water Supply Faecal Coliforms	0	Advise public to boil water in case of failure to meet the guideline values.
Coliform Organisms	0	

* Number/100 ml

Table 4: Methods for Water Analysis

S.No	ANALYSIS	METHODS
1	pH	By pH meter
2	Turbidity	By Nephlometer Tested the same day at which it was collected
3	Alkalinity	According to the standard methods
4	Total Hardness	The total Hardness was determined by EDTA Titrimetric method.__ The Phosphate buffer solution was added in samples to attain desired pH range and were titrated against EDTA, using Erichrome black T as indicator. The hardness was reported in terms of $CaCo_{3.}$ To determine the calcium hardness, 1ml of NaOH and .2gm of ammonium purpurate was added to 50ml of samples and was titrated EDTA. The magnesium hardness was calculated by subtracting calcium hardness from total hardness.
S.No.	ANALYSIS	METHODS
5	Chlorides	(As per standard methods) Agentometric method was selected to determine chloride. pH of samples was adjusted in the range 7 to 10 and were directly titrated with $AgNO_3$ using Potassium dicromate as indicator to a pinkish yellow end point.
6	Fluoride	Alizarin Visual method is used in accordance with standard methods. Standard 100ml nessler tubes were used and standard fluoride solutions were prepared with concentration intervals of .05mg F/l. 5ml acid zirconyl - alizarin reagent was added to 100 ml samples and were compared with standards after one hour
7	Conductivity	By conductivity meter as per standard methods
8	Heavy Metal (Cr & Ni)	Measured on the atomic absorption spectrophotometer.
9	SS & TDS	As per standard methods. The measured volume of samples were filtered through a standard glass fiber filter and filtrate was dried in evaporation dish at 180 degree C for one hour to measure the dry solids. The filter was kept at 105 degree C to examine suspended solid content.

Table 5. Results of Water Sample Analysis

Ward No.	Place/Station	pH	Cl^-	Alkalinity mg/l as $CaCO_3$	T.H mg/l	Conductivity x 100ms	Turbidity NTU	S.S. mg/l	Fluorid mg/l	TDS mg/l	E-Coli No. / 100ml	Cr. mg/l	Ni mg/l
47	Jeevangarh, JNHP	7.3	17.9	21.3	180	1.6	5	0.86	0.8	160	3	0	0
47	Koarsi, JNHP	8.2	17.9	23.0	160	2	6	0.85	0.9	129	-	0	0
51	Gandhi Eye Hospital, JNHP	7.3	102	51.0	170	1.9	5	0.90	0.30	174	-	0	0
60	Sasni Gate, JNHP	7.3	277	45.0	323	1.6	1	0.90	0.70	198	0	0	0
60	Near Sasni Thana, OHP	7.4	240	42.7	425	2.0	2	0.93	0.8	210	-	0	0
43	Mallah Ka Nagla, OHP	7.3	74.9	45.6	172	1.7	5	0.94	0.7	190	3	0	0
	Barhaiti, JNHP	8.0	112	45.5	227	1.9	3	0.98	0.6	128	-	0	0
	Dhorrah, JNHP	8.1	13.9	34.5	176	2.0	5	0.76	0.6	99	-	0	0
49	Dodhpur, JNHP	7.7	49.9	32.7	282	1.9	2	0.97	0.7	123	-	0	0
59	Railway Road, JNHP	7.9	152.9	41.0	221	1.8	2	0.95	0.6	127	0	0	0
	Maheshpur, TW	8.3	34.9	25.0	145	1.95	1	0.66	0.7	90	-	2.9	1.1
51	Center Point, JNHP	8.0	126	68.0	198	2	2	0.97	0.9	123	-	0	0
43	Mallah Ka Nagla, TW	7.4	6.9	35.2	254	2	2	0.6	0.3	97	0	0	0
22	Surender Nagar, OHP	7.3	286	35.6	303	1.6	2	0.74	0.4	121	3	0	0
57	AMU Campus, OHP	7.4	299	45.0	266	2	2	0.69	0.4	132	-	0	0
5	Bibi Sahey, JNHP	7.5	373	21.0	760	1.9	3	0.90	0.9	94	-	0	0
49	Dodhpur, Aligarh, TW	7.7	42.9	46.0	329	1.8	1	0.64	1	108	0	0	0
25	Upper-Fort, JNHP	7.3	465	25.6	737	1.95	4	0.89	0.4	210	-	0	0
60	Sasni Gate, JNHP	7.2	308	38.2	472	2	2	0.85	0.1	118	0	0	0
43	Mallah Ka Nagla, OHP	7.3	71.9	45.0	239	2	7	0.89	0.6	214	70	0	0

OHP = Ordinary Hand Pump; JNHP = Jal Nigam Hand Pump; TW = Tube Well

Ward No.	Place/Station	pH	Cl^-	Alkalinity mg/l as $CaCO_3$	T.H mg/l	Conduc-tivity x 100ms	Turbidity NTU	S.S. mg/l	Fluorid mg/l	TDS mg/l	E-Coli No. / 100ml	Cr. mg/l	Ni mg/l
52	Bara Bazar, City, JNHP	7.2	312	28.8	558	1.7	5	0.87	0.9	93	-	0	0
36	Hamdard Nagar, OHP	6.6	19.9	45	319	1.8	3	0.79	0.8	172	-	0	0
	Manzoor Gade, JNHP	7.5	8.9	39.9	239	1.6	3	0.8	0.8	123	0	0	0
30	Jamalpur, JNHP	7.8	3.9	41.4	309	1.9	5	0.62	1.0	148	-	0	0
30	Jamalpur, JNHP	6.6	2.9	41.9	292	2	3	0.99	0.8	188	-	0	0
01	Gandhi Park , JNHP	7.4	356.8	44.3	374	1.95	3	0.8	0.8	126	0	0	0
01	Mamu Bhanja, JNHP	7.1	496.8	34.7	864	1.9	4	0.75	0.70	154	-	0	0
30	Jamalpur Nagla, JNHP	6.5	3.9	43	315	2	4	0.79	0.10	121	-	0	0
	Cherat, JNHP	7.8	113	68	258	1.9	2	0.79	0.5	94	-	0	0
30	Jamalpur Masjid, JNHP	7.6	9.9	33.8	215	2	2	0.83	0.90	242	0	0	0
57	Opp. Chemistry JNHP	7.7	68.9	52	211	2.1	2	0.84	0.5	146	-	0	0
57	Shamshad Mkt., JNHP	7.9	28.9	39.6	227	2	2	0.73	0.70	216	-	0	0
49	Aslam Mkt., OHP	7.4	50	35	377	1.9	2	0.66	0.50	124	26	0	0
53	Bhamola Police Station, JNHP	6.7	72.9	40	407	2.0	7	0.9	0.2	117	0	0	0
52	Badar Bagh, OHP	7.2	113	42	370	1.9	3	0.88	0.60	202	-	0	0
57	S.S. House, OHP	7.4	71.9	81.5	392	1.7	3	0.84	0.90	116	-	0	0
49	Zakaria Mkt., JNHP	7.3	7.9	38	241	2	1	0.9	0.5	120	0	0	0
49	Medical College, OHP	7.4	58.9	39.9	247	1.95	2	0.79	0.7	178	-	0	0
11	Hari Nagar, JNHP	7.2	361	48.5	450	1.6	2	0.94	0.6	125	-	0	0
60	Hathras Adda, JNHP	7.4	438	39	505	1.7	3	0.57	0.3	117	-	0	0
58	Madar Gate, JNHP	7.1	406	49.2	852	1.6	2	0.9	0.7	129	0	0	0

OHP = Ordinary Hand Pump; JNHP = Jal Nigam Hand Pump; TW = Tube Well

Ward No.	Place/Station	pH	Cl^-	Alkalinity mg/l as $CaCO_3$	T.H mg/l	Conduc-tivity x 100ms	Turbidity NTU	S.S. mg/l	Fluorid mg/l	TDS mg/l	E-Coli No. / 100ml	Cr. mg/l	Ni mg/l
59	Pathar Bazar, OHP	7.5	31.9	41.2	388	1.9	2	0.81	0.8	192	24	0	0
50	Rasal Ganj, JNHP	7.4	58.9	49.8	245	2	3	0.72	0.80	166	-	1.5	0.1
1	Agra Road, JNHP	6.9	200	50.4	507	2	2	0.91	0.70	123	-	0	0
59	Kutte Ki Kabar, JNHP	7.8	97.9	57.8	211	1.7	4	0.87	0.7	120	0	0	0
14	Maqsudabad, JNHP	7.4	77.9	38	249	1.7	2	0.85	0.2	125	-	0	0
18	Sootmill Crosing, JNHP	8	21.9	28	198	1.95	3	0.92	0.8	120	-	0	0
08	Raghuvirpuri, OHP	7.6	21.9	38.4	345	2	8	0.89	0.9	98	3	0	0
18	Police Stn. Sootmill,OHP	7.3	159	42.8	329	2	6	0.99	0.2	218	-	0	0
18	Mellrose Biscuits, JNHP	7.2	43.9	41	341	2.0	2	0.85	0.20	198	-	0	0
14	Bannadevi, JNHP	7.2	39.9	41.3	329	1.95	4	0.9	0.4	118	-	0	0
14	Tehsil Kol, JNHP	8	31.99	34.8	247	1.9	3.0	0.89	0.5	190	0	0	0
14	Bannadevi Thana, JNHP	6.9	75.9	41.3	264	1.95	2	0.81	0.80	122	-	0	0
09	Exhib. Ground, JNHP	7.3	63.9	38.9	256	1.9	2	0.8	1.0	124	-	0	0
44	Marris Road, OHP	7.7	73.9	33.5	252	2	2	0.81	0.7	240	32	0	0

OHP = Ordinary Hand Pump; JNHP = Jal Nigam Hand Pump; TW = Tube Well

Table 6. Results of Unsuitable Water Samples

Ward No.	Place/Station	pH	Cl^-	Alkalinity mg/l as $CaCO_3$	T.H mg/l	Conduc-tivity x 100ms	Turbidity NTU	S.S. mg/l	Fluorid mg/l	TDS mg/l	E-Coli No. / 100ml	Cr. mg/l	Ni mg/l
	Maheshpur, TW	8.3	34.9	25.0	145	1.95	1	0.66	0.7	90	-	2.9	1.1
06	Bibi Sahey, JNHP	7.5	373	21.0	760	1.9	3	0.90	0.9	94	-	0	0
25	Upper-Fort, JNHP	7.3	465	25.6	737	1.95	4	0.89	0.4	210	-	0	0
43	Mallah Ka Nagla, OHP	7.3	71.9	45.0	239	2	7	0.89	0.6	214	70	0	0
01	Mamu Bhanja, JNHP	7.1	496.8	34.7	864	1.9	4	0.75	0.70	154	-	0	0
49	Aslam Mkt., OHP	7.4	50	35	377	1.9	2	0.66	0.50	124	26	0	0
58	Madar Gate, JNHP	7.1	406	49.2	852	1.6	2	0.9	0.7	129	0	0	0
59	Pathar Bazar, OHP	7.5	31.9	41.2	388	1.9	2	0.81	0.8	192	24	0	0
44	Marris Road, OHP	7.7	73.9	33.5	252	2	2	0.81	0.7	240	32	0	0
50	Rasal Ganj, JNHP	7.4	58.9	49.8	245	2	3	0.72	0.80	166	-	1.5	0.1

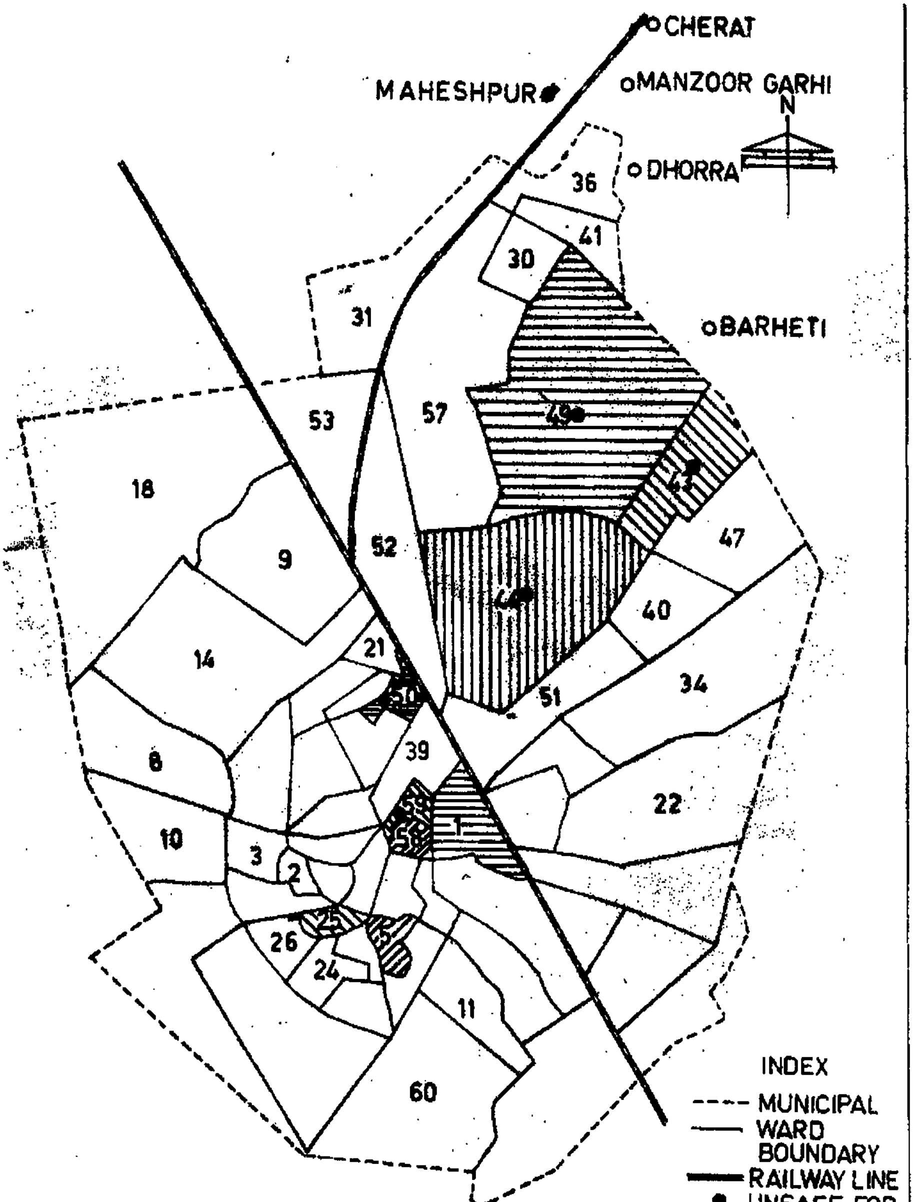

Fig.1 LOCATION OF SAMPLING SITES AT ALIGARH

Domestic Water

Design Concepts of a Major Water Transmission Projects in Bahain – An Overview

A.M.H.A. Karim and J.V.R. Murthy

DESIGN CONCEPTS OF A MAJOR WATER TRANSMISSION PROJECT IN BAHRAIN - AN OVERVIEW

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ABSTRACT

The Ministry of Electricity & Water of Bahrain has embarked on an ambitious programme for upgrading its electricity & water infrastructure during the development period 1996 - 2000.

The most important components of this programme are the construction of a Power & Water Plant at Hidd and the associated projects for the transmission of power & water. The production plant is being developed in three phases with the ultimate station capacity being 910 MW of power generation and production of 90 Mgd of desalinated water. Phase-I of the plant has recently been completed resulting in the availability of 30 Mgd of desalinated water.

The Hidd Water Transmission Project – Phase-I is concerned with the transmission of the available distillate from Hidd to the consumption centres in Manama & Muharraq areas. It includes the laying of large Transmission Mains and the construction of Forwarding Pump Stations, Blending Stations and Storage Tanks at the respective sites.

The project incorporates many unique features like Branched Pumping mains, Variable Speed Pumps and Distributed Control Systems (DCS) for controlling and supervising the pumping operations. The pumping concepts are based on real-time monitoring of the consumption at the receiving stations by the DCS and varying the pumping capacity accordingly. Further, the control system also determines when the flow should switch from Gravity system to Pumped system based on the total demand and head loss criteria. An interesting requirement of this project was to integrate the control system and the associated SCADA system for this development with an ongoing major SCADA project for the Water Control Centre. Some of these concepts addressed in this paper.

The implementation of this project will result in the satisfaction of the long-term demand of water with a reduction in the use of ground water by about 15 Mgd & an improvement in the quality of potable water.

Key words : Distillate Forwarding Station (DFS), Blending Station (BS), Branched Pumping Mains, Variable speed Pumps, Distributed Control System (DCS), Water Control Centre (WCC).

1.0 INTRODUCTION

The sources of water supply in Bahrain are Desalination Plants and Ground Water. The water from both these sources is blended and then supplied to consumers. The supply is affected through a network of Forwarding Stations, Blending Stations and Distribution Stations. Some Blending Stations also serve as Forwarding and/or Distribution stations. Generally the Blending Stations are located near their associated distribution zones.

The Desalination Plants use the technology of the Multi Stage Flash Distillation (MSF) or the Reverse Osmosis (RO). Ground water of acceptable quality is abstracted from Aquifer 'B' which generally has a salinity of some 4000 mg/litre or more.

Before the commissioning of the Hidd Plant, the existing desalination plants were producing about 35 Mgd of water. In order to meet the 'capped' supply of 70Mgd, the total ground water abstraction was also of the order of 35 Mgd. The abstraction of so much ground water was resulting in the rapid deterioration of its quality due to seawater intrusion. This was in-turn affecting the quality of blended water being supplied to the consumers. The TDS levels were approaching 1200 mg/litre or more in most of the distribution zones. Furthermore, due to the restriction imposed on the amount of ground water that could be abstracted, the supply was falling short of the demand.

In order to meet the future water demand, limit the ground water abstraction and alleviate the problems related to the quality and quantity of the daily water supply, a master planning of the water distribution system was undertaken [1]. The strategy set in the master plan was to develop new sources of desalinated water and limit the ground water abstraction to 12 Mgd.

The combined Power and Water Production Plant Phase-I at Hidd with the capacity of 30Mgd was the optimal option for combined development. However, from the view point of water transmission, this location posed a number of challenges requiring a modification in the transmission network philosophy and the adoption of a new criteria for the design of transmission mains, storages, pumping plant and control systems. The purpose of this paper is to outline briefly some of the salient design features related to this project.

The authors wish to note that at the time of writing this paper, some 90 % of the system has been commissioned and the ground water usage has already dropped to the desired levels.

2.0 MODIFICATIONS TO EXISTING TRANSMISSION NETWORK

Under the existing arrangement [Fig.1], the Blending Station at W.Riff'a in the Central Region and the Forwarding Station at Umm Al Hassam in Manama region were serving as the focal points for receiving desalinated water from the plants and forwarding blended /desalinated water to other stations. The Umm Al Hassam Station was forwarding distillate water to most of the Blending Stations in Manama and Muharraq Island.

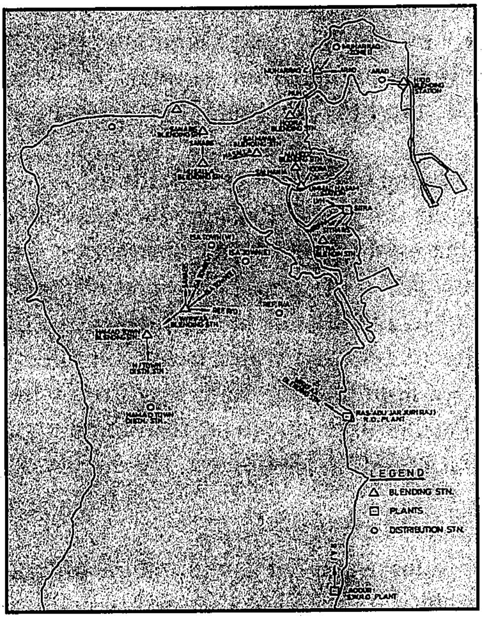

Figure: 1

However, with the availability of 30Mgd of desalinated water at Hidd, geographical considerations dictated that the stations in Muharraq and Manama requiring immediate supply of desalinated water be fed straight away from a distillate forwarding station at Hidd (Hidd DFS). Thus, the blending stations at Muharraq, Hidd, Hoora and Sanabis were proposed to be fed from Hidd DFS. An emergency connection was provided to Umm-Al-Hassam.

Another network modification that was done under this project was in the transmission of blended water to the Distribution stations at Janusan, Budaiya and Sar in Northern Manama. Due to an increase in the demand within the Sanabis distribution zone, it was no longer possible to continue with this arrangement. A new blending Station was thus proposed at Seef (Seef BS) to blend the distillate received from Hidd DFS with the ground water at Seef and forward the blended water to these distribution stations.

Figure 2 depicts the schematic of the Water Transmission System with the Hidd Plant in place.

The cascading effect of the above modifications was that there was an increase in the availability of the desalinated water at the W. Riff'a station. Hence it was proposed to increase the blending capacity at this station by building a new blending station namely, the W.Riff'a-II BS.

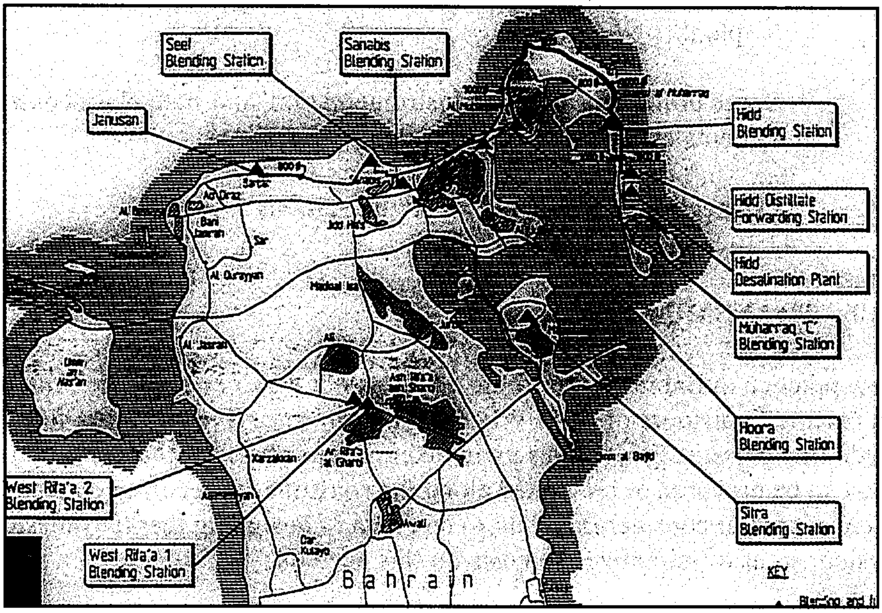

Figure: 2

Also, the Distillate available at Umm al Hassam is transmitted to the remaining stations in Manama resulting in the improvement of the quality of blended water supply at these stations.
In this manner, the available resources have been optimally utilized.

3.0 PROJECT DETAILS

The Project comprises the following:

- 45 Km of Ductile Iron Transmission Mains mainly 800 mm and 1000mm in diameter.

- 12 No. Storage Tanks located as follows:
  - Three 10 Mg tanks at Hidd DFS, a 5 Mg tank and three 1 Mg tanks at Seef BS and two 5 Mg tanks and three 2 Mg tanks at W. Riff'a-II BS

- Distillate Forwarding Pump Station at Hidd DFS of 30 Mgd nominal capacity, with two sets of pumping plant – one for the Muharraq system and one for the Manama system.

- Blending and Forwarding Pump Station at Seef BS of 10 Mgd nominal capacity comprising three sets of pumping plant;
  - Blending and forwarding Pump Station at W.Riff'a-II BS of 19 Mgd nominal capacity comprising three sets of pumping plant.

- Surge protection systems, Instrumentation, and state of art control systems at each of the above pumping stations.

- Connection works at the receiving stations.

4.0 TRANSMISSION MAINS

The practice in Bahrain is to locate all the major services of public utilities in reserved corridors of land. When the task of reserving corridors for the Hidd transmission project was undertaken, it was observed that land would have to be procured or reclaimed along the coastline for securing corridors. Hence, careful consideration had to be given in designing the transmission system so as to minimize the costs on this account.

Since all the stations to be connected to Hidd DFS were more or less linearly placed along the proposed route, the most practical solution was to lay a trunk main from Hidd DFS with branches to the individual stations. One advantage was that the pipeline costs would be much lesser than laying a number of pipelines of smaller diameter along the same route. Another advantage was that only one set of larger pumps would be required instead of number of sets pumping individually to each of the receiving stations.

However, from the viewpoint of security of supply, it was felt that segregating the Muharraq and Manama transmission system would be advantageous. Moreover, the future demand pattern in both these areas is different from each other. So, by segregating the two systems, enhancements to the pumping capacities could be fine-tuned to meet the actual requirements. Thus it was decided to lay two sets of branched transmission mains parallely in the same corridor with interconnections at regular intervals. The hydraulic analysis of the system showed that such interconnections could be established at approximately 5Km intervals without severely affecting the flows in either of the systems.

A similar concept was applicable for the transmission system from Seef BS to the distribution stations at Janusan, Budaiya and Saar. Here, the proposed transmission was running parallel to the existing transmission main permitting an interconnection between both of them for ensuring security of supply.

The following issues had to be considered while designing the branched transmission systems[2]:

- Optimum sizing of the pipelines.
- Surge control requirements for operating an interconnected, branched transmission system.
- Effect on the sizing of the pumping plant under varying flow conditions because different stations would be demanding water at different rates and times depending upon their consumption pattern.
- Control requirements for the pumping plant under variable flow conditions.

These main aspects are discussed in more details below.

4.1 Optimal Sizing

The sizing of the transmission mains was done on the basis of minimizing the life time costs while providing flexibility for future development and avoiding the need to duplicate the mains in the foreseeable future. A Net Present Value (NPV) analysis of the variable lifetime costs against pipe diameters for various flow rates was conducted for the transmission system. The analysis showed that the optimum diameter for flows up to 16 Mgd is that which gives a velocity in the pipeline between 1.0 and 1.5 m/sec. For velocities up to 2.0 m/sec the increase in cost was some 10% above the minimum cost. Thus by slightly oversizing the pipes initially, it was possible to substantially increase the system capacity in future by just increasing the pumping plant capacity. With this criteria the velocities in the Hidd Transmission system were restricted to 1.0 m/sec.

4.2 Surge Considerations

The transmission pipelines are subject to transient conditions under the following conditions:

- Automatic closure of an inlet valve on any of the pipeline branches to a receiving station when the tanks have been filled i.e. the station is not demanding water.
- Single Pump trippings
- Multiple pump trippings (total power failure)

The surge analysis depicted that the last condition cited above is the most severe case resulting in maximum negative pressures in the system. The negative pressures are serious concern because all the pipelines under this project have a flat profile over long lengths and any positive pressure available in the pipelines is only due to the levels of discharges into the receiving tanks. Since the pipelines are buried in high ground water table conditions, the risk of contamination at pipeline joints due to negative pressures is very high. Also, the air valves would open under negative pressure creating air pockets and leading to high pressures on their collapse.

It was considered necessary to design a surge protection system which will ensure that at any point in the transmission system, under any possible operating conditions,

- The maximum transient pressures are within the test pressure of the pipeline
- The minimum transient pressures do not fall below 0.3 bar above atmospheric pressure.

However, following exceptions were found to be acceptable to minimize the surge vessel volumes:

- Pressure on the suction side of the pumps could fall below 0.3 bar gauge pressure but not below atmospheric pressure.
- Pressures down to atmospheric were permitted in the immediate vicinity of the highest point in the pipeline (bridge crossing). Under this condition the air valve was expected to operate.
- Pressures up to 0.1 bar gauge permited in the Hidd DFS to Manama system when the water level in the suction reservoir was below +5.0m A.D

Several measures were evaluated to achieve this level of control such as, increased pump inertia, the installation of upstream and down stream feed tanks and the use of surge vessels. Finally, the use of Surge Vessels with downstream Feed (Surge) Towers of about 20 Sq. m surface area was found to be the most optimum combination. The Surge towers would be floating on the transmission mains at each of the receiving stations. For the

Pumping main from Seef BS to the distribution stations at Janusan, Budaiya & Sar feed towers were not necessary because the delivery was into elevated service reservoirs.

The analysis for sizing the surge vessel was done for varying conditions of flows and reservoir levels (lift conditions) and was run for sufficient time to ensure that the expanding air in the vessel had reached maximum volume. The duty volume thus calculated was divided into two or more vessels such that the overall volume was not less than 115% of the duty volume.

The volumes of the surge vessels required are as follows:

- Hidd DFS - Manama - 170 Cu.m
- Hidd DFS - Muharraq - 190 Cu.m
- Seef BS - Janusan, Budaiya & Sar - 35 Cu.m

As a second step the effect of the closing of valves at any of the receiving stations was analyzed. The effect of the changes in the open areas of one or more valves during transient condition was evaluated using the butterfly valve closure equation:

$Ao/Af = 1- \cos(\pi/2 - \theta)$ where $0 = \theta. \leq \pi/2$

In all cases, the effect of the surge pressure on the volume of the surge vessel provided for the pump tripping condition was checked. It was found that the volume provided was sufficient.

A schematic of the surge protection measures is shown in Figure 3.

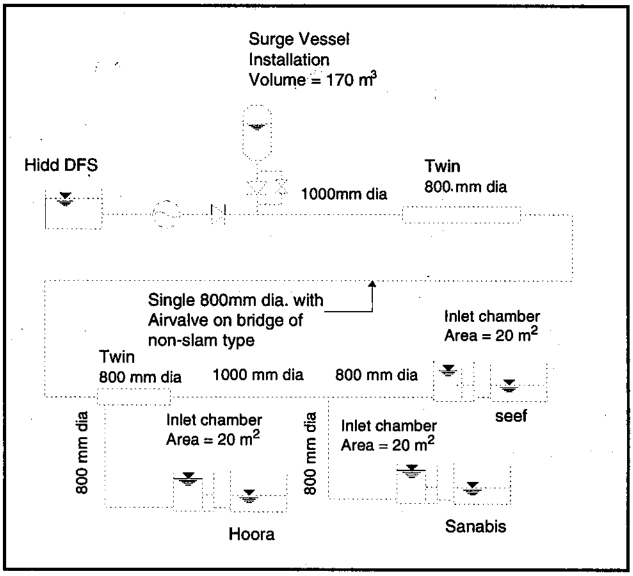

Figure: 3

4.3 Pipeline Materials and Corrosion Protection

The transmission system between the various stations is of Ductile Iron pipeline Class K-9 manufactured to ISO 2531, with internal cement mortar linning to ISO 4179. The pipes come with an external coating of two coats of zinc rich primer followed by 3 coats of Bitumen. At site, external corrosion protection is determened based on a study of resistivity survey of the soil conditions along the route. For this particular project, the pipes were protected by a two layer PVC tape system followed by Sacrificial Anode Cathodic Protection System using high purity. zinc anodes.

The product water is presently being dozed with NaoH to raise its pH value. Full scale chemical treatment to improve the Langlier Index is envisaged in the near future.

5.0 PUMPING PLANT & ELECTRICAL DESIGN ASPECTS.

5.1 Pumping plant

Horizontal centrifugal pumps with flat efficiency curves have been selected in this project both, for the purpose of forwarding and for blending.

The flows in the branched pumping mains are constantly varying depending on the demand at various receiving stations. Also, the discharge levels at each station are different. Thus, the forwarding pumps have to constantly operate under varying head and flow conditions. Because of this requirement, it was necessary to couple the pumps to variable speed drives.

Blending of desalinated water and ground water is done in the blended water main to which the desalinated water and the ground water pumps are connected. By monitoring the conductivity of the blended water the blending process is controlled. Since ground water contributes to the conductivity, it is necessary to vary its flow to achieve the target conductivity value. Thus the ground water pumps are of the variable speed type.

The philosophy of building in spare capacity has been adopted in the design of the pumping plant which requires minimum increment in expenditure for future requirements.

The Civil works, & plant piping are designed to readily add one pump in the near future and another pump in the remote future.

Power supply arrangements, and other ancillary works are designed to readily add the future forwarding pump as well as accomodate the increase in the impeller diameters.

Addition of the future pump unit will allow for increasing the overall system capacity by 25%. This will meet the water demand for year 2015.

Standby capacity reduces from 50% to 33% when the future pump unit is installed.

At Seef BS and W.Riffa'a BS the forwarding pumps have been designed on the same basis as the forwarding pumps at Hidd DFS. However the design of the Distillate & Ground water blending pumps is such that the increase in flow by 25% can be achieved by changing the impeller only. A spare plinth is provided for these pumps to allow plant expansion in the remote future.

All variable speed pumps have been designed to achieve the full range of flows by ramping the speed from 65% to 100%. The isolation valve on the delivery branches of these pumps is a special type of control valve which can be modulated by the control system to maintain the required back pressure on the pumps over the full range of flow.

The Barr's approximation of the Colebrook-White equation has been used to calculate the frictional losses [3]. The pumps have been basically designed for a pipe roughness factor(Ks) of 0.3mm and a water temperature of 30degrees C under the maximum lift conditions. Their performance has then been checked by varying the Ks from 0.03mm for the minimum lift case to 1.0mm for the maximum lift case. Correspondingly, the temperature was varied from 50 degrees to 15 degrees C and the fitting roughness factor was varied from 0.03mm to 2.0mm.

5.2 Gravity Flow

The hydraulic analysis showed that due to the difference in the heights of the tanks at Hidd DFS and at the receiving stations and by virtue of the pipe sizes provided a substantial amount of water could flow by gravity. For a full tank at Hidd DFS, flows of about 12 Mgd and 9 Mgd could take place in the Muharraq and Manama transmission systems respectively. The gravity flow system curves for the Hidd to Seef transmission system are shown in Figure 4.

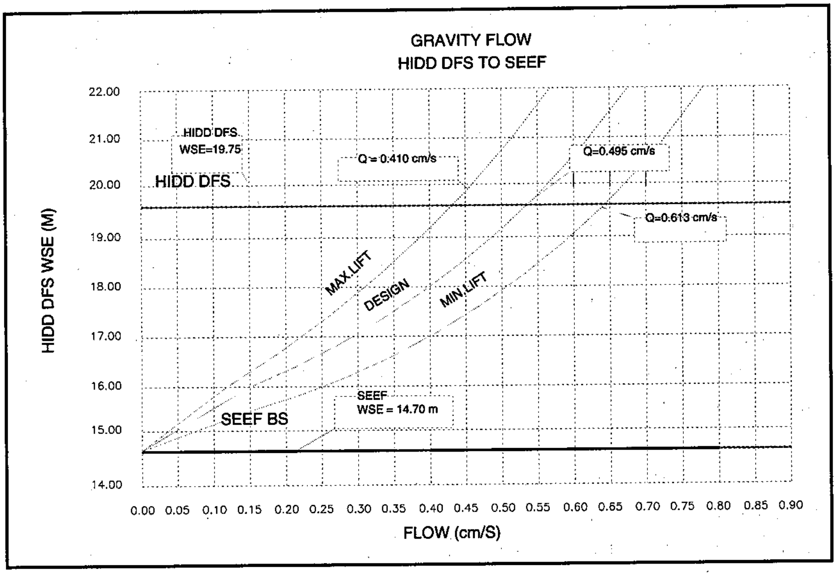

Figure : 4

5.3 Electrical design considerations

The Ministry's distribution network supplies the pumping stations at 11 kV. The 400V, 3-phase power supply is derived from a 11/0.4 kV sub-station. The sub-station comprises the transformers (duty + standby), 11 KV breakers and Air Circuit Breakers of 2500A rating on the LV side of the transformers. The transformer rating at all the stations is such that outage of one transformer will not effect the operation of the station. An auto-changeover scheme ensures the continuity of the power supply to the plant if a failure occurs in one of the transformers.

The variable speed drives (VSD) control the pumping volume. These drives are Thyristor controlled based on 12 pulse devices designed to meet the G5.3 standards for harmonic levels. The other auxiliary loads in the plant are the air conditioning and ventilation system, plant & site lighting, compressors UPS and valve motor control centre.

The LV bus bar is sectionalized with the duty loads and the standby loads uniformly distributed to provide maximum security in the operation of the plant. A power factor of 0.9 is targetted under all operating conditions of the plant achieved by means of an automatic power factor correction capacitor banks. The TN-S system of Earthing is adopted for the plant. Equipotential bonding is achieved throughout the plant by interconnecting all exposed metallic components to the plant to the Earthing system.

6.0 CONTROL SYSTEM PHILOSOPHY

In order to achieve the pumping regime explained in section 4 above, an automated system based on Distributed Control System (DCS) has been adopted. The Purpose of the DCS is mainly two-fold:

- To control the operation of the forwarding pumps which forward distillate or blended water to the various stations as per the demand at these stations.
- To control the operation of the ground water & Distillate water blending pumps at the blending stations to meet the demand of the blended water.

The other functions of the DCS are to supervise and control the various sub systems in the station like surge protection, chlorination, tank maintenance routines etc. The DCS also communicates with the central Water Control Center (WCC) to provide the various indications and alarms at these stations. The overall system architecture is such that control can be taken over by the WCC as and when required.

6.1 Control Regime

The control of the distillate or blended water forwarding pumps involves the following control sequences:

Total Demand Calculation
Calculate the total demand target for each set of pumps by summing the remote site demand value signals for the associated sites. The calculation of the site demand value is discussed further below.

Suction Tank Water Storage Control
At Hidd DFS the suction tanks are the distillate storage tanks while at Seef BS and W.Riff'a BS these are the blended water storage tanks. The DCS at the station ensures that the suction tanks are sufficiently full for satisfying the total target demand either by operating the forwarding pumps or by gravity flow (only in the case of Hidd DFS).

At Hidd DFS, the distillate storage tanks are filled under the automatic control of the pumps at the adjacent Hidd production plant. An electrically operated isolation valve is provided on the inlet pipework of these tanks. The site DCS provides continuous tank level signals and the valve status signals to the control system of the production plant at the interface point.

At the blending stations the site DCS continuously receives the level signals from the blended water storage tanks and also the status signals of the inlet valves to these tanks. When the level reaches a set point, the DCS operates the blending pumps to maintain sufficient water levels in the blended water tanks to enable the operation of the forwarding pumps.

6.2 Pump Control.

Starting and stopping

The DCS automatically alternates the duty arrangement of the pumps on a daily basis to ensure even wear on all pumps. Once the pumping is started, the plant is arranged to run for a minimum period to be defined by the pump supplier while restricting the number of starts to one per hour. Unless intervened manually, the DCS shall operate the plant only if these criteria are met.

Cavitation control

Each pump is provided with a closed loop pressure control system which maintains the pump discharge such that cavitation does not occur. The pump discharge pressure signal is used as the process variable to manipulate the pump discharge valve position for this purpose. The set point for the control loop is an operator input for the range of operation of the pumps.

Speed Control

Each set of pumps is provided with a closed loop flow control system to maintain a preset common output flow. In the automatic mode this preset value is the total demand target set for the pumps. The system uses the discharge flow signal as the process variable to manipulate the speed of the pumps.

Fail-safe pump protection

Hard-wired pressure switch control circuits protect the pumps against low suction pressures and high discharge pressures.

Surge protection system interlock

An interlock is provided in the DCS to ensure that the pumps shall not start unless the surge protection system associated with those pumps is available in a healthy state.

Pump operation when communication fails

In case the DCS system at the forwarding station receives invalid signals or loses communication with the remote sites then, the pumping plant (if running) shall continue to run at the last set point and an alarm shall be raised. Further, if the communication is not restored within a pre determined time, the system shall prompt the operator to contact the remote sites and adjust the pump operation manually.

Gravity bypass flow

When the distillate storage tanks at Hidd DFS are sufficiently full, flow to the remote blending stations shall be by gravity. The DCS monitors the gravity flow continuously and compares this process variable against the total demand target for the pumps. If the flow falls short of the demand then the gravity flow bypass valve is closed and the corresponding pumps are cut in at the required speed to meet the demand. A reverse sequence of actions take place when the pumping plant is running and the distillate tanks at Hidd DFS become sufficiently full. Except that in this case the operator shall be prompted, by the DCS, that the pumps are going to be stopped and gravity flow is going to begin.

Surge Protection

The surge protection systems provided on the pumping mains have their own self-contained automatic control system to maintain the water levels and the internal pressures at predetermined set points. These set points are operator determined. Monitoring signals from the surge protection system are connected to the DCS for remote monitoring purposes.

6.3 Blending Control

The control of the blending pumps (operation) involves the following control sequences:

Operational regime of the distillate and ground water pumps

The distillate pumps are connected to the Distillate water storage tanks and the ground water pumps to the ground water tanks. The distillate pumps are of the fixed speed type and the ground water pumps are of the variable speed type. The starting and stopping of these pumps is according to the automatic controls described in the blending routine described below. In addition the pumps are protected by low level cut-off switches in the storage tanks, storage tanks outlet valve closed cut-off, low suction pressure and high discharge pressure hard wired cut-offs and blended water storage tank high level cut-off.

Blending routine control

In the automatic mode, the ratio controller in the DCS uses the signal from a water conductivity meter mounted on the blended water line as the process variable and compares it with the preset target conductivity value for the blended water to provide the desired blending ratio. The DCS then carries out the speed adjustments to the ground water pumps while operating the distillate water pumps as necessary. The DCS continuously monitors the level in the blended water tanks and triggers the blending routine every time the blended water level drops below the preset point and stops the routine when the level reaches the 'tank full' set point.

In the manual mode, the DCS allows the operator to input the required blending ratio of ground water to distillate water, at the MMI, within the permissible limit of 1:7 for Phase I.

Semi-Automatic Control

The water storage tanks are configured to operate under semi-automatic control. This type of control is required to enable the operator to take a particular tank out of service for maintenance and assign its duty to an adjacent tank. For example if a blended water tank has to be taken out of service then the adjacent ground water tank may be used for storing blended water and one of the distillate water tanks may be used to store ground water temporarily.

The DCS prompts the operator to operate the key valves in the correct order to carry out the tank swapping routine. All these valves are operable remotely. The DCS then checks if the functionality of the level controls and interlocks is properly activated between the tanks and the associated set of pumps pursuant to the swapping exercise.

The following control sequences are involved at the receiving stations i.e. the blending stations receiving distillate from Hidd DFS or the distribution stations receiving blended water from Seef BS:

Site Demand Calculation

At Seef BS the DCS automatically derives the site demand value and transfers it to Hidd DFS for control purposes as described earlier. While at all the other stations, a dedicated site monitoring and control system is being provided for this purpose. This is of the programmable logic controller (PLC) type. The calculation of the site demand value involves the following sequences:

- ✓ Check the water level in the receiving tank (distillate storage tank or elevated service reservoir)
- ✓ Check the water inlet flow from the forwarding stations.
- ✓ Check the outlet flow from the receiving tanks

If the tank water level is equal to or greater than the operator set point then the site demand value is zero. If not then, Site demand value = storage tank outlet flow + K(operator level set point – storage tank water level)

Where K equals a multiplier to take account of the storage tank dimensions with bias to account for system hydraulic loses. It is possible for the operator to adjust the frequency of the update of the site demand value

Receiving tank level control

The level is controlled automatically by a closed loop level control system using the tank level signal as the process variable. This signal manipulates the position of the inlet flow control valve. The valve permits a modulating type of control by which the valve begins to open when the level drops to an adjustable preset level (L1) and reaches its fully open position when the level drops to L2. On rising water levels the valve begins to close at L1 and reaches its fully closed position at the full level set point Lsp. The Lsp for this control loop is an operator input. Thus L2<L1<Lsp and the opening and closing actions ramp between these limits. It should be noted that under normal operating conditions, the water level can be maintained between Lsp and L2 at all times.

Over flow level switches are provided in the receiving tanks and are interlocked with the actuator of the inlet valve. In case an overflow occurs then the inlet valve shall be closed and an alarm will be raised.

The above control philosophy is schematically depicted in Figure-5 using Seef BS as an example. It may be observed that Seef BS acts as a receiving station, blending station and a forwarding station.

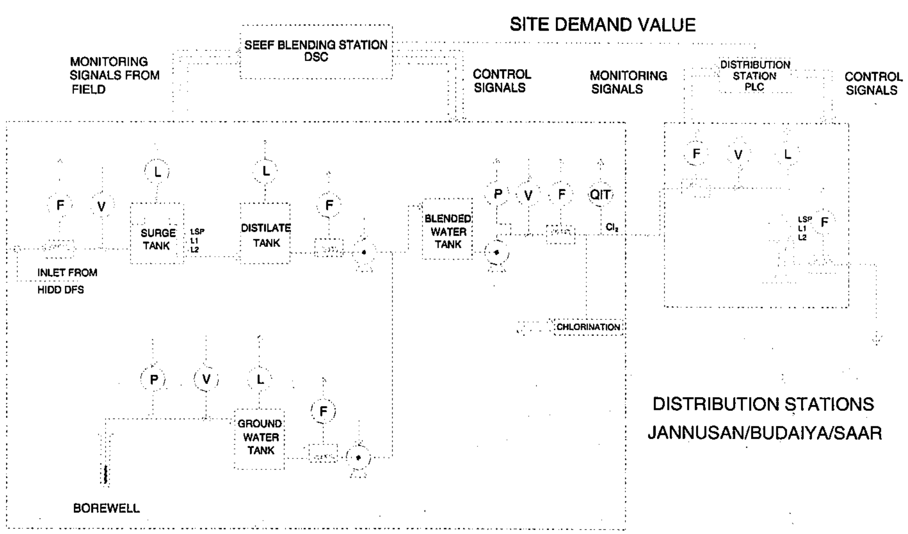

Figure : 5

7.0 INTERFACE WITH WATER CONTROL CENTER

An interface point is defined as either a fixed point in space at which the responsibilities for the same type of work (wiring and connections to defined terminal points) change or, software changes in the control system devices (DCS or RTUs or WCC) to implement the required automation.

In this project, interfacing with the WCC SCADA network is required at the three new DCS stations viz. Hidd DFS and Seef & W.Riff'a BS as well as the Nine existing receiving stations. (See Figure 2). Both, the fibre optic network and the WCC are being provided under a separate contract.

A simplified network schematic of these water sites is shown in Figure 6. It shows the master-slave relationships envisaged between the DCS and RTU systems at the water sites and any two DCS sites along with a list of key signals to be transmitted between the sites for control and monitoring purposes. This network forms a part of the overall Tele-control network for the WCC covering all the water stations in Bahrain.

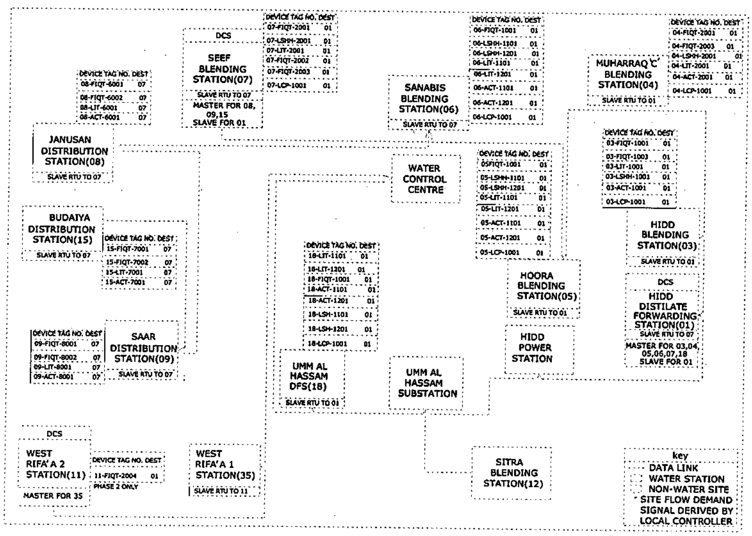

Figure: 6

The proposed mode of communication is either point to point (i.e. DCS to slave RTU/DCS site) or party line (i.e. DCS station to several slave RTU/DCS sites) by means of modems. The communication of all control and monitoring signals is achieved through IEC 870-5-101.1 Tele-communication protocol.

At Hidd DFS, Seef BS and W.Riff'a II BS the DCS and associated infrastructure to generate the required signals to be communicated to WCC are provided as part of the Hidd Water Transmission Project. Whereas the actual telecommunication equipment required to transmit these signals is being provided under the contracts associated with WCC, the interface point is at the "Main Distribution Frame (MDF)" which is located in a special communication room in the pump station. The site DCS 4-wire VFT signals are interfaced with the WCC system at the MDF. The schematic of this interface scheme is shown in Figure 7.

At the other Nine existing sites, the RTUs and associated equipment (SCADA Interface cabinet, Remote control Cabinet, Modems etc) are being provided under the contracts associated with WCC. The RTUs are provided with input and output marshalling terminals located in the SCADA interface cabinet. These marshalling terminals serve as the interface point with the WCC. The schematic of this interface scheme is shown in Figure 8.

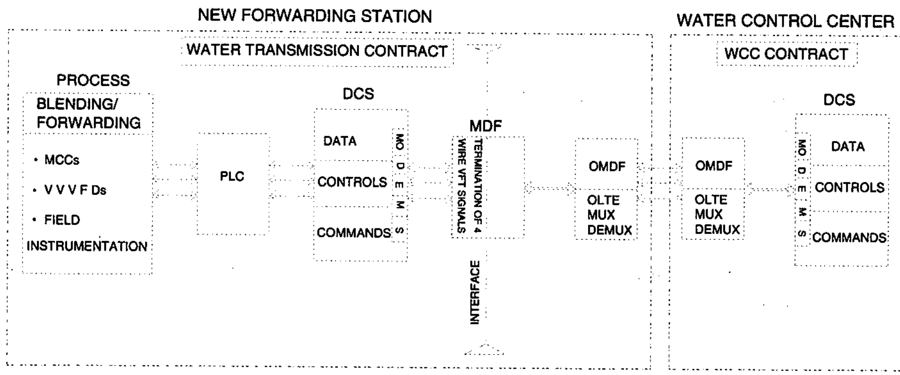

Figure : 7

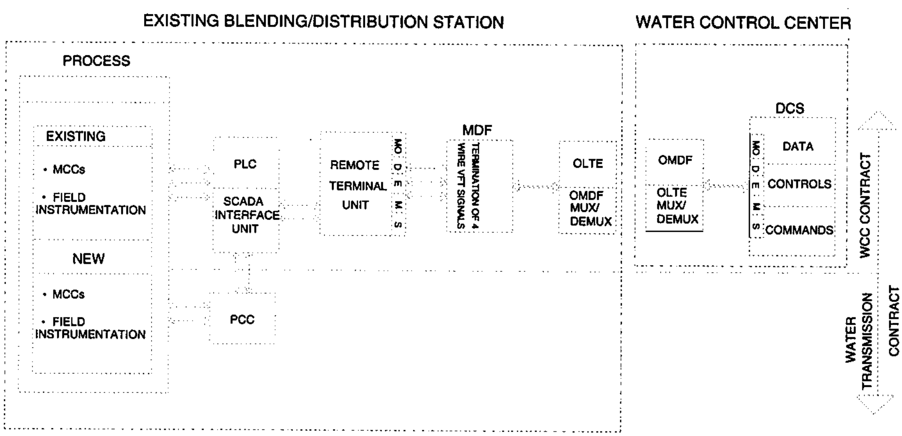

Figure : 8

8.0 CONCLUSION.

The Hidd Water Transmission project is the single largest project of this nature implemented till date in Bahrain. It encompasses many modern concepts for the transmission of water within a network of stations having complex functions.

Careful consideration to the operational regime of the network was given at the design stage; which in turn necessitated the requirement of a complex control system, as highlighted in this paper. The project will increase the distillate supply in the network by 30 Mgd and will reduce the usage of ground water by 15 Mgd. A substantial improvement is expected in the quality of water supplied to the various distribution zones under this project.

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Blending Control in Modern Water Stations

Subhash S. Natu & Saleh Ebrahim

BLENDING CONTROL IN MODERN WATER STATIONS

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ABSTRACT

Availability of abundant ground water and blending of same with the distillate is the normal process of producing potable water in Bahrain. However, depleting ground water quality over a period of time and increase in demand of potable water is exerting tremendous pressure on the water transmission and distribution network.

The last quarter century has witnessed remarkable technological progress in the control and monitoring systems employed in water control centers around the world . The Ministry of Electricity & Water has recently commissioned its new water control centre which uses latest software and hardware for blending ratio control in the Sate of Bahrain.

The paper deals with various methods that are being tried to achieve the desired quality of the blended water with the state-of the art technology which is now available.

This paper deals with the evolution of the Water Control Center (WCC) in Bahrain from its primitive beginning in the eighties to the implementation of new project and presents it as a case study.

INTRODUCTION

In Bahrain, Water Distribution Directorate provides potable water to the consumers in accordance with standards laid down by WHO and Gulf standards. The water transmission network has expanded over the past several years to the level of facilities which include 43 water stations (ground water pumping stations, blending stations, distillate forwarding stations and distribution stations) feeding water in to 164 kms. of water transmission mains followed by more than 1000 kms. of distribution network.

The directorate is responsible for controlled extraction of ground water, blending of this ground water with desalinated water, chlorinating the blended water, its quality control and distribution of the potable water to the consumers.

The need of a centralized water control centre to have proper blending and other control functions was felt and a modest beginning was made in earnest in 1980 only for the urban stations. Subsequently the rural stations were added to the network and the control system was partly upgraded along with the old system and with added advantages.

In the year 2000, a completely new water control centre (WCC) was commissioned along with LDC and DCC.

This paper on blending ratio control is explained in the following manner:

- Blended water production philosophy.
- Blending ratio Control Concept.
- Conductivity Control Concept.

WATER STATION PROCESS

Please refer to Figures 1 & 2 which depict the blended water production philosophy in the following manner:

Fig.1: Stations Fitted With Blended Water Tanks

These stations are : Hamad Town B.S, Hidd B.S, Muharraq B.S, Sitra B.S. and West Riffa B.S

Each blending station receives ground water from localized bore holes or nearby minor stations. The ground water thus extracted is stored in the ground storage tanks. The station also receives desalinated water from the production plants directly or from the intermediate distillate forwarding stations. The distillate is stored in the ground storage tanks

All incoming and outgoing water flow rates are measured for leak detection and material balance.

The ground and distillate water is then blended to predetermined ratio. This control is the key to blending process. Blending ratio or conductivity acts as the set point to the control algorithm. This basically is a cascade loop with flow acting as slave set point.

Blended water thus produced is stored in blended water tanks. The water is then chlorinated and water quality is tested with help of on-line analyzers for conductivity, pH and residual chlorine content of water. The blended water is then pumped to the elevated tanks and is ready to be supplied to the consumers. The line pressure in the distribution mains is controlled through motorized valves in the outlet of the elevated tower with a preprogrammed pressure regime.

The instrumentation used includes flow transmitters, level transmitters, pressure transmitters, water quality analyzers, motorized valves, indicators, alarm annunciators, trip amplifiers etc.

All measured signals are available to the station operator (on the control panel) as well as to centralized control centre. The transmission of signals to the control center is achieved with the help of remote terminal unit (RTU) The equipment in the station operate in three modes viz.: Local Hand, Local Auto and Remote control i.e. from WCC.

Fig 2:Stations NOT Fitted With Blended Water tanks

These stations are Hoora B.S, Mahooz B.S., Musalla B.S. and Salmaniya B.S. In some stations the interim storage of blended water is avoided and blended water is directly pumped to the elevated tanks.

Blending Control Concept

Please refer to Figure 3 which gives the blending control philosophy used in water stations up to 1999.

Problems encountered in operating this control concept:

- Rapid fluctuation in ground water speed was observed as soon as the blending ratio controller was put in Auto mode. This behavior was considered to risk electrical and mechanical parts of the ground water pump.

- Lack of the sufficient distillate was also one of the reasons for not being able to put this controller in to service

- The system was designed in such a way that the ratio control should be able to achieve with 1 distillate pump and one ground water pump in the duty mode. However the pump capacities in many stations prevented the ratio settings to beyond 1: 3.

BLENDING RATIO BASED ON CONDUCTIVITY

In the year 1997, Ministry of Electricity and Water, State of Bahrain, decided to completely upgrade the old water Control Centre along with LDC and DCC and prepared terms of reference.

Figure 4 shows the SCADA system concept.

The salient mile stones and features of this project are:

The WCC system hardware is based on servers and workstations cooperating in client-server configuration through redundant LAN.

- The Technology uses open system hardware with dual redundant SCADA servers for data processing and user interface software

- Redundant communication using telemetry links, fiber optic cables and microwave network

- Dual redundant communication front end server for data acquisition from RTU

- Latest RTU using industrial open system protocol IEC 870 – 5 – 101.

- Geographical positioning system clock for time synchronization.

- Graphic user Interface

- Smart instrumentation for Flow, Level, Pressure and Water Quality parameters

BLENDING CONTROL CONCEPT FROM YEAR 2000

Please refer to Figure 5. In order to circumvent the problem of indirect control through blending ratio, it was decided to switch over to the direct conductivity control. In this case the water control centre calculates the desired blended water conductivity as the set point to the local controller. This set point is based on the ground water and distillate water conductivity. The local controller will act on the deviation between set point and actual measured values and vary the speed of the ground water pump.

The advantages of this method are :

1. There is no limitation on ratio of mixing Ground Water and Distillate.

2. This method takes care of deteriorating Ground Water quality.

CONCLUSION

This paper has shown that experience along with state-of–art control centre techniques can improve the quality of potable water. The blending control is now switched to conductivity control instead of the blending ratio control which has surmounted the ground water pumps from tripping due to speed changes.

The control will continue to function irrespective of the deteriorating ground water quality and as long as the distillate water is available in sufficient quantity.

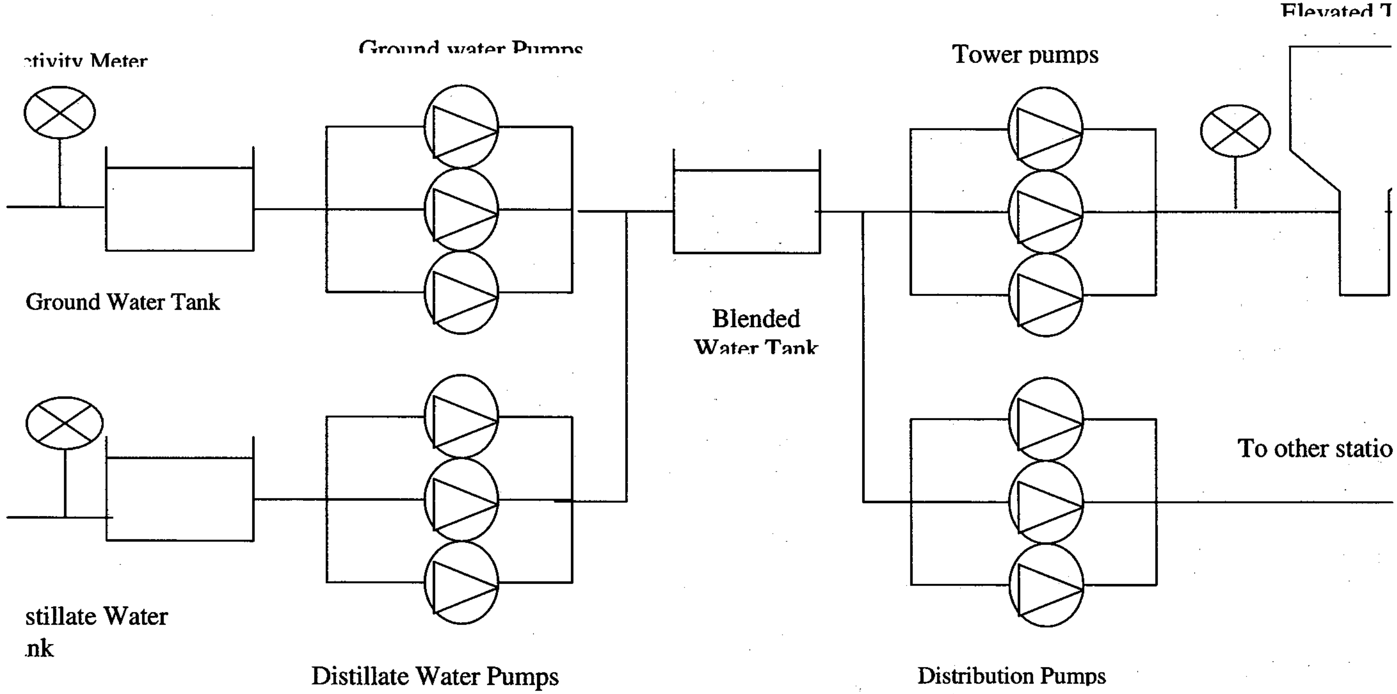

Fig – 1 **BLENDED WATER PRODUCTION PHILOSOPHY IN BAHRAIN**

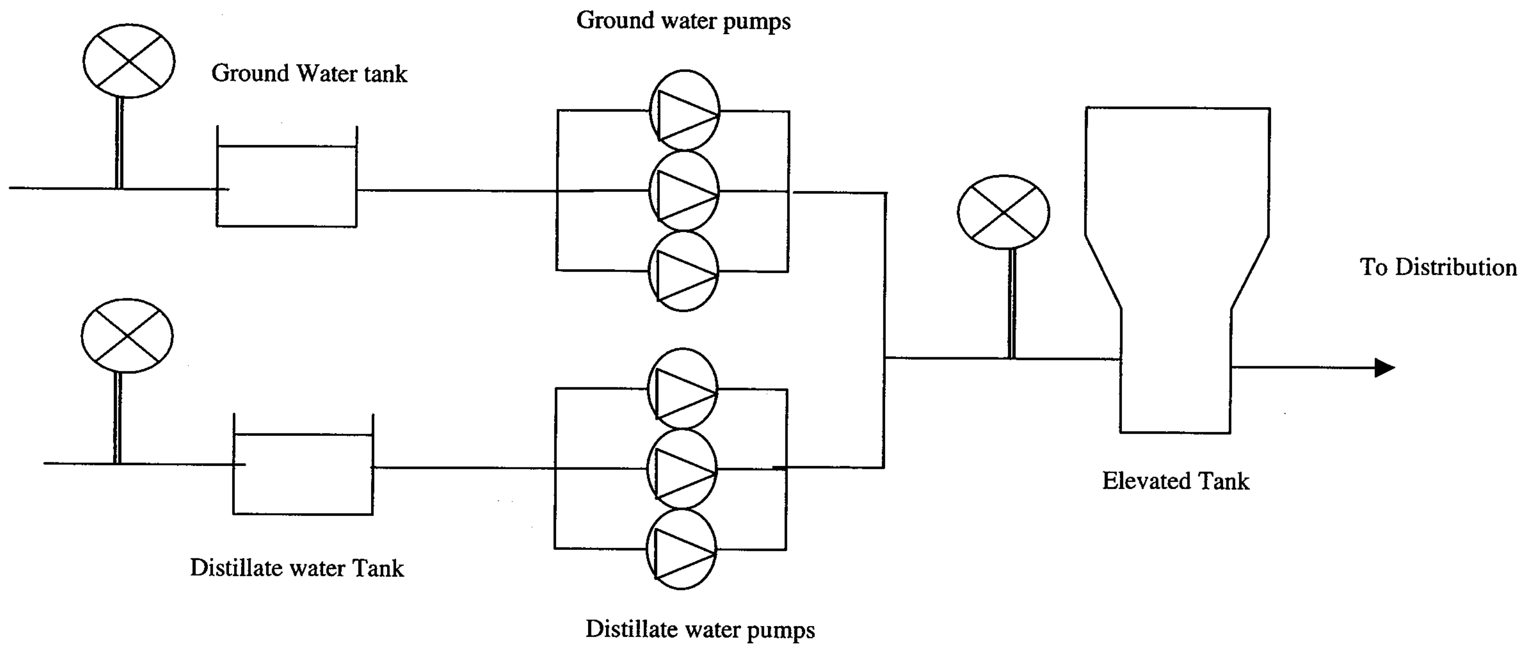

Fig – 2 __BLENDED WATER PRODUCTION PHIOSOPHY IN BAHRAIN__

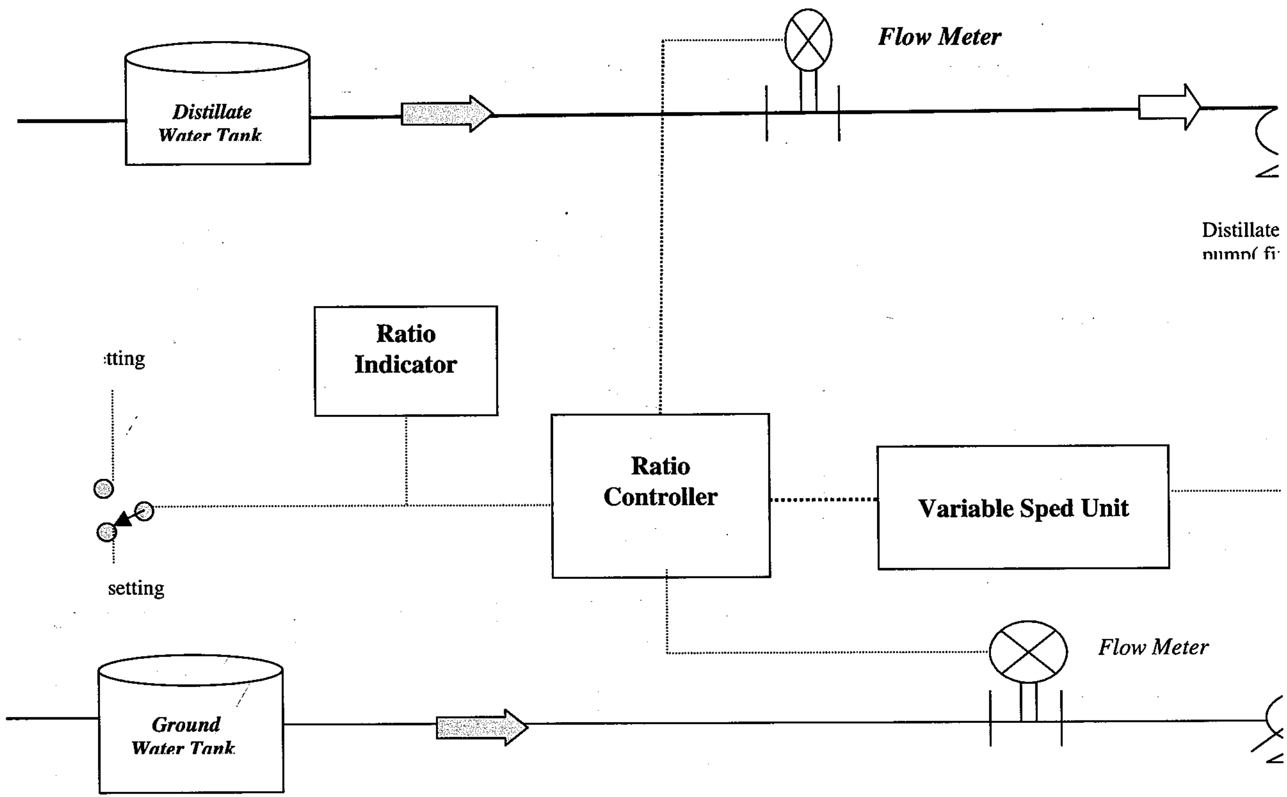

Fig – 3 <u>**Blending Ratio Control Schematic Diagram**</u>

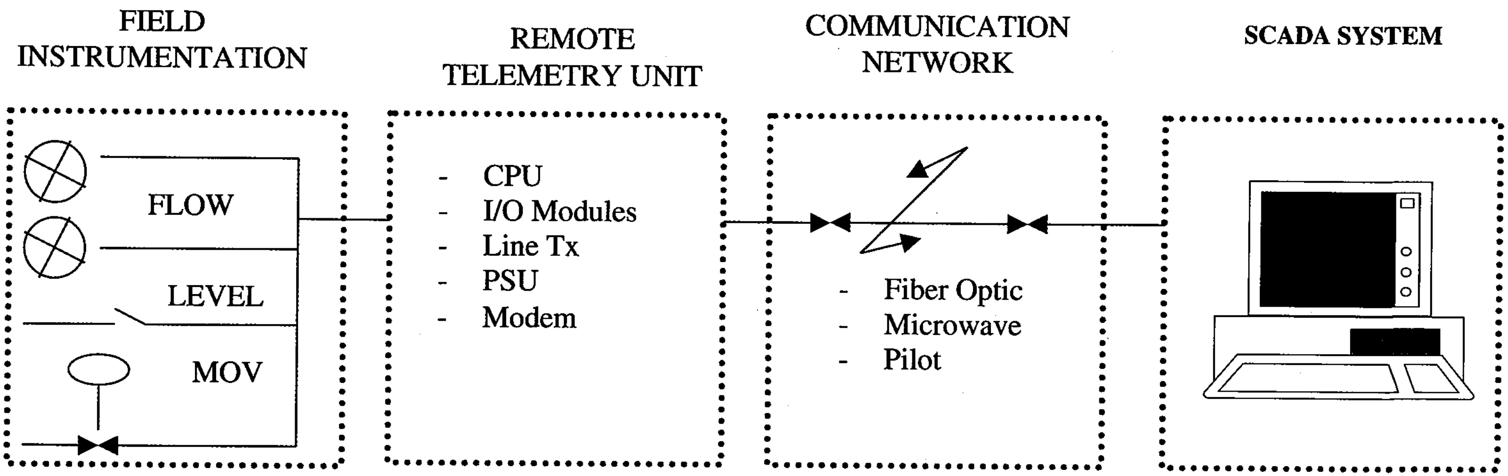

Fig – 4 <u>**Schematic Diagram of Water Control Centre**</u>

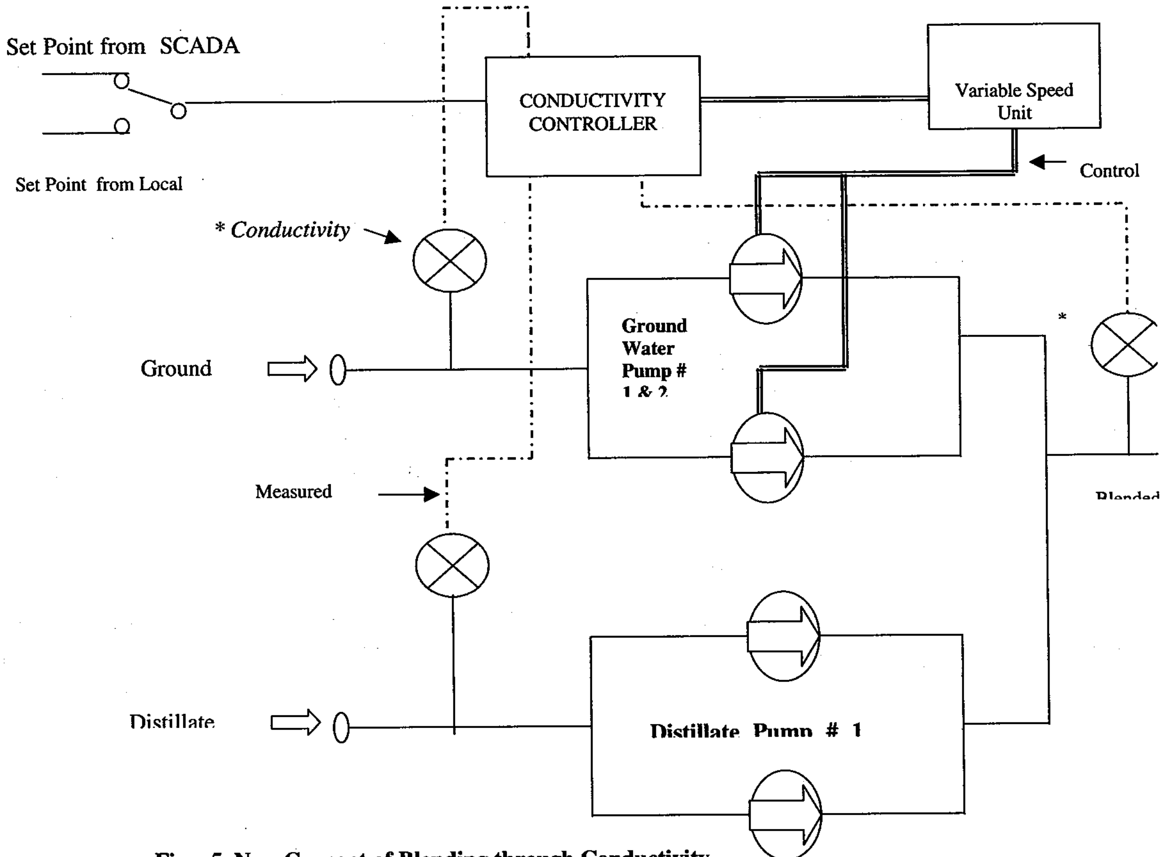

Fig – 5 **New Concept of Blending through Conductivity**

Leakage Control Experience in Bahrain

Ms. Hana Hussain Al-Maskati

LEAKAGE CONTROL EXPERIENCE IN BAHRAIN

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ABSTRACT

With extremely limited natural water resources the majority of Gulf Cooperations Council countries depend on water desalination to satisfy drinking and other municipal water demand.

Due to high cost of water production by this process, Bahrain recognized the importance of minimizing wastage of water. The initial study of unaccounted-for water (UFW) on Bahrain water distribution network showed an alarming rate of distribution losses of 45%, this figure was reduced to 25% by applying various waste control techniques, such as:

- Waste control exercises,
- Non standard defective mains replacement,
- Pressure control,
- Improve workmanship
- Introduction of supply ceiling,
- Water conservation.

The paper reviews the techniques being presently used in reducing the leakage rate, and shows their effect on demand forecast. For example water demand in 1999 was reduced from 533.81 x 10^3 m^3/d to 307.74 x 10^3 m^3/d. Further reduction in future water consumption is expected to be between 10%- 15% due to reduction of leakage control programme applications.

Key words: Waste management, pressure control, water conservation, waste zone, Bahrain.

1.0 INTRODUCTION

Until 1975 Bahrain depended entirely on ground water to meet the demand Simple chlorination technique was done and water was pumped directly in the distribution network through pumps running for 24 hours. Due to the absence of automatic monitoring system to control flow and pressure, the pressure increased tremendously in the network during low consumption creating large number of leaks.

The rapid development witnessed during the 1980's and the growth in population were the impetus for development of alternative water resources. For example since 1980 Bahrain average daily consumption has risen by approximately 29%. This was the beginning of the construction of desalination plants era in the country to enhance the water production capacity. Until very recently Bahrain had 3 water desalination plants with a combined production capacity of 69.12 M m^3/y. 49.77 M m^3/y of ground water were used for blending purposes to meet the demand of water. The new Hidd Power and Water desalination station phase I with a design capacity of 49.77 M m^3/y of distilled water output came into operation by April 2000.

Construction of such plants was followed by construction of more blending stations. Which are equipped with automatic system to facilitate the control and monitoring the quantity, quality, chlorination and pressure. Also the system was controlled and monitored by control center, which was built in late 1980's. The massive information provided by the system has largely improved the reports generated in respect of daily reports, storage and water situation, and systems deficiencies.

The improvements had also covered the distribution network, as the network was built from cast iron, Copper and Galvanize pipe, which was undergoing a series of problems, such as corrosion and abrasion. In the beginning it was replaced by Low Density non standard Polythene Pipes (L.D.P.E). And that was in the beginning of early 1970's, but unfortunately, due to the absence of monitoring tools to insure the suitability of such pipes in resisting the ground condition, they fracture after a while. To understand the problem in its proper perspective the Ministry initiated a study with other consultant to study the problem and a recommendation was to use light and medium density Polythene pipe (MDPE) per British standard.

Part of the changes in the distribution network maintenance was to computerise Complaint Center to look after, and monitor over 24 hours, leaks, short water complaints, metering. This center has helped to change direction of lots of programme by providing accurate information about the system deficiencies.

The information provided by the complaint center, gave the Ministry the guidelines to set the priorities for those programme related to construction, waste detection, water conservation and pipe replacement and had significant input in reducing leakage.

At present the water distribution network caters primarily to sectors of economy such as domestic, commercial & industrial consumers, Ministry of Electricity and Water supply operates over 109 m^3 of water per year to them through a network of 54 reservoirs and water Towers, 145 km of water trunk mains between blending stations, 1000 km of water distribution mains in the distribution network, 3 Km of service mains, and 43 pumping stations. Agriculture & landscape irrigation depends almost entirely on ground water and treated sewerage effluent (TSE), and it is the responsibility of other body (Ministry of Works & Agriculture).

Population in Bahrain has increased recently, due to the development and improved of standard of living. This has an effect on water demand. Ministry faced growing in water demand because of high per capita consumption and high level of unaccounted for water (25%) in water network, which has an impact on the need for future desalination plant. The fact that Bahrain is located within an extremely arid region. It has limited renewal fresh water, which have been nearly fully developed. In addition high cost production of desalination plant construction as well as their cost of operation and maintenance, Bahrain recognized the importance of minimizing the wastage of water by adopting practical and economical leakage control programme and applying various waste control techniques, such as:

- Waste control exercises,
- Non standard old defective mains replacement,
- Pressure control,
- Improve workmanship
- Introduction of supply ceiling
- Water conservation

2.0 AN OVERVIEW OF LEAKAGE CONTROL PROBLEM

The initial study of unaccounted for water (UFW) on Bahrain water distribution network was carried out in 1984 by Water Research Center WRC (England). It showed an alarming rate of distribution losses. Exercises done in the trial zones reported a gross UFW figure of 45% [1]. With the very high cost of water production, dwindling ground water resources and increasing demand, the Ministry of Electricity and Water, Water Distribution Directorate launched the leakage control program in 1985. The first test was carried out in three different areas to identify leakage levels and to evaluate the leakage control programme impact in reducing leakage level. Table (1) shows the result that can be listed below:

1) The total daily water in the three locations was reduced by 36% of the initial water consumption.

2) The minimum night flow in the areas was between 46 l/prop/h and 120l/prop/h it was reduced to 4 l/prop/h in one location.

3) Most leaks were found in (LDPE) none standard pipes.

Waste management is often carried out in a crisis management situation in response to an increase in leakage level. There is often a similar approach to the replacement of pipelines in response to frequent water quality failure or economically unacceptable frequent of burst.

3.0 THE TASK LEAKAGE CONTROL

The unit has the prime responsibility lower the high rate of water losses from the distribution network (before the customer meter) to an economically viable limit in an efficient, scientific & financially feasible manner. The unit has been assigned with the following tasks:

1. Planning and establishing of small and manageable distribution network areas termed as "waste zones".

2. Monitoring the consumption and minimum night flow information of waste zones on a daily basis, for a limited number and identified waste zones using special built computer software & data collection equipment.

3. Conducting leak detection exercises to locate & repair unseen leaks in established waste zones, and periodically monitor the supply to these zones on weekly basis for verification if any.

4. Identifying night consumers and advise the Water Conservation Directorate to check for leaks on consumer side of the meter or mark them as candidates for water conservation efforts.

Table 1: First test exercises results

Location Block	Property #	Initial minimum Night Flow	Initial Consumption	Final Minimum Night Flow	Final Consumption	Daily Saving in consumption	Costing of exercise BD.
West Riffa Ministry of Housing **Block 901** **East Riffa**	63	2.1 l/s 120 l/prop/h	185 Cum/day	0.07 l/s 4.0 l/prop/h	98 Cum/day	87 Cum/day 47%	3,600
Ministry of Housing **Block 901** **& Block 931**	342	9.5 l/s 100 l/prop/h	1,212 Cum/day	0.85 l/s 9.0 l/p/h	676 Cum/day	536 Cum/day 44%	16,670
Hamad Town **Block 1204**	869	11.2 l/s 46 l/prop/h	1,725 Cum/day	4.2 l/s 17.4 l/p/h	1,225 Cum/day	500 Cum/day 29%	6,800

5. Analysing the network using Information Technology database, identify repeated leak areas and then arrange for main replacement.

6. Continue applying pressure regime as it has successfully achieved the control on demand/ leakage.

This paper, highlights the development of computerized controlled district metering system which designed to provide the most cost effective method of controlling leakage and saving out staff effort, travelling time, and cost.

3.1 Role of Waste detection Unit in reducing leakage

In order to quantifying the leakage more accurately, the unit has established waste zones to cover the entire water distribution network. Subject to new township development, at present it is estimated that 460 zones are required for complete coverage. As of September 2000, 434 zones have been established around Bahrain mounting to coverage of approximately 94% of the distribution network.

Realizing the importance of simulating the effects of waste zone isolation, Watnet network analysis software is used for zone planning purposes.

Zone establishment criteria :

- Whether the zone can be fed from a single line without risking significant drop in supply pressure throughout the zone.

- Size of the zone is manageable; typically not exceeding 300 properties.

Figure (1) shows Waste zone schematic drawing.

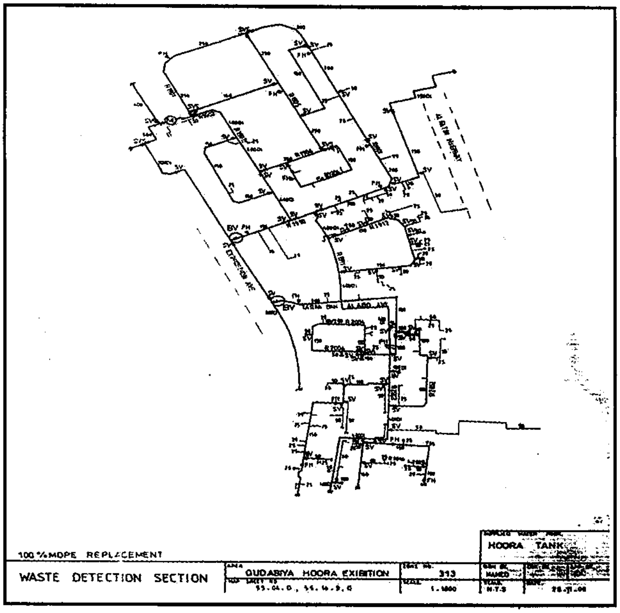

Figure: 1

3.2 Monitoring and leakage control record management system

An in-house computerized record management system, which was developed & established in 1991 to effectively manage the data of all waste zones data and generate management information reports. As shown in Table (2).

In 1995 period a remote flow and pressure data gathering system via PSTN (Public Switched Telephone Network) was installed on a trial basis in 33 waste zones. The telemetry system was supplied & installed by M/S Radcom Technologies Ltd., England in collaboration with Water Distribution Directorate. The system has lot of advantages as it a tool for monitoring flow and pressure for some of Zones. Unfortunately the reliability could not be insured because of the repeated failure often due to humidity accumulation in the system.

3.3 Leak detection exercises and leak repairs

Leakage detection carried out by Water Distribution Directorate is focussed on analysis of night flows measurements in Waste zones. A dedicated team is responsible for conducting site surveys using the latest available equipment to study the initial and final night flows, and finding out the percentage of unaccounted for water in each zone contributed to the largest reduction in the quantity supplied.

Table 2: Summary night exercises report of Waste Detection Zones
For the completed exercises on July 2000

SR. NO.	Zone # & Name	IMNF L/S	IMNF L/D/HR	FMNF w/o/c L/S	FMNF w/o/c L/D/HR	FMNF w/c L/S	FMNF w/c L/D/HR	# of Leaks Found	initial Cons cu.m/d	final Cons cu.m/d	Cons Saving %
1	616 Sitrah B. 608	1.71	410.40	1.54	369.60	0	0	0	221.05	199.87	9.58
2	H37 Hamad T. B. 1214	2.72	53.22	0.86	16.83	1.06	20.74	6	704.20	531.80	24.48
3	H42 Hamad T. B. 1216	4.66	65.28	0.92	12.89	0.12	1.68	13	878.91	800.90	8.88
	Total		**571.69**		**418.49**			**19**	**1583.11**	**1332.70**	**15.82**

3.4 Achievements during 1985 - 1999

Up to year-end 1999 Waste Detection exercises have been carried out (at least once) in 382 waste zones. This unit has completed waste detection exercises in an area where the total consumption is approximately 394,253 m^3/d and achieved an initial saving of 46,565 m^3/d or more than 11.8%. As per July 2000, the leakage is now reduced to a range of 15-17% of the total supply in about 50 % of the zone established. The contributing factors other than waste detection for this reduction were; replacement of old polyethylene pipes, water conservation campaigns, and pressure control of the distribution network. The achievement in some areas is more outstanding; for example a leakage figure of more 15 % has been achieved in about 50 % of the zones established. Table (3) shows cost and water saving through waste detection exercise during the period 1993-1999. Figure (2) indicate the exercise achievement (Percentage saving in minimum night flow) during the period 1985-1999. While table (4) Figure (3) shows that the total daily consumption in areas where exercises were completed in 1999 dropped from 42,258.11 m^3/d to 38,554.64 m^3/d, approximately 8.76%.

Table 3 : Cost and water saving through Waste Detection Exercise during 1993-1999

Year	# of Leaks	Consumption Saving m^3/day	Total Cost of repair BD	Unit Cost of repair BD	Annual Water Saving in M^3	Unit Cost of saving BD/m^3
1993	610	5,967	48,667	80	2,177,955	0.022
1994	358	5,427	29,625	83	1,980,855	0.015
1995	114	2,505	25,069	220	914,325	0.027
1996	155	3,903	30,750	198	1,424,595	0.022
1997	290	5,824	44,336	153	2,125,760	0.021
1998	225	3,079	29,253	130	1,123,835	0.026
1999	276	3,703	40,666	147	1,351,595	0.030
Total	*2,028*	*30,408*	*248,366*	*1,011*	*11,098,920*	*0.163*
Average	*290*	*4,344*	*35,481*	*144*	*1,585,560*	*0.023*

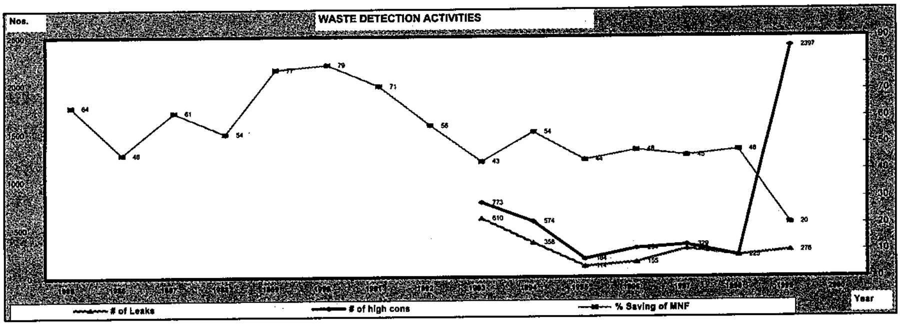

Figure 2 : Waste detection exercise achievement during 1985-1999

No. of waste zones established	**:**	**432**
Saving in Daily Consumption	**:**	**3,703 Cubic Meters Per Day**
% Daily Consumption Saving	**:**	**8.76% (Compared with initial consumption)**
Saving in Minimum Night Flow	**:**	**102.90 Litres Per Second**
Saving as a % of IMNF	**:**	**20.31% (IMNF - Initial Minimum Night Flow)**

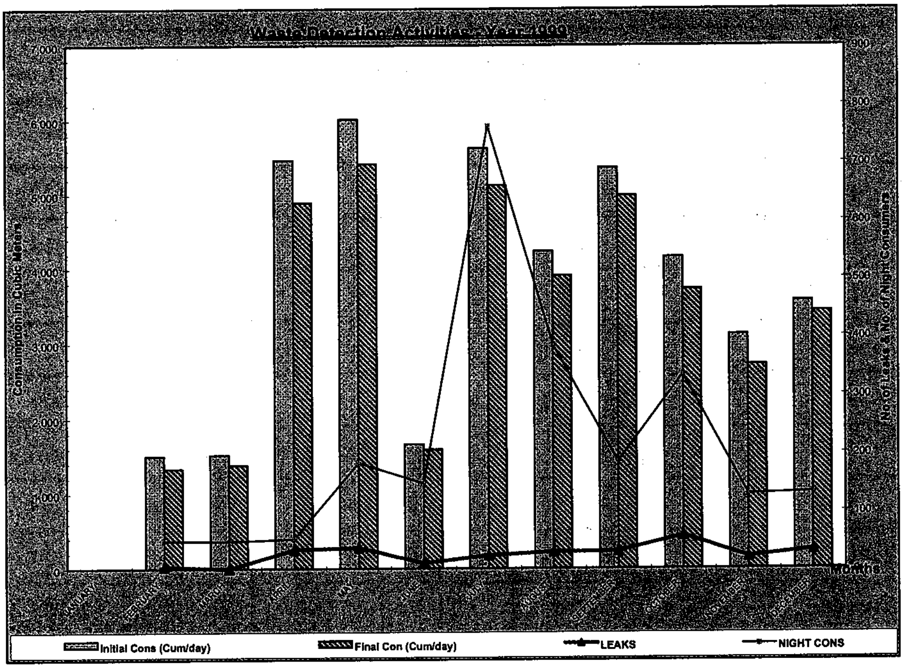

Figure 3 : Waste detection exercise achievement during 1999

Table 4 :Achievement of waste detection exercise during 1999

	MONTH	NO. OF DWELL	INTIAL		FINAL		NUMBER OF		CUMULATIVE	No. of Zones Exercised
			CONSUMP. (Cu.M./Day)	MNF (L/S)	CONSUMP. (Cu.M./Day)	MNF (L/S)	LEAKS	NIGHT CONS	COST OF EXERCISE	
1	JANUARY	Waste Detection Activities Confined to Day Time - Holly Month of Ramadhan								
2	FEBRUARY	858	1,505.59	7.98	1,338.87	3.19	4	48	1,968.68	5
3	MARCH	1,464	1,521.61	10.99	1,386.17	5.62	0	47	1,337.38	3
4	APRIL	1,545	5,464.95	125.13	4,895.74	48.94	33	51	3,358.85	5
5	MAY	3,307	6,013.18	71.11	5,414.11	210.42	36	182	7,191.13	13
6	JUNE	773	1,664.07	16.35	1,594.26	9.59	10	147	1,978.10	5
7	JULY	2,528	5,621.93	63.30	5,125.14	22.54	23	762	5,106.92	11
8	AUGUST	2,473	4,240.14	37.75	3,914.99	15.70	29	383	4,292.80	10
9	SEPTEMBER	2,208	5,363.46	66.42	4,988.61	31.49	30	184	4,542.88	9
10	OCTOBER	1,868	4,163.18	47.44	3,736.65	27.04	57	333	3,939.68	10
11	NOVEMBER	1,417	3,124.07	27.85	2,721.49	10.49	21	128	3,556.85	7
12	DECEMBER	1,314	3,575.93	32.22	3,438.61	18.62	33	132	3,392.43	6
	TOTAL	**19,755**	**42,258.11**	**506.54**	**38,554.64**	**403.64**	**276**	**2,397**	**40,665.67**	**84**

4.0. REPLACEMENT OF OLD DEFECTIVE MAINS

In order to exhibit low values of UFW, the Ministry of Electricity and Water has supplemented active leakage control policies with a comprehensive, annual main replacement programme for replacing old defective service connections.

The Ministry has set a replacement program, which started in 1985. This programme is based on static report received from complaint center indicating number of repeated leaks in the main. The report showed the banning of un appropriate materials for example Polyethylene mains and adoption of newer materials such as Low Density Polyethylene (LDPE), and Medium Density Polyethylene (MDPE), which the later has super hydraulic and resistance properties. This has made a further contribution towards leakage reduction, and hence lower UFW. The report also guides waste detection where to start night exercises. Table (5) below shows replacement activities during 1992-1999

Table 5: Replacement activities during (1992 - 1999)

Activities	1992	1993	1994	1995	1996	1997	1998	1999
Length of poly pipes Replaced (m)	155449	57701	92050	79954	113640	152624	134751	10670
New Connection (No.)	3314	2941	3590	3619	2154	2143	2307	2752

5.0 PRESSURE CONTROL IN DISTRIBUTION NETWORK

As mentioned earlier in the past, water pumped in the distribution network was controlled by flow level. Operation did not cater for peak demand, static pressure was building up at night under low flow condition, causing large number of leaks. Also the Low Density non standard Polyethylene pipes which were laid at that time were not capable of withstanding high pressure which caused rate of leakage.

Further reduction in wastewater was achieved by adopting pressure regime for districts, as leakage rate is roughly proportional to the pressure in the mains. A possible stopgap measure is to reduce the pressure where possible.

The Ministry adopted pressure system control in 1987. The pressure established and controlled from the stations vary from one area to another depending on topography of the land, and nature of the population. The system was very effective in reducing supply, solving short water complaint, and minimising the leaks in the distribution network.

6.0 WATER CONSERVATION

Ministry of Electricity and Water has launched water conservation programme starting in 1986, to reduce water consumption by adopting the following measures:

- School campaigns
- Enforce the use of Treated effluent in irrigation
- Use of universal metering
- Use of more efficient water saving appliances in Bahraini households
- Reduction of sprinkler and garden watering,
- Installation of water saving devices in mosques, hotels, hospital, school, etc.
- Identify places with illegal connections and cancel it
- Identify places with connections but without meters and meter it.

The programme began with slow progress. The proper creation and development of conservation programme started in 1992.

6.1 Achievement during 1999

Table (6) shows the Water Conservation Directorate achievement during 1999.

7.0. LESSON LEARNT BY ADOPTING LEAKAGE CONTROL PROGRAMME

It is considered that significant improvement in water saving can be achieved by an intensified leakage reduction programmes which has its own role to change the direction of demand. Also by applying various methods of water conservation. Both have large potential to conserve the supply, maintain the ceiling of 70 mg/d, minimizing the deterioration of ground water, monitor and control water consumption.

Ministry of Electricity and Water adopted the two methods, which had an effect on the water demand forecast during the last decade.

By looking at the consumption statistics for the past 14 years (1985 – 1999) as shown in Table (7), we find that percentage of average increase on consumption dropped from 6.7% to 1.4 % between 1985 -1998, while in year 1999 it was -0.19 % due to water ceiling of 70 mgd. (1mgd = 4545 m^3d)

Table 6: Summary of water Conservation achievement during 1999

	Sudden increase in consumption	Bulk consumers	Ministry of Interior	Ministry of Education	Ministry of Information	Mosque	Additional Connection	Use TSE	Total	Total Saving BD
No. of visits	5482	905	40	38	1	34	122	302	6924	
Locations where leaks detected	2164	155	4	23	0	5	16	0	2367	
Rate of leakage (Cubic meter / day)	12643	1241	67	361	0	60	91		14463	
Saving in agriculture (Cubic meter / day)	7008	2669	600	127	30	0	0	0	10434	
Daily saving due to water consumed equipment	184					31	41		256	
Total daily saving (BD.)	7,934	1,564	267	195	12	36	53			10,061
Total annual saving (BD.)	2,895,910	570,860	97,382	71,248	4,380	13,257	19,316	0		3,672,353

Table 7: Consumption statistic during (1985 - 1999)

Year	Average daily Consumption mgd	Average daily Consumption m³/d	% increase in 10 years	% annual increase
1975	16	72720	-	-
1985	48	218160	67%	6.7%
1995	64.38	292607	25%	2.5%
1996	65.64	298333	-	1.9%
1997	66.92	304151	-	1.9%
1998	67.87	308469	-	1.4%
1999	67.71	307741	-	-0.19%

The reduction achieved was the result of continuous coordination and continuous follow up, of all the programs.

Figure (4) shows that in 1999 the average consumption was 307.74 x 10^3 m^3/d, while the expected demand should have been 533.81 x 10^3 m^3/d, where there was a saving of 226 x 10^3 m^3/d.

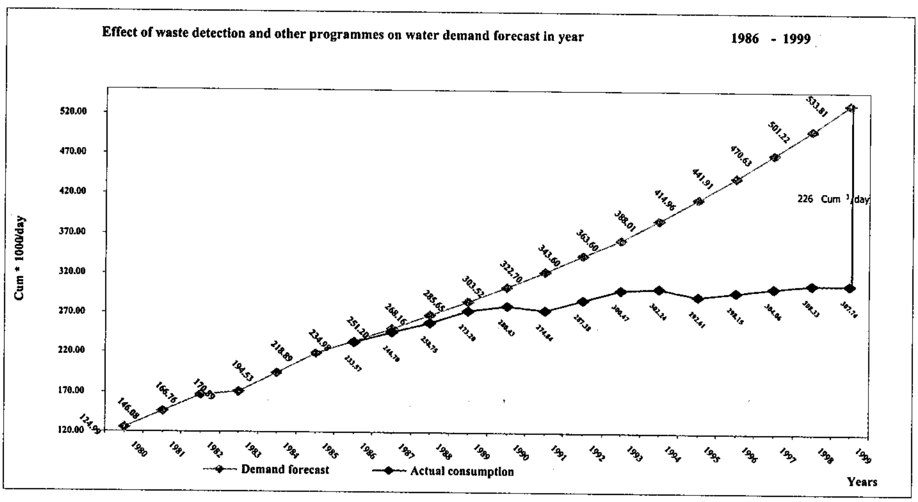

Figure: 4

8.0 COMMON PROBLEM FACED

a. The minimum Night Flow (MNF) does not represent the leakage entirely. It is also influenced by the legitimate consumption during night e.g. filling tanks, gardening etc.

b. The night pressure reduction has also influenced the leak detection exercises.

c. Difficulties if there was illegal connections, would waste the time of inspector in doing exercise of step test looking for leaks.

d. Working environment for example, In winter season, climate is not good for sounding due to winds.

e. Passing Boundary valves and Passing Sluice valves during step test

f. Opening of boundary valves by Maintenance staff due to meter blockages/ pressure problems, etc.

g. House meters located inside the compound & not accessible for night fieldwork.

h. Equipment failure.

9.0 FUTURE PLAN

1. Continue establishing waste detection zones till maximum coverage is achieved.

2. Expand the consumption monitoring system to cover all the waste zones to enable remote reading of pressure and flow.

3. Continue replacement of old polyethylene pipes.

4. Enhance the accuracy of the billing system and introduction of hand held computers for meter readers.

In additional to above it is proposed to install two vital telemetry controlled Waste Zones for each tower / ground station feeding a township area & install loggers to collect all information during night exercises instead of depending on manual readings & data. This will eliminate human error & allow us to narrow down our decisions based on more reliable & correct data. It is also planned to use noise loggers (which operate automatically) without interfering with the distribution network especially in urban areas to identify areas of potential leakage for further investigation & control.

10.0 CONCLUSION

a. UFW and leakage controls are extremely important and can make a major financial impact. For instance by applying all the above measures, a further reduction in future water demand is expected, and it is assumed to be between 10% - 15%. As indicated in Figure (5). The forecasted demand depend on: population forecast, per capita usage, and conservation measures.

This demand forecast projection is based on situation during 1990's and the new millenium which will under go drastic change in view of policy of the government population growth, and water conservation measures which are implemented.

We may be able to satisfy Bahrain population demand (with annual growth of about 5 %) with 377.23 x 10^3 m^3/d – 386.32 x 10^3 m^3/d during the year 2000.

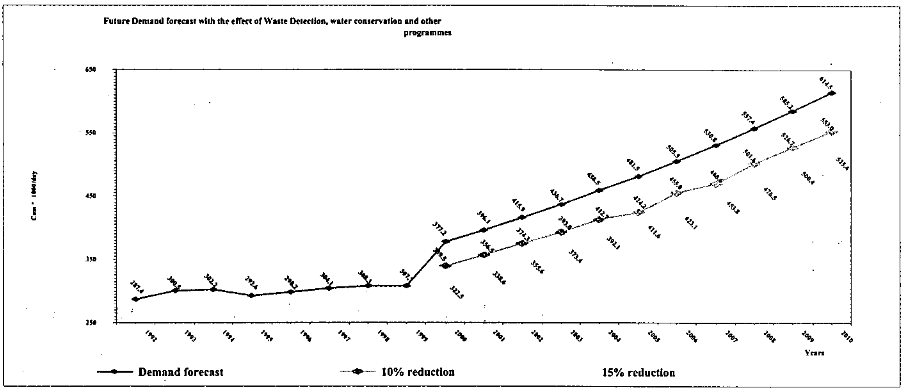

Figure: 5

b. Saving cost for construction of new water tanks and distribution network system.

c. Reduce energy used for transmitting and distributing water.

d. A thorough knowledge of the distribution system is required to operate such programmes efficiently

e. The leakage control activities programmes that are adopted by Bahrain must be maintained if the improvement gained are not to be lost. Leakage control must therefore be viewed as a major component of the regular operation and maintenance activities undertaken by Water Distribution Directorate, with fully dedicated and well trained staff allocated to monitor, detect and control leakage.

f. In view of the increasing demand for water and its scarcity world wide greater emphasis must be given to leakage control and UFW programmes if we are to avoid major problems in the future.

11.0 RECOMMENDATION

a. UFW and leakage control programmes require the development of modern detection equipment.

b. UFW and leakage control programmes require a major investment in human resources as they entail fairly labour intensive activities despite the development of modern detection equipment.

ACKNOWLEDGEMENT

The author gratefully acknowledge the advice and co-operation of the Director, the Manager of Water Distribution Directorate, and other Maintenance and Engineering Services Department staff for their assistance and help.

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Fluoridation of Public Water Supplies & the Experience of Qatar

Fahed Bin Mubarak Al Dalaimi and K.J. Hayes

FLUORIDATION OF PUBLIC WATER SUPPLIES & THE EXPERIENCE OF QATAR

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ABSTRACT.

The paper outlines the history of fluoridation in Qatar and describes the initial use of hexafluorosilicic acid. The distillate treatment process is outlined and the problems associated with the first fluoridation plant are described, as is the re-appraisal of the plant after several years' operation. The paper continues with the description of a survey undertaken to find the current practices elsewhere in the world and their relevance to the Qatar situation. Some conclusions are drawn and the future plans for a revised strategy using sodium fluoride are given.

Key words : Fluoridation, Sodium fluoride, Distillate treatment, World policies

INTRODUCTION

For a number of years relatively untreated distilled water was supplied to consumers in Qatar. In 1986 it was decided that a full distillate treatment plant would be built at the main water production facility at Ras Abu Fontas 'A' Power & Water Station (RAF 'A'). This Station provided over 80% of the country's total water supplies at that time and a fluoridation plant would be included. Water from the station is distributed by a separate Department of the Ministry that controls the water network, water towers and reservoirs. This Department also takes into the network water from a second, smaller desalination complex and the water wellfields. A further station, RAF 'B', was later built and commissioned in 1998-9. It also has a distillate treatment plant but not a fluoridation plant. RAF 'B' is not therefore considered in this paper. The total production into the water network is approximately 100 million imperial gallons per day (MIGD).

THE TREATMENT PROCESS

The main aim of the treatment plant is to add minerals to the distillate to make the water wholesome and compliant with World Health Organisation Guidelines. This is partly achieved by recovering the carbon dioxide released from the sea water in the multistage flash distillation units. The carbon dioxide is dissolved in water and the resultant liquor is reacted with limestone in reactor vessels. The output from the reactor vessel is then added to the distillate increasing its hardness. Subsequent to this treatment fluoride, a small amount of sodium carbonate (to adjust the pH) and traces of sodium hexametaphosphate (to complex any iron in solution) are added. Finally, the product is sterilised by chlorination. The chlorine is generated by the electrolysis of sea water and is in the form of hypochlorite. As the hypochlorite is produced as an approximate 1000 parts per million (PPM) solution in sea water a small amount of sea water is passed into the distillate which also increases the mineral content of the water. The final concentration of the chlorine in the water is about 0.7 PPM. A typical analysis of the finished product water is given in Table 1. A simplified general arrangement drawing of the distillate treatment plant is also given as Illustration 1. It will be noted that the plant does not use sea water blending into the product apart from that which goes in with the hypochlorite solution. This is a deliberate policy to eliminate the possibility of undetected contamination entering the potable water supplies.

The inclusion of the fluoridation plant as part of the distillate treatment process was requested by the Ministry of Public Health. This request was agreed and a letter of intent for the entire plant was issued to the contractor in August 1987. Work on the plant was started and the expected commissioning date was July 1989. The total cost was slightly over 56 million Qatar Riyals.

OPERATIONAL EXPERIENCES

As is usual during the construction of any major plant various problems arose but the only significant one to affect the fluoridation plant at this stage was the supply of chemicals. Earlier enquiries had shown that the preferred and most widely used material for fluoridation is hexafluorosilicic acid (fluorosilicic acid, H_2SiF_6) and accordingly the plant was designed to use this material. This acid is very dangerous and many reputable companies are reluctant to ship or even handle the material. Whilst it was comparatively easy to find manufacturers it proved very difficult to arrange transport. This situation has become more difficult as time passes and more and more stringent rules and regulations are passed worldwide in the interests of environmental and personal protection.

In the end it was necessary for the Ministry to purchase 24 special, rubber lined, ISO type, bulk delivery tanks in container frames to send to the acid supplier for filling. These containers can each hold up to 21,500 kg. of acid. It was also necessary to have the tanks certified by the American Bureau of Shipping and registered with the Bureau International Des Containers for a code mark. Without this certification and registration the containers are not acceptable for shipping and if the code marks are allowed to lapse the containers have to be re-certified. This meant that careful control of the containers was essential.

Eventually suitable quantities of hexafluorosilicic acid were obtained and delivered to site and the plant was eventually commissioned in February 1990. The next problem was with the containers themselves. In June 1990 it was noticed that the rubber lining of 3 tanks was badly blistered and wrinkled. The tanks had been holding acid for about a year. An investigation was carried out in conjunction with the suppliers and it was discovered that the rubber used to line the tanks contained large amounts of silicon dioxide. This material was used as filler in the rubber manufacture and can react with the small amounts of hydrofluoric acid (HF), which is normally present in commercial grades of hexafluorosilicic acid. This discovery required all the tanks to be returned to the manufacturer for replacement linings as they became empty. There have subsequently been several other failures due to imperfections in the linings even though the tanks were thoroughly inspected after repairs. This was expected to be an ongoing problem.

A RE-APPRAISAL OF THE PLANT

The plant continued to run relatively uneventfully until November 1992 when an overall appraisal of the plant and its operation was carried out by the station staff. This was prompted by a number of relatively minor leaks of acid from pumps and flanges and the general difficulties in maintaining the equipment. In addition some new technical advice on the construction and operation of fluoridation equipment had been received and the plant was examined taking into consideration this information [1,2].

The results of the review were unequivocal. The plant had many defects and shortcomings in the design of the equipment, its layout and safety features. For example it was found that the neutralising facilities were greatly undersized, the flushing connections were insufficient to clear many lines, pipe work runs were made over unprotected power and instrument cables and inadequate isolations were provided.

By the conclusion of the review it was necessary to begin the purchase procedures for a new supply of hexafluorosilicic acid. However it was decided to postpone the purchase whilst consideration was being given to the problems of distribution of treated water to the consumers. As mentioned earlier the Ministry has only one fluoridation plant but several water producing centres. It is therefore possible to treat the RAF 'A' output to the accepted concentration only to have it later mixed with untreated waters diluting the fluoride concentration. As the water distribution network is, of necessity, flexible the frequent changes within the network mean that it is not always possible to be certain where the product of a particular water source goes. As many consumers always receive undiluted RAF 'A' water it is not possible to overdose at source to allow for subsequent dilution. As a result of this any consumer receiving mixed source water will be receiving a low dose of fluoride. It is generally considered that there is a threshold concentration below which fluoride is ineffective so the treatment is of no use to many consumers. There is also, of course, a maximum fluoride level above which medical problems can occur.

THE NEXT STEPS

As a result of these factors and because no disposal facilities were available it was decided that the plant should continue to run to use up the remaining stocks of acid. In the meantime advice would be sought on the latest thinking on both the necessity and effectiveness of fluoridation. The results of this review would help decide what action to take on the existing plant. Additionally it would help define the future policy of the Ministry. Several letters [3] were sent to Water Authorities & Institutions in the UK, Holland, America, Scandinavia and the GCC. The letters all posed six questions that were thought relevant to our situation. The questions were:

1. Does current thinking still regard fluoridation as necessary?

2. If yes, is fluoridation using hexafluorosilicic acid the best way to go or are other materials preferable.

3. If no, what were the reasons for stopping?

4. Are there any alternatives to fluoridation of water supplies that are presently in use?

5. Did privatisation of water supplies change company policies in any way?

6. What are the legal requirements covering the safe disposal of fluorides in your area?

THE RESULT OF THE ENQUIRIES

Over a period of weeks several replies were received each of varying detail but all of which addressed the questions asked. It is clear that there is a significant variation of view as to whether or not to add fluorides to drinking water. This controversy has been raging for a long time and has not been resolved to date. However it was apparent that the latest practice, certainly in Western Europe and also in other developed countries, was to move away from mass fluoridation and on to more individual methods such as fluoride containing toothpastes, tablets and bottled water. The answers also indicated that the most usual route to implement fluoridation is for the local Health Authority to ask for treatment to be carried out and then the Water Authorities are free to decide if they wish to do it. In Western Europe most decline to do so. In the majority of developed countries there is no statutory obligation on the Water Authorities to carry out the wishes of the Health Authority. Medically it appears that there is no respected or significant research indicating adverse health effects resulting from fluoridation at the currently recommended levels. There is, however, evidence of benefits. In spite of this fluoridation remains unpopular with the general population.

Austria, Switzerland and Germany have stopped treatment after doing so for extended periods and France does not dose, Sweden and Holland actually ban the addition of fluorides. The British Government encourages fluoridation but the Water Authorities are not following their lead.

Answers from seven areas in the U.K. disclose that three do not treat, two areas dose very small amounts (<5% of their customers) and two add fluorides but did not detail to what extent. In effect, therefore, the U.K. does not fluoridate. In the USA some States dose and some do not. Countries fluoridating on a mandatory basis are Bulgaria, Greece, Brazil, Eire and some of the States in America. Other areas using some fluoridation are Russia, Canada, Australia and New Zealand.

Answers concerning the methods of applying fluorides indicate hexafluorosilicic acid is the preferred material and almost universally used. In the U.K. the "Code of Practice on Fluoridation" issued by the Department of the Environment [4] is still current and indicates the standards to which the plants should be built.

Plant safety was stressed in several of the replies, as was the need for very strict monitoring of fluoride levels in the product waters. There are statutory requirements in the U.K. concerning dosing levels (in those areas where fluorides are used) and some plants have had to be updated to meet these demands. Some updating has been in excess of the Department of the Environment (D.O.E.) Code of Practice. This would suggest that this Code has been found to be the minimum standard to which a plant should be designed and operated.

The replies received to the question on the disposal of fluorides were not very explicit or helpful. The usual comment was that the acid should be neutralised and then disposed of to a controlled tipping site. In several replies reference was made to the necessity of obtaining consent from various sources before disposal. The over all impression left on this topic was that none of the correspondents has ever disposed of fluoride in significant quantities. This was probably because they only buy small amounts each time as they are close to the acid producers and can have weekly or monthly deliveries. This, of course, is not possible for most Gulf plants which must hold substantial stocks.

An interesting comment relevant to plant and equipment was raised in one reply. This stated that damage had occurred on concrete structures and this was thought to be due to fluoridated water. Subsequent investigation showed the damage was limited to areas adjacent to the injection points and poor mixing and thus high local concentrations could be the explanation. This point should be borne in mind whenever considering the disposal of fluorides or the acid. The RAF plant has suffered some damage to badly prepared welds in stainless steel pipe work and this is also thought to be due to locally high fluoride concentrations.

It should be added that as part of the study for the new RAF 'B' Station a report was prepared on fluoridation in general. This report focused on the difficulties of transporting, handling and the dosing of fluoride to potable water. The study also highlighted the need to decide on indemnity considerations. Should fluoridation be discovered to have long-term negative health effects it is likely that the water suppliers will have to pay massive compensation claims to their customers. The definition of responsibilities between the Water Suppliers and Health Authorities for setting the dosing rates and control of the application of fluorides is therefore essential. The reports final recommendation was not to install equipment until all such questions have been resolved.

The result of all the information received was to confirm the earlier view that the best course of action would be to use up the existing stocks of acid and then shut down the plant pending a final decision concerning the future of fluoridation. This was done and the plant was flushed, mothballed and taken out of service on 10th January 1994.

THE FUTURE

As a result of State commitments the Ministry was required to reconsider fluoridation and a decision was made to investigate the use of other materials as the fluoridating agent. Sodium fluoride was selected as the most promising possibility. This material is not commonly used but has been successfully applied in a few plants. Whilst poisonous, it is not so dangerous to handle as hexafluorosilicic acid and is not difficult to transport as it can be supplied as granules in 50kg bags. When dissolved the solution, though poisonous if ingested, is not otherwise dangerous or difficult to handle. As it was known that a sodium fluoride plant was in use at Ghubrah Power Station in Oman arrangements were made to visit the station and inspect the plant. The Omani Authorities were most helpful and as a result of the visit it was decided that the way forward was to scrap the existing facility and to build a dosing system using sodium fluoride. A scope of work and technical specifications were drafted and financial approvals sought prior to going to tender. It was also envisaged that similar plants would be included in all future water production centres and as a retrofit to RAF 'B' station.

However in July 2000 the Ministry was re-organised into a Corporation, the Qatar General Electricity and Water Corporation, which is charged with the supply and distribution of power and water in Qatar. The Corporation is the first step towards privatisation of the industry and is intended to be a cost effective entity. This has completely changed the focus of the organisation and to date no decisions have been made as to whether or not to proceed with fluoridation.

CONCLUSION

The fluoridation of public water supplies is a complex matter raising, in addition to technical matters, questions of the desirability of adding fluorides. It is undoubtedly beneficial for a proportion of the population but many are against mass medication and prefer to act for themselves. There are also commercial considerations for privately owned water companies. They are concerned over the possibility of compensation claims should fluorides be accidentally over dosed or found to have long term adverse health effects as well as the treatment costs. The application of fluorides should therefore always be considered on a case by case basis before using them to treat public water supplies.

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Seven Trent Water
North East Water
Central Scotland Development Board
Wessex Water
South West Water

Holland
KIWA
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U.S.
US Environmental Protection Agency
Private Correspondence

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Code of Practice on Technical Aspects of the Fluoridation of Water Supplies

CV OF FAHED AL DOLAIMI

Fahed Al Dolaimi has a Bachelor Degree in Electrical Engineering from Oakland University, USA. After graduation, in 1982, he joined the Ministry of Electricity and Water as Electrical Maintenance Engineer at Ras Abu Fontas Power & Water Station. He eventually became Station Superintendent and then Director of the Generation & Desalination Department. In 1999 he transferred to the Water Networks Department as Director where he remains as Director under the new Qatar General Electricity & Water Corporation.

CV FOR K. HAYES

Kevin Hayes was trained as a Power Station Chemist by the British Engineering Board. He has over 30 years experience in the power water industry as a chemist holding many senior positions in both government sectors and with major industry contractors. He has also 10 years experience as a corrosion engineer with large oil companies. He was Station Chemist at RAF A for over 8 years and is currently Head of Water Quality Control for the Qatar General Electricity & Water Corporation.

Table -1

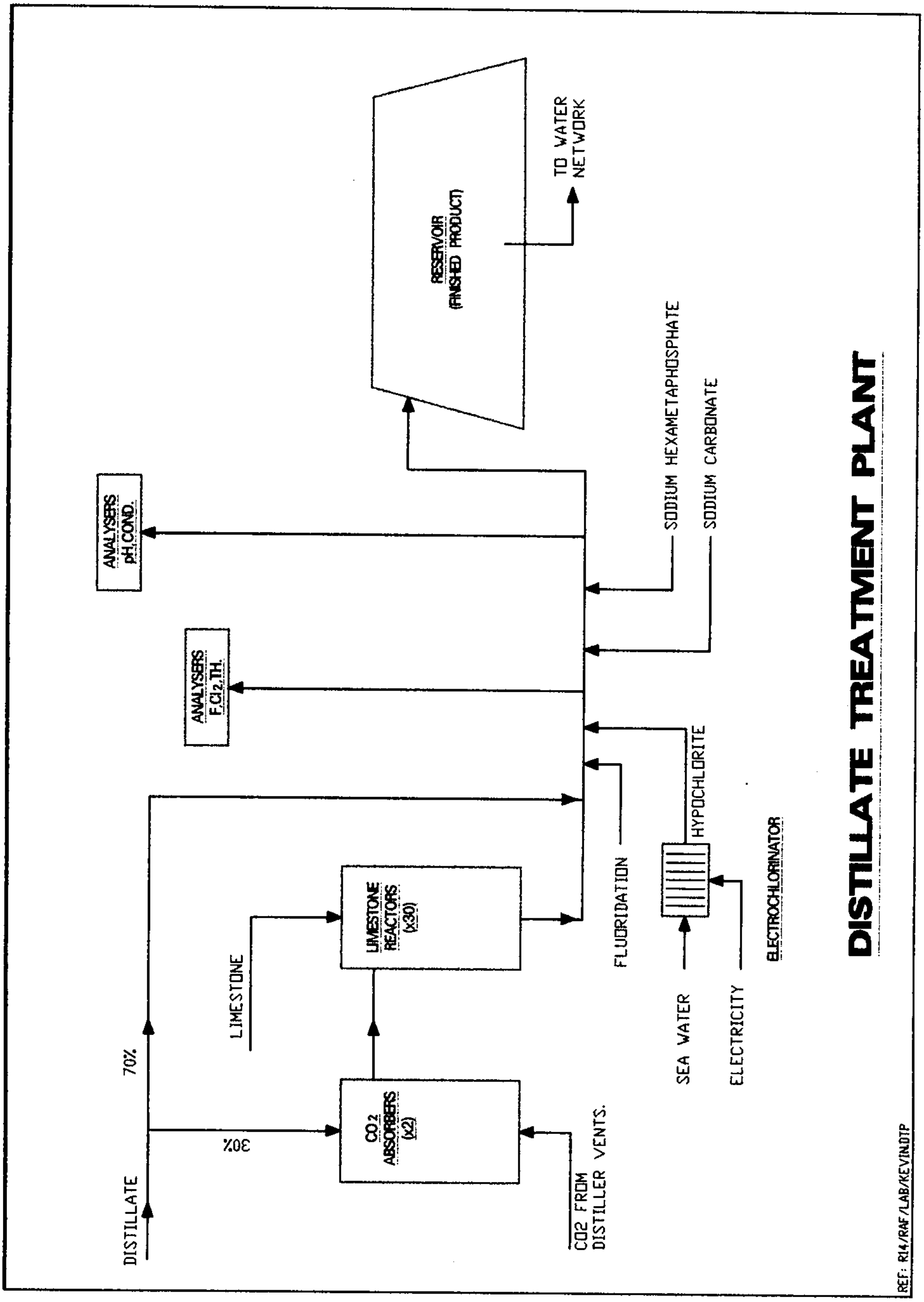
POTABLE WATER - TYPICAL ANALYSIS

		USUAL RANGE		WHO STANDARD
		MAX.	MIN.	
CONDUCTIVITY	µS	400	250	
pH		7.8	7.6	
TOTAL DISSOLVED SOLIDS	(PPM)	200	125	<1000
TOTAL ALKALINITY	(PPM $CaCO_3$)	80	60	
TOTAL HARDNESS	(PPM $CaCO_3$)	104	80	
CALCIUM HARNESS	(PPM $CaCO_3$)	80	60	
CHLORIDE	(PPM Cl^-)	75	35	<250
* FLUORIDE	(PPM F^-)	0.7	0.5	<1.5
SOD. HEXAMETAPHOSPHATE	($NaPO_3$)	0.8	0.3	
FREE CHLORINE	(PPM CL_2)	1.0	0.7	
SULPHATES	(PPM SO_4)	10	5	<250
CARBONATES	(PPM CO_2)	NIL		
SILICA	(PPM SiO_2)	0.1		
TOTAL IRON	(PPM Fe)	0.05		<0.3
TOTAL COPPER	(PPM Cu)	0.05		<2
SUSPENDED SOLIDS	(PPM)	NIL		
AMMONIA	(PPM NH_3)	NIL		<1.5
HYDROGEN SULPHIDE	(PPM H_2S)	NIL		<.05
CHLORINE DEMAND		NIL		
NITRATE	(PPM NO_3)	<0.02		<50
NITRITE	(PPM NO_2)	<0.02		<3

* WHEN DOSED.

Note: (1) Potable water is usually nearer the mamimum figures than the minima.

KJH/Zak.


DISTILLATE TREATMENT PLANT
DISTILLATE
70%
30%
CO_2 ABSORBERS (x2)
CO2 FROM DISTILLER VENTS.
LIMESTONE
LIMESTONE REACTORS (x30)
FLUORIDATION
SEA WATER
ELECTRICITY
ELECTROCHLORINATOR
HYPOCHLORITE
SODIUM CARBONATE
SODIUM HEXAMETAPHOSPHATE
ANALYSERS F, Cl_2, TH.
ANALYSERS pH, COND.
RESERVOIR (FINISHED PRODUCT)
TO WATER NETWORK
REF: R14/RAF/LAB/KEVIN.DTP

An Investigation of Water Saving Devices: Performances and Saving Studies

Dr. Yousef A. Al-Rumikhani

AN INVESTIGATION OF WATER SAVING DEVICES: PERFORMANCE AND SAVING STUDIES

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ABSTRACT

Among various ways of water conservation, the use of water saving devices is a promising one. Water saving devices are water devices, those save water compared to their conventional ones still fulfilling the user needs. A series of experiments have been carried out in the laboratory using the hydraulic flow rig to examine the performance of the various types of water saving device like self closing taps, auto-faucets, aerators, showerheads etc. In rig test, it is observed that water saving showerheads save 26% to 87% at low pressure and 46% to 92% at high pressure. The water saving aerators save 73% to 90% at low pressure and 53% to 91% at high pressure. Moreover, an ablution test has been employed as an example to demonstrate the actual water saving using aerator, auto-faucet and self-closing tap. Here it is observed that 41% saved using aerator, 35% saved using self-closing taps and 20% saved using auto faucet. Full description of facilities and hydraulic rig are provided in the paper.

Key words: Water saving devices, WSD, Aerator, Faucet, Showerheads, Self-closing tap, Ablution, Rig, Hydraulic, Water, Conservation

INTRODUCTION

The earth's total water volume is constant - none gained or lost. Water goes through a continuous hydrologic cycle of precipitation, infiltration, runoff, evaporation and transpiration by plants. However, unequal distribution of rain at any given time or location can create shortages.

Water usage often tends to be taken for granted owing to historically cheap and abundant supplies. This is no longer the case; supply and discharge costs have been rising by more than the rate of inflation in some countries for some years. Total cost can, in fact, be three times higher than the basic charges if pumping, maintenance, capital depreciation, treatment and loss of valuable materials are included.

In real sense, water is an expensive commodity and the one for which one pays twice-sewerage charges are based on supply quantities, so by reducing consumption one makes double saving on water bills. Moreover reduction in hot water use results in energy saving and lower fuel bills. A lot of work has been carried out on saving water for cost reduction. Agthe1 analyzed the relationship between water price and the installation of low flow faucets, toilets, showerheads and drip irrigation of plantings, for apartments and individual households. Maunder[2] pointed out that water costs can be reduced effectively by understanding the need of how, where and why water is used in each particular area. Having collected all the essential data, the use of 'cost effective water saving devices and practices' can help the decision on the most relevant cost-saving measures for a company. He discussed a variety of projects and devices with paybacks.

Numbers of water saving strategies have been evolved. EPA of USA report[3] explains the relationship between the quantity and quality of water, and how water quality can be improved through greater water use efficiency and conservation. Pinnes[4] presented a report that provides an overview of the current status of water conservation and describes a number of measures aimed at achieving greater efficiency in water use.

Average home water use varies from 190 to 285 liters per person per day and breaks down as follows: toilet 42%, bathing 32%, laundry 14%, kitchen 8% and cooking 4%. Domestic water use outdoors usually amounts to 50-60% of total domestic use. Water use in homes under construction, can be reduced by selecting and installing water saving devices and appliances. Water use in existing homes, can be reduced by modifying existing water fixtures. Osann[5] published a report highlighting case studies of several communities and real world problems they seek to address through water conservation. Cortez[6] presented laboratory experiences regarding low consumption devices, standards, test procedure and results. Conclusions from the works are referred to the potential impact of those devices on urban water demand, if extensively used. Pacetti[7] proposed a program to design a brochure on energy and water conservation. The brochure includes benefits of decreasing utility bills through conservation, and comparison of old appliances to newer water conserving models. The report presented by Jones[8] provides an update on showerhead and faucet technology, tables of estimated water and energy savings, marketing angles and legislation. It discusses the various ways of developing residential retrofits programs, such as rebates, direct installation, water and energy utility partnerships and school programs. Babcock[9] briefly discusses a number of factors that should be considered in evaluating devices to use in a utility sponsored residential retrofit program. A brief discussion of showerheads emphasizes consumer acceptance. In pipe and at the faucet devices for reducing flow are compared in terms of cost and consumer acceptance. Sharpe[10] has discussed some information on the performance of water conservation devices. Water reduction efficiency, installation problems, costs, toilet devices, shower devices, faucets, testing programs, setting flow rates, automatic washing machines, leak detection indicators, pressure reducing valves and spray taps are covered here. Sharpe[11] has shown that significant reduction in both cold and hot water usage results from the installation of flow control devices on showerheads. The report published by US Government Printing Office[12] describes various water conservation devices for residential use e.g.; plastic bottles, water saving toilets, faucet aerators, spray taps for sinks and basins, showerhead and faucet flow control devices, pressure reducing valves. Waste flow reduction and the economic benefit of some devices are discussed.

The water conservation program is more important particularly in arid areas where water is a scarce resource like here in Saudi Arabia and Kuwait. Saudi Arabia has to depend mainly on non-renewable groundwater and desalinated seawater to meet the agricultural and domestic water demand. As a desert country with limited rainfall of 90mm/year on an average and no river flowing, it deserves all available means of conservation measures to be adopted to ensure proper and efficient utilization of this resource[13]. Viswanthan[14] has described appropriate water conservation strategies for Kuwait including public education programs, metering and billing at appropriate rate, use of water saving devices and leak detection and prevention use of fresh water for landscaping and agriculture. According to the author, it is expected that the implementation of these measures could potentially result in a 35-45% reduction in water consumption.

Testing the water saving, using different types of water saving devices (WSDs) e.g. aerators, non-aerators, faucets and showerheads, are the primary concern of the present study. For the purpose of measuring hydraulic properties such as pressure and flow rate of various WSDs, the Hydraulic Flow Rig is employed in the present study.

Measuring the flow rate is not just enough for human water use activities; it's the time consumed which is to be taken into account too. For the completion of present study the ablution test is taken as an example. Ablution testing apparatus is easy to install and collect data from sensors e.g. flow meters, pressure and temperature sensors. Devices employed here for the ablution test include ordinary tap, aerators, auto faucet and self-closing faucet.

LABORATORY TESTS

Methodology

The performance tests of WSDs are conducted using the Hydraulic Rig in the Water Technology Lab at King Abdulaziz City for Science and Technology, KACST. Water Saving Devices, WSDs tested in the present study included ordinary taps, showerheads, aerators, auto-faucets and self-closing faucets. The hydraulic flow rig consists of two water tanks; the first one is fodischarge and connected by water conduit to the settlement-recycling tank. Three water pumps are employed to deliver water from the settlement tank to the test outlets via the manifold at flow rates of 300 lit/min, 100 lit/min and 30 lit/min respectively. This range is sufficient to handle most types and sizes of water saving devices having a wide range of pressures and flow rates. Six stainless steel flow lines (laterals) of different diameters, located equidistant, emerge from the manifold to handle a variety of water saving devices. The size diameters of the laterals used are ¼", ½", ¾", 1", 1.5" and 2". Pneumatic Proportional Differential Actuator (PDA) controller controls the manifold pressure. Converting the digital signal into analog signal from the data acquisition system operates the pumps and PDA controller. The data acquisition system contains 24 input channels to receive analog signals from the sensors and 4 analog out put channels, which are used to control the PDA controller and Pumps. The hydraulic rig is also equipped with a high-speed data logging system (1200 samples/sec) for testing water hammer effect on the WSD.

After receiving feedback of manifold pressure at set cycle time thus maintaining manifold pressure. Analogue signal from flow sensors, water pressure and temperature sensors are converted to digital signal. Analogue signals to operate the pumps are made through Data Acquisition System. Water Hammer controlling system is also provided with the hydraulic rig. The whole system is computerized using software Compend 2000.

During experiment a test sequence was followed. Firstly Manifold pressure was set for 14.6 psi and it took few seconds to rise to set pressure through out the piping system. After maintaining the pressure of set value, the data is stored in computer for following 60 sec. The data consist of flow of water, pressure just before the outlet, temperature of flow, velocity of flow, discharge coefficient and Reynolds number of water device attached at the outlet. Then again Manifold pressure is set for 29.2 psi and accordingly related data were stored in computer for this set pressure. The test was performed in this sequence until Manifold pressure becomes 73 psi and correspondingly related data is stored in the computer.

Schematic diagram of hydraulic flow rig is shown in Fig. (1a) and two picture of the hydraulic flow rig is shown in Figure (1b) and (1c):

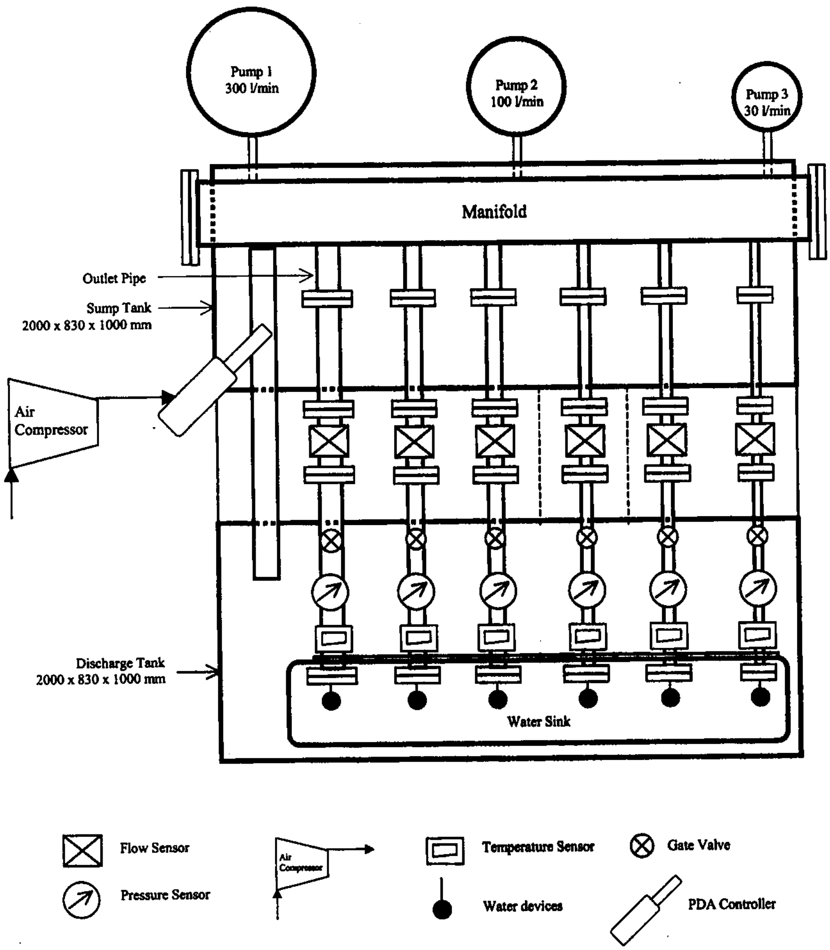


Fig. (1a): shcematic diagram of hydraulic flow rig

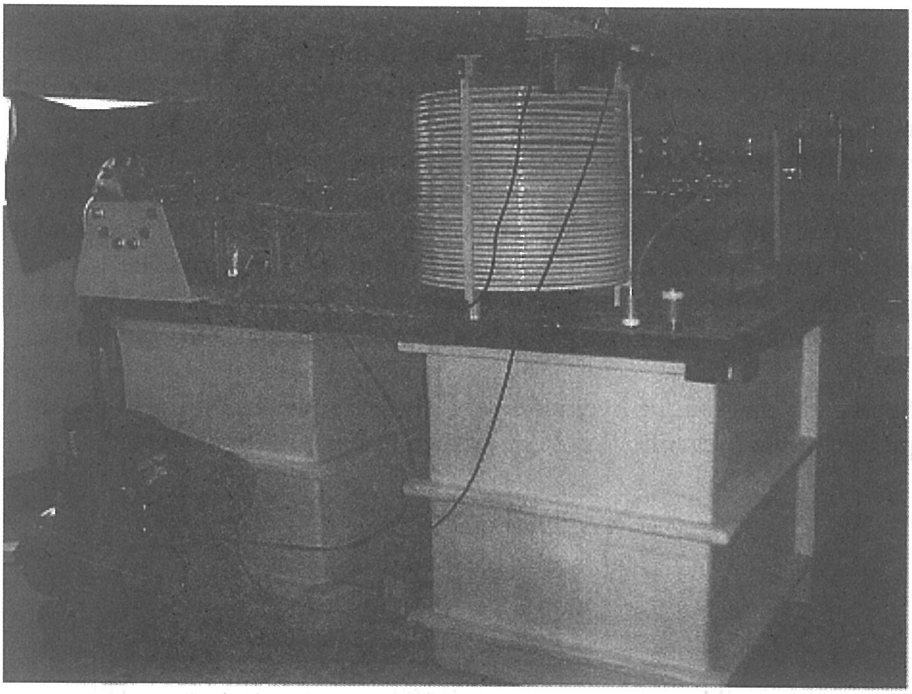


Fig.(1b): Left side view of the hydraulic flow rig

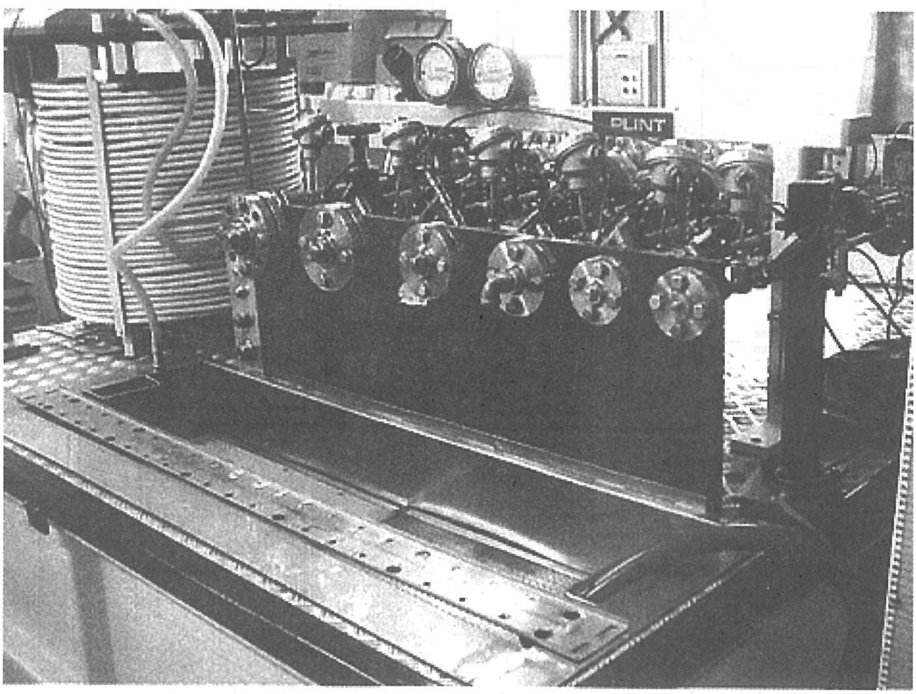


Fig.(1c): Right side view of the hydraulic flow rig

Samples of Water Saving Devices (WSD)

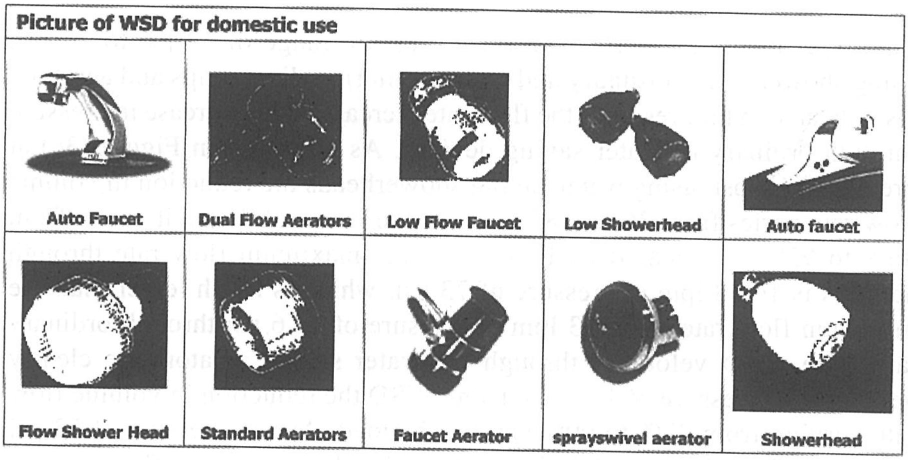


Fig.2: Some Samples of Water Saving Devices (WSD)

Description of various water saving and ordinary water devices which were tested in Hydraulic Rig are as follows:

Test No.	Types	Physical properties
1	Water saving Showerhead	Stainless steel body having 10 small outlet of 1.9 mm sizes each
2	Water saving Showerhead	Stainless steel with plastic body.
3	Water saving Showerhead	Stainless steel with plastic body having 30 mall outlets of 0.43 mm sizes each
4	Water saving Aerator	Stainless steel body
5	Water saving Aerator	Stainless steel body having 50 holes
6	Water saving Aerator	Stainless steel body having lot of holes
7	Ordinary Taps	Stainless steel body having 16 holes
8	Ordinary Taps	Stainless steel body having 16 holes
9	Ordinary Taps	Stainless steel body having 1 hole
10	Ordinary Showerhead	Stainless steel with plastic body having total 54 small hole.
11	Ordinary Showrehead	Stainless steel with plastic body having 40 small outlets pf 0.51 mm sizes each
12	Ordinary Showerhead	Stainless steel with plastic body having 75 small outlets of 0.51 mm sizes each

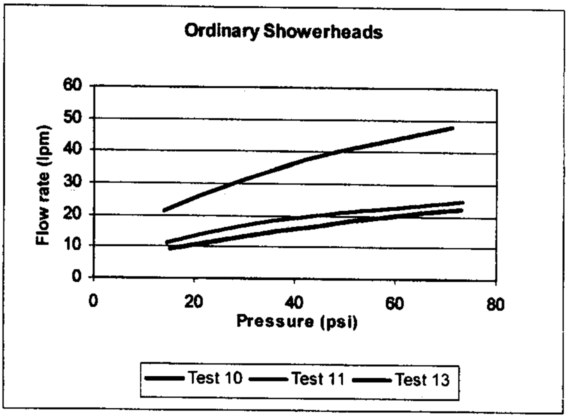
Table 3: Physical properties of various water saving and ordinary water devices

RESULTS AND DISCUSSION

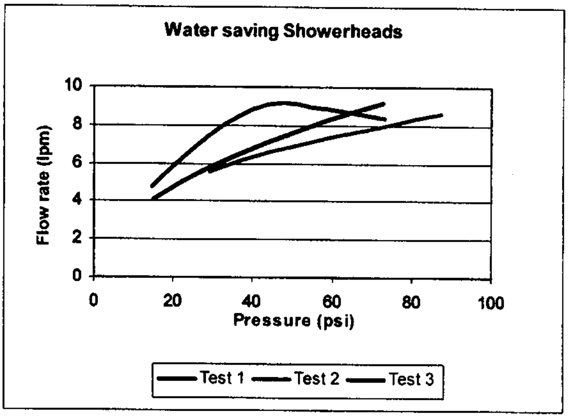
The experiments are performed for a pressure range of 13 psi to 73 psi, using showerheads (ordinary and water saving), ordinary taps and aerators. As indicated in Figures (3,4) the flow rate increases with increase in pressure through ordinary or water saving devices. As indicated in Figure (3c) at pressure 14.6 psi, using water saving showerheads the reduction in volume flow rate varies from 26% to 87%. And at pressure of 73 psi it varies from 46% to 92%. As clear from Figure (4), the maximum flow rate through aerators is 10.58 lpm at pressure of 73 psi, which is much lesser than the minimum flow rate of 13.13 lpm at pressure of 14.6 psi through ordinary taps. The outlet velocities through the water saving aerators are clearly very low. At pressure of 14.6 psi, using WSD the reduction in volume flow rate varying from 73% to 90% can be obtained. And at pressure of 73 psi this varies from 53% to 91%. The curves of ordinary taps for flow rate get apart more and more away from each other at high pressures. And so is with the flow rate through WSDs.

As depicted in Figure (4) the curves for ordinary taps show larger rate of change than those do for WSDs. Since the flow rate is changing with pressure in WSDs so the devices tested are non-pressure compensated. At higher pressures greater reduction or saving in flow rate can be achieved by using WSDs but WSDs will be consuming more water than at lower pressure case. Very close to pressure compensated flow can be achieved at pressure range of 30 psi to 40 psi as clear from Figure (4c).

a)



b)



c)

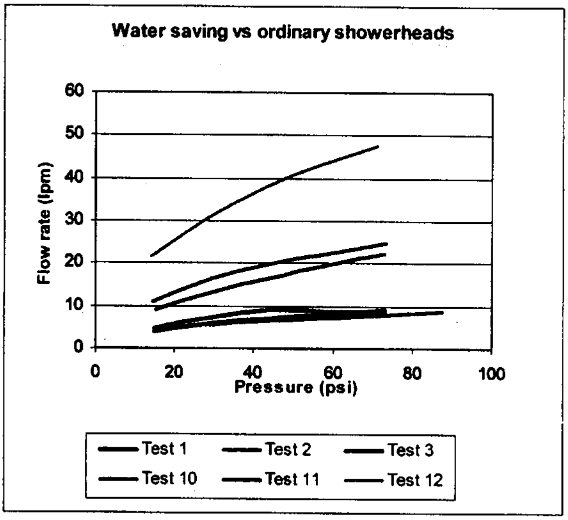
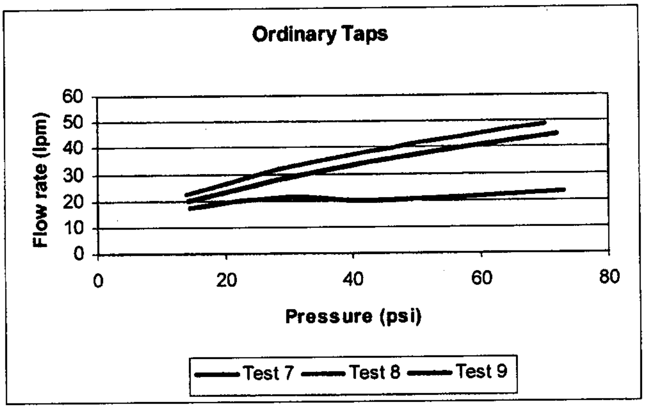


Fig. 3: a) Graphs for Pressure vs Flow rate for ordinary showerheads
b) Graphs for Pressure vs Flow rate for water saving showerheads
c) Graphs for comparisons between water saving and ordinary showerheads

a)



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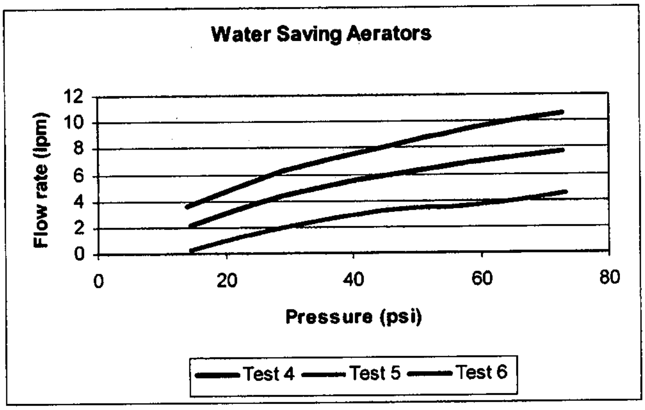

c)

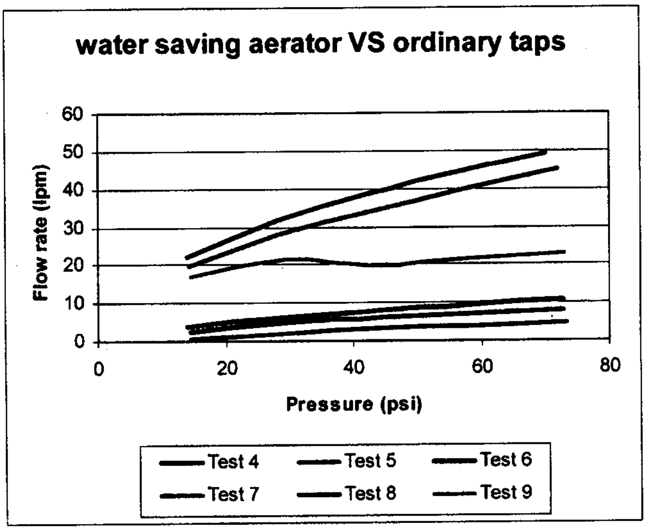

Fig. 4: a) Graphs for Pressure vs Flow rate for ordinary taps
b) Graphs for Pressure vs Flow rate for water saving aerators
c) Graphs for comparisons between water saving aerators and ordinary taps

HUMAN TEST

Methodology

To calculate the time consumed by a normal person during ablution, three tests are conducted at each pressure. Then the means of these three times values represent to a good extent the time taken by a normal person. Measuring time at a certain pressure does not reflect the true picture of the whole process, for the time is subjected to change with change in pressure/flow rate. So time taken by the normal person at each pressure is measured along with the corresponding flow rate, using WSD. To check the results for saving, ordinary devices are also tested at different pressures. It is worth nothing that this experiment is altogether human factor based. Taking the mean of three persons is also a step to minimize this factor as much as possible, but can't be ignored totally. This is because of this factor that the flow rate/volume curve is not smooth. Multiplying the flow rates at different pressures with the corresponding time consumed gives the volume consumed during ablution. The saving in water using WSD is obtained by subtracting the volume-consumed using WSD for that using ordinary device.

RESULTS AND DISCUSSION

Clear from the Table (3) that flow rate for aerator shows increase with increase in pressure, as expected. But the volume consumed (Table 3) shows a mixed behavior of dropping and rising and this is because of the time consumed not conforming to the flow rate. It is clear from the Figure (5) that change in volume consumed using aerator, self closing taps, and auto faucet are 0.56 liters, and 1.12 liters respectively (from 20 psi to 40 psi). Whereas it is about 2 liters for the same change of pressure, using ordinary tap, as shown in Figure (5). Though the WSDs used here are not pressure compensated, yet minimum change of volume consumed over the pressure range indicates its water efficiency. The volume consumed in ordinary tap is a bit linear with a considerable slope, as shown by the height of the bars (Fig 5).

The differences in volume consumed using aerator and ordinary device, become more and more considerable at higher pressures as shown in fig (5). This means that saving in water for ablution test using aerator is more and more at higher pressures as shin fig (6). Auto faucet and self-closing shows the same nature of behavior. Self-closing taps is set to supply water for duration of 15 sec irrespective of the applied pressure. Auto faucet and self-closing tap show saving in water comparatively less than that presented by using aerator as clear from fig (5). The saving in water using aerator and auto faucet is almost constant for a pressure range of 20-30 psi as shown in fig (6), though the flow rate is varying as indicated in Table (2) while self closing tap does not present. Such constant saving in water and this is because of constant time set for the tap operation. Also it is clear that saving in water saving aerator is considerably higher than that using auto faucet and self-closing tap, for the whole pressure range applied in the present study. Average water consumed by auto faucet is higher than that in self-closing and aerator as shown in fig (7).

The saving in water saving aerator, auto faucet and self closing tap is about 2.5 to 3 liters, 1.27 to 1.06 liter and 1.48 to 2.09 liter respectively for a pressure change of 20-30 psi. These changes correspond to 40-41 % saving in aerator, 20% saving in auto faucet and 24-29% saving in self-closing tap, compared to ordinary tap for ablution test. On average aerator save more water than auto faucet and self-closing tap as shown in fig (8).

Person	Ablution	Time Consume (Sec)	Avg. Flow Rate (lpm)	Avg. Pressure (psi)
1st	1	85	3.77	18.68
	2	75	4.39	24.53
	3	70	4.81	29.71
	4	75	5.08	34.88
	5	75	5.44	40.23
2nd	1	55	3.76	19.70
	2	45	4.22	24.21
	3	45	4.68	29.61
	4	45	5.08	34.35
	5	35	5.47	40.65
3rd	1	50	3.59	19.43
	2	40	4.11	24.95
	3	50	4.47	30.05
	4	45	4.83	34.99
	5	40	5.18	40.03

Table 2: Result of ablution test for water saving Aerator

Devices	Ablution	Total flow volume (liter)	Avg. Pressure (psi)
Ordinary Taps	1	6.31	19.89
	2	6.62	25.19
	3	7.24	30.40
	4	7.45	35.63
	5	7.93	40.56
Aerator	1	3.91	19.27
	2	3.77	24.56
	3	4.27	29.79
	4	4.58	34.74
	5	4.47	40.30
Self Closing Taps	1	3.78	20.00
	2	4.83	25.00
	3	4.59	30.00
	4	5.15	35.00
	5	4.86	40.00
Auto Faucet	1	5.04	20.00
	2	5.13	25.00
	3	6.18	30.00
	4	6.01	35.00
	5	6.16	40.00

Table 3: Total flow volume consumed at different pressure for different devices

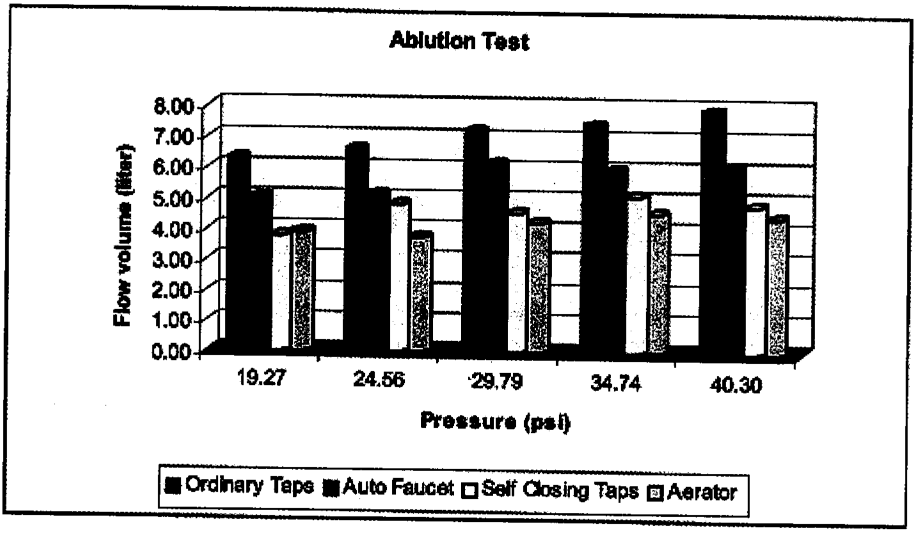

Fig 5: Graph for comparison between Water saving and ordinary taps

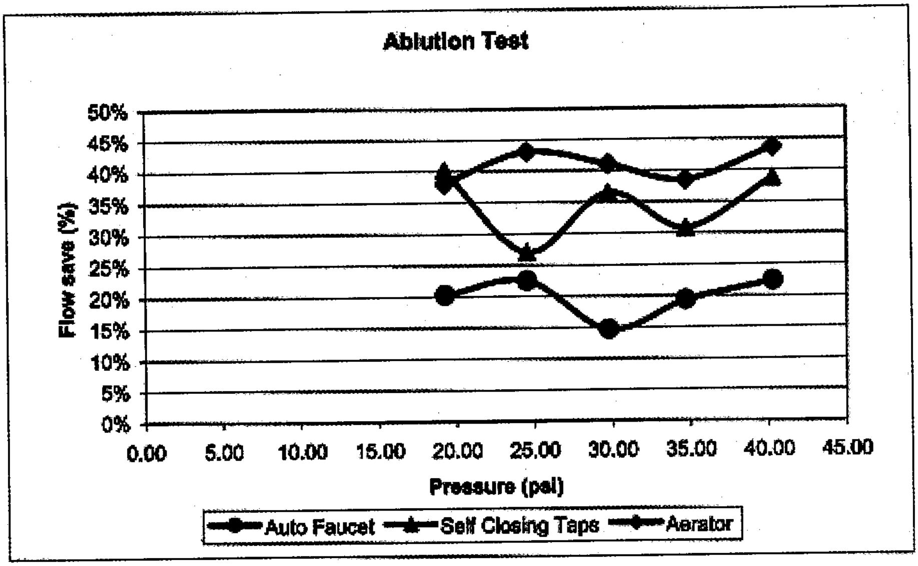

Fig 6: Graph for water saving by different devices with respect to ordinary taps

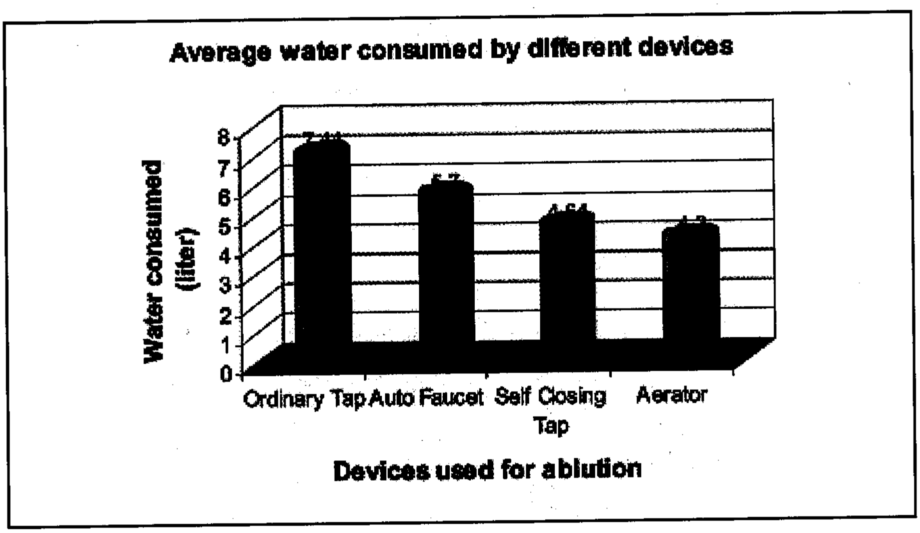

Fig 7: Average water consumed by different devices for ablution

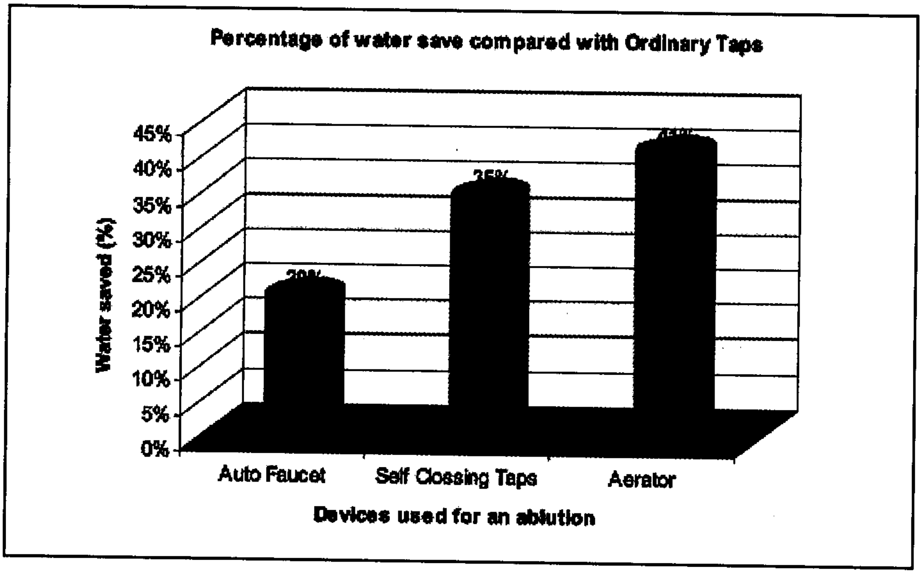

Fig 8: Precentage of average water saved compared with ordinary taps

CONCLUSION

More than 70% of water flow rate can be reduced using aerators at same pressures. Non pressure compensated aerators can be employed as pressure compensated for a close but reasonable pressure range. Rate of change of flow rate using water saving aerators is very low compared to ordinary devices. About 41% water consumed during ablution can be saved using aerator for a pressure range of 20 psi to 40 psi and about 35% can be saved using self closing taps. Self-closing tap is more efficient than auto faucet employed for human activity, ablution test.

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