Advanced System of Integrated Recovery

Ivan Dulic
Gauff Ingenieure, Frankfurt, Germany

Abstract

The global warming, desert propagation, rapid population growth and industrial progress, combined with pollution of natural water resources and withdrawal of groundwater during recent decades, contributed to the increase of soil and water salinity, reducing quality and availability of natural drinking water in the large desert belt of the Middle East and Northern Africa.

With the knowledge that only environmentally friendly engineering can provide sustainable solutions, research has been dedicated to development of safe and long term water supply in desert region. The objective of the "Advanced System of Integrated Recovery" (ASIR) is introduction of innovative approach in project design and creation of energy efficient, large water supply system, adapted to the prevailing desert environment and integrated with the recovery of depleted and saline regional aquifers in the land interior and the fertile coastal belt.

The innovative elements: Qanat WR, Telescopic Wells; Collector Wells, Silver Spring and Seashore WR, intellectual property of the author, are combination of modern engineering and clever ancient solutions. Designed to operate in the integrated hydraulic circle to provide maximal efficiency, with water and energy recovery; the innovative water supply system is cost efficient, environmentally friendly alternative to the conventional MSF seawater desalination.

Keywords: Innovative, Water Supply, Groundwater, Energy, Recovery, Desert

Introduction

Ancient communities, cradle of our modern civilisation in the Middle East and North Africa *(MENA)* were created in a friendly natural environment, in the shade of green trees and usually near ancient rivers or water springs, with fresh water available for drinking and in sufficient quantity for agricultural needs. The initial cores of a majority of large settlements of the world were established along surface water sources, large rivers, lakes or sea shores but with fresh water available nearby, sufficient for the population of that time[1].

Although it started before some 5 000 years, the gradual increase in global warming brought about many changes in the region and had has, particularly during the last few decades, a dramatic impact on survival in the hostile natural environment of this largest arid belt on our planet.

The majority of old settlements remain dependent on surface water resources, although this represents less than 0.011% of all water resources available on our planet (Table 1). Fresh groundwater with , as a safe and sustainable resource for supply and agriculture has been neglected in the past; except in desert areas were 100 m deep wells and *qanats* (excavated water transmission galleries) have been in use for more than 3 000 years.

Water scarcity with desertification and population growth generated there the ever growing water demand with the pressure on fossil groundwater resources, contributing to groundwater depletion and increase of soil and water salinity in many of irrigated areas. The excessive water withdrawal reduced groundwater levels and supports the intrusion of saline seawater to the land interior, along the fertile coastal belts of the Arabian Peninsula and Northern Africa.

Development and existence of the *MENA* countries is now dependent on the large Multi Stage Flash (*MSF*) seawater desalination plants.
Although less than 5% of the total water consumed in the *MENA*, is provided by conventional *MSF* seawater desalination, where use of hazardous chemicals in the process, have dramatic impact on the natural marine environment while supply of the remote desert areas and communities on high mountain plateaus with desalinated water - remains almost impossible mission.

With the knowledge, that only environmentally friendly engineering can provide sustainable solutions, research has been dedicated to development of safe and cost efficient water supply in the desert. The main objective of the "Advanced System of Integrated Recovery" *(ASIR)* is introduction of new approach for design and construction of energy efficient, large scale regional water supply system adapted to the natural environment in the arid region, and integrated with the units for efficient recovery of depleted and saline aquifers.

Integrated Recovery

The flexible *ASIR* engineering can be applied in different natural environments with favourable land morphology and geological conditions, but in first place it is created for desert environment, to provide a safe and sustainable water supply; with use of the renewable water resources and power recovery. Development, design and construction of the integrated "energy free" rainwater harvesting and recovery of groundwater resources are foreseen to be realised in mega project, respecting the prevailing natural conditions within the design area.

Groundwater in desert region is usually available where needed and with the efficient rainwater harvesting and recovery, natural aquifers could be a reliable source for water supply in the arid environment.

The design of the new system is based on modern engineering solutions and "know how", with use of renewable resources, for:

- Rainwater harvesting with groundwater recovery in desert interior

- Water intakes, wind energy for water withdrawal, regional transmission
- Mountain ridge tunnels, with electric power generation on gravity sections
- Water supply along the transmission system and for coastal belts
- Recovery of coastal aquifers as large water reservoirs
- Control of fresh water loss and seawater intrusion
- Cost efficient water supply in desert area

Identification of possible construction sites for the *ASIR* engineering are defined on the basis of satellite imagery or topographic maps; with the additional data collection on regional climate, geology, groundwater resources, water quantity and quality, population density, water demand categories and condition of the existing water supply infrastructure in the targeted area[2].

The Arabian Peninsula and Northern Africa have a number of favourable sites for design and construction of water supply, based on the innovative concept.

Annual quantity of rainwater (renewable sweet water), on the mountains of the region, exceeds present water requirements. Precipitations in the mountain areas are in the range of 250 mm to 500 mm annually (Table 2). However less than 5% of the received rainwater naturally infiltrates to recharge the regional aquifers, while the remaining fresh water, in runoff over fractured rocks and sandy surface, erode fertile soil and either evaporate on surface of inland *playas* or saline coastal *sabkhas,* or is lost in the contact with seawater.

It is estimated that some 25 % of received rainwater in the region is conveyed by *wadies* (ancient rivers) and on reaching seacoast is lost to the sea.

Along the coasts of the Mediterranean Sea, Arabian Gulf, Arabian Sea and Red Sea, over 250 km^3 of groundwater is lost annually, or 680 million m^3 of water daily. This quantity of groundwater is equal to the capacity of the River Nile, sufficient for supply of more than 500 million people, but its permanent loss along the seashores of the *MENA* remains unnoticed. Although fishermen and pearl divers in the region have known in the past for fresh groundwater streams along the seacoasts and have used it for stay on the open sea.

Using favourable natural environments with new concept, efficient rainwater harvesting, groundwater recovery, regional water transmission and supply with power recovery, replenishment of coastal aquifers and control of unattended water loss along the seashore; providing sufficient quantity of sweet water for population and a sustainable development of agriculture can be provided.

Natural Environment

The *ASIR* water engineering solution is mainly intended for the mountain areas. Suitable natural conditions prevail on the Arabian Peninsula, with the Hijaz and over 3 000 m high Asir Mountain ridge. Where gentle slop to the east of the subcontinent and steep escarpment on the west, is extended with 25 to 40 km wide and over 2 000 km long Tihamat coastal plane. Design and construction of integrated water recovery there, adapted to the natural conditions (topography and geology), can provide environmentally friendly water supply.

Similar natural conditions also exist on the Northern African coast, along the Atlas Mountain chain. Geological environment is different, but the area receives a considerable quantity of rainfall, which could be used for groundwater and power recovery for the regional water supply systems[3].

Some of large ancient rivers created by abundant rainfall in the past and visible on satellite maps, are water intake sites for the *ASIR* programme.

Replenished by rain on the eastern side of the Hijaz Mountain, the ancient 'Dune River' had a flow length of over 850 km, with the source near At Ta'if, where several wadies recharge the Mecca groundwater basin. Rainwater has created there a drainage network on the eastern side of the water divide line of the uplifted Arabian Plate. Along the river's upper stream, surface water flowed by the Wadi Batin, along the regional fault near Buraidah, crossing the subcontinent and ending as a large delta in Kuwait on the Arabian Gulf.

One of the largest and the longest ancient river in the area was the Abu Bahar (Old River) in the Asir Mountains. Several hundred years ago, the Abu Bahar as a perennial water stream crossed the dry desert of the peninsula, with a total length of some 1200 km. The water source of the river was fed by a drainage network of surface streams and a series of prominent wadies including the Wadi Bishah. Cutting the way through the high gorge of the Jabal Tuwayq (as Wadi Dawasir), at As Sulayil, the Abu Bahar flowed northeast along the As Suman barrier to Harrat. There, abundantly replenished with water from a number of wadies from the Riyadh area, it changed direction and ended as a large inland delta in the Arabian Gulf, on the border with the Arab Emirates.

The ancient 'Sand River' with its source near Najran is now covered by the vast sand sea of the spacious Ar Rub Al Khali, with perennial ground water stream it drains to the Sabkhat Matti as the inland delta in the Arab Emirates. Although presently covered with sand seas *(ergs)* and gravel plains *(hamada)* and saline flat areas *(playas)*, the Empty Quarter had a number of lakes replenished by the ancient river streams from Oman and Yemen.

The process of the global warming and desertification in the region, converted all of the ancient rivers to perennial groundwater streams in regional wadies. The ancient Arabian rivers with river terraces, alluvial sediments and the sand dune covered water streams are valuable shallow water reservoirs, recharged by rainfall from the uplifted Hijaz and the Asir Mountains. Downpours and flash floods in the Asir Mountain, with temporary surface water flow of short duration, occur in the upper streams of the ancient rivers.

In the recent past sufficient fresh water was conveyed by the ancient rivers to the Arabian Gulf and the Red Sea, to maintain the interface of fresh water and seawater in balance; preventing seawater inland intrusion. Some of the large wadies within the area, including Wadi Bishah, have been studied of the flood frequency - for recharge of regional groundwater basins[4].

"Many conservational practices have been thought of in order to attain rational management for these precious water resources. One of these practices consists of building dams across the numerous wadies in the country, with the sole aim of recharging their pooled water to the underlying aquifers. In spite of the contradicting views expressed in the local and international literature on the efficiency of such dams for recharge purposes, over 200 of them have already been constructed and more are planned to follow in the near future“(1986) [5].

An area of 20 000 km^2 with a conventional dam impoundment recharge system provides about 225 million m^3 of water annually, according to a report issued by the Saudi Ministry of Planning (1980). However recharge of alluvial aquifers with rainwater, using dams between wadi banks, is exposed to high evaporation loss from the open water surface, sometimes over 2800 mm annually (7.5 mm daily). Siltation in water impoundment with rainwater streams reduces recharge efficiency. After a certain period of time the contact surface with shallow aquifer is closed with silt, radically reducing infiltration rate.

Groundwater recharge wells are constructed in some arid areas for recovery of aquifers, but with problem of rainwater gathering, while turbid water blocks the well screens, demanding frequent redevelopment with uncertain results.

Innovative Technology

Innovative rainwater harvesting groundwater recovery is provided by the efficient ‘energy free’ *Qanat WR* (Fig 1). Design of the patent pending *Qanat WR* system enables its efficient application in various natural conditions, including *wadi* sediments or rocky areas. It can reduce evaporation loss, with flood and erosion control in *gully* or *wadi* by safe transfer of more than 25 % of received precipitation to the regional water tables. Recharge wells at screened pipeline junctions, are fitted with remotely controlled water level and conductivity devices and vortex units to collect silt and sand (for removal by airlift).

Installed in conventional water recharge impoundments *Qanat WR* can greatly improve infiltration rate, reduce evaporation loss and siltation problems, while recharge wells can provide water for irrigation and supply in dry season.

Water intakes for the *ASIR* programme are aquifers recharged by the ancient rivers in land interior. Telescopic Wells installed in well fields are foreseen, with collector reservoirs and booster pumps for water transmission. Wind electric generators (stand by diesel set), are envisaged to pump water from the land interior to the mountain ridge. Pressure transmission lines could provide water to local communities (via branch lines), before termination with a break pressure tank at the mountain ridge, entering a large diameter tunnel designed as a strategic service reservoir for capacities of up to 500 000 m^3.

Water head difference between 300 and 1500 m on seaside of the ridge with gravity section is used to generate electric power by Kaplan (Fig 2), Francis or Pelton turbines (Diagram 1). If only brackish or saline water is available in the well fields, water head difference also could be used for “energy free” reverse osmosis (RO) desalination - to produce fresh water for distribution.

Produced saline brine water (under pressure) should be conveyed by gravity lines to the sea, to protect groundwater resources within the coastal belt.

Drinking water delivered to the sea side, is either adequately fitted to distribution networks, or used for irrigation and recovery of depleted and saline aquifers in the fertile coastal belt. Aquifer recovery is there provided by the *Qanat WR* systems installed for rainwater harvesting along the mountain foothill.

Groundwater seepage, loss of delivered water and seawater inland intrusion at the seashore interface, within the project area is prevented by the innovative underground barrier system. The patent pending *Seashore WR* system consists of cut-off wall with “pump free” barrier wells to operate on groundwater and sea tide level difference for discharge of saline water to the sea (Fig 3). The innovative *Collector Wells* with *Silver Spring*, chemicals free water desalination, can prevent development of sabkhas providing water for irrigation upstream, while clean disinfected saline brine water is discharged to the sea, to upgrade the pumping performance of the barrier wells along cut-off wall downstream.

The *ASIR* mega project contains innovative elements: *Qanat WR*, *Telescopic Wells*; *Collector Wells, Silver Spring* and *Seashore WR* designed by the author this paper as his intellectual property are intended to operate in the integrated hydraulic circle to provide maximal efficiency, water and energy recovery in a sustainable, environmentally friendly water supply system.

However, each of the innovative elements also could be designed and installed separately - to efficiently operate as independent unit.

Project Development

Implementation of the large (mega) projects based on the Advanced System of Integrated Recovery (*ASIR)* requires multidisciplinary approach and “know how” with engagement of qualified and experienced professionals. The large scale projects stress the importance of the project objectives, planning, financing, legal, contractual, socioeconomic, the environmental and technical points of view. Realisation is planed by stages: desk study, prefeasibility study, feasibility study, pilot exploration, tendering, construction and operation.

Desk Study with project appraisal is based on available information and should provide analyses of important data on geology, geomorphology, hydrogeology, regional climate and topography for technical, environmental and commercial evaluation, with preliminary cost estimate based on Conceptual Design.

Prefeasibility Study, statement on the main objectives and alternative strategies, clarification of requirements, satellite mapping, groundwater and geology, data on water supply infrastructure, project staging and ownership, cost estimates and contract strategy should be provided with Master Plan.

Feasibility Study consists of the field reconnaissance, geological, geophysical, meteorological, topographic data, assessment of groundwater resources, water analyses, recharge, velocity, gradient, existing infrastructure, with technical alternatives, socioeconomic, environmental, commercial evaluations with time schedule, detailed cost estimate and Preliminary Design.

Pilot Programme contains design and construction of Qanat WR, Seashore WR pilot structures as the first integral parts of the system with exploratory drilling of observation and production wells, pumping tests with water sampling, chemical analyses, topography of construction sites with detailed geological, geophysical, geotechnical exploration provided for Master Design.

Project development starts with the Master Design, containing sufficient details for pre-qualification of consultants and contractors, tendering and construction procedure, with contract strategy for the project financing, as the Build Operate Own *(BOO)*, Build Operate Transfer *(BOT)* or similar concept

Request for Proposal (RFP) should be provided with technical specifications, method statements, timing schedule, milestone dates for the construction works and services, with form of commercial proposals and Contract Documents.

Plant construction, civil, mechanical, electrical works and equipment installation, supervision, testing and quality control, is based on detailed Plant Design.

Construction activities: civil, mechanical, electrical works with site supervision, plant operation performance tests, maintenance manuals, repair programs, supply of spare part, training, commissioning, completion reports, financial and cost benefit analyses, are the final stages of mega projects.

Important conclusions

The MENA countries can benefit from the global warming. The region probably will receive more rainfalls in the future, but in the form of turbulent rainstorms, with cyclones, floods and hail storms. Instead of the uncertain destiny, the countries in the region may have a brilliant future with more attention paid to the national programmes for the recovery of saline and depleted aquifers, and with monitoring, protection and rational use of available water resources.

Based on the renewable water resources and power recovery, the *Advanced System of Integrated Recovery (ASIR)* adapted to natural conditions, represents sustainable and cost efficient engineering solution of water supply in desert.

The Arabian Peninsula receives an estimated 75 mm of rainfall annually (or an average of 500 million m^3 daily), as a renewable water source for the innovative system. Less than 5% of rainwater naturally infiltrates to reach water table.

The innovative *Qanat WR* is the cost efficient, enhanced rainwater harvesting and recharge system, for recovery of aquifers; reducing evaporation, erosion and siltation problems, when installed in water recharge impoundments.

Mega project based on the *ASIR* engineering, with single water transmission system can provide 0.5 to 1 million m^3 of water daily for the settlements on the mountain plateau and in costal belt. The power recovery system, installed on the gravity section, generate surplus energy on water head difference.

Loss of delivered water and seawater inland intrusion can be controlled by the *Seashore WR,* in 20 to 40 km wide (100 to 300 m deep) and hundreds km long coastal aquifers. Groundwater recovery can provide billions of m^3 of fresh water for the sustainable development of agriculture and rangelands.

The *Advanced System of Integrated Recovery* is combination of the innovative project design, modern water engineering and clever ancient techniques.

Protection of precious groundwater resources on the large desert belt should be provided with the regional water management programmes:

- Meteorological stations, observation wells with recorders
- Monitoring and control of groundwater quality and withdrawal
- Control of seawater intrusion and fresh water loss along sea shores
- Development of rainwater harvesting and groundwater recovery
- Protection and rational use of renewable water resources

Strategically positioned meteorological stations with observation wells, should be equipped with the remote controlled (*GSM)* recorders of: temperature, air humidity, precipitation, groundwater levels, pH and conductivity, for daily data transfer and interpretation. The large capacity production wells should have installed digital water metering systems to record extraction. Groundwater quality and withdrawal should be supervised by monitoring centres, established in the agricultural and intensively irrigated desert areas.

Uncontrolled exploitation of groundwater in the region can be compared to the withdrawal of cash from a bank account - without records.

Case study:

Asir Mountain Water Project, Kingdom of Saudi Arabia, Desk Study (completed Feb. 2007), with conceptual design and cost estimate of USD 5 000 million for a bulk water delivery of 12.50 million m^3 daily at cost of USD 0.2 per m^3.

Table 1: World's water
Estimated water inventory on our planet

Reservoir / Volume	million km^3	Percent
Oceans and seas	1 350.00	97.276 %
Inland saline seas	0.10	0.007 %
Polar icecaps and glaciers	29.20	2.104 %
Groundwater resources	8.35	0.602 %
Fresh surface water	0.15	0.011 %
World's water	1 387.80	100.000 %

Modified and compiled from various sources

Table 2: Water deficit
Annual water deficit in the region

Classification	Precipitation	Crop fields	Rangeland
	mm	mm	mm
Hyper arid	less than 50	deficit 1500	deficit 500
Arid	50 - 250	deficit 750	deficit 250
Semiarid	250 - 500	deficit 250	deficit 50
Dry	500 - 1000	deficit 50	deficit 0

Modified and compiled from various sources

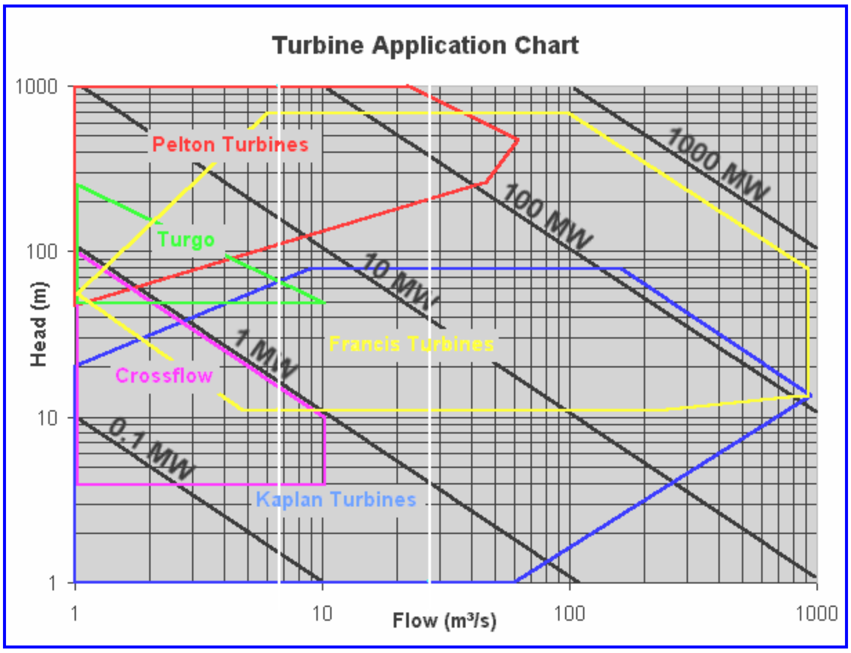

Diagram 1: Power recovery and water head of gravity section

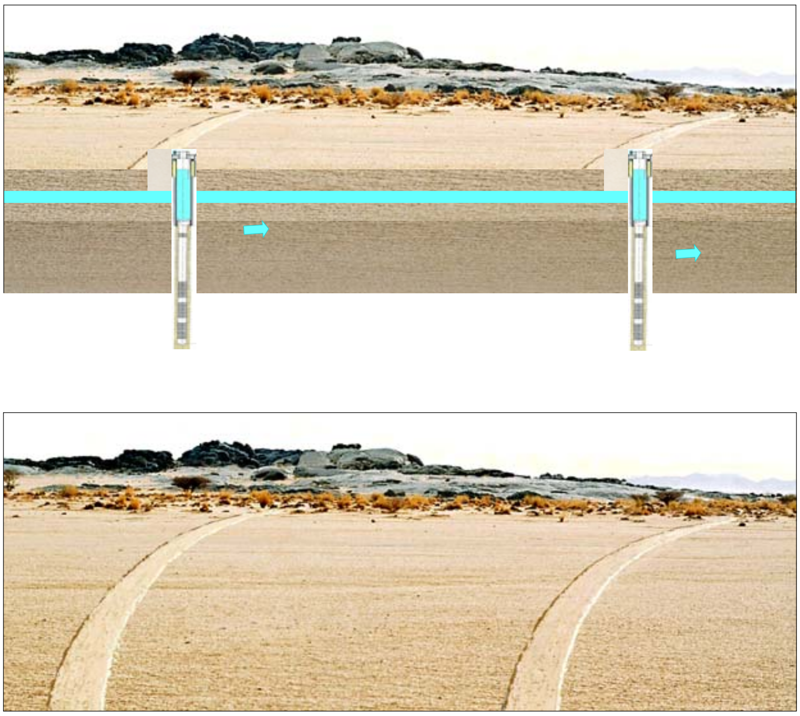

Fig 1: Water recovery system Qanat WR

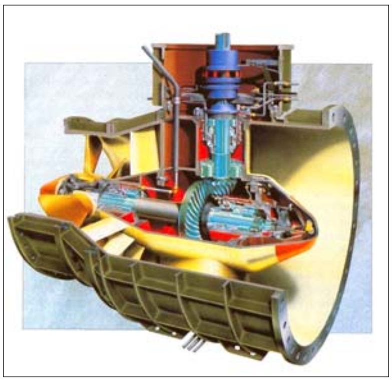

Fig 2: Kaplan turbine

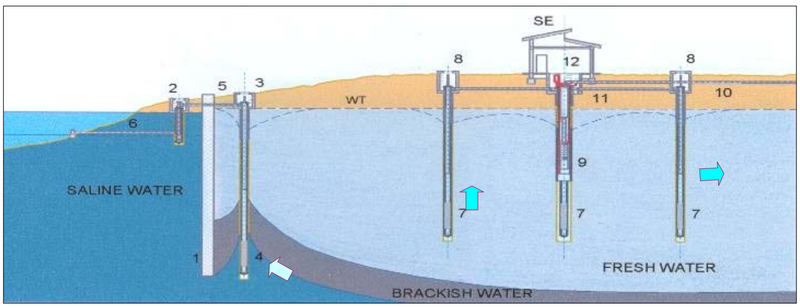

Fig 3: Coastal interface with Seashore WR

References

1. Ivan Dulic: Water in Desert, Middle East and Northern Africa (unpublished material on water engineering, new technology, prepared for book, 2008)

2. Robin Clarke and Jannet King: The Atlas of Water, mapping the world's most critical resources (Printed by Myriad Editions Limited, 2004)

3. Richard Chiles and Paul Karwinski, NPA Satellite Mappings: Above the World (Printed by Cassell Illustrated, London, 2005)

4. Ali Akhtar Quraishi and Abdulaziz S. Al Turbak: Regional flood frequency of Wadi Bishah (King Saud University, Riyadh, 1986)

5. Fouad F. Al Muttair and Abdulaziz S. Al Turbak: Recharge characteristics from dammed wadies in central Saudi Arabia (Riyadh, 1986)