INTEGRATED WATER RESOURCE MANAGEMENT – THROUGH DESALINATION, REUSE AND AQUIFER RECHARGE

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Abstract

Global urbanisation, the growth of mega cities, shanty towns and poor rural communities continues to challenge the water industry. Extremes in weather patterns and environmental disasters demonstrate the need for more robust and flexible water management strategies. Increased water demand from population and economic growth, high dependency on irrigation for agricultural yields and over abstraction of groundwater resulting in seawater ingress and soil salinisation are all factors that create water and food shortages, agricultural employment problems and urban growth. These problems are highly relevant as the majority of the world’s population lives near to the sea.

Desalination technology is an essential tool in providing rapid and reliable alternative water sources. The majority of advanced reuse projects include desalination technology with brackish water reverse osmosis. However, it is essential to manage our ground and surface water efficiently and recognise the real value of wastewater use for aquifer recharge, indirect potable use, food production and the demands of industry.

This paper considers alternative solutions, which conform to sustainable solution premises whilst being economically beneficial to the community. Case studies are described that demonstrate the solutions including the benefits of proven hydrogeological expertise, water resource management in very poor developing regions, alternative supplies for industry, cash crop production by reusing brackish municipal wastewater and aquifer recharge for seawater ingress and indirect potable use.
I. INTRODUCTION

Integrated Water Resource Management (IWRM) is becoming recognised as the only sustainable solution. This holistic water resource approach referred to as the Dublin – Rio principle (UNCED Rio de Janeiro 1992) highlights that fresh water is finite, vulnerable and that it is essential to sustain life, economic development and the environment. Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.

The 21 coastal states of the Mediterranean Sea have a total of 427 million inhabitants. 145 million live near the sea with an additional 180 million tourists each year. By 2025 the population is expected to increase by 17-19% and the tourist population by 40%. Eleven countries in the Mediterranean region are predicted to have used more than 50% of their renewable water resource by 2010. In 2025 the percentage used is predicted to exceed 100% in 8 countries and more than 50% in 3 others. We are experiencing the impact of climate change with a proven increase in the average temperature and a reduction in rainfall in the Mediterranean area. This will require optimisation of water resource management, increased water reuse and desalination. [1]

The European Union’s policy and the majority of the leading environmental institutions and governments are promoting sustainable solutions which include water reuse to mitigate groundwater degradation, economical utilization of municipal wastewater and brackish waters, and increasing the availability of potable water through local recycling projects. These accepted policies are encouraging the development of more robust and flexible water resource management strategies and projects.

II. DEVELOPING NEW AND SUSTAINABLE GROUNDWATER RESOURCES

Sustainable groundwater management requires a reliable knowledge of resource availability, recharge and demand. Bank Filtration and groundwater recharge are known as low cost and efficient technologies for treating drinking water. Both processes are of high interest for the future for the water supply of the city of Berlin and will certainly be potential treatment technologies in other parts of the world for the new millennium.

Groundwater is the principal resource of the city of Berlin and provides about 620,000 m$^3$/d of water for domestic and industrial purposes, 70% of the total volume comes from bank filtration and groundwater recharge. The hydrological and hydrogeological conditions are quite favourable. The city is located in a glacial valley bordered by plateaus and crossed by a series of rivers and lakes providing an excellent basis for the city water supply.

Hydrological trends and the development of anthropogenic pollutants may pose a threat to the future of the groundwater resource. It is therefore important to measure the capacity of soil aquifer treatment to answer such developments, and to secure the use of bank filtration and groundwater recharge systems through the development of the most appropriate practices and related technologies.

The important research in Berlin will improve understanding of bank filtration and groundwater recharge processes as a prerequisite for the future development of this natural and multi-barrier technology. Both processes have been used as treatment processes for a long time, but the mechanisms of the removal of impurities and the chemical reactions of the water components have not been understood sufficiently.
Trinidad has historically faced annual water shortages and the Water & Sewage Authority (WASA) of Trinidad & Tobago determined that an additional 57,000 m$^3$/day of sustainable groundwater was needed to supplement the surface water and desalination resource to provide an adequate water supply. The project was completed in two phases over an 18 month period. Phase 1 included a hydrogeological reassessment of Trinidad’s groundwater resources as a fixed price contract. Phase 2 included well construction, testing and water delivery. The reimbursement of this phase was linked to productivity targets with increments of 5700m$^3$/day. The study needed to answer the following questions:

- How much water is needed to create sustainability?
- What was the rate of natural aquifer recharge?
- Where are the best locations for drilling?
- What is the best well design and well test protocol to suit each location?

Phase 1 desktop studies included data acquisition with existing well data, GIS, geologic maps, remote sensing data, geophysical data, and meteorological data. This existing data was integrated to create a conceptual model of the subsurface of each watershed to determine the character and volume of groundwater. Data gaps were also noted and supplemented with additional fieldwork to create a robust data set to improve existing hydrogeologic mapping. Once conceptual models of each watershed were created a lineament analysis was conducted on remote imagery (aerial photos, satellite imagery, side-looking airborne radar (SLAR) to determine the location of fractured bedrock zones or sand and gravel deposits, which are considered as areas of preferential groundwater flow.

Phase 2 of the project consisted of fieldwork to locate optimal drilling locations, well construction and aquifer testing to verify well yields and aquifer characteristics. Geophysical surveys were conducted using various techniques (resistivity, gravity, electromagnetic) to verify the presence of the delineated fracture zones in the crystalline bedrock aquifers and was relied upon to determine the extent and depth of conductive aquifers in unconsolidated sands and gravels. Once the fracture zones or sand / gravel deposits were geophysically correlated, drill sites were selected and construction of high-yield production wells commenced. Test wells were installed to verify yield and water quality and then either reconstructed for production or a new production well was installed a minimal offset distance from the test site. A monitoring well network was also constructed around each successful production site to analyse the aquifer’s response to pumping and determine hydraulic parameters to verify the sustainable volume of groundwater in the aquifer. The success of this phase of the project was critical to all concerned as remuneration was linked to rate of production as a “no flow, no fee” contract.

To date, approximately 57,000 m$^3$/day of sustainable, high-quality groundwater resources have been developed in Trinidad to meet the current and future water use demands of the island and alleviate the potential for future water shortages.

III. IWRM EXPERIENCE IN VERY POOR DEVELOPING REGIONS

IWRM promotes a holistic approach for the finite water resource that considers all users, planners and policy makers. One practical benefit that has resulted from the numerous high level environmental conferences has been the increase in communication between municipalities, non government organisations (NGO) and private enterprise.

The recognition of the need and desire to work together in partnership has emerged as one of the only workable responses to the serious water problems for the World’s poor. Private sector water
professionals want to play a more direct role in a joint approach in which they can make a positive contribution to sustainable solutions.

A good example of this type of initiative is the work carried out in the South African townships. These informal settlements provide a home for 26% of the population in Durban.

The KwaZulu-Natal pilot project formed part of the Worldwide “Business Partners for Development” (BPD) programme by the World Bank in 1998. The objective was to demonstrate that a tri-sector partnership between private companies, NGO’s and public authorities brings added value to both the communities and to all three parties.

The project partners locally were:

- Durban Metro - Municipal authority managing a recent population increase from 1 to 3 million due to regional amalgamation of 30 local authorities.
- City of Pietermaritzburg - Municipal authority with 450,000 populations
- Umgeni Water - Regional water board supplying the municipalities
- Mvula Trust - NGO charitable trust focusing on improving water and services to poor communities
- The Water research commission - National applied water research
- Vivendi Water - International Private water partner

The aim of this 3 year project was to provide an adequate, acceptable and affordable supply of water and sanitation. Education and community ownership was a key priority for the partnership running the project where the NGO specialised in community liaison and education, municipality focused on legislation and regulation and the private water industry partner on service provision and finance.

The water system implemented included a low-pressure water distribution that continually feeds a potable water tank in the customer’s property with a maximum of 200 litres per day. Trained water bailiffs selected by the community manage the system as well as the standpipes available for those who are not connected to the low-pressure system. Trained local staff work with the Water bailiffs to provide maintenance. Customers using less than 200 litres per day are supplied free of charge following an initial US$24 connection fee.

The personal relationship and trust developed between the partners meant that neither partner assumed a dominant management position. There was shared ownership and accountability for all activities. This was developed through the recognition that by pooling their unique assets and expertise all would gain. This was especially true of the local community who gained a real voice in the development of their water services.[2]

This approach has also been developed with the international emergency aid agencies where Vivendi’s WaterForce provides support with personnel experience and equipment as part of a multi-disciplined partnership with the Red Cross and many other leading Emergency Relief agencies.

Durban Water Recycling (DWR) is a Durban Metro : This is a public private partnership that provides a 20 year build-own-operate and transfer service to Durban Metro which started operation in May 2001. The project includes treating primary sewage and repurifying the reclaimed water at 47,500 m³/day. This system treats 7% of the wastewater being discharged to the sea and guarantees a lower cost, high quality water supply to the Mondi Paper mill and Sapref Refinery.[3]
These sustainable solutions in Durban provide the following benefits:

- Community partnership with affordable water supplies in poor informal settlements
- Making available an additional 8% potable water for the community
- Guaranteeing water costs 25% lower than potable for industry (40% cost reduction currently being achieved)
- Reducing flow to overloaded long-sea outfall thereby extending its life.

Other new projects are now under development for poor communities in Haiti, Chad and Niger as initiatives with local partners.

IV. HAWAII – IWRM SOLUTION

Honouliuli, Hawaii. One of the largest and most innovative new wastewater projects utilizing a public-private partnership to recycle 45,360 m³/day that began operation in August 2000. In mid 1990’s city planners were faced with a federal consent decree demanding that the City and County of Honolulu recycle a minimum of 37,850 m³/day by July 2001. This decree was due to a series of needed but delayed improvements within the wastewater system. This innovative public private partnership includes the following scope:

- Design, Build and Operate a tertiary treatment system with sand filters and UV disinfection with for the production of R1 – Unrestricted Reuse Water. The feed source is the City and County’s 106,000 m³/day Secondary Wastewater Treatment Facility. Treated water is utilized at golf courses, highway greenbelts and cooling tower applications.
- Design, Build and Operate of a 50 km R1 pumping and distribution system.
- Design, Build Operate an integrated membrane system with microfiltration and reverse osmosis to repurify the wastewater to produce boiler feed water for multiple power generation and oil refinery customers.
- Design, Build and Operate a 13 km RO pumping station and delivery system.
- Plant operation marketing & distribution of the tailored water products for a 20 year period.

Fiscally the project saved over 35% utilizing a design/build approach to the construction. Additionally the project saved an additional US$ 48 Million (2001) over the contract term as a result of USFilter developing water purchase contracts with 7 private water users. These users included refineries and power supply facilities. The benefits to the community include that 45,000 m³/day of potable water was made available for drinking, alternative competitive water was made available for industry and reducing the wastewater discharged to sea also extended the life of the long sea outfall.

V. MAJORCA – RAPID POTABLE PRODUCTION BY DESALINATION

The City of Palma had an urgent need for additional potable water to satisfy the growing tourist industry. An 8,000 m³/day seawater reverse osmosis system was supplied and operating within 45 days by using standard value engineered skid mounted systems. There are hundreds of installations on islands ranging from small RO systems to large thermal desalination systems that use the waste heat from power stations to distill seawater at competitive costs. Membrane systems are generally more competitive when waste energy is not available.
VI. CASH CROPS PRODUCTION AND EMPLOYMENT IN SOIL SALINISED REGIONS

In some regions of the Mediterranean 58% of coastal aquifers suffer from saline ingress.[4] Over abstraction of groundwater results in rising salinity of the produced water due to saline ingress. This has resulted in 25% of the irrigated agricultural land being salinised in some areas. Soil salinisation kills the agricultural industry, stops local food production and creates unemployment. This is a global problem with 10% of global water usage being sourced from over abstracted groundwater. 20% of global irrigated agricultural areas have been salinised.[5]

Water reuse in Spain has increased dramatically with tertiary treated disinfected secondary sewage and desalinated brackish secondary sewage. Over 400 desalination plants have been installed for agricultural irrigation in Spain. Currently a 120,000 m$^3$/day SWRO plant is being installed in Southern Spain for agricultural irrigation [6].

One problem is caused by seawater leaking into the sewerage system before biological treatment in low-lying areas so that the secondary sewage has too high a salinity for irrigation. Brackish secondary sewage is an attractive and valuable water resource to treat. The reuse of brackish secondary sewage is a substantially lower cost option to seawater desalination and is being reliably used in multiple sites in Spain. The repurified water is being used in high efficiency irrigation systems in a controlled environment. Cash crops grow in manmade soil on seed beds supported above the salinised soil.

VII. BENEFITS OF INDIRECT POTABLE USE

Southern California is a semi-arid desert with a rapidly expanding population. Los Angeles is the second largest city in the USA with a population of 16.7 million out of a California population of 34 million. Water supplies are inadequate and there are serious concerns about the sustainability of the imported water from the Colorado river (increasing salinity) and Northern California, which also has an expanding population and water shortage issues.

Over abstraction of groundwater resulted in saline ingress up to 8 kilometres inland along the Californian coast in the 1950. Three fresh water injection barriers have been created to control saline ingress. The imported fresh water has been injected for over 40 years and for 25 years repurified wastewater treated to drinking water standards has been used to provide saline ingress control and aquifer recharge for indirect potable use.

The Orange County Water District (OCWD) supplies approximately 2 million people with potable water. The population is expected to increase to almost 3 million within the next 20 years. To meet the increased demand, OCWD and Orange County Sanitation District (OCSD) have developed a cost-effective solution to provide a supplemental source of high quality water. The two agencies are sponsoring a water purification project, known as Groundwater Replenishment System (GWRS), that will purify for reuse highly treated wastewater that is currently discharged to the ocean.

The GWRS will treat secondary wastewater from OCSD through microfiltration, reverse osmosis and ultraviolet disinfection. Approximately 80% of the potable quality water produced by the GWRS will be piped 13 miles to the OCWD recharge facilities, while the balance will be used to expand the existing seawater intrusion barrier.
The aquifer recharge project provides 75 - 80% of the potable water source for the area through direct injection and surface percolation ponds in the Santa Ana river basin. The GWRS will be capable of supplying approximately 22% of the water needed to recharge the groundwater basin by the year 2020.

OCWD opened their Water Factory 21 in 1976 as an advanced water treatment plant to treat secondary sewage from the LA Hyperion wastewater treatment plant. The repurified water is blended with deep well water (62% reclaimed water with 38% deep well water) and then injected into four different aquifers through 23 injection wells. A total of 431 wells are used to inject, produced and sample to monitor quality. The aquifer recharge project provides 75-80% of the potable water source for the area through direct injection and surface percolation ponds in the Santa Ana river basin.

In 1992 OCWD confirmed that the key issue to be resolved was identifying the most effective RO pre-treatment solution based on their 16 years experience of operating RO on lime clarification and rapid gravity sand filtration. This experience led to the long-term pilot study (> 53,000 hrs) at their world renowned test centre so that they could select and budget for their 405,000 m$^3$/d system. Their Ground Water Remediation (GWR) project includes three growth stages:

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity (m$^3$/d)</th>
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<tr>
<td>2004</td>
<td>236,000</td>
</tr>
<tr>
<td>2010</td>
<td>321,000</td>
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<tr>
<td>2020</td>
<td>405,000</td>
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The result of earlier piloting work led to the operation of a 2,712 m$^3$/d MF/RO demonstration system which has been running since 1994 to generate detailed water quality data, develop detailed costs, and refine design criteria for the full-scale system. The long term large-scale pilot studies with four alternative pretreatment systems evaluated the reliability, cost and plant size differences as well as confirming the economic benefits of the GWR system compared with water importation. Reclaiming secondary sewage with the GWR system consumes only a fraction of the energy to import water from Northern California or from the Colorado river. The reclamation of wastewater will also delay by 10 years a $150 Million investment in a new ocean outfall. The power consumption comparison is estimated to be:

<table>
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<th></th>
<th>State water project</th>
<th>Colorado river</th>
<th>GWR system</th>
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<tbody>
<tr>
<td>kWh/m$^3$</td>
<td>2.84</td>
<td>1.82</td>
<td>1.21</td>
</tr>
<tr>
<td>kWh/acrefoot</td>
<td>3500</td>
<td>2240</td>
<td>1490</td>
</tr>
</tbody>
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As a result of the extensive pilot studies with small scale low pressure membrane systems and demonstration studies with large scale systems OCWD were able to go out for competitive tenders from three manufacturers of pre-qualified RO pre-treatment microfiltration systems. The selected supplier of the pre-treatment, based on a 25 year life cycle evaluation was USFilter’s Memcor CMF-S submerged microfiltration.

This project is not unusual. It is an example of how environmental problems associated with potable water supply and wastewater disposal can be addressed. There are over 40 aquifer recharge projects and over 100 in various stages of development in the USA [7] and countless more worldwide. There are also over 20 membrane based water reclamation plants in the USA built or under construction treating 670,000 m$^3$/day [8] along with almost the same wastewater volume per day in the rest of the world. 62% of the USA projects and 85% of the flowrate is treated using CMF, BWRO and similar technology.
VIII. ECONOMIC BENEFITS TO THE COMMUNITY

The economic benefits to the community have to be calculated based on local priorities and costs. A tailored IWRM approach is needed to add the maximum benefit to the community. Typical benefits that support the economy include:

- Planning for a sustainable future requires a reliable knowledge of resource available, recharge, future demand and a positive involvement of the community.
- Partnerships that provide affordable water supplies to poor communities by building on local experience and skills.
- Increasing the availability of potable water and reducing the water cost by repurifying wastewater for industry and irrigation.
- Providing a drought proof water resource through reuse.
- Growing cash crops and creating employment in areas blighted by soil salinisation.
- Positively controlling saline ingress and recharge aquifers to create a sustainable water resource.
- Reducing wastewater disposal to sea and protecting bathing beaches.
- Supporting the tourism industry through irrigation of landscapes and golf industry with repurified water.

IX. CONCLUSION

Integrated water resource management needs a holistic long-term approach. This must be supported by legislation, agreed quality standards and international finance to enable projects to take place. This is helped where one government water agency is responsible for all water resource issues - ranging from fresh water to wastewater treatment - rather than separate regulators responsible for a single part of the total solution.

The only solutions to water shortage are; to maximise the efficiency of water management, reuse, desalinate or import. The increasing global experience in large high efficiency systems is continually reducing the production costs. The cost of power, finance, equipment and membranes are the key to maximising the opportunity for sustainable projects. This is where Hybrid systems can provide a real benefit by taking advantage of the process synergy between power generation, desalination, reuse and aquifer recharge in one system.

These innovative solutions enable coastal Cities to move rapidly towards Integrated Water Resource Management.

REFERENCES

1 Michel Batisse, Plan bleu, A tool for the Mediterranean people. www.planbleu.org
3 Rob Vriends, Christian Mavet. Water reuse for the SAPREF refinery in Durban, South Africa. First Shell Industrial water Management Conference 1999
4 European Environmental Agency, Seawater intrusion in coastal aquifers
http://reports.eea.eu.int/92-9167-056-1/en/


8 Scott Freeman, Gordon F Leitner, James Crook, William Vernon. Issues in the application of membranes for water reclamation. AWWA Water Sources Conference Las Vegas January 2002