Innovation and Sustainable Management of Water Resources: the New Paradigms in Small Islands

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Abstract

A water resources management scheme for a small island in Cyclades, Greece is presented. To identify the most appropriate scheme of water resources management, the modelling of alternative water supply options and the identification of the least cost capacity expansion option are evaluated. The most appropriate combination of alternative solutions is identified through the minimization of the water supply costs for the period 2002 – 2030. The identified solution involves the combined use of underground water, surface storage reservoir, conventional and wind powered desalination and water transfer.

1 Paradigms in water management

In small islands the limited groundwater is the basic option for covering the water demand for all uses. Groundwater is in most cases adequate to cover the household demand but this is only a small fraction of the peak summer demand.Tourism, which is a highly seasonal activity, creates significant pressures on existing natural water resources that lead to an increasing seasonal water deficit.

In Greek islands, the dominant water management responses are restricted to a very limited set of water supply options. The first priority has been the increased exploitation of groundwater resources due to its low cost and flexibility. In many islands, the next choice is water transfers from the mainland although it represents by far the most expensive solution. Recent trends in water management for small islands recognise the long-term impacts of traditional responses. These impacts include increasing salinisation of underground water resources due to overexploitation, very high cost of water supply due to very high contribution of water transfers and increasing water deficit due to the low recharging of underground resources. Consequently, there is an increasing dependence on conventional or RES powered desalination. (NTUA 2002)

As water resources management shifts away from traditional unsustainable responses a new paradigm is formulated. The shifting paradigm (Figure 1) introduces the exploitation of surface water in combination with the underground resources to cover the basic requirements while exploitation of conventional or renewable energy powered desalination is also employed to meet a significant portion of the demand. Surface water storage is regarded as a potential solution for both permanent and seasonal water shortage problems but due to the morphological conditions of Greek islands and the low precipitation levels it is difficult to meet the entire demand especially in the peak summer period. Water transfer is employed only as a last resort but contributes significantly in the high cost of water supply for these regions. Demand side management has also been extensively applied through appropriate water pricing structures that raise significantly the cost of water for the consumers. (Gleick 2000)

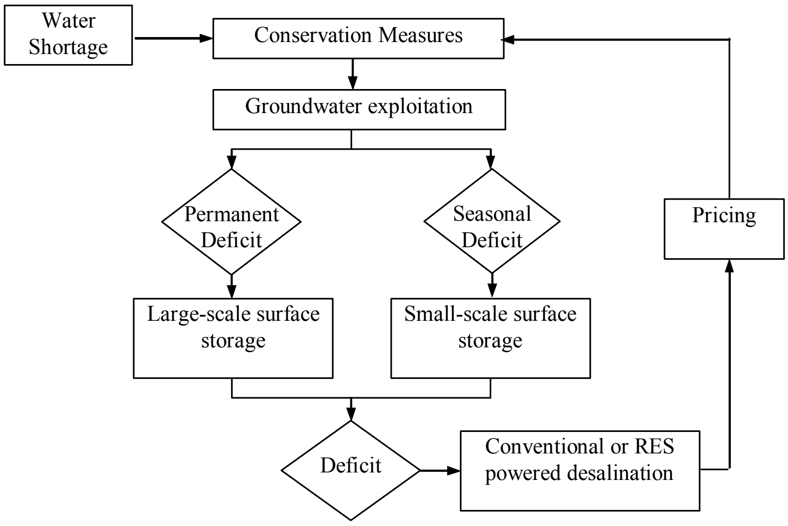

Figure 1. Potential solutions in water supply development

Cyclades is a complex of 39 islands in the south Aegean Sea in Greece. The population is 112.000 while tourists' arrivals reach 400.000 annually. In the most developed islands the population during the summer (especially in July and August) increases as much as 5 times or more. As a result all islands present significant water deficit that reaches up to 72.000 m^3/d.

One of the islands where the most extensive shortages occur is Paros, which is a small island in the middle of the complex with a population near 13000. The typical profile of the water demand indicates that the demand during August is more the 8 times higher than the demand in winter. Groundwater resources that represent the only source of fresh water in the island are highly overexploited during the summer in an effort to follow the demand profile. Even so they could not meet the demand for water and a significant seasonal shortage occurs that may reach to 200000 m^3/month.

Projections of population and tourism indicate that the situation is expected to be even more difficult in the future. With underground resources tapped, there is an urgent need for technical interventions to balance the demand to supply through a sustainable water resources management. Financial goals should be set to minimise the cost of the applied solutions and avoid a large pressure on water prices, while clear environmental objectives should be set to protect the fragile water reserves and allow the rehabilitation of the aquifers.

2 Alternative water supply options

The identification of the appropriate technical interventions to match water supply and demand requires a consistent modelling and comparison of all available options that include:

- Conventional natural resources exploitation through groundwater or surface storage
- Alternative options based on conventional or RES powered desalination units and water transfer from the mainland

Groundwater drillings is the traditional and preferred water supply option but expansion of the existing capacity in most Greek islands would create significant long-term impacts to the quality of the supplied water and the future availability of groundwater resources. Consequently, the contribution of this option to the future water supply system should not increase substantially.

Surface storage reservoirs represent an economic and efficient solution for exploitation of run-off potential. However, available water quantity is highly dependent on climatic conditions. The available quantity in a storage reservoir is a function of the monthly inflows and the abstracted quantities. Inflows represent precipitation in the water basin that reaches the reservoir excluding water that is evaporated from the surface of the reservoir. Inflows could be modeled by the area of the water basin, the overall runoff coefficient and monthly precipitation data. Abstracted quantity is estimated as a percentage of the unmet water demand and does not exceed the available stored quantity. The water production cost includes construction cost (estimated on the basis of data from existing storage reservoirs in the region) and operation and maintenance costs.

Desalination is a mature technology that is characterized by high flexibility in meeting demand variations but involves several environmental impacts related mainly to the use of conventional energy sources. For small-scale plants, reverse osmosis is the most appropriate solutions since it presents high modularity, low energy requirements and reduced need for extensive supervision. The most important components of the capital costs for conventional desalination plants include the membranes and electromechanical equipment costs. The main components of the operation and maintenance costs include the energy cost that may reach 60 % of total costs.

Environmental impacts could be substantially reduced if renewable energy technologies are used to provide the energy required by desalination. From the wide array of potential RES and desalination technology combinations, wind powered reverse osmosis is the most common option applied in small islands. It involves higher capital costs but the running costs are substantially reduced. Modeling of a wind powered desalination plant requires data on the characteristics of the selected wind turbines, the wind speed at the site and the desalination plant capacity. The capacity of the power unit depends on the desalination plant power requirements, the nominal capacity of the selected wind turbines and the power curve. The plant operation is modeled by assuming that the desalination plant is connected on both the wind unit and the grid. When wind speed is low the desalination unit operates on electricity from the grid. For higher wind speeds the wind unit provides the energy for the desalination plant and any excess energy is sold to the grid (NTUA 2000).

Water transfer is one of the traditional options employed to meet the water requirements during the peak demand period. However, it is also the most expensive one due to the high transportation cost that range from 2.2 to 7 EUR/m^3.

Figure 2 presents the average water production cost for the potential solutions that have been discussed for Paros. The capacity of the reverse osmosis plants is 1000 m^3/d and the energy consumption is 5 kWh/m^3, the wind speed at the site is assumed at 8 m/s, the storage reservoir capacity is 250.000 m^3.

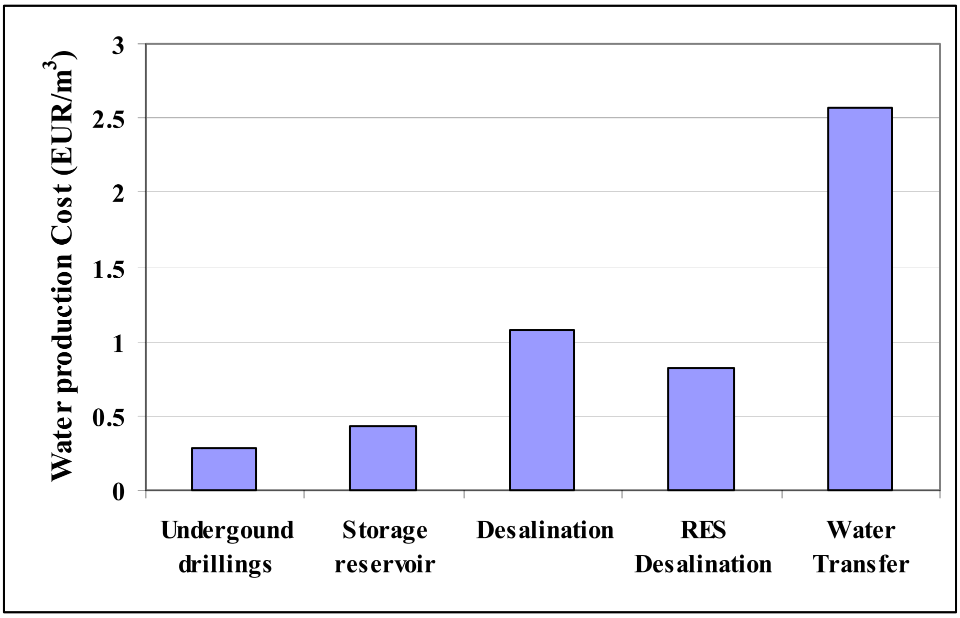

Figure 2. Comparison of the water production costs for alternative water supply options

3 Water supply capacity expansion

The identification of the most appropriate capacity expansion option for meeting the future water demand could not be based only on the comparison of the average annual costs. It represents an optimization problem that takes into account the water demand profile and the contribution of each alternative source. The objective function, the decision variables, the constraints and the assumptions are determined according to the specific conditions and available supply options found in different situations (Nishikawa 1998, Reca et al 2001, Watkins and Makiney). In the framework of the shifting paradigm for water management in small islands the optimum solution is defined so that the system costs are minimized. In this case the objective function represents the minimization of the net present value of the total annual costs for water supply in the analyzed period (Eq. 1)

$$\mathrm{Min}\left[\mathrm{NPV}(C_{2001}, C_{2002}, \ldots C_{2030})\right] \quad (1)$$

The annual costs for each of the solutions examined include both constant costs that in most cases depend only on the plant capacity and running costs that depend primarily on the produced water. Eq. 2 presents the estimation of the total annual system costs.

$$C_i = \sum_{j=1-4} CC_j + OM_j \cdot Q_j \quad (2)$$

C_i= Total water supply cost for year i

CC_j= Annual depreciation for option j

OM_j= Operational cost for option j

Q_j = Annual water production from j

The decision variables and the respective constraints in the specific problem include:

- Percentage of boreholes used (that should not exceed 100%)
- Storage reservoir capacity (maximum capacity is 250000 m^3 that has been determined form a study for a storage reservoir in the specific location)
- Monthly coverage of the unmet demand by the reservoir (defined as fractions of the demand in the range 0 – 100%)
- Desalination plant capacity (in the range of 100 – 2500 m^3/d)
- RES desalination capacity (in the range of 100 – 2500 m^3/d)

The optimisation problem assumes that the water demand is met at all times. The monthly contribution of each option is determined for the entire period until 2030 on the basis of the assumption that plants are employed successively according to their average costs with cheaper options first.

Figure 3 presents the water supply options for 2010 according to the optimum solution identified. Groundwater is used at 100% of the existing capacity due to the very low cost compared to all other options. The storage reservoir capacity has been identified at 250000 m^3 which is the maximum capacity determined by the problem constraints. The contribution of the storage reservoir in May, June and July has been determined during the optimisation at 26%, 11% and 51% of the demand not covered by groundwater. In this way, the reservoir holds enough water for use in August when the peak demand occurs. Alternatively if the usage of the reservoir in this period is more extensive then in August most of the demand will be cover by water transfer and the total costs will be higher.

The capacity of the conventional desalination plant has been determined at 1500 m^3/d and the capacity of the wind powered plant at 2500 m^3/d. This is justified by the fact that the operational costs of the wind powered plant are much lower that the costs of the conventional desalination plant. Desalination plants are used to their maximum capacity from May to September. The capacity of the conventional desalination plant is not further increased because constant costs exceed the cost of water transfers that are employed for July and August.

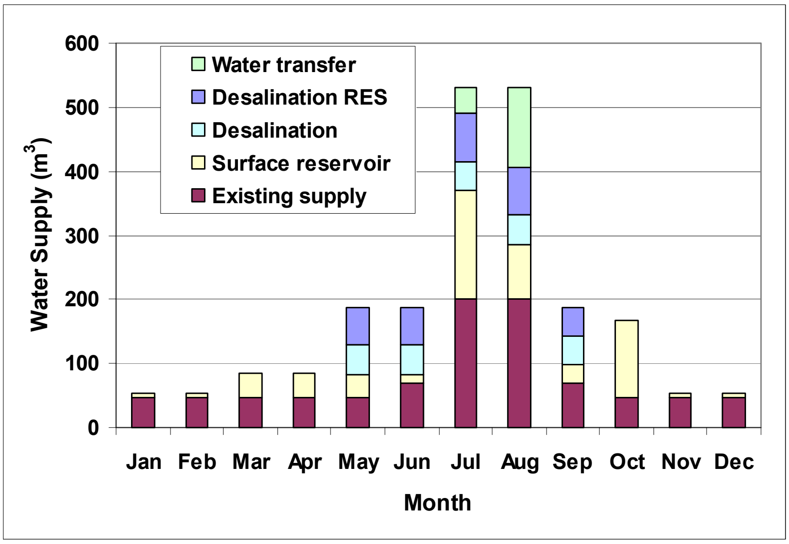

Figure 3. Contribution of alternative options in 2010

4 Discussion

The presented paradigm introduces a coherent approach in modelling alternative technical interventions and identifying the economically optimum water supply scheme to match demand and supply. This approach provides the tools and the methods to assist in the implementation of a balanced demand and supply towards the technical sustainability of water resources management. Moreover the identification of the least cost water schemes for small islands is of significant importance towards financial sustainability of the water supply scheme.

The management of the limited and fragile water resources in small islands requires the adoption of innovative practices and solutions both on the supply and demand side of the water systems. Consequently, the successful implementation of the shifting paradigm is a good starting point in an effort for sustainable water management in small islands. In this framework, a new paradigm in water resources management should aim at the achievement of additional goals that may include (Hofwagen and Jaspers, 1999):

- Social sustainability through the stability of demand and willingness to pay
- Economic sustainability through economic development & welfare of society
- Institutional sustainability through capacity to plan, manage & operate the system
- Environmental sustainability through no long-term negative or irreversible effects

5 References

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