WRECXI

INVITED PAPER

Optimisation methods and tools for sustainable water resources management. Experiences and trends.

by

Emilia Kondili, John K. Kaldellis

Aim and contents of the work

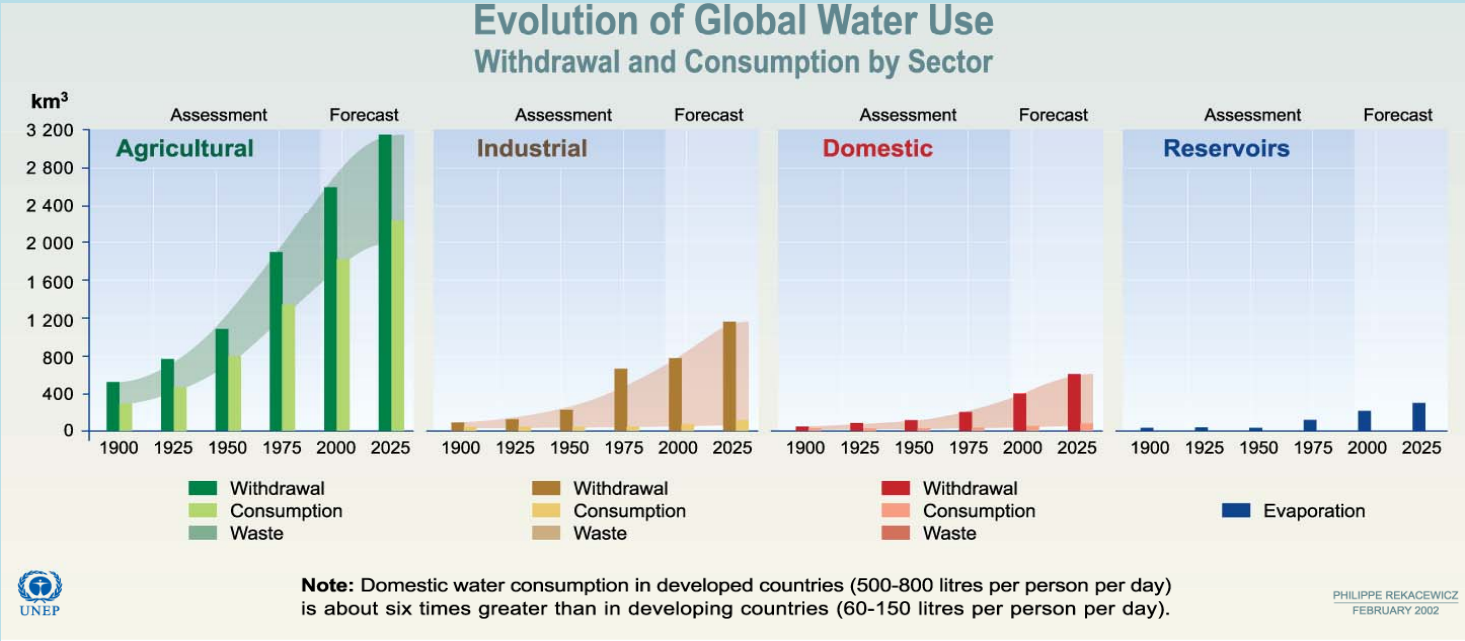
- The significance of the water shortage problem
- Its relevance with our (geographical) areas – the problem and the opportunity
- The optimisation approach for the water resources management
- Our work in the field

Why water issues in a RES conference?

Water shortage: a global problem

Water is a key resource and its **efficient use and allocation** are critical to sustainable development.

By 2030 at least 60% of the world population will face water shortage problems



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

Water and Energy relationships

- Water and energy in engineered and natural systems are intricately linked.
- Water is needed to generate energy and energy is needed to generate water.
- Many engineering approaches apply equally well to both resources.
- Both resources are limited.
- Sometimes the problems may be solved together.

The Water-Energy Nexus

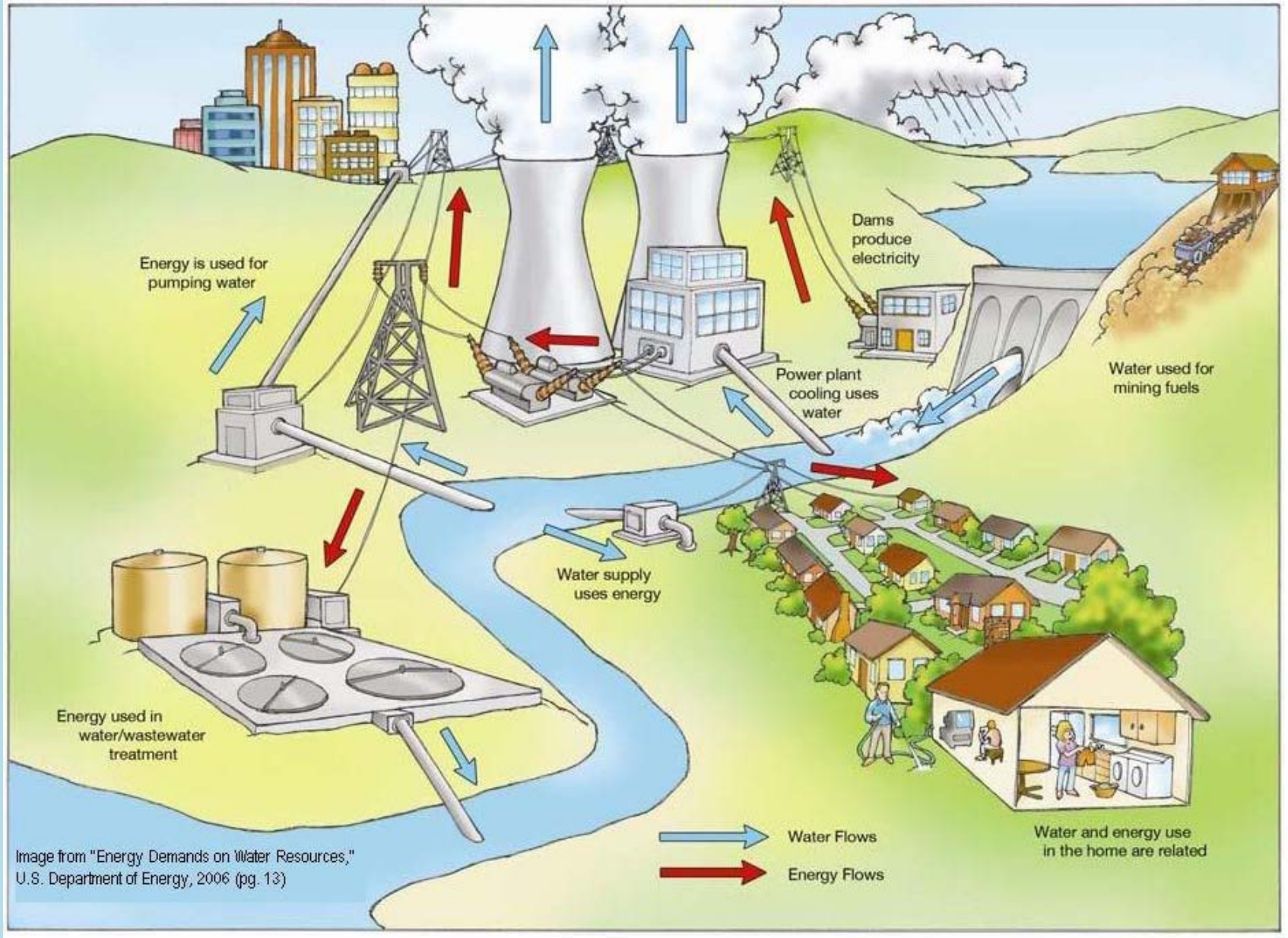


Image from "Energy Demands on Water Resources," U.S. Department of Energy, 2006 (pg. 13)

Water Resources Management…

- Encourages planning and management on a natural water systems basis through a dynamic process that adapts to changing conditions;
- Balances competing uses of water through efficient allocation that addresses social values, cost effectiveness, and environmental benefits and costs;
- Promotes water conservation, reuse, source protection and supply development to enhance water quality and quantity; and
- Protects and supports as much as possible the sustainability of the Resource

The spatial and temporal dimension of the Water Resources Management

Various complex and continuously varying parameters determine the solution of the problem.

The ‘optimal’ solution changes according to the time, the place, the conditions.

Therefore, the use of a properly designed Decision Support System DSS is of paramount importance.

The significance of the problem in our places

The south and east Mediterranean, the Arab countries (…here) are facing serious water shortage problems.

Therefore, ideas, experiences and efforts in this direction could be very useful and essential.

What type of problems are encountered?

Traditionally many academics, researchers and practitioners are involved in the development of either generic or specific solution approaches for the continuously increasing water shortage problem.

Modelling, simulation and optimisation have been some of the methods that have been exploited.

The modelling and optimisation approach in the Water Resources Management

Optimization methods have been used in most areas of engineering, business, and sciences for decision-making purposes.

In recent years, various planning problems (e.g. energy planning) have been addressed combining simulation models with mathematical optimisation.

The complexity of the WRM problem

✓The water resources management problems are very complex, requiring to take into account a wide spectrum of parameters and dealing with rather complex natural systems.

✓Usually there are conflicting demands by various users and conflicting objectives in the solution of the problem itself.

✓The environmental and sustainability considerations that need to be included in any optimisation effort are also very difficult to quantify.

The main advantages of the optimisation approach

✓Therefore, generic optimisation models are very useful in the water resources management since they can accommodate various objectives of the water system as well as any type of technical of physical constraint.

✓The resulting optimisation models (linear or integer programming, multicriteria optimisation) are usually solved using optimisation solvers.

✓ These optimisation models are included in Decision Support Systems facilitating any decision maker in various strategic and/or operational decisions.

Some more characteristics of the optimisation approach

✓Inspite of its profound merits, the optimisation approach has difficulties, especially because of the very large size (thousands of variables and constraints) of the mathematical models, resulting from a significant representation of the system.

✓In addition, sometimes stochastic models are required to represent reliably and correctly the uncertainty in many system parameters.

✓Finally, the sustainability considerations are difficult to be included in an economic objective function.

and the limitations…

✓Therefore, inspite of the very interesting and generic approach, what is finally done is solving specific problems in specific areas with rather well known characteristics and quantifiable parameters.

✓On the other hand, the 'optimal' solution depends on who is solving the problem. For example, the criterion for the optimisation may be the profit maximisation for a private water company or the overall maximisation of the water 'value' in its uses (for a municipality, a govermenetal organisation, etc.)

Our work in the field

- In our labs we have been involved in various R&D projects in many different aspects of water resources optimization, e.g
- Optimisation of water systems planning
- Water recycling and reuse
- RES based desalination
- Integrated systems for water and energy needs

Water Systems Optimisation in Areas with Limited Water Resources

Model Development for the Optimal Water Systems Planning

Emilia Kondili[a], J. K. Kaldellis[b]
(a) Optimisation of Prod. Systems Lab., (b) Soft Energy Applications and Envir. Protection Lab.,
Technological Educational Institute of Piraeus, Greece
e-mail address :ekondili@teipir.gr, Website: http://ikaros.teipir.gr/mecheng/OPS

Objectives of the Work

- To study different technical and economic parameters of water supply methods and (water) uses
- To define the evaluation criteria and the constrains in water systems' operation
- To develop and implement an appropriate model for the optimal design and operation of the water systems

The Problem

- Water is a constrained resource exhibiting shortages in many areas.
- The required water quantities may be supplied from various sources, each one at different cost and capacity (desalination, imports, dams, ground reservoirs).
- The users pose different water demands, presenting also time variation (urban users, irrigation, industry).
- There is a serious problem of water systems planning, in order to satisfy the most valuable needs.

The Mathematical Model

Optimization criterion : Maximisation of

(the Total Benefit from the use of Water – the Total Cost)

$$Max \sum_i \sum_j B_{jt} * Q_{jt} - [\sum_i \sum_j C_i * F_{jt} + \sum_i \sum_j p_{jt} * (D_{jt} - Q_{jt})]$$

Constraints

The water balance in the water storage tank:

$$V_t = V_{t-1} + \sum_i F_{it} - \sum_j Q_{jt}$$

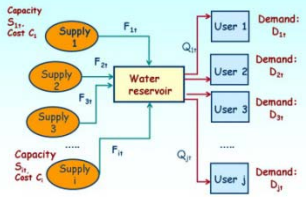
Upper and lower bounds of the water in the reservoir: $V_{min} <= V_t <= V_{max}$

Capacity limitations of each supply scheme: $F_{it} <= S_{it}$.

Flows allocated to each user should not exceed the corresponding Demands. Also minimum water quantities may be allocated to some users.

$$Q_{jt}^{min} <= Q_{jt} <= D_{jt}$$

The Structure of the Mathematical Model



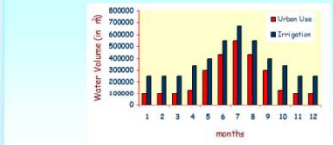
Application

Time Horizon	Twelve months, 1 month Time interval
Supply Sources	Desalination (1), ground reservoir(2), transfer by ships (3)
Users	Urban (A), Irrigation (B)
Q_{jt}^{min}	50.000 m^3
S_i	300000, 200000 and 500000 m^3/month respectively
P_{jt}	The same for both users, 10 €/m^3

C_1= 3 €/m^3, C_2= 4,4 €/m^3, C_3= 7 €/m^3

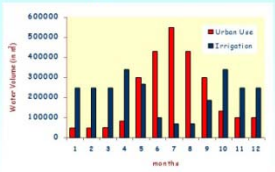
Months	1	2	3	4	5	6	7	8	9	10	11	12
B_{1t}	5	5	5	10	15	15	15	15	10	5	5	5
B_{2t}	5	5	5	5	5	5	5	5	5	5	5	5

Benefits for the users of the Case study for twelve months (in €/m^3)



Water demand profile for the application

Application Results



Application Results - Water distribution to users

Conclusions

- A mathematical model has been developed for the optimal operation of complex water systems, with multiple supply sources and multiple users.
- Water demands may exceed available supplies.
- The work introduces the idea of the optimal existing resources allocation in order to eliminate inefficiencies.
- The methodology may well be applied to other resources.

This research has been conducted within the framework of the "Archimedes: Funding of Research Groups in TEI of Piraeus Programme", co-funded by the EU and the Greek Ministry of Education

On going research

✓Development of a mathematical model for the optimisation of water systems in case of limited availability.

✓Development of a Decision Support System to support decisions on water supply and water allocation

✓Novel feature: the so called 'value' of water being determined by the sustainability of the resource and its final use

✓.. Setting in fact a set of priorities in its supply sources and uses.

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Development and Operation Issues of a Decision Support System for Water Management in Areas with Limited Water Resources

Seville, October 07

Emilia Kondili[(a)], J. K. Kaldellis[(b)]

(a) Optimisation of Prod. Systems Lab., (b) Soft Energy Applications and Envir. Protection Lab., Technological Educational Institute of Piraeus, Greece

e-mail address :ekondili@teipir.gr, Website: http://ikaros.teipir.gr/mecheng/OPS

Objectives of the Work

- To investigate the possibility of developing a decision support system for the optimal operation of water systems in areas with limited water resources
- To identify the critical parameters for the successful implementation of this system
- To underline the significance of the optimisation model that dictates the results of the decision support system

The Problem

- Water is a constrained resource and in many areas there are serious temporal or permanent shortages.
- The sustainable use of water is critical for the future of the resource.
- The water users pose conflicting demands that may not be feasible be totally satisfied.
- There is a need for decision support system that will suggest the water allocation, according to priorities and taking onto account all system parameters.

IMPORTED WATER QUANTITY IN CYCLADES ISLANDS

IMPORTED WATER QUANTITIES IN DODECANESE ISLANDS

The Optimisation Model

Optimization criterion : Maximisation of

(the Total Benefit from the use of Water – the Total Cost)

$$Max \sum_i \sum_j B_{ij} * Q_{ij} - [\sum_i \sum_j C_{ij} * F_{ij} + \sum_i \sum_j p_{ij} * (D_{ij} - Q_{ij})]$$

Constraints

The water balance in the water storage tank:

$$V_t = V_{t-1} + \sum_i F_{it} - \sum_j Q_{jt}$$

Upper and lower bounds of the water in the reservoir: $V_{min} \le V_t \le V_{max}$

Capacity limitations of each supply scheme: $F_{it} \le S_{it}$.

Flows allocated to each user should not exceed the corresponding Demands. Also minimum water quantities may be allocated to some users.

$$Q_{jt}^{min} \le Q_{jt} \le D_{jt}$$

The Structure of the Optimisation Model

Application Data

Time horizon	12 months, time step 1 month
Water supply sources	1: Desalination 2: Ground reservoir, 3: Transfer by ships
Water Users	A: Urban Use, B: Irrigation
Water Demand	(Figure 1)
Benefits	(Table 1)
y_{min}, y_{max}	1.000.000 m³ and 10.000 m³ respectively
Capacity of water supply	S_{1t}= 300000, S_{2t}= 200000m³/month, S_{3t}=1000000 m³/year
Water supply cost	C_{1t}= 3 €/m³, C_{2t}= 4,4 €/m³, C_{3t}= 7 €/m³

Months	1	2	3	4	5	6	7	8	9	10	11	12
A_{jt}	5	5	5	15	20	25	25	25	10	5	5	5
B_{jt}	5	5	5	5	5	5	5	5	5	5	5	5

Application Results

Water demand profile for the application

Water distribution to users

Water storage distribution

Implementation issues

- The suggested DSS introduces a novel approach in the water resources management, especially in areas where the demand is more than the water availability.
- Its successful implementation requires correc tand reliable data.
- Even more critical is the determination of the water use benefits and the penalties for not satisfying the demand.
- The definition of these values should be consistent and agreed between the various interesting parties.

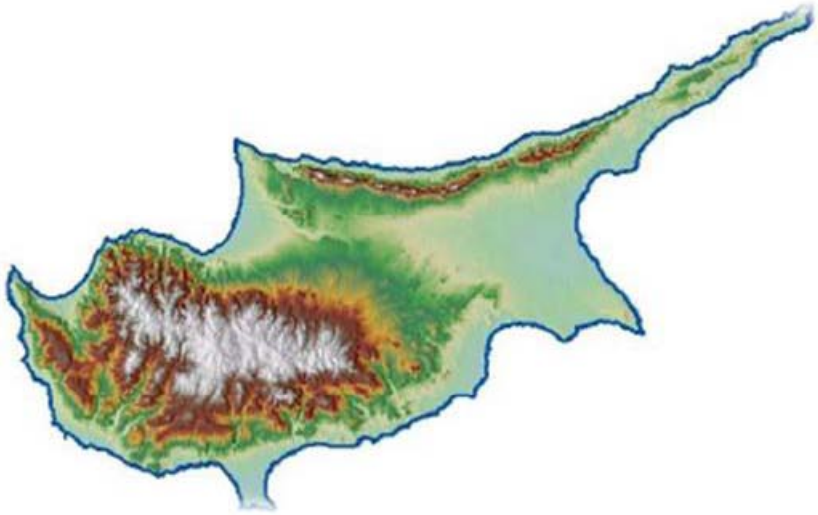
Conclusions

- A mathematical model has been developed for the optimal operation of complex water systems.
- A decision support system is suggested, based on the optimisation model, that will be a valuable tool for determining the operation of water systems.
- The decision support systems will determine the quantities of water to be allocated in each user, according to their priorities.
- The implementation of the system will rationalise conflicts and optimise the use of a very valuable resource, the water.

This research has been conducted within the framework of the "**Archimedes:** Funding of Research Groups in TEI of Piraeus Programme", co-funded by the EU and the Greek Ministry of Education

Integrated Water Resources Management for specific areas

Analysis and design of water supply and demand for Cyprus. Design of integrated solution.

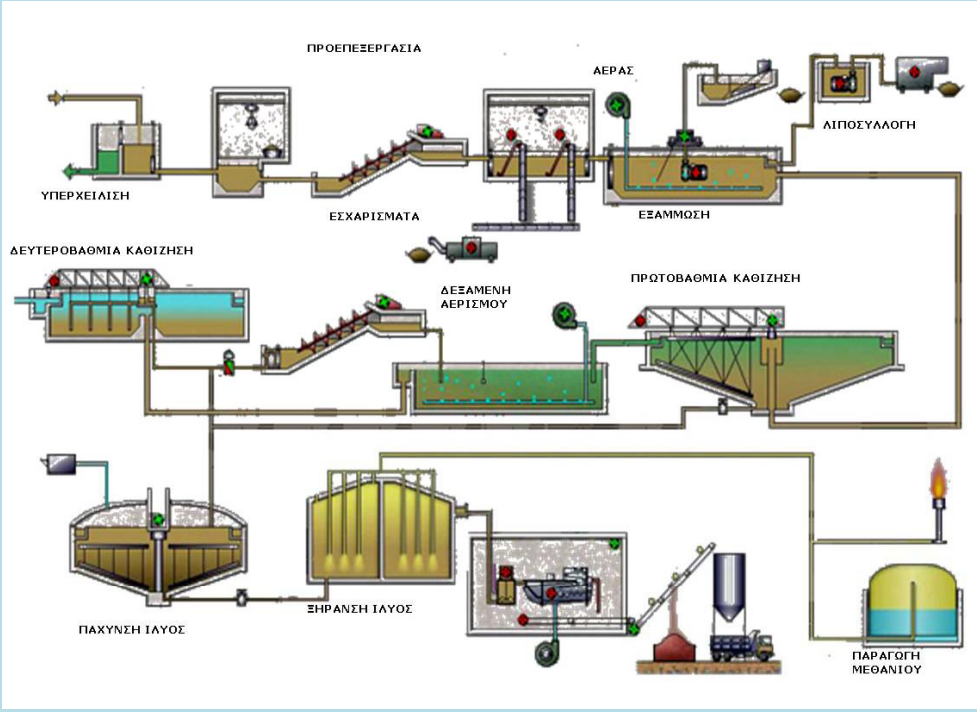


Development of methods and tools for the optimal evaluation of water and energy infrastructure projects

This R&D work aims to the development of a methodology for evaluating different alternative solutions for different water and energy supply infrastructure projects in specific geographical regions, taking into account various parameters.

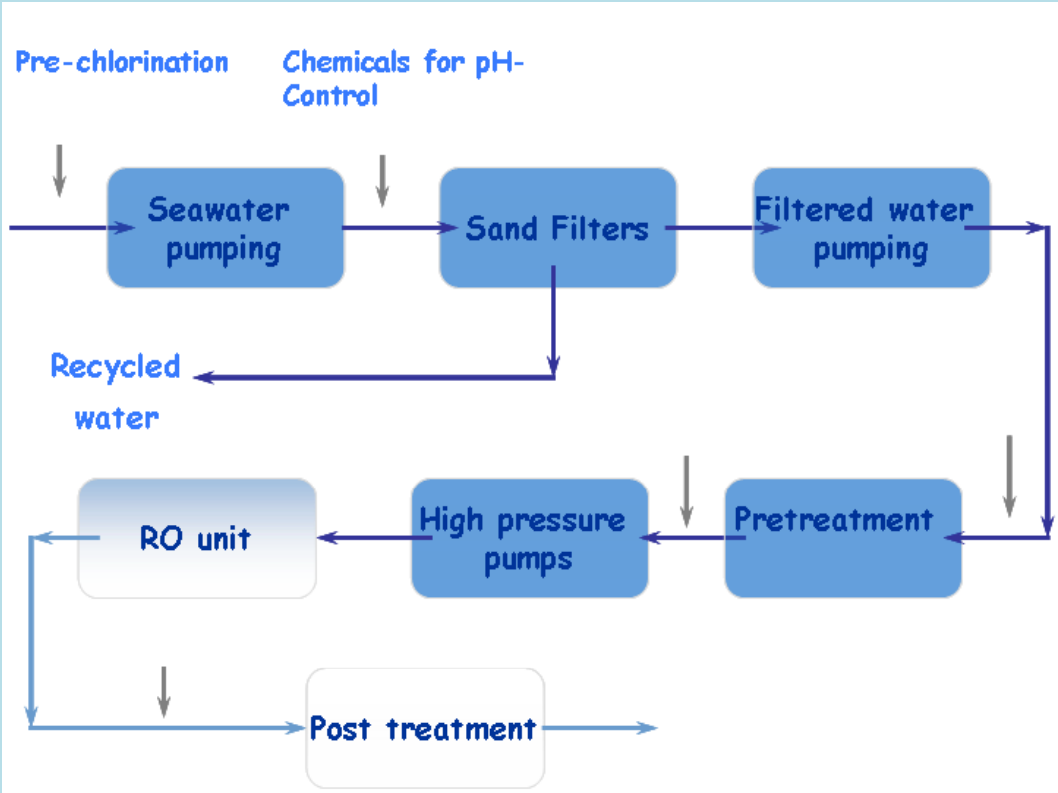
Feasibility of water recycling and reuse from wastewater treatment plants

Development of a method for investigating the feasibility of investing in tertiary treatment in waste water treatment plants for water recycling and reuse. Exploitation of GIS.



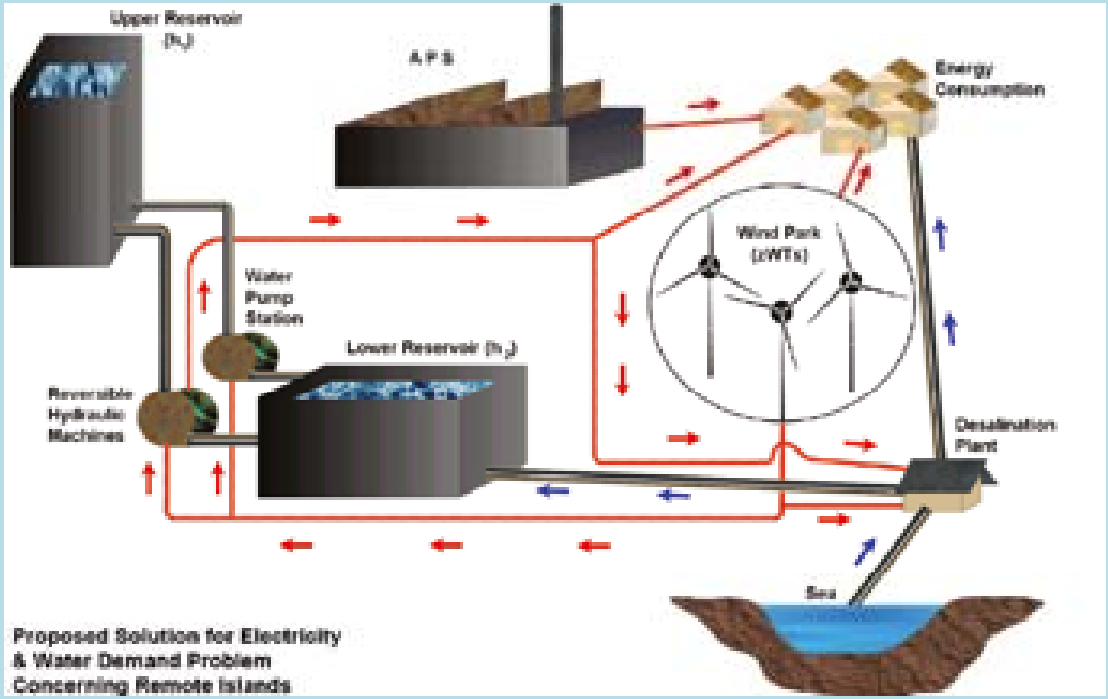
Design of RES based Desalination Plants for Aegean islands

Detailed analysis and design of RES based desalination units for the Aegean islands with specific water and energy demand profiles.



Energy and clean water coproduction in remote islands to face the intermittent character of the wind energy

Development of the design of a system that meets the electricity and water needs of a small to medium size island.



Conclusions and Discussion…

- Water resources management remains a serious and challenging problem because of the continuously increasing water deficit problems in many areas of the planet.
- Methods and tools being developed should take into account sustainability considerations.
- Research efforts in progress for the water resources optimisation can be an interesting area for cooperation between regions facing similar problems.