Water scarcity management: part 1: methodological framework

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Abstract: Water scarcity and water availability puts significant constraints in the social and economic development of many regions and countries around the world, especially the arid and semi-arid regions, as well as deteriorates the quality of life. The current problem of water scarcity consists of the adverse result of ineffective water resource management and policies, as well as the availability of water in these regions. This paper presents a methodological overview of a sustainable water resource management framework through technical and scientific analyses of water scarcity management in regions vulnerable to drought and water scarcity. The methodological framework consists of procedures, including database development, climate variability and modelling, water quantity and quality modelling, a summary of hierarchical drought analysis, water demands assessment. In case of significant reduction in water availability, the analyses are expected to explore alternative water resource solutions, such as non-conventional measures related to marginal waters, including rain enhancement, desalination, water treatment and reuse potential, water harvesting, trends and practices under drought and water scarcity conditions. Once the water demands are assessed, a water resource management scheme is implemented, along with an economic model to evaluate the economic feasibility of the management scenarios.

Keywords: water scarcity; water demands and availability; non-conventional measures.

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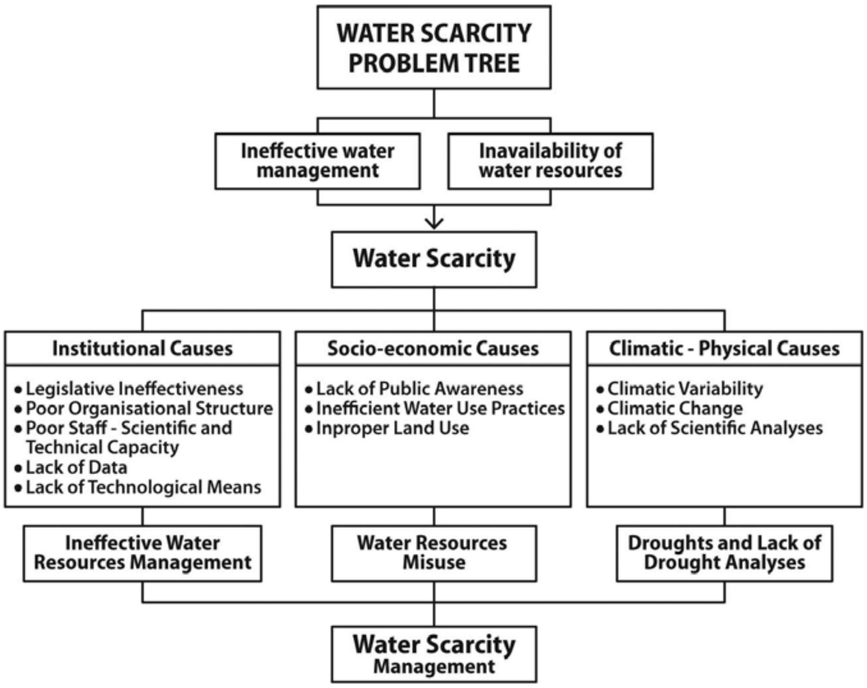
1 Prolegomena

Many parts of the world face the problem of water scarcity. Especially in semi-arid regions and arid countries, such as the Mediterranean region, this problem becomes of major concern. The water scarcity and water availability puts significant constraints in the social and economic development of these regions and countries, as well as deteriorates the quality of life. A key economic sector in most of these countries around the world is the primary sector and their economy is based on agricultural production. Agriculture accounts for more than 80% of the total water consumption and water shortage has a direct effect on the quantity and quality of the agricultural products and thus on the economy of these countries. Additionally, the water consumption for domestic purposes increases due to population growth, which presses for high water quality. On the other hand, the availability of water is declining due to natural climate variability and potential climate change, among several factors. Hence, it is clear that there should be an effective management of the available water resources within specific hydrological units, i.e. river basin or watershed.

Figure 1 The hierarchical structure and relationships of the water scarcity problem tree



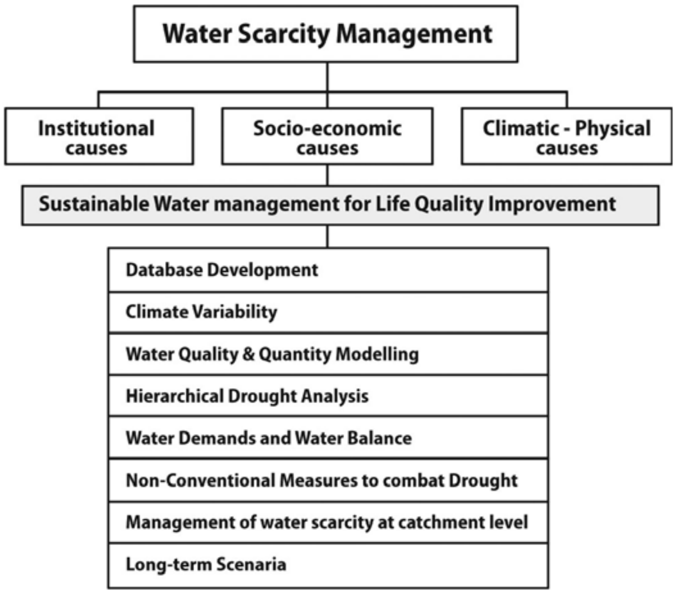
The current problem of water scarcity consists of the adverse result of ineffective water resources management and policies, as well as the availability of water in these regions and countries. There is extensive literature in the subjects of water scarcity and drought integrated into a three-volume publication (Eslamian, 2016). The causes for the water scarcity can be institutional, socio-economic, and climatic-physical (Figure 1). The institutional causes result into ineffective water resources management and polices and they can be summarised as the inadequate and ineffective water rights legislation, inappropriate organisational structure of the water authorities that manage the water, poor scientific and technical staff capacity, lack of water quantity and quality data and unavailable technological means. The socio-economic causes result in water misuse and overuse due to lack of information and awareness of the general public and the stakeholders (i.e. water users), inefficient water use practices and improper land use management. The shortage of data prohibits the scientific analysis of the availability of the water. The ineffective water resources management and the lack of water availability analysis along with the presence of prolonged drought periods caused by the climate variability and climate change, the water overuse and misuse and the addition of new water demands lead to water scarcity. For the effective and optimal management scheme and structure of water resources within hydrological units (river basins or catchments), which are targeted to address and resolve all the above causes of the water scarcity, is necessary.

The main subject of this paper is to present a methodological overview of a sustainable water resources management framework through technical and scientific analyses of drought and water scarcity management in regions and countries vulnerable to drought and water scarcity. These analyses are expected to explore alternative water resource solutions, such as non-conventional measures related to marginal waters, including rain enhancement, desalination, water harvesting and water treatment and reuse potential, trends and practices under drought and water scarcity conditions. In such a framework, capacity building can also be used to mitigate and alleviate mainly the institutional and the socio-economic causes of the ineffective water resources management. On the other hand, the thematic part, i.e. water scarcity management, provides the scientific basis to apply optimum water resources management practices in the affected areas.

The implementation of the water scarcity management scheme is based on the outcome of a methodological framework consisting of procedures, which usually start with a database development, where all the existing studies are reviewed, the available historical data are documented and archived and a geographic information systems (GIS) is developed. Having archived and documented the meteorological and climatological data, an analysis of the historical climate variability is performed, along with projections of the future climate scenarios. This is followed by water quantity and quality modelling involving hydrological, hydrogeological and water quality models. Once the historical and simulated water quantity data are available, a hierarchical drought analysis is conducted by considering the different types of drought sequentially based on indices and models, namely meteorological, agricultural, hydrological and socio-economic drought. This drought analysis and assessment leads to the prevailing drought components and interventions, which are necessary to alleviate the impacts of drought. By analysing these results a drought early warning system (DEWS) can be developed.

The methodological procedure continues with the assessment of water demand. Indeed, in order to manage the water resources detailed analysis of the water demands, a water balance within the watershed should also be computed. In case that the water availability is reduced significantly, the applicability of non-conventional measures, such as the use of marginal waters, i.e. water treatment and reuse, for increasing the water quantity should be analysed with respect to the water quality. Once the water quantity and quality demands of the various uses in the watershed are known, a water resources management model is developed and implemented at the watershed and regional scale. Furthermore, an economic model is developed to evaluate the economic feasibility of the management scenarios. These scenarios refer to the future conditions and follow specific economic development criteria derived by national development plans or by expanding the economic trends. By changing the components of the water resources management for the future, it becomes necessary to iterate the whole procedure with forecasted or estimated physical and economic data. In this sense, various future climate and water resources management scenarios can be tested and evaluated for economic and water resources sustainability. This procedure helps pointing up the optimal water resources use and management practices for long-term (future) conditions. The above described methodological procedure is delineated in Figure 2, which presents an objective tree analysis of water scarcity management.

Figure 2 Objective tree analysis of water scarcity management



2 Background

At the present time, a great number of developing countries import even more than 50% of their food requirements and demand for food grows faster than the rate of increase in agricultural production. As a consequence, the mobilisation of land and water resources is proceeding fast. The development of irrigation is especially dynamic, because it is often the most important factor for increasing agricultural production. Normally, a small portion of the cultivated area of the order of 30% in these regions is irrigated, but produces about 75% of the total agricultural production. In many areas, agriculture is impossible without irrigation (Papadopoulos, 1995). This rapid development of irrigation translates into a sharply increasing water demand and the most accessible water resources, such as rivers and shallow aquifers, are usually almost entirely committed in these regions. Alternative water resources are, therefore, needed to satisfy further increases in demand. This is mainly a necessity in regions, which are characterised by severe mismatches between water supply and demand, often associated to generally low water resources availability and asymmetries of availability and demand in a temporal and regional basis and a peculiar relationship among water and environment raise specific problems. Moreover, the natural climatic diversity of these regions is largely amplified by other geographic characteristics, namely the demographic ones. As an example of this situation, it can be observed that in the Mediterranean region the mean annual precipitation varies roughly from 300 to 3,000 mm, i.e. by a factor of 10, whereas the internal resources per inhabitant vary by a factor of 160. Currently, 70% of the total water extracted worldwide is used for irrigation, compared with 19% for industrial purposes and 11% for municipal ones, and the forecast is that by 2025, the volume of water used for irrigation is expected to increase up to 2,300 km^3, leading to water reuse in order to cope with this demand.

Besides conventional measures to combat drought and water scarcity (Dalezios et al., 2009), as already mentioned, there exist significant non-conventional measures with regards to marginal waters, which are also included in the subject of this paper (Salgot et al., 2016). These non-conventional measures could be applied as a supplements to additionally support the efficiency of the water management schemes with significant impact in arid regions and could be applied in different ways, such as the reuse of wastewater effluents and other marginal waters for agricultural irrigation or for the replenishment of the aquifers (Angelakis et al., 1999; Tsagarakis et al., 2001).

It is stated that the first element to be evaluated before using marginal waters is the quality of water in terms of the presence of potentially toxic substances or of the accumulation of pollutants in soil and crops. It is important to perform preliminary toxicological tests and to check microbiological changes in irrigated soil not only to assess the presence of heavy metals, but also that of synthetic chemicals that are normally present in urban wastewater (oils, disinfectants, etc.). On the basis of surveys and experiments performed, heavy metals are predominantly accumulated in sludge and not in the liquid wastewater, with consequent advantages regarding the latter's use for irrigation purposes. Another aspect to be assessed in order to guarantee a correct hygienic use of wastewater is the presence of coliforms and other pathogenic bacteria and viruses in general. There are currently hotly disputed debates about the applicable microbiological quality standards according to the type of irrigation practiced and the type of crop irrigated (Asano and Levine, 1996). The issues are essentially confined to 'unrestricted' irrigation, such as in vegetables that can be consumed raw, in sports fields and similar cases.

In many parts of the world, such as the Mediterranean basin, wastewater has been used as a source of irrigation water for centuries. In addition to providing a low cost water source, the use of treated wastewater for irrigation in agriculture combines three advantages. First, using the fertilising properties of the water, the so-called fertirrigation, eliminates part of the demand for synthetic fertilisers and contributes to decrease the level of nutrients in rivers. Second, the practice increases the available agricultural water resources and third, it may eliminate the need for expensive tertiary treatment. Irrigation with wastewater also appears to give some very interesting effects on the soil and on the crops. As a result, the use of reclaimed wastewater for irrigation has been progressively adopted by virtually all Mediterranean countries (Marecos do Monte et al., 1996). Because irrigation is by far the largest water use in the world and the quality requirements are usually the easiest to achieve among the various types of wastewater reuse, it is by far the largest reuse application in terms of volume. However, wastewater is often associated with environmental and health risks. As a consequence, its acceptability to replace other water resources for irrigation is highly dependent on whether the health risks and environmental impacts entailed are acceptable. It is therefore necessary to take precautions before reusing wastewater. As a result, although the irrigation of crops or landscapes with sewage effluents is in itself an effective wastewater treatment method, a more effective treatment is necessary for some pollutants and an adequate water storage and distribution system must be provided before sewage is used for agricultural or landscape irrigation.

In summary, water is a valuable natural resource, which has to be managed in such a way to sustain the economic development and the environment. The main current problems that have to be resolved are the incapability of the water resources organisations to effectively manage this natural resource at local and national level. This incapability is the result of the internal organisational structure, the water legislation, and the inexistence of analyses for the water availability and water demand. All the above problems become acute when droughts reduce the water availability. In order to provide feasible solutions to this problem, there is a need, at first, to address the causes of the problem and propose solutions at both scientific and organisational levels. The problems at the scientific level are addressed by making all the necessary analyses for the water availability, water demand and drought monitoring at local watershed level, as well as proposing the necessary organisational structure and the legislative needs. It is expected that when the causes of water scarcity have been alleviated through a detailed water resources management program and plan, the water use at the level of watersheds and areas becomes optimal. Eventually, the effective water quantity and quality management leads to sustainable economic growth and protection of the environment, which both lead to an improvement of the quality of life.

3 Database and climate modelling

This is the beginning of the presentation of the methodological framework for water scarcity management. Specifically, this section includes the first components of the framework, namely database development, climate variability and/or change and climate modelling. A brief description follows.

3.1 Database development

The development of a database is an essential initial step for the integration of a methodological procedure for drought and water scarcity management. This database includes several stages.

3.1.1 Data collection and archiving

At first, review and assessment of existing environmental and research activities and studies, hydrological and hydrogeological conditions, irrigation and hydroelectric systems, as well as development programs. Data collection and archiving include: meteorological data consisting of recorded conventional meteorological observations; hydrological data, which include available stream flow and river gauging data, watershed characteristics and land use, digital topographic maps, hydrographic network data; geological and hydrogeological data, which include geological maps, hydrogeological maps showing springs, drills, shafts, hydrochemicals, polluters, groundwater data, plotting of water level-water supply curves; water quality data, which include collection and classification of source water quality data, and data from both surveillance and operational monitoring in the identification of long-term anthropogenically induced upward trends in pollutant concentrations and the reversal of such trends and collection and classification of animal quality data; economic and water use data, which include all the economic and water use data for each water use in the river basin. The economic model for the economic evaluation of each water use utilises these data. Specifically, these data include agricultural economic data, animal production economic data, fisheries and aquaculture economic data, domestic water supply and sewerage economic data, industry economic data, and hydroelectric energy production economic data.

3.1.2 GIS development

The GIS allow the coding, storing, analysing and retrieving of geographic data. GIS provides a range of analytical capabilities, which are able to combine spatial and non-spatial attributes. These capabilities of synthesis allow the user to work interactively or not in order to perform the required analysis (Burrough, 1986). The database design consists of two basic steps, namely the articulation of a logical data model and the physical implementation of database models. The former refers to the precise definition of the set of objects of interest, whereas the latter model develops the physical database based on the logical database model. The GIS development scheme follows certain steps, such as modelling the data requirements, defining objects and relationships, selecting geographic representation, matching to database elements, and organising the database structure. The synthesis of all the geographic information, such as topographic and cartographic elements, as well as land uses, takes place in GIS. Additionally, the non-spatial attributes, such as hydrological information, population, cultivated areas, time series and similar aspects, are inserted in databases (DB). Indeed, the DB allows the coding, storing, analysing and retrieving of the available geographic and non-geographic data from the available maps in the study areas.

3.2 Climate variability/change and climate modelling

3.2.1 Climate variability

To understand the variations of ecosystem components in response to changing climate and environment a detailed analysis is carried out involving several sets of data. Continuous monitoring of hydrological conditions are necessary to identify and track drought conditions leading to water scarcity. Actual measurements of precipitation, stream flow, lake levels, ground water levels, and water use are all essential to understanding and characterising drought and water scarcity. New technologies and systems such as remote sensing (RS), GIS, as well as numerical modelling and statistical techniques, provide the means to analyse, understand and mitigate the impacts of climate variability. The use of contemporary technologies can help to reduce the response time resulting in more effective management of the required resources and financial sources. Analysis of meteorological data includes calculation of mean and variance, as well as monthly, seasonal and annual statistics of several meteorological variables, such as precipitation, temperature, humidity, wind speed and direction, cloud types and cloud cover and pressure.

Moreover, climatic analysis also includes spatio-temporal distribution of meteorological observations (Dalezios and Bartzokas, 1995), extreme value analysis (EVA) and precipitation depth-duration-frequency analysis (Dalezios and Eslamian, 2015), as well as calculation of potential evapotranspiration (PET) and estimation of actual evapotranspiration (AET). In addition, analysis of hydrometric data is conducted, such as calculation of mean monthly, seasonal and annual stream flows, temporal flow trends in specific sites and comparison with precipitation trends. Moreover, analysis of maximum and minimum flows for estimation of extreme hydrological events is considered and calculation of watershed flood flows. Similarly, hydrological characteristics of existing lakes are considered and analysis of hydrogeological data, such as piezometric level of aquifers, trends in piezometric surface of aquifers, correlation between flow of drillings and natural sources, analysis of flow time series and estimation of water balance of each examined watershed.

3.2.2 Climate modelling

Predicting drought depends on the ability to forecast two fundamental meteorological surface parameters, namely precipitation and temperature. Since drought is a slowly developing phenomenon, which depends on various factors, the results of data analysis are viewed based on the most recent global climate system reviews and global circulation models (GCMs) (IPCC, 2007), among others. Analysis of coupled atmosphere – ocean circulation models focuses on downscaling large-scale GCM output to regional scale. Indeed, downscaling of global forecast model products improves the existing knowledge and assists in producing methods for regional drought forecasting based on either dynamic or statistical forecast models. Moreover, interpretation and application of climatological information including climate forecasts is conducted, as well as development of methods to produce forecast information customised for specific users. The objective remains the study of future possible impacts on climate and water balance in regional scale using the most updated future climate scenarios. It is expected that downscaling large-scale GCM output to regional scale and investigation of the adaptation of the model into specific regions in eastern Mediterranean to produce more accurate predictions. The methodology involves analysis of major scenario characteristics, driving forces, and their relationships, which is followed by the selection of GCM that best fits into climate characteristics of the selected region. Atmosphere general circulation models are applied to predict future climate conditions, based on future scenario. A three-dimensional GCM is used representing the atmosphere coupled to the land surface and cryosphere. The model produces projections for decades or centuries using a coarser level of detail compared to weather forecast models. Statistical downscaling of the GCM output is considered, which uses statistical relationships between synoptic meteorological conditions and hydro-climatic parameters derived from correlation analysis of data series. The climate modelling effort results into the development of objective analysis methods, data assimilation methods, and numerical prediction models. Moreover, climate variability is assessed based on time series analysis of all major predicted meteorological and hydrological variables for the future, usually up to 2,100, in monthly or possibly daily time intervals, as well as the assessment of all major changes comparing observed datasets with predicted series.

4 Water quantity and quality modelling

In this section, the developed database is used as input to existing hydrological, hydrogeological and water quality models. These models are calibrated and tested with historical data and used for the estimation of surface water discharge, groundwater flow, and water quality indicators for periods that there are no data.

4.1 Water quantity modelling

4.1.1 Hydrological modelling

Watershed deterministic models are used, such as the UBC watershed model (Quick and Pipes, 1976), which has been updated continuously to its present form. This model has been applied to variety climatic regions (Loukas et al., 2002a), which ensures that the model is capable of simulating runoff under a large variety of conditions. The UBC is a continuous conceptual hydrologic model and calculates daily or hourly streamflow and uses limited data of precipitation, and maximum and minimum temperature data. The model conceptualises the watersheds as a number of elevation zone, since the meteorological and hydrological processes are functions of elevation in watersheds. A simplified energy budget approach, which is based on limited data of maximum and minimum temperature, is used for the estimation of the snowmelt. Furthermore, the geophysical parameters of a watershed, such as impermeable area, forested areas, vegetation density, open areas, aspect, and glaciated areas are described for each elevation band and can be estimated from maps or remotely sensed data. Hence, it is assumed that the elevation areas are homogeneous with respect of the above geophysical parameters. The runoff from rainfall, snowmelt and glacier melt is distributed into four runoff components, namely surface runoff, subsurface soil runoff, groundwater, and deep groundwater, for each elevation zone, and this distribution is achieved with a soil moisture control mechanism. The flow routing is separately calculated for each one of the four runoff components and it is achieved by using the linear reservoir cascade technique. Apart from the total watershed runoff, the UBC watershed model provides information on snow-covered area, snowpack water equivalent, PET and AET, soil moisture interception losses, groundwater storage, surface and subsurface runoff for each elevation band, separately, and for the whole watershed.

4.1.2 Hydrogeological modelling

The hydrogeological models mathematically describe the hydrogeological processes in an aquifer of a watershed and estimate groundwater runoff and the groundwater level. Thus, they need as input estimates of the groundwater recharge, which can be estimated by the meteorological, soil and geological data or through simulation of a surface hydrological model, and the physical description of the aquifer in terms of soil data, geological and hydrogeological data, groundwater level data and similar information, and produce the time series of groundwater flow. Such a deterministic model is the MODFLOW model, which has been developed by the USGS and has been updated continuously since then. It is one of the most commonly used hydrogeological models worldwide. It implements the finite difference method to solve the state partial difference equation of the groundwater flow. MODFLOW can compute the groundwater flow in three dimensions for steady state and unsteady state flow conditions and it estimates the changes in the groundwater potential head in points of the aquifer for homogeneous and heterogeneous, isotropic and anisotropic aquifers. Furthermore, it has the ability to simulate the effect of groundwater pumping and recharge from a large number of wells, the regional recharge, the evapotranspiration, and other relevant parameters.

4.2 Water quality modelling

The water quality models can be subdivided into surface water quality models and groundwater quality models. The surface water quality models can be either empirical or conceptual models. Input requirements for these models are relatively simple, consisting of flow gauge data for model calibration, rainfall and temperature or evaporation data, land use data and pollutant concentration data. The most complex of these models runs on a daily time step, requiring daily series for most of these inputs, with the exceptions of concentrations and land use.

4.2.1 Surface water quality modelling

4.2.1.1 Empirical surface quality models

The catchment model scale simulation (CMSS) is a simple catchment scale empirical model developed to analyse the likely impacts of land use and land management policies on the nutrient load delivered to rivers, in particular, the effect on total phosphorus and total nitrogen loads reaching waterways within a catchment (Davis and Farley, 1997). Nutrient generation rates must be obtained through either local or expert knowledge of the catchment, or from previous model application. Nutrient generation in the model is not sensitive to rainfall events within the catchment. CMSS does not attempt to model processes, such as rainfall-runoff or infiltration. Pollutant loads are calculated as the sum of generation rates per unit area times total area for the different land uses in the catchment.

4.2.1.2 Conceptual surface quality models

The QUAL2E model is a steady-state, one-dimensional (longitudinal) stream water quality model developed by the U.S. Environmental Protection Agency (EPA). A dynamic flow version of this model has been developed by U.S. Geological Survey (CE-QUAL-RIV1). Both models have been applied for a wide variety of conditions, such as regulated streams, i.e., navigable waterways with multiple locks and dams and stream re-regulation), reservoir tailwaters, and large rivers. CE-QUAL-RIV1 is developed for highly unsteady flow conditions, such as storm water flows and streams below peaking hydropower dams. The QUAL2E model is used for studies, where steady, or slowly varying, flow can be assumed. The enhanced stream water quality model (QUAL2E) is applicable to well mixed, dendritic streams. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric re-aeration and their effects on the dissolved oxygen balance. It can predict up to 15 water quality constituent concentrations. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of non-point sources. By operating the model dynamically, the user can study diurnal dissolved oxygen variations and algal growth. However, the effects of dynamic forcing functions, such as headwater flows or point source loads, cannot be modelled with QUAL2E.

4.2.2 Groundwater quality modelling

One of the most commonly used groundwater flow and quality modelling system is the groundwater modelling system (GMS), being the only system, which supports TINs, solids, borehole data, 2D and 3D geostatistics, and both finite element and finite difference models in 2D and 3D. Currently supported models include MODFLOW, MODPATH, MT3D, FEMWATER, and SEAM3D. The MODFLOW model has been described above and is the main module of GMS, since the selection depends upon the availability of data. The model is calibrated and verified for the selected catchments. The outcome of the modelling procedure is used as input for water resources assessment and also data from the climate variability are used as inputs to water quantity and quality models to assess the long-term scenarios, either under existing conditions, or under crisis or in optimum conditions, with the objective to maintain the sustainability of water resources.

5 Hierarchical drought analysis

This section of the paper presents a general overview of the hierarchical drought analysis, since a detailed presentation of the satellite-based composite drought analysis for water scarcity management is covered in another paper (Dalezios et al., 2016c). Drought is part of nature's climate variability. Indeed, drought is considered as a natural regional phenomenon with a temporal periodicity. Essentially, droughts originate from a deficiency or lack of precipitation in a region over an extended period of time. This is why droughts are also referred to as 'non-events' and can be considered as extreme climatic events associated with water resources deficit. Moreover, drought is considered as one of the major natural hazards with significant impact to several sectors of the economy, society and environment (Sivakumar et al., 2005). There are several unique characteristics, which differentiate droughts from other environmental hazards, namely its slow onset often characterised as a creeping phenomenon, its non-structural impacts, which can be regional or local lasting for a long time or a very short time, as well as the absence of a universal definition leading to inaction (Wu and Wilhite, 2004; Loukas et al., 2002b). Moreover, the impacts of droughts may be severe and are neither immediate nor easily measured. All the above may accumulate difficulties in drought assessment and response, which may result into slow progress on drought preparedness plans and mitigation actions.

There is a need to establish the context in which the drought phenomenon and its associated impacts are being described leading to a better definition. If drought is considered as a phenomenon it is certainly an atmospheric phenomenon. However, by considering drought as a hazard, there is a tendency to define and classify droughts into different types. Definitions of drought help in identifying the duration and severity of drought and are useful in recognising and planning for drought (Dalezios et al., 2009, 2000). Four operational definitions are commonly used, namely meteorological or climatological, agricultural or agrometeorological, hydrological and socioeconomic drought (Keyantash and Dracup, 2002). With the exception of meteorological drought, the other types of drought, such as agricultural and hydrological, emphasise on the human or social aspects of drought, in terms of the interaction between the natural characteristics of meteorological drought and human activities that depend on precipitation (Dalezios et al., 2016a, 2016b). As their names imply, these diverse drought types impact different sectors, but in most instances the impacts related to each sector overlap both temporally and spatially. Drought concepts refer to conditions of precipitation deficit, soil moisture, streamflow, plant wilting, wild fires, famine, as well as other components. Indeed, drought is multi-faceted issue and drought quantification requires a multi-faceted assessment. Moreover, drought monitoring involves climate data, soil moisture, streamflow, groundwater, reservoir and lake levels, snow pack, short-, medium- and long-range forecasts, as well as vegetation health/stress and fire danger.

There is a medium confidence that droughts are expected to intensify in the 21st century in seasons and areas due to increased evapotranspiration and/or reduced precipitation. Regions include southern Europe and the whole Mediterranean, Central Europe, Central North America, Central America and Mexico, NE Brasil and S. Africa (IPCC, 2012). As already mentioned, all droughts begin with a deficiency of precipitation in a region over a period of time. These early stages of accumulated departure of precipitation from normal or expected are usually considered as meteorological drought (Sivakumar et al., 2010). Thus, a meteorological drought in terms of lack of precipitation is the primary cause of a drought. A continuation of these dry conditions over a longer period of time, sometimes in association with above-normal temperatures, high winds, and low relative humidity, quickly results in impacts in agricultural and hydrological sectors. Indeed, it usually first leads to an agricultural drought due to lack of soil water. If precipitation deficiencies continue a hydrological drought in terms of surface water deficits develops. The groundwater is usually the last to be affected, but also the last to return to normal water levels. Meteorological droughts are characterised by a change in the local meteorological conditions, such as the prevailing of a high pressure ridge. The geomorphological and climatological characteristics of a region play an important role in meteorological drought, since they may imply different precipitation regimes. Meteorological droughts can develop quickly, but they can also end just as quickly, if the precipitation deficits are relatively small. However, these types of drought may also develop into a multi-seasonal event leading to one of the other types of drought.

5.1 Drought quantification

Drought quantification and assessment can be implemented through the use of indicators and/or indices. Drought indicators are measures of climate variables, which describe features of drought, and provide an indication of potential drought related stress or deficiency. Data analysis, interpretation and aggregation leads to drought indicators, where several of them can be synthesised into the development of a drought index. Indeed, an index is a method of deriving 'value added' information related to drought and constitutes an attempt to quantify drought and its magnitude (Palmer, 1965). It is also important to note that indices are indicators as well. Clarifications are always required about the scientific and operational validity of an index, i.e., how each indicator is combined and weighted in the index and how an index value is related to geophysical and statistical characteristics of drought (Steinemann et al., 2005). There are several review studies on the use of drought indices (Heim, 2002) based on both conventional and satellite data (McVicar and Jupp, 1998; Dalezios et al., 2012). It should be noted that the progression of drought indices development emphasises on the derivation of a number or value that can constitute an expression of drought severity. Many drought indices have the potential to be used in multiple applications, or can be applied to various sectors.

5.2 Drought monitoring

Drought monitoring is an equally important issue. Given the complexity of drought phenomenon, it is necessary to know how droughts develop and what indicators are available to quantify drought identification and monitoring. Gathering information about the primary weather and climate characteristics of a region is an important first step needed to understand both the climate and drought climatology of the region in order to monitor droughts. Moreover, in order to assess and monitor droughts and to alleviate the impacts of droughts it is necessary to detect several drought features, such as severity, duration, periodicity, areal extent, onset and end time (Dalezios et al., 2012, 2014). Indeed, conventional and/or remote sensing data and methods can be used to delineate the spatial and temporal variability of several drought features in quantitative terms (Keyantash and Dracup, 2002). Moreover, DEWSs focalise on monitoring drought conditions and constitute an important part for adequate drought preparation (Wilhite, 2009; WMO, 2011). Nevertheless, DEWS for monitoring of drought evolution and development are of critical importance in economically and environmentally sensitive regions and are very significant inputs in any drought preparedness and mitigation plan (Dalezios et al., 2009). Needless to say, without adequate planning and preparedness, drought impacts may lead to even more severe consequences for many sectors.

6 Water demand and water balance

The management of water resources for both quality and quantity at a river basin or watershed scale requires specific determination of the water uses, their water quantity and quality demands, and their temporal and spatial distribution. This information is combined along with the availability of surface water and groundwater in the river basin in order to develop a master management plan for effective and sustainable water resources management with future perspectives. The objective consists of addressing this issue under water stress conditions as this is expressed by the existence of drought conditions and water scarcity resulting in potential changes and reallocation of water uses, changes in the water use practices, such as changes in the irrigation methods, development of water resources works, such as dams, changes in the water pricing and similar aspects.

6.1 Water demands

Assessment of water demands involves analysis of the water use infrastructure and water uses. Specifically, there should be documentation and mapping of all the economic activities that require water in the river basin, description of the existing water development works and analysis of their operation. In this framework, estimation of the water use for agriculture, domestic use, industry, tourism, fisheries and aquaculture, hydroelectricity, and environmental sustainability is considered.

6.1.1 Water use for agriculture

Agriculture is by far the major water consumer especially in agricultural countries and regions, where it may use more than 80% of the total water consumption. Hence, it is necessary to determine the irrigated areas, irrigation techniques used and the source of the water used for irrigation. This consists of the analysis of irrigation reservoirs, irrigation and drainage networks, the determination of the water uptake and transport of these water works, the operation of pumping stations, as well as the efficiency of the irrigation networks. In order to make this analysis, there should be collected and documented discharge data for the irrigation and drainage networks, data about the cultivated species, and determination of water consumption for each cultivated species, and data about the cultivation period and their phenological stages of each cultivated species.

6.1.2 Water use of animal production

Animal production activities within the river basin, their type, e.g. pastural or not, their water needs, and the methods used for the processing and disposal of the animal production wastes, as well as the quantity and quality of the effluent should be documented.

6.1.3 Water use for fisheries and aquaculture

Fisheries species in the interior waters, such as rivers and lakes, within the river basin and their needs for water quantity and quality are specified. There is also documentation and mapping of the existing units for pisciculture and aquaculture, the cultivated species and their needs for water quality and quantity. Finally, the methods used for the processing and disposal of pisciculture and aquaculture wastes, as well as the quantity and quality of the effluent are documented.

6.1.4 Domestic and industrial water use

The water supply needs for domestic use are identified and documented. The water resources development works are also documented and mapped. These works include water intakes, pumping stations, water supply networks and their water losses. Furthermore, the existing sewage networks and the capacity and quality of the effluent of wastewater treatment plants (WWTPs) are identified and mapped. The existing water consuming industries and their water demands are identified, documented, and categorised, along with the quality and quantity of each industry.

6.1.5 Water use for hydroelectricity production

Hydroelectric plants are mapped and the reservoir characteristics, such as area-volume-elevation curves and spillway features, along with the characteristics of the hydroelectric plants, are documented. Data of primary and secondary energy are also collected.

6.1.6 Water use for environmental sustainability

All the water ecosystems, wetlands and their characteristics are identified, mapped and documented. The minimum water volumes and water quality that are required to sustain the ecological systems of wetlands and the water ecosystems are estimated.

6.2 Water balance

When all the water demands within a river basin are specified and the surface water and groundwater resources are determined, the water balance of the basin is estimated. In this procedure, the available water quantity and quality for each specific water use can be specified and the shortage and the surplus of water of specific quality available in the river basin can be estimated. Apart from the physical availability of water for each use, information about the development of the water resources is also useful. Such information can include the priorities of meeting the water demands in the river basin, the cost of water, property status of water resources and responsibility for the water development projects and works operation.

7 Non-conventional measures

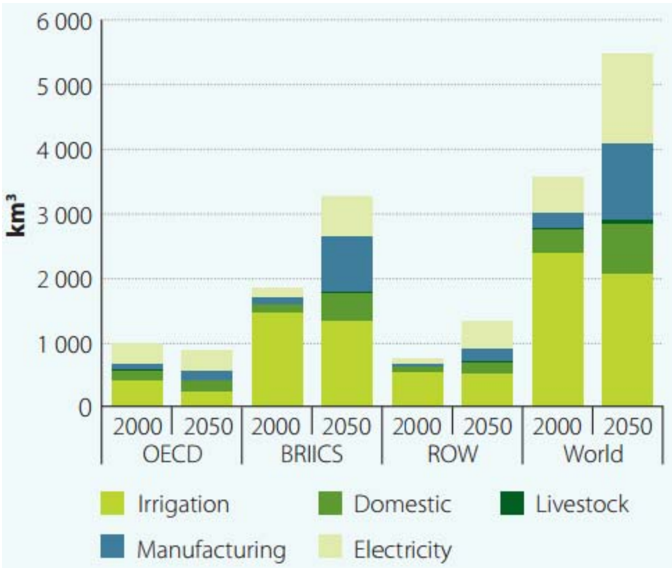
The world's population is growing by about 80 million people per year. It is predicted to reach 9.1 billion by 2050, with 2.4 billion people living in Sub-Saharan Africa, the region with the most heterogeneously distributed water resources (Pandey, 2015). In addition, Pandey (2015) is reported that because water use is unregulated and often wasteful in many nations, and since water pollution remains largely ignored and unpunished, safe drinking water supplies would continue to dwindle unless drastic action is taken. Total water demand is expected to increase from 4,000 today to 5,500 billion m^3/yr in 2050 (Figure 3). This global population boom, urbanisation and the climate variability and change have severely reduced water supplies. Furthermore, tapping fresh water for metropolitan areas has become more difficult, if not impossible. Without any doubt, the future relies on the implementation of 'NEWater' technologies, such as desalination, treated wastewater and rainwater harvesting, which are presented. Moreover, weather modification in terms of rain enhancement, which constitutes a hydrometeorological measure, is also considered.

7.1 Hydrometeorological measures: rain enhancement

Studies in several areas around the world have shown that drought periods are often characterised by a large decrease in the amount of rainfall per rainy day, by an increase in the continentality of clouds and by lack of rain-producing clouds. In general, droughts have been shown to be associated with persistence of ridges or centres of high pressure systems at middle-level in the troposphere. Furthermore, the corresponding reduced cloud cover results in positive temperature anomalies in the lower atmosphere, which produces the middle-level pressure anomaly and favours subsidence at high level keeping the atmosphere significantly drier and more stable than normal (Dalezios et al., 1991).

Weather modification is a field of applied meteorology covering the subjects of rain enhancement and hail suppression. Moreover, rain enhancement is a non-structural intervention to increase the available water mainly for agriculture, recreation as well as domestic and industrial use in arid and semiarid regions. Water demands are related to historical conditions in these regions and the lack of adequate water resources to meet seasonal and long-term water needs. Precipitation enhancement in selected areas is expected to improve the quantity of water in the hydrological system. It has long been recognised that cloud seeding is one approach for rain enhancement over a region.

Figure 3 Global water demands in 2000 and 2050 (see online version for colours)



Cloud seeding is an attractive approach to water augmentation, because it does not require large permanent construction or major fixed operation and maintenance costs. A decision for cloud seeding can be made on an annual or seasonal basis or even on a storm-to-storm basis within a season. At the present time, cloud seeding seems to be the most cost-effective means for securing additional water in a region. Other options that can be considered are desalination, importation, evaporation suppression and vegetation management. Desalination and importation require high construction costs. Evaporation suppression technology is usually not adequate for existing reservoirs. The combined effect of weather modification and vegetation management in the same area seems to increase water more than if the two were supplied separately. Several research-oriented and operational cloud seeding experiments for rain enhancement have been conducted during the last 40 years around the world. The success of such experiments heavily depends on a thorough and in-depth investigation of all the components of such an experiment including the prevailing meteorological and microphysical conditions of the region. A brief review of the rain enhancement methodological procedure follows.

7.1.1 Feasibility study

The feasibility study involves analysis of precipitation and cloud climatology, as well as microphysical features of clouds. The expected outcome is the delineation of all the available synoptic rain and cloud climatological data for the regions under consideration. Moreover, in planning weather modification projects, either for research or operational purposes, it is also necessary to first carry out studies of the structure and microphysics of clouds. These preliminary investigations should clarify whether the natural processes are efficient, and therefore, seeding is likely to be effective (Dalezios and Papamanolis, 1991). If seeding experiments appear to be physically feasible, then the prospective benefits and cost of seeding should be investigated to determine if experiments are economically justified.

7.1.1.1 Synoptic climatology

The synoptic climatology involves the investigation of the prevailing weather systems and the precipitation producing systems at synoptic and sub-synoptic scale (Dalezios and Papamanolis, 1991). The study should also involve the temporal variability and occurrence, as well as the areal extent of the prevailing systems. This part of the feasibility study should be integrated along with rainfall and cloud climatology and the microphysical cloud features, which lead to the design of a potential rain enhancement experiment.

7.1.1.2 Rainfall climatology

Analysis of rainfall datasets should focus on whether the non-rainy days constitute the majority. Similarly, light rain may constitute the major portion of the rainy days per year. These findings, among others, can be used for improving and optimising agricultural planning and suggests that there are shortages of rainfall amounts during agriculturally critical periods. The purpose of this precipitation analysis consists of exploring some precipitation characteristics that would be useful in assessing the need for further studies on the potential for precipitation enhancement. The analysis involves frequency analysis, seasonal grouping of monthly precipitation and frequency analysis of daily rainfall data.

7.1.1.3 Cloud climatology

Clouds are one of the most crucial elements, but least understood components of the climate system. Cloud classification and observations depend on station location, hour of the day and to some extent on the observer's experience. There is a need to classify clouds in three categories: low, middle and upper clouds depending on the level of the cloud base. Low clouds are usually selected to represent the five precipitation categories and all middle and upper cloud cases are grouped under the name 'other'. A seventh category represents the clear weather cases (Table 1). The analysis is expected to be performed on a monthly basis and it would assist in assessing the seasonal duration of a potential rain experiment.

Table 1 Cloud categories

1	CB (cumulonimbus)
2	TCU-CU (towering cumulus-cumulus)
3	SC (stratocumulus)
4	ST (stratus)
5	CF-SF (cumulus fractus-stratofractus)
6	*Other*
7	*Clear*

7.1.1.4 Microphysical features

Large cloud water droplets exist in the high liquid water content region of the cloud. These large droplets rise in the updraft with some freezing during the ascent. Ice crystals from near cloud top are descending in downdrafts. In those conditions, graupel and ice pellets form by riming (Dalezios et al., 1996). Ice multiplication seems most common in the cloud tops of cumulus congestus with large droplets. The ice multiplication mechanism can only be verified by measurements of the size distribution of cloud droplets and concentration of precipitation-sized particles. Such measurements require a wider range of particle-sizing instrumentation and require measurement by instrumented aircraft and digitised weather radar data. The objective of this process is a monthly climatological summary of total occurrences, such as the number of observations over the number of observations with rain, for all stations under consideration.

7.1.2 Design of a rain enhancement experiment

A feasibility study is expected to include information on the selected area, required number of aircrafts, radar equipment and database for a rain enhancement experiment. The objective of this activity is to determine the rain enhancement potential in the region under study. The design of a rain enhancement experience should examine the cloud seeding hypothesis, the cloud seeding procedure, the operational component, as well as the evaluation methodology and the associated costs.

7.1.2.1 Cloud seeding hypothesis

Two seeding hypotheses and one seeding agent (silver iodide) are being tested during the rain experiments. The two hypotheses have come to be called the static and the dynamic modes, respectively. In static-mode seeding two assumptions are usually made: a deficiency in concentrations of natural ice crystals is the reason for delay, or even failure, of precipitation formation in certain cloud conditions; and, moderate increases in ice crystal concentrations, obtained by glaciogenic seeding of such clouds, result in rainfall enhancement either by making the already existing process of rain formation more effective or by inducing precipitation formation in clouds that otherwise would not have precipitated naturally. The basic assumption behind seeding for dynamic effects is that increased cloud buoyancy, achieved through conversion of supercooled water to ice by seeding, causes an increase in cloud depth, which in turn results in stronger rainfall intensities, areas and durations. It should be mentioned that one of the successful rain enhancement experiments, namely the Israel II experiment was a static-mode seeding project (Gagin and Neumann, 1981). A moderate amount of silver iodide is arbitrarily defined as one 20 g flare every kilometre of flight through a cloud. Similarly, a large amount of silver iodide is arbitrarily defined as one 20 g flare every 200 m of flight through a cloud.

7.1.2.2 Cloud seeding procedure

The seeding procedure in the selected area involves, at first, the identification of the experimental unit (e.g. rainy day or semi-isolated cumulus congestus), which should result from the feasibility study. Secondly, the procedure involves the establishment of the cloud seeding criteria. The criteria consist of threshold values of selected thermodynamic, microphysical and/or radar parameters, which justify cloud penetration and/or cloud seeding (Dalezios et al., 1996). Usually, a set of cloud characteristics is being specified, which is believed to represent a cloud that responds positively to seeding and is in its developing stage of evolution. It also involves flying speed and height and regional seeding details. Indicative parameters include firm and continuous cloud base indicative of inflow, radar echo, cloud depth, cloud top temperature, liquid water content and cloud diameter just to mention a few.

7.1.2.3 Operations

The operational part of the design consists of a detailed procedure to run the program on a daily basis. Having specified the required personnel, aircraft, radar equipment and instrumentation, the starting point is the daily specific weather and hail forecasting and/or nowcasting, which should be quantitative, analytical and at mesoscale level with the objective of assessing the daily operational status in terms of aircraft part or seeding, radar surveillance and similar aspects. Another key operational (and not only) part is the availability, status and maintenance procedures of weather radar. Similarly, the flight safety and security procedures are also established, along with the status and maintenance of the allocated aircraft, for the potential project. Moreover, data acquisition, processing and analysis should be established in detail, which should be used, besides operations, in evaluation and overall project management.

7.1.2.4 Evaluation

A statistical evaluation procedure is usually followed in rain enhancement experiments. The selected area is splitted into target and control areas and randomisation is used at the beginning of each period, e.g. winter season. The duration of the experiment is divided in two phases, namely the exploratory and the confirmatory phase, respectively. During the exploratory phase several response variables are measured or estimated through microphysical instrumentation, radar parameters, as well as ground level data. At the end a thorough statistical analysis is followed and a few dominant response variables are identified, which are then used during the confirmatory phase for the final evaluation of the experiment. Moreover, the operational part is also evaluated. Finally, a cost-benefit analysis should include the associated costs for operation, evaluation and similar aspects, as well as, the benefits from the overall efficiency of the experiment.

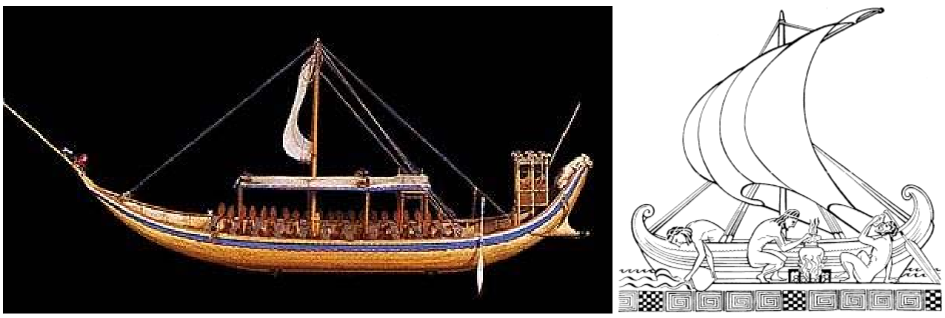
7.2 Desalination

7.2.1 Historical development

The global water demand is continuously increasing due to population growth and economic development. The amount of precipitation falling on land is almost 110,000 km^3/yr. Almost two-thirds of this amount evaporates from the ground or transpires from vegetation (forest, rangeland, and cropland). The remaining 40,000 km^3/yr is converted to surface runoff (feeding rivers and lakes) and groundwater (feeding aquifers). These are called renewable freshwater resources. Part of this water (one tenth) is being removed from these rivers or aquifers by installing infrastructure. Global water withdrawals exceed 4,000 billion m^3/yr and about 25% of the world population encounters fresh water scarcity (UN OCHA, 2010). At global level, the withdrawal ratios are 70% agricultural, 11% municipal, and 19% industrial (AQUASTAT, 2015). In response to the increasing demand, desalination has become the most important source of water for drinking and agriculture in some world regions under water scarcity (e.g. California, Middle East, North Africa, and some of the Caribbean islands).

Desalination has a long history. One of the first mentions was by Aristotle, who wrote of seawater distillation in 320 BC (IDA, 2012). There are indications that Minoans, which are consider as thalassocrats, desalinate seawater during their long stay at sea. Different techniques were used during the ages: Rome's Pliny the Elder described seawater distillation with condensation on fleece in *ca*. 70 AD, Greece's Alexander of Aphrodisias described seawater distillation (Figure 4) with condensation on sponges 130 years later (*ca*. 200 AD), French explorer Jean De Lery reported the successful distillation of seawater during a voyage to Brazil in 1565, and James Cook desalinated seawater during his circumnavigation of the world in 1772 (IDA, 2013).

Figure 4 Ancient Greek ships, (a) model Minoan ship by display in fresco at Akrotiri in Santorini (b) sailors desalinate seawater in ancient Greek ship at sea (Alexander of Afrodisias 200 AD) (see online version for colours)



(a) (b)

The development of desalination processes took a major step forward in the 1940s during World War II, when military establishments operating in arid areas needed a way to supply their troops with potable water. By the late 1960s, commercial desalting units producing up to 8,000 m^3/d (Table 2). Zotalis et al. (2014) reported that there are about 8,000 desalination plants worldwide, with a global capacity of 35 million m^3/d in 2004. About 60% of feed water used in these plants is seawater (IEA-ETSAP and IRENA, 2012). Global water withdrawals amount to around 4,000 billion m^3/yr and in some regions, especially the Middle East and Northern Africa regions, desalination has become the most important source of water for drinking and agriculture. Today's global desalinated water production amounts to about 90 million m^3/d (33 billion m^3/yr), equivalent to 0.65% of global water supply (Table 2). The Middle East and Northern Africa regions accounts for about 38% of the global desalination capacity, with Saudi Arabia being the largest desalinating country. Major desalination technology options are based on thermal processes using both heat and electricity, and membrane technologies using electricity only.

Table 2 Evolution of desalination production since the World War II

Year	*Plants*	*Capacity (Mm3/d)*	*References*
1945	Limited no	0.003	Jiménez et al. (2011)
1960s	Limited no	0.008	IDA (2013)
1980	> 1,000	5.00	Zotalis et al. (2014)
2004	8,000	35.00	Zotalis et al. (2014)
2008	14,000	52.33	IDA (2008)
2010	na	65.2	IEA-ETSAP and IRENA (2012)
2011	15,000	71.70	IEA-ETSAP and IRENA (2012)
2014	17,000	89.00	Estimation

Note: na: not available.

The basic pillars of the management of Israel's water resources are the desalination and the reuse of treatment of wastewater mainly for irrigation. Israel has doubled the quantity of desalinated water in recent years (from 300 million m^3/yr in 2010 to 600 million m^3/yr today). A production of 2 billion m^3 desalinated water in 2050 is expected, representing about 70% of total water supply needs of the country (Tenne, 2010).

7.2.2 Technologies and performance

Major desalination technologies are thermal processes and those of membrane-based processes (Table 3). Today the dominant technology is reverse osmosis (RO), which accounts for 60% of the global capacity, followed by that of thermal processes multi stage flash (MSF), with a 26.8% share (Figure 5). The larger desalination plants can reach a capacity of up to 800,000 m^3/d or more. Renewable energy can play an important role in desalination. Renewable technologies that are suited to desalination include solar thermal, solar photovoltaics (PV), wind, and geothermal energy. Solar technologies based on solar heat concentration, notably concentrating solar power (CSP), produce a large amount of heat that is suited to thermal desalination. Photovoltaic and wind electricity is often combined with membrane desalination units (e.g. RO and electrodialysis).

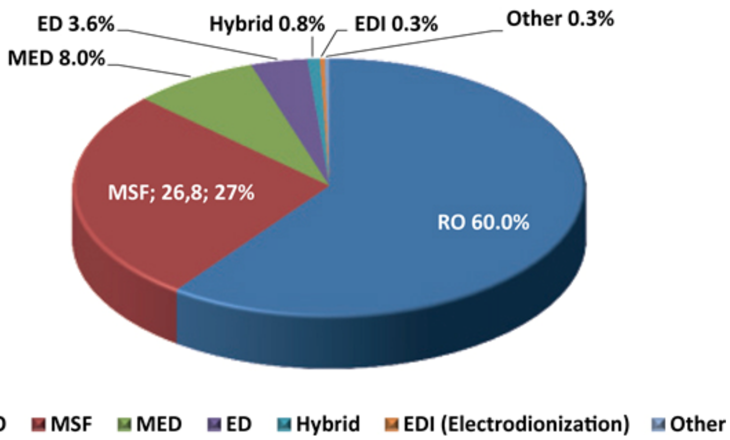
Table 3 Major desalination technologies

Thermal	*Membrane-based*
Multi stage flash (MSF)	Electrodialysis (ED)
Multi effect distillation (MED)	Reverse osmosis (RO)
Vapour compression, VC	

7.2.3 Potential and barriers

The global desalination demand is projected to grow by 9% per year between 2010 and 2016, with a cumulative investment of about 80 € billion. In the Middle East and North Africa regions, water demand is expected to increase from 9 billion m^3 in 2010 up to 13.3 billion m^3 in 2030 while groundwater resources are projected to decrease (IEA-ETSAP and IRENA, 2012). As a consequence, desalination capacity in the Middle East and North Africa regions is expected to grow quickly from 21 million m^3/d in 2007 to nearly 110 million m3/d by 2030, of which 70% is in Saudi Arabia, the United Arab Emirates, Kuwait, Algeria and Libya. As desalination requires a considerable amount of energy, water production in worldwide will contribute significantly to increase the energy use. The total electricity demand for desalination in the Middle East and North Africa regions is expected to rise to some 122 TWh by 2030, thus tripling compared with the 2007 level (IEA-ETSAP and IRENA, 2012). Desalination demand is also expected to grow in Asia and the Caribbean region. China and India are high potential markets for desalination due to growing population and economies, and water shortage. The need for desalination grows much faster than the economy as a whole, and the associated energy need is projected to increase accordingly.

Figure 5 Desalination technology market (see online version for colours)



Source: IEA-ETSAP and IRENA (2012)

7.2.4 Performance and costs

Desalination requires a considerable amount of energy. Seawater desalination via MSF consumes typically 80.6 kWh of heat energy (290 MJ thermal energy/kg) plus 2.5 to 3.5 kWh of electricity/m^3 of water, while large scale RO requires only about 3.5 to 5.0 kWh of electricity/m^3. The global production of about 65.2 million m3/d of desalinated water in 2010 involves the use of at least 75.2 TWh per year, which equals about 0.4% of the global electricity consumption (IEA-ETSAP and IRENA, 2012). The cost of RO desalination has been decreasing over the last years down to 0.45 €/m^3, while market prices for desalinated water are typically between 0.90 €/m^3 and 1.80 €/m^3 (Table 3). However, cost of desalination for thermal technologies is still very high (Table 3). Therefore, desalination is currently fordable for middle-income regions, not yet for the poorest countries. The desalination of brackish water is of considerably lower cost (usually much < 1 €/m^3), compared to the desalination of seawater. This cost reduction may be over 50%, mostly because the cost for the removal of dissolved salt is lower at power salt concentrations (Zotalis et al., 2014). Also the desalination cost is reduced as the capacity of the plant is increased. With capacities > 8,000–10,000 m^3/d the cost drop to less than 1 €/m^3 (Table 4).

Table 4 RO desalination production cost compared to thermal desalination technologies cost, per feeding water and production capacity

Feedwater	*Plant capacity (m^3/d)*	*Cost (€/m^3)*
Brackish water RO	<20	4.50–10.32
	20–1,200	0.62–1.06
	40,000–46,000	0.21–0.43
Seawater RO	<100	1.20–15.00
	250–1,000	1.00–3.14
	1,000–4,800	0.56–1.38
	15,000–60,000	0.38–1.30
	100,000–320,000	0.36–0.53
MSF	<100	2.00–8.00
	12,000–55,000	0.76–1.20
	>91,000	0.42–0.81
MED	23,000–528,000	0.42–1.40
VC	1,000–1,200	1.61–2.13

Source: Zotalis et al. (2014)

The economics of renewable desalination depends on the cost of renewable energy as the cost of desalination is largely determined by the energy costs. In general, the cost of renewable desalination is still higher if compared to the cost of conventional desalination based on fossil fuels as the energy input. However, the costs of renewable technologies are quickly decreasing and renewable desalination can already compete with conventional systems in remote regions where the cost of energy transmission and distribution is higher than the cost of distributed generation (IEA-ETSAP and IRENA, 2012). Finally, future technical developments will include availability of low-cost renewable energy and energy storage technologies to face the variable nature of renewable energy.

7.2.5 Environmental impacts

A key issue is the disposal of brine. High salt-content brine is the desalination waste to be disposed of or recycled. At present, it is mostly discharged into the sea or diluted and sprayed into an open space. However, the negative impact of brine on the ecosystems and the growing desalination capacity mean that a sustainable solution is needed for disposal and/or brine recycling to avoid environmental impacts. Integrating membrane distillation (MED), which is much less sensitive to concentration with RO, more fresh water can be produced and the RO brine volume can be furthermore reduced in the MED unit (Gude et al., 2010). Thus the reduction of the quantity of brine produced leads to a lower environmental impact. Evaluation and development technologies to treat brackish water for brine minimisation should be considered. The principal processes used for brine minimisation are summarised by Raucher and Tchobanoglous (2015).

From an economic point of view, the identification of niche markets and proper policy frameworks may help attract private investors for renewable desalination to take off (Papapetrou et al., 2010). Not least, more cooperation and integration is needed between energy sector and water sector, and more attention needs to be paid to barriers for developing countries, including high investment and operation costs, and trained personnel to run the plants (IEA-ETSAP and IRENA, 2012).

7.3 Water reuse

7.3.1 Background and evolution

Wastewater treatment and reuse is not a new technique, and knowledge on it has been accumulated along humankind history. Land application of domestic wastewater is an old and common practice, which has gone through different development stages with time, knowledge of the processes, treatment technology, and regulations evolution (Paranychianakis et al., 2015). It was practiced by prehistoric civilisations (e.g. Mesopotamian, Indus valley, and Minoan), since the Bronze Age (*ca.* 3200–1100). Thereafter wastewater has been used by Hellenic civilisations and later by Romans, in areas surrounding cities (e.g. Athens and Rome) for disposal, irrigation, and fertilisation purposes (Tzanakakis et al., 2007). In more recent history, the earliest documented ‘sewage farms’ (i.e. wastewater application to the land for disposal and agricultural use) were operated in Bunzlau (Silesia) in 1531 and in Edinburgh (Scotland) in 1650, where wastewater was used for beneficial crop production (Tzanakakis et al., 2014). In the following years in many rapidly growing cities of Europe and the USA, ‘sewage farms’ were increasingly seen as a solution for the disposal of large volumes of the wastewater generated. Some of them are still in use. Paris was a typical example with the first sewage farms established at Gennevilliers in 1872, handling, after an extension, the wastewater of the whole town. At the beginning of the last century, the sewage farms reached their maximum extent in France, established in four different areas; in Gennevilliers (900 ha) and Achères (Achères plain, 1,400 ha, Pierrelaye, 2,010 ha and Triel, 950 ha) supplied with raw wastewater by the Colombes pumping station in Paris (Kamizoulis et al., 2003). Also, a large ‘sewage farm’ was established in Melbourne, Australia in 1897 (Reed et al., 1995; Kamizoulis et al., 2003; Tzanakakis et al., 2014).

The use of the land treatment systems continued along the 20th century in central Europe, USA, and other locations all over the world; not without causing serious public health concerns and negative environmental impacts. However, by the end of the first half of this century these systems were not easily accepted any more, due to certain drawbacks, such as large area requirements, field operation problems, and the inability to achieve the higher hygiene criteria requirements issued (Tzanakakis et al., 2014). Modern sewage systems were first built in the mid-19th century as a reaction to the exacerbation of sanitary conditions brought on by heavy urbanisation and industrialisation. Also the first projects of the intended water reuse were implemented in California at the beginning of the 20th century. The scarcity of water and the benefits of water recycling to crop yield were the main drivers which promoted the expansion of this practice. The State of California recognising the environmental and economic benefits in line with the potential health risks set in 1918, the first regulations worldwide governing water recycling in the agriculture (California State Board of Health, 1918).

Water reuse, as an alternative water source, can provide significant economic, social and environmental benefits, which are key motivators for implementing such reuse programmes. These benefits include (Alcalde Sanz and Manfred Gawlik, 2014):

a increased water availability

b integrated and sustainable use of water resources

c drinking water substitution; keep drinking water for drinking and reclaimed water for non-drinking use

d reduced over-abstraction of surface and groundwater

e reduced energy consumption compared to using deep groundwater resources, water importation or desalination

f reduced nutrient loads to receiving waters

g reduced manufacturing costs of using high quality reused water

h increased agricultural production

i reduced application of fertilisers

j enhanced environmental protection by restoration of streams, wetlands and ponds

k) increased employment and local economy (e.g. tourism and agriculture).

Treated wastewater has been increasingly used around the world for a number of applications, including irrigational, industrial, urban and in some rare cases, for direct potable use (Asano et al., 2007; Paranychianakis et al., 2011; Gikas and Tchobanoglous, 2009; Tchobanoglous et al., 2014). The major water reuse categories are: irrigation (both agricultural and landscape), industrial use, non-potable urban uses, recreation and/or environmental uses, indirect potable use, and direct potable use. These water reuse applications and the relative constrains that prevent expansion are shown in Table 5. The principal causes preventing the expansion of effluent reuse worldwide are public health and environmental concerns (Angelakis and Gikas, 2014). To reduce the potential risks to acceptable levels, many countries have set regulations or guidelines governing effluent reuse (Salgot and Angelakis, 2001; Angelakis et al., 1999). Notice that regulations refer to actual rules that have been enacted and are enforceable by governmental agencies. Guidelines, on the other hand, are not enforceable, but can be used in the development of a reuse program. Both regulations and guidelines include minimum quality requirements.

Table 5 Major water reuse applications and constrains

Application	*Major constrains*
Agricultural irrigation	Seasonal demand and need for winter storage
	Usually away from the point of water reclamation
Landscape irrigation	Dispersed nature of landscape irrigation
	Cost of parallel distribution system
Industrial use	Constant demand but site specific
	Limited demand
Non-potable urban uses	Limited demand
	Requirement for dual piping systems
Recreation/environmental uses	Site specific
Indirect potable reuse	Most communities lack suitable hydrology for groundwater recharge
	Availability of nearby suitable surface storage
Direct potable use	Public perception issues

Source: Adapted from Angelakis and Gikas (2014)

7.3.2 Challenges and trends

Municipal wastewater reuse offers the potential to significantly increase water availability especially in countries under water scarcity. Only in the EU countries and in USA, more than 150 and 120 M m^3 of municipal wastewater effluent every single day is discharged nationwide in the oceans, seas, rivers, and lands, respectively. Water reuse is today a common practice in several countries worldwide. Also numerous approaches are available for reusing wastewater effluent to provide water for industry, irrigation, and potable supply, among other applications, although limited estimates of water reuse suggest that it accounts for a small part (< 1%) of EU and USA water use (National Academy of Sciences, 2012). Water reclamation for non potable applications is well established, with system designs and treatment technologies that are generally accepted by communities, practitioners, and regulatory authorities. Also indirect potable (or unplanned) water reuse is a reality since the existence of humans in this planet. The *de facto* reuse of wastewater effluent as a water supply is common in many of the nation's water systems, with some drinking water treatment plants using waters from which a large fraction originated as wastewater effluent from upstream communities, especially under low-flow conditions (National Academy of Sciences, 2012).

An analysis of the extent of *de facto* potable water reuse should be conducted to quantify the number of people currently exposed to wastewater contaminants and their likely concentrations. Such an analysis in EU and USA would help water resource planners and public health agencies understand the extent and importance of *de facto* water reuse.

Future technical developments that will promote water reuse include the need for enhanced wastewater treatment, the development of alternative treatment processes, and integrated wastewater effluents as a real water source (Tchobanoglous et al., 2014). Water reuse not seen as a component of integrated water management approaches in EU. However, it is important to notice that other water sources in EU and elsewhere (e.g.

surface waters) are in the most of cases of lower quality than the wastewater effluents discharged to the environment (Leverenz et al., 2011). Thus, treated wastewater should be considered equally to the other surface waters by the EU legislations, such as WFD (2000/60/EC), the Groundwater Directive (2006/118/EC) and the Environmental Quality Standards Directive (Directive 2008/105/EC). Also, it should expand water protection to all waters included non-conventional resources.

One of the major problems with some advanced treatment schemes, such as reverse osmosis, is the possible impacts to the environment. To deal with this issue, a variety of new advanced treatment processes are currently under development for the oxidation of trace organics, without the removal of dissolved solids. The current trend in water and wastewater systems design can best be described as incrementalism. What is needed is the development of integrated water management systems in which new WWTPs are planned and designed from the ground up to optimise treatment performance with respect to the production of purified water, along with the recovery of energy and resources (Leverenz et al., 2011).

7.3.3 Water reuse paradigms

There are at least over 60 countries around the world practicing various categories of water reuse. It is difficult to conclude which countries are reusing the largest volumes of wastewater due to the lack of international standardised databases (Angelakis and Gikas, 2014; Raucher and Tchobanoglous, 2015). Regarding the technological achievements California, Singapore, Israel, and Japan are probably pioneers.

a Singapore. Water reuse project in Singapore has been well accepted by the public, as a result of a systematic governmental promotion program. As the contract with Malaysia for water importation will expire in 2061, Singapore is preparing to increase the use of NEWater and desalinated water from 30% and 10% in 2010 to 50% and 30% in 2060, respectively (Angelakis and Gikas, 2014).

b Israel. As it is already mentioned, another pillar of the management of Israel's water is the treatment of wastewater for reuse mainly for irrigation. Today reuses 80% of the generated wastewater and aims to increase the ceiling (95%) the next ten-year period (Angelakis and Gikas, 2014).

c California. The energy required for water supply to the Orange County water system is significantly higher, compared to the energy required for the reuse of high quality water. Recently, Angelakis and Gikas (2014) reported that the relative energy requirements for supplying 1 m^3 to the above system are 3.00 kWh for desalinated seawater, 2.83 kWh for State Project water, 2.03 kWh for Colorado River water and 0.65–1.22 kWh for the high quality reclaimed water from treated wastewater. However, water reuse in agricultural or landscape applications or even for indirect potable reuse through storage in appropriate aquifers is generally restricted due to various factors, which are summarised in Table 5. Based on the above, it looks that the most favourable option is the reclamation of high quality water at the WWTPs of Southern California, and reuse it for direct potable applications.

d In Cloudcroft, New Mexico, in the USA, the construction of a new direct potable reuse system is scheduled for completion this spring. Purified wastewater will be blended with a slightly greater amount (51%) of spring water or well water or a blend of the two, and placed into a storage reservoir (blending tank) for a two-week detention. This water will be treated in a water treatment plant before added into the water supply distribution system (Raucher and Tchobanoglous, 2015).

e The Australian Government itself committed to a national target of wastewater recycling 30% of wastewater by 2015. In addition, many major cities and several states have set targets to achieve specific percentages of wastewater recycling.

f The National Aeronautics and Space Administration has used recycled water in the space stations for consumption for many years. The source water is urinary distillate and air condensate recovery. The process includes multifiltration, vapour compression distillation, catalytic reactor, ion exchange, and iodine disinfection (Cotruvo, 2014).

h More paradigms are provided (Raucher and Tchobanoglous, 2015).

7.4 Rainwater harvesting

7.4.1 History and evolution

In the prehistoric world, the low water availability in several regions of the world, particularly in arid and semi-arid regions, resulted in the construction of various water reservoir types for collection and storage of rainwater (e.g. in Minoan islands, in Indus valley, in China, and pre-Columbian civilisations). Rainwater harvesting was known even in the Mesopotamian plain where fresh water from the Tigris and Euphrates was secured. There, rainwater harvesting was used to secure drinking water supply. Since then, the technology of construction and use of several types of cisterns and other collection and storage facilities has been further developed, by different civilisations (Mays et al., 2013). Advanced rainwater harvesting technologies were invented, with a peak in the Classical and Hellenistic periods that follows Alexander the Great, during which they spread over a geographical area from Greece to the West (central and south Italy) and to the East (Egypt and probably eastern and southern of Egypt). The Romans inherited the Greek technologies and developed them further mainly by changing their application scale from small to large and implementing them to almost every large city (Haut et al., 2015). Development of cost-effective decentralised water supply management programs based on the harvesting and the storage of rainwater, especially in water-short areas, is a sustainable technology. In addition, during floods, one of the basic ideas is to increase water storage in order to achieve the maximum possible water retention effect together with minimum investment (e.g. construction of local embankments for the towns). This can also be achieved by construction of various types of rainwater harvesting technologies.

7.4.2 Rainwater harvesting technologies

In several parts of the world, modern water technologies started to be developed at the end of 19th and the beginning of 20th century. They were based on the technologies of the past (Koutsoyiannis et al., 2008). It was continued with an advanced manner after the World War I, and even more after the World War II, i.e. the middle of the last century (Haut et al., 2015). The use of water harvesting systems for water supply was a common practice in several parts of the developed world. Such systems to collect rainwater are still the main part of water supply systems in various arid and semi-arid regions of the world. In these regions, people face malnutrition and vitamin deficiency; water is so scarce that the most efficient way to provide it is to harvest rainwater.

Rainwater harvesting systems ranged from to big reservoirs (dams) both concrete and fill (embankment) to macro- and micro-catchment systems. In this short review only macro- and micro-catchment systems are considered. These water systems are simple in design and may be constructed at low cost. Therefore, they are easy to replicate and to adapt. They have a high runoff efficiency than the macro- catchment systems, and usually do not need a water conveyance system. Soil erosion may be controlled and sediment directed to settle in the cultivated lands (Oweis et al., 2004). Also these systems could eliminate the risk of flood if they manage appropriately. The major such systems are:

a Water cisterns. Such systems are very well known in urban areas worldwide, since the prehistoric times. Cisterns are indigenous surface or subsurface reservoirs with a capacity ranging from 10 to 500 m^3. However, there are known cisterns up to 3,000 m^3 in capacity in Roman and Byzantine periods (Angelakis et al., 2014; Antoniou et al., 2014). These systems are still used in several Mediterranean countries, in west Asia, in North Africa, and in Latin America. Two cisterns: one from Roman time and one of present times are shown in Figure 6.

b In rural areas are known bigger subsurface systems with a capacity ranging from 500 to 3,000 m^3 for agricultural use. These systems are known in several Mediterranean countries called *layette collinari* (small lake in foot hill areas) in Italy and *limnodexames* (lake and reservoir) in Greece (Figure 4).

c In west Africa and north Africa are used numerous of macro- and micro-catchment systems. The major of those systems are:

   1 micro-catchment systems are: contour ridges, semi-circular and trapezoidal bunds, small pits, small runoff basins, runoff strips, coutour bench terraces, and rooftop systems

   2 macro-catchment and floodwater systems are: wadi-bed systems (such as small reservoirs, bed cultivation, and jessour) and off-wadi systems (such as water-spreading systems, large bunds, tanks and hafair, cisterns, and hillside-runoff systems).

d The case study of Seoul's Star City. In recent years, seasonal climate extremes have intensified, resulting in huge socioeconomic damages. As an adaptation strategy for coping with climate extremes, an ancient concept of rainwater harvesting is getting revisited. Recently, researchers have reappraised the decentralised multi-purpose rainwater harvesting system as a useful infrastructure to mitigate water-related disasters such as flooding, sudden water break and fire events, especially in highly developed urban areas (IWA, 2008).

The Star City rainwater harvesting system in South Korea is a successful case that is designed with an intention of alleviating water-related disasters. Star City a large commercial/residential complex consisting of a department store and four apartment buildings, each having between 35 and 57 stories. In total, there are 1,310 apartments, meant to accommodate 4,000 to 5,000 people. The catchment area comprises 6,200 m^2 of four rooftop areas and 45,000 m^2 of terraces and gardens throughout the complex. During the design stage, a 3,000 m^3 rainwater tank was introduced at the fourth floor of building B, and divided into three tanks, 1,000 m^3 each (Haut et al., 2015).

Figure 6 Cisterns in Crete, Greece, (a) historical times carved cisterns at Roman Aptera Roman town of 3 M m^3 capacity (by permission A.N. Angelakis) (b) modern time reservoir in rural area of plateau Lasithi in eastern Crete of 1 Mm^3 capacity (by permission of M. Kritsotakis) (see online version for colours)

(a) (b)

Several innovative concepts have been applied in implementing the rainwater harvesting system at Star City. The first is the concept of a multi-purpose system; the system at Star City serves the purpose of flood mitigation, water conservation, water and heritage and emergency preparation. The second is the concept of proactive management of flooding; the Star City system has a remote control system for monitoring and controlling the tank water level. The three different tanks also store water separately according to water quality. The risk of flood can be controlled pro-actively with the remote control system by emptying or filling the tanks appropriately. The third innovative concept applied in this project was the city government's incentive program for the developer, so that government will allow more floor space to build to compensate the extra cost for rainwater harvesting system. During the seven years operation, some technical data are reported (Mun and Han, 2012). This successful demo project convinced the city officials and lawmakers, and triggered to make a city ordinance and propose a national law for rainwater management.

8 Management of watershed water scarcity

8.1 Water resources management and economic modelling

Water resources management simulation is conducted covering domestic needs. The models serve both as a training tool and as a policy experimentation environment. The modelled hydro-systems behave according to the real systems based on the available data. Thus, policy makers are able to experiment with alternative policies without the high risks associated with actual implementation. The simulation model follows the development of the hydrological model. Based on the model developed on the basis of fieldwork, the model seeks to integrate the water demand and supply components into an integrated system. The model is developed using the system dynamics leading to a comprehensive and interactive model of the water system, which represents to a high degree the behaviour of the real system. The final model is incorporated in an interactive environment in the form of management flight simulator, which serves as a training tool, as well as a policy implications estimation tool. In particular, the model consists of two interacting subsystems, namely the hydrological subsystem representing the behaviour of the natural system, and the demand subsystem representing the human activities that are related to water consumption and management. The two interacting subsystems are connected though a generic model, and are subsequently calibrated according to the watershed conditions and the system is completed with an interactive interface.

The water resources management model conceptualises the river basin as a number of nodes. The water demands and the water availability are distributed in these nodes. The model simulates the spatiotemporal distribution of quantity and quality characteristics of water availability and water demand in each node and their continuous interaction. The model estimates the water quality and quantity balance for all the nodes. The nodes of the water system are interconnected transferring all the water quantity and quality parameters from upstream to downstream, estimating new water balance for each node, changing the water storages and the quality of water in every node, satisfying the prescribed water demands according to the priorities, constrains, and demands of minimum water quantity and quality in specific nodes. At each time step and each node, the results of the model are the water quantity and quality, the water shortages, the satisfaction or not of the water demands, and the satisfaction of the quality and quantity constrains and targets that have been specified. The developed model is implemented in selected watersheds covering the following tasks in order to complete the full simulation environment for each area, namely the natural water subsystem model, the demand subsystem model, the interactions between the two subsystems and the integration of the system, the interactive interface, as well as calibration of the subsystems and full-system models for each watershed, along with documentation for each model.

8.1.1 Economic modelling

An economic model for the cost-benefit analysis and the estimation of the financial result is developed. Specifically, the economic model uses the economic and water use data collected and archived and the water shortage for each water use, such as agriculture, animal production, fisheries and aquaculture, domestic water supply, industry, and hydroelectric energy production, in each node of the river basin estimated by the water management model. Thus, the economic model estimates costs and benefits for each water use under water scarcity conditions in each node of the system. The summation of the benefits for each water use and the consideration of the environmental cost leads to the integration of a cost-benefit analysis at the watershed level.

8.2 Long-term scenarios

Assessment of the future water availability, water demands, and water balance based on estimations for the future climate and water management scenarios is considered. This is a backward-forward procedure.

8.2.1 Long-term water availability

The long-term availability is estimated by considering the projected climate. The meteorological data for the future climate in the catchment are estimated based on the downscaling of the estimated GCM outputs. These data are then used for the estimation of the quantity and quality of surface water and groundwater. Furthermore, these estimates are then used in the water balance analyses and as input to the water management model.

8.2.2 Long-term water demand

The long-term water demands are projected in the future by estimating the development trends of each water use and/or using existing development plans, if these exist, and/or using synthetic water demand scenarios. The water demand scenarios consist of changing specific characteristics of the water use for each economic sector, i.e. changing the water pricing policy, changing the production processes, changing the cultivated plant and animal species, estimating the future population, changing the economic development priorities, introducing new and more effective water development works, such as reservoirs or new irrigation systems. These scenarios provide various future estimates of water demands for each water use. These estimates are then used in the water balance analyses and as input to the water management model.

8.2.3 Long-term water balance and management

The results of the future water availability and water demands specified above are used in the water balances analyses and as input to the management model resulting in the development of various management scenarios. Each one of these scenarios has to be financially evaluated using the economic model. In this way, the optimum management scenario can be selected considering both the sustainability of the water resources in the watershed and the financial evaluation. The optimum water management scenario can then be used as a guide to a detailed master management plan for the watershed development.

9 Epilogue

The main subject of this paper has been the presentation of a methodological framework leading to a sustainable water resources management scheme through technical and scientific analyses of drought and water scarcity management in regions and countries vulnerable to drought and water scarcity. The implementation of the water scarcity management scheme is based on the outcome of a methodological approach consisting of a sequence of scientific procedures. Having archived and documented the meteorological and climatological data, an analysis of the historical climate variability and modelling is performed, along with projections of the future climate scenarios. This is followed by water quantity and quality modelling involving hydrological, hydrogeological and water quality models. Once the historical and simulated water quantity data are available, a hierarchical drought analysis is conducted by considering the different types of drought sequentially based on indices and models, namely meteorological, agricultural, hydrological and socio-economic drought. This drought analysis and assessment leads to the prevailing drought components and interventions, which are necessary to alleviate the impacts of drought. By analysing these results a DEWS can be developed. The trend remains the development of a global composite drought risk modelling system.

The methodological procedure continues with the assessment of water demand. These analyses have explored alternative water resource solutions, such as non-conventional measures related to marginal waters, including rain enhancement, desalination, water harvesting and water treatment and reuse potential, trends and practices under drought and water scarcity conditions (Gikas and Angelakis, 2009). Once the water quantity and quality demands of the various uses in the watershed are known, a water resources management model is developed and implemented at the watershed and regional scale. Furthermore, an economic model is developed to evaluate the economic feasibility of the management scenarios. By changing the components of the water resources management for the future, it becomes necessary to iterate the whole procedure with forecasted or estimated physical and economic data. In this sense, various future climate and water resources management scenarios can be tested and assessed for economic and water resources sustainability. This procedure contributes to the optimal water resources use and management practices for long-term conditions. The overall objective of wastewater re-use is to lead to greater allocative and distributive efficiency of water resources and includes these non-conventional measures in the technical solutions to combat drought and water scarcity (Gikas and Angelakis, 2009). Comparison of actual wastewater re-use in agriculture to potential wastewater re-use in enhanced exploitation is considered and estimation of the decrease of marginal lands that otherwise be wasted is conducted. The analysed non-conventional measures are briefly summarised.

9.1 Desalination

The global population boom, urbanisation and climate change have severely reduced water supplies. Furthermore, tapping fresh water for metropolitan areas has become more difficult, if not impossible. Without any doubt, the future relies on the implementation of ‘NEWater’ technologies such as desalination and direct potable reuse of treated wastewater (Zotalis et al., 2014). Desalination, especially in coastal areas, is the most cost-effective approach to long-term water supply sustainability, compared with other options. Desalination of sea and brackish water for both water supply and irrigation in arid and semi-arid coastal regions of the world seems to be a very promising technology. In fact, desalination is already a competitive alternative in regards to other options; as the water produced is low-priced in most cases, energy requirements have been significantly reduced and last but not least, it is friendly to the environment, especially when the process powered by renewable energy sources. Also it should be noted that the combination between desalination and renewable energy sources in autonomous independently operating desalination systems, is a unique solution for water in coastal, relatively isolated areas with weak and limited possibilities of local energy supply networks.

9.2 Water reuse

Water reuse will be a critical element in the development of sustainable strategies for water resources management. Technology is now available to produce water for any use, including direct potable pipe to pipe reuse. A saving of up to 30% in total water use may be achievable in some regions by proper water recourses management, including the production of high quality water from WWTPs, for reuse (Angelakis and Gikas, 2014). The aforementioned percentage may increase further in the near future as the percentage of wastewater conveyed to WWTPs for treatment increases, and as WWTPs are upgraded to produce effluent complying with the reuse guidelines or regulations. In order to achieve this, international water policy should be improved the wastewater treatment technology and extended to encourage the safe use of recycled water for various applications. It is expected that controlled water reuse will prevail, as more countries will establish quality criteria. The regulations or guidelines should be simple, flexible, and easy to operate, making sure the water can achieve the desired performance objectives. The development of a regulatory instrument that includes treatment processes, reclaimed water quality, and monitoring frequency, should be based mainly on water reuse experience in the EU Member States and elsewhere (e.g. USA, Israel and Australia) and on international research results (Alcalde Sanz and Manfred Gawlik, 2014). The possibility of establishing criteria per water use category (dirking, irrigation etc), independently of the water source or origin (fresh water, recycled wastewater, etc.) instead of per category of the water should be considered (Paranychianakis et al., 2015).

9.3 Rainwater harvesting

Rainwater harvesting continues to be practiced globally, and there is renewed interest in its revival, the system nonetheless has fallen to disrepair. Climate policy and water policy would require to be streamlined to promote that technology in the water-stressed regions of the world. Pandey et al. (2003) reported that neither the water policy nor the climate policy discussions appears to notice the worth of the rainwater harvesting, especially in urban areas where water resources are fast depleting due to rapid increase in population and unrestricted use of water. Today more than 2.6 billion people do not use improved sanitation and 1.1 billion practice open defecation. Also 1 billion people have limited access to drinking water. Thus there is a huge need for sustainable and cost-effective water supply and sanitation facilities, particularly in cities of the developing world (Bond et al., 2013). Historical studies on rainwater harvesting, collection, and storage technologies provide insights into possible responses of modern societies to the future sustainable management of water resources.

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