Development of an Integrated Water Management Model to Reduce Water Wastage

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Abstract *– The increasing water demand, due to the pharmaceutical companies, agricultural and other socio-economic sectors, threatens groundwater resources. This situation represents a limiting factor and it may result in conflicts between water users. This raises the demand for an integrated water resources management. This methodology consisted in carrying out water balances between resources and demands for the current year and for the next 10 years; identifying, and modelling solutions for reducing water deficit (water management options). All these steps involved collecting data, which was performed through literature reviews, measurements, surveys, socio-economic and technical studies, and the obtained results may support decision makers in improving water management*

Key Terms *– integrated water resources management, pharmaceuticals*

INTRODUCTION

The motivation for this project is that water is very important in daily life and should be utilized in a very efficient way. Also, for society to have knowledge on the environment and how water plays a very important role in it. The increasing water demand, due to many factors such as industrial, agricultural, and socioeconomic development, threatens groundwater resources in terms of quantity and of quality. This brings the need for Integrated Water Resources Management. This approach deals with the management of water resources, demand, and supply in order to achieve sustainable water resource uses.

The objective of this project it to develop an effective model that can be utilized for effective water management in order to reduce the wastage of water.

LITERATURE REVIEW

Water Cycle

The annual water cycle from rainfall to runoff is a complex system where several processes (infiltration, surface runoff, recharge, seepage, infiltration, moisture recycling) are interconnected and interdependent with only one direction of flow: downstream. A catchment is therefore one single system and more than the sum of a large number of subsystems. Water use is embedded in the hydrological system. It is therefore important to consider the hydrological system and locate the water use in it [1].

Characteristics of water

Water has at least three important attributes with a bearing on management:

- Fresh water is *vital* to sustain life, for which there is no substitute. This means that water has a *value* to its users.
- Although water is a renewable resource, it is practically speaking *finite*. Many uses of water are therefore *subtractable*, meaning that the use by somebody may preclude the use by somebody else.
- Water is a *fugitive* resource. It is therefore difficult to assess the *stock* and *flow* of the resource, and to define the *boundaries* of the resource. This complicates the planning and monitoring of withdrawals as well as the *exclusion* of those not entitled to abstract water. Its fugitive nature makes it also more costly to harness, requiring the construction of reservoirs [1].

Water Resources Management

There is growing awareness that comprehensive water resources management is needed, because:

- Freshwater resources are limited.
- Those limited freshwater resources are getting more polluted, rendering them unfit for human consumption and also unfit to sustain the ecosystem.
- Those limited freshwater resources have to be divided amongst the competing needs and demands in a society.
- Many citizens do not have access to sufficient and safe freshwater resources.
- It is increasingly realized that there is a huge potential to increase crop production and achieve food security through more efficient use of rainfall through improved soil and water conservation and harvesting techniques.
- Structures to control water may often have undesirable consequences on the environment.
- There is an intimate relationship between groundwater and surface water, between coastal water and fresh water, etc. Regulating one system and not the others may not achieve the desired results [1].

Hence, engineering, economic, social, ecological, and legal aspects need to be considered, as well as quantitative and qualitative aspects, and supply and demand. Moreover, also the ‘management cycle’ (planning, monitoring, operation, maintenance, etc.) needs to be consistent.

Integrated water resources management, then, seeks to manage the water resources in a comprehensive and holistic way. It therefore has to consider the water resources from a number of different perspectives or dimensions. Once these various dimensions have been considered, appropriate arrangements could be made.

The hydrological cycle

The hydrological cycle can be studied at different spatial scales. One starts with considering a certain area. It is crucial for a system’s approach to carefully define the boundaries of the area under consideration, and any water fluxes that cross them. These are either inflows into the area under consideration, or outflows. Subsequently all other sources of water into the area are identified, and all types of consumptive uses, as well as any return flows from such uses [1].

Water Balances

Besides rainfall (P) and evapotranspiration (E) the soil also plays an important role in the water balance. Some rain runs off the surface or at depth (R = runoff) and some may be stored in the soil and the change in storage is expressed as $D\ S$. For the complete water balance, refer to equation (1).

$$P = E + R + D\ S \tag{1}$$

The water balance plays an important role in the lives of plants and animals and in their distribution. Even in areas where it is believed that water is always freely available, like in tropical rainforest areas, was recently found that periods of water deficit occur, whose frequency, duration, and severity varies from year to year [2].

Groundwater Resources

Groundwater should be considered a finite mineral resource, which can be used only once, after which it is finished. Renewable groundwater is groundwater that takes an active part in the hydrological cycle. The latter means that the residence time of the water in the sub-surface has an order of magnitude relevant to human planning and considerations of sustainability. The limit between fossil and renewable groundwater is clearly open to debate. Geologists, that are used to working with time scales of millions of years will only consider groundwater as fossil if it has a residence time over a million years. A hydrologist might use a time scale close to that. However, a water resources planner should use a time scale much closer to the human dimension, and to the residence time of pollutants. Groundwater can be split up into fossil groundwater and renewable groundwater [3].

ANALYSIS APPROACH

Resources/Demand Water Balances

A conceptual scheme is a simplified but realistic representation of the socio-hydro system of the studied area. It identifies and describes water resources called “Hydrological units”, water demands called “Socio-economical units” and water flow transfers between the different units. Wastewater treatment plants are considered as water resources which belong to socio-economic units [4]. The principle of the conceptual scheme is presented in Figure 1.

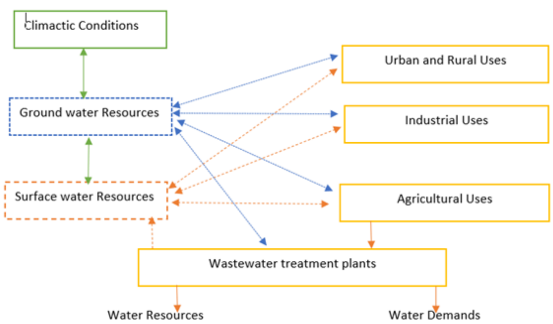

Figure 1
Conceptual Scheme

In order to have a better understanding of the main hydrological processes in the regions under study, a GIS database was produced and the main components of the water resources (groundwater, surface water) were characterized and modelled.

Water Resources Characterization

Groundwater diffuse recharge, surface runoff and evapotranspiration were calculated with WetSpass, a spatially distributed and physically based water balance model [5]. This software, initially designed to be used on European regions, was specifically modified for a proper application to the regions in PR. These modifications consisted in including specific arid regions parameters about land cover, soil texture and topography. Moreover, since arid regions are characterized by a strong irregularity of rainfall, evapotranspiration being higher than rainfall during the dry season, a seasonal time step assuming that the annual recharge is totally made up during the wet season had to be considered.

Groundwater systems and their interactions with surface waters (rivers) were simulated with MODFLOW, the well-known USGS hydrogeological model [6]. An extension of the MODFLOW model allowing combination with the WetSpass model was used here [7]. This coupling allowed considering not only diffuse recharge, but also inflows from wadis and alluvial valleys, these latter being taken into account through boundary conditions.

Solutions for reducing water deficit

Water management options were selected and described carefully. These options aimed at either increasing the available water resources or reducing the water demand. Increasing resources can be reached with the groundwater desalination or the use of non-conventional water resources such as treated municipal wastewaters or phosphate mine washing water. Even if only uses which require low water quality can use these waters (no drinking water), complementary treatments can still be necessary and acceptability problems can be faced. Reducing the demand can be obtained with the implementation of technological innovations for water saving in the pharmaceutical agricultural or drinking water supply sectors.

Water resources characterization over time was simulated with the hydrological (WetSpass) and hydrogeological (MODLOW) models previously developed. These models take into account the foresight of water demand and of climate. For climate evolution, a weather-based forecasting model was built based on statistical analyses of rainfall, temperature, humidity, and wind speed time series data on the study area. Statistical properties include temporal characteristics frequency characteristics and the identification of the law of frequency division. By combining all this information, the forecasting model allowed simulating climate evolution over the next 10 years with a monthly time step. It was then possible to perform resources/demands water balances for the projected year. As for the reference year, this water balance aimed to highlight potential problems on water resources balance i.e. water resources that would be overexploited or nearly overexploited.

RESULTS

The northern region of Puerto Rico contains the most productive aquifers on the island. These are generally referred to as the limestone aquifers of the Karst Region, although they are composed of layers or mixtures of sedimentary deposits of marine and volcanic origins, and alluvium in the valleys on the limestone rocks. These limestone and alluvial deposits occupy a surface area of approximately 650 square miles, forming two important aquifers, currently identified as the Flat or Upper Aquifer, and the Deep or Lower Aquifer. For the purposes of this report, from now on we refer to these aquifers by their names of Upper Aquifer and Lower Aquifer of the Karst Region.

Barceloneta has various industries like Pfizer, Abbot, Abbvie and Fresenious. Barceloneta is located in the Karst region, which stores in its depths the largest supplies of groundwater on the island. Practically all the coastal municipalities from Dorado to Hatillo, and the industries that reside in them, are supplied by these supplies. Many of the northern bodies of water, such as rivers, also receive part of their flow from these underground sources.

This industry demands large volumes of water, very few constraints regarding water consumption have been imposed to it so far. However, is a region having other water users such as agriculture and drinking water supply which results in competition for water resources. These other water users are also confronted to water related impacts from the pharmaceutical industry (discharges polluting water and soils) and other types of impacts (noise, tremors). The climatic factors combined with the continuous increase in water demand due to the fast-growing pharmaceutical activities, the extension of irrigated areas and the population growth result in depletion and degradation of the water resources. The previously described methodology was implemented to this case study in order to improve the situation of water scarcity without hampering the development of economic sectors such as agriculture.

The evolution of water demands was evaluated up to 2030. However, since several assumptions were made to estimate the evolution of the driving forces up to 2030, there are some uncertainties about the water demands foresight. In order to account for these uncertainties, several scenarios could be built. Regarding water resources, their evolution was simulated up to 2030. In particular, it was assumed that the water quality and the exploitable volume of groundwaters will not change over these 10 years.

These works allowed performing water balances for the current year and for the projected years. Results of these water balances are presented in Tables 1 and 2. Table 1 shows that the pressure on shallow groundwaters is very high due to the agricultural sector's water needs. Indeed, the northern aquifer is currently overexploited level. On the other hand, deep groundwaters have a positive balance, their exploitation rate being lower than 80%. These groundwaters are mainly used by the pharmaceutical industry (66%) but also for agriculture (21%) and for drinking water supply (13%).

In 2025 (Table 2), it is expected that the water demand for each sector will increase. In particular, the mining water demand is expected to increase by 6 Ft^3 (+ 24.9%), and the irrigated water and drinking water demands are expected to increase by 2 Ft^3 (+ 21.7% and + 42.9% respectively). This will lead to a deterioration of the water scarcity situation observed in 2020. In particular, two water resources units will be overexploited in 2030.

Table 1
Resources/Demands of water for reference situation (2020)

		Situation in 2020					
	Exploitable volume	Extracted Volume	Water balance	Exploitation Rate	Agriculture	Drinking Water Supply	Pharmaceutical
	1.7	1.7	0	100	1.7	0	0
Shallow	0.6	0.7	0.1	116.7	0.7	0	0
Groundwater	10	5.7	4.3	57	0.7	2.3	0
Deep	18.8	14.7	3.7	78.2	2.7	1.9	12.1
Groundwater	15.2	11.5	4.1	75.7	3.4	0	8.8
Total	46.3	34.3	3.7		9.2	4.2	20.9

Table 2
Resources/Demands of water for projected year 2030

		Situation in 2030					
	Exploitable volume	Extracted Volume	Water balance	Exploitation Rate	Agriculture	Drinking Water Supply	Pharmaceutical
	1.7	1.7	0	100	1.7	0	0
Shallow	0.6	0.7	0.1	116.7	0.7	0	0
Groundwater	10	6.8	3.2	68	4	2.9	0
Deep	18.8	21.4	2.6	113.8	2	3.1	16.3
Groundwater	15.2	12.6	2.6	82.9	2.8	0	9.8
Total	**46.3**	**43.2**	**3.1**		**11.2**	**6**	**26.1**
	% increase of 2020	**25.9**			**21.7**	**42.9**	**24.9**

CONCLUSION

The methodology developed for the building of an integrated water resources management tool is presented in this paper. This methodology consisted in carrying out water balances between resources and demands, identifying and modelling solutions for reducing water deficit (water management options), and identifying indicators and criteria for results presentation.

Its application to the case study of the aquifer system showed that it constitutes a powerful way for helping decision makers in improving the situation of water scarcity without hampering the development of economic sectors such as pharmaceutical industry and agriculture. However, this work also highlighted difficulties to collect detailed data and to develop a tool which perfectly fit local stakeholders needs, i.e., taking into account their knowledge about computer science and their feelings about modelling results.

The aquifers in Puerto Rico capture a small fraction of the rainfall and sometimes can store it for years. This paper can be used for further investigations of other aquifers, since they have an history of contamination. Other areas of the island where agriculture, industries, and public use could use this methodology to see how they can change or improve their water resources management. Therefore, alternative water management options could be implemented to reduce the pressure on water resources. Water management options could be identified. Definition and characterization of water management options, carried out with the support of stakeholders, includes an exhaustive description of each option and an evaluation of its potential impacts for the environment, the economy, and its acceptability.

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