CHAPTER 1

Optimization and water resources management

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Abstract

This introductory chapter includes some thoughts on the essence of optimization and on its role in water resources management. First, the relevance of the notion of optimization to most scientific fields is pointed out, using the example of Aristotle’s Ethics. Then the importance of optimal management of water resources is stressed and certain issues related to the definition of optimization problems and to the role of flow simulation models are selectively discussed.

Keywords: ethics, flow simulation, optimization, water resources management.

1 The concept of optimization

Optimization could be defined rather simply as culmination of an improvement process. Optimization problems are encountered more or less frequently, in almost every scientific field (e.g., Floudas and Pardalos [1]). Schwefel [2], quoted by Michalewicz [3], puts it in the following way:

“There is scarcely a modern journal, whether on engineering, economics, management, mathematics, physics, or the social sciences, in which the concept ‘optimization’ is missing from the subject index. If one abstracts from all specialist points of view, the recurring problem is to select a better or best (according to Leibniz, optimal) alternative from among a number of possible states of affairs.”

Even when the term is not explicitly used, the notion of optimization can be traced in very diverse scientific fields. A prominent example can be found in Aristotle’s Ethics [4], where ethical virtue is defined as “μεσοτητις” (usually translated in English as mean or mean state), between two extremes: a deficiency and an excess. Tassios, though, has proposed that optimization is a more appropriate term [5]. Most probably this interpretation is closer to the philosopher’s mind, for the following reasons:
Aristotle cautions us not to consider each virtue as similar to an arithmetic mean between the respective extremes. Moreover, he stresses that it is an extreme, with respect to excellence andrightness.

Aristotle also mentions that one extreme could be worse than the other and that the respective virtue could be closer to one of them, which could be even mistaken for virtue. An example is bravery and its excess.

Moreover, he states that one could err in many ways, while the correct behavior is unique, as if speaking for a function with one extreme value only. At the same time, he stresses that we do not blame those who deviate from the optimum only slightly.

Based on these remarks, we could construct the diagram of Fig. 1, regarding wealth management. Rightness is shown on the y-axis, whereas disposition toward getting and giving money on the x-axis.

By the way, Aristotle proposes an interesting way to arrive to the optimum: (a) avoid first the extreme which is the more opposed to the mean and (b) notice the errors to which one is more prone and move as far as possible toward the opposite direction.

As optimization penetrates very different scientific areas, its character (qualitative or quantitative) and its precision depend on the features of the particular application field. It is worth mentioning, though, that even when we concentrate to engineering problems, we may have to deal with costs and benefits that cannot be easily expressed in monetary units. This is the case of the so-called intangibles, such as the aesthetic value of a spring or a river, or the social cost of the displacement of the inhabitants of a village in order to build a dam and an artificial lake.

1.1 Optimization techniques

There are already many optimization methods, starting from simple differentiation (if the features of the problem permit its application) to sophisticated heuristic techniques. As the “no free lunch” theorem states, no method is superior to all others for every problem (e.g., Wolpert & Macready [6]); or, as Reeves & Raw [7] put it,
“there is no royal road to optimization.” Moreover, there is no general rule for selecting the most suitable method, not even the best features of a certain method. Experience, intuition, and use of more than one optimization approaches may help with this process.

2 Optimal use of water resources

Fresh water availability is a basic prerequisite for the development of human activities. Unfortunately, their distribution is uneven in space and time. Moreover, human activities are often concentrated in areas with poor water resources, such as coastal areas, which are also vulnerable to salt water intrusion. Meanwhile: (a) water resources availability may tend to decrease in many parts of the world, due to unfavorable climatic change (i.e., reduction of precipitation or change of its pattern); (b) population increases continuously, particularly in poor countries; and (c) per capita water demand grows, following quality of life standards. Under these circumstances, the call for optimal management of both the supply and the demand side of fresh water balance is urgent.

2.1 Definition of an optimization problem

The first step for solving an optimization problem is to accurately define it. When one deals with water resources management, this might prove a difficult task, involving a set of assumptions. A holistic approach requires consideration of both sides of the water balance. Nevertheless, dealing with water demand is inherently and explicitly a very approximate process. It requires accurate data on and projections of population growth, per capita water demand, agricultural, tourism, and industrial growth. So, in many cases some rough estimates are used as data instead of variables in the optimization problem and elasticity of the demand is ignored.

The supply side of the water balance is generally considered a more accurate and precise engineering exercise. Optimal management usually requires combined use of surface and groundwater resources. Optimization of each resource, though, is in many cases separately considered, despite hydraulic interaction between the two. The benefit of this separation is simplification of the problem. The pitfall, on the other hand, is that the global optimum may not coincide with the sum, or combination, of partial optima. It is safe to optimize separately “closed” subsystems only.

In many cases, water quantity cannot be considered separately from water quality. This is quite clear in coastal aquifers, for instance, where saltwater intrusion sets the limit to water extraction. Moreover, development priorities may be based on water quality considerations. Usually, groundwater resources have better quality, since they are naturally more protected. It should be mentioned though, that if they are polluted, their restoration is more difficult.

Energy use is an important issue, too. In some cases, it enters as a discrete variable in water resources management optimization problems, for example, when desalination is considered as a water resource option. Moreover, energy production
is usually part of the objective function in reservoir management problems. Even when not explicitly considered, though, energy may be the decisive factor. Pumping cost, for instance, is actually energy cost.

During problem formulation, it is possible to leave out a secondary factor, because its mathematical expression is difficult, or because its inclusion leads to disproportionate increase of the overall computational load. In these cases, use of optimization techniques that end up with more than one good solutions is advantageous; they allow a final choice that will take into account the omitted factor. This point is also discussed in Chapter 2 of this volume, in connection with the method of genetic algorithms.

2.2 Optimization and flow simulation

An important part of most water resources optimization problems is flow simulation. It results are used either in the objective function or in constraint-related calculations. If water quality is involved, mass transport should be simulated, too. So, accuracy of the results of optimization models depends on the choice of the flow simulation models that are involved.

The accuracy of flow simulation models depends on the validity of underlying assumptions (e.g., steady-state flow, constant aquifer properties, etc.). Computational load increases with the complexity of the model. Total computational volume may be a restricting factor in model choice, in particular when evolutionary optimization techniques are used. In such cases, use of surrogate (simplified) models might be the best choice for the overall accuracy of the optimization process. This point is further discussed in Chapter 2 of this volume and, more extensively, in [8].

Moreover, accuracy of the results obtained even by the most sophisticated simulation models, depends on the quantity and quality of input data. Data collection presupposes the existence of a suitable monitoring network, which might have substantial cost. For this reason, input data are quite often insufficient. In such cases, a good solution, that is rather insensitive to changes of input parameters values, might be a better choice than an “optimal” solution, which is very sensitive to such changes.

3 Concluding remarks

With population of our planet exceeding seven billion already, funds for infrastructure works being limited worldwide, and climate change affecting water resources, their optimal development and management is literally vital. The development of optimization tools and methods and their use in water resources management could be very helpful in meeting the aforementioned challenge. The rest of this book is dedicated to them. Hopefully, this introductory chapter has pointed out two, superficially contradictory, things: (a) that optimization methods used in water resources can be transferred successfully to quite different scientific fields and (b) that optimization techniques are mere tools, and understanding their limitations (i.e., their validation) is a prerequisite for their correct use.
References