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Name of the Authors

Christos C. Anastasiou*, Marios Charalambides and Andreas Kalli**

*Assistant Professor. Dept. of Civil Engineering; Frederick University, 7 Y. Frederickou Street; 1036 Nicosia, Cyprus. E-mail: c.anastasiou@frederick.ac.cy

**Lecturer, General Department (Math-Physics), Frederick University, 7 Y. Frederickou Street; 1036 Nicosia, Cyprus. E-mail: bus.chm@fit.ac.cy

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CO	Confidential, only for members of the Consortium (including Commission Services)	

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ABBREVIATIONS

DS_SLOM: Decision Support System - Salt Lakes Optimization Model

ABSTRACT

In the framework of an EU funded, LIFE+, project, entitled "Strengthening the Scientific Foundation of Water Quality Programs in Cyprus" (see *http://www.life-water.eu)*, a quantitative methodology for the integrated management of water quality, at the watershed level, is being developed, and will be demonstrated for the river basin of Kalo Horio, Larnaca, which feeds the unique aquatic ecosystem of the Larnaca Salt Lakes in Cyprus (Anastasiou, and Panayiotou, 2011).

One of the central themes of this effort is the introduction of the concept of the Total Maximum Daily Load (TMDLs) as a mean of enhancing the procedures for water quality management. In our procedure, essential descriptors of an ecosystem, such as hydrologic parameters, water quantity inflow, are simultaneously considered with pollution source descriptors, such as key pollutants, pollution sources. The actual development of TMDLs will be accomplished through the use of quantitative, optimization, models that can integrate pollution sources with ecosystem functions.

Within this context, this paper presents an optimization model for supporting decisions concerning water quality in watersheds, applied to the Kalo Horio, Larnaca watershed. From the development of a rudimentary form of the decision models, it proved to be exceptionally challenging to quantify the manner in which such things as biodiversity, or aesthetic value, can be influenced by basic factors such as nutrient and BOD inflows to the system. The decision variables of the model were defined to be the area of new development in the region (e.g. the land area to be devoted to agricultural activity), the number of animals to be permitted for the region (e.g. the number and size of animal farms to be allowed), or the number of new residential space that could be permitted in the region. These decision variables are connected to one another through a set of basic parameters that include water quantity flows in the watershed (affecting salinity regimes), inflow of basic macro-nutrients (Nitrogen and Phosphorus) and BOD. Among objectives to be examined, reduction of treatment costs, maximization of economic profit, maximization of biodiversity (and/or biomass productivity), and minimization of aesthetic deterioration, are singled out. Among the constraints, environmental laws and regulations are imperative, as well as possible budget constraints, or town-planning zoning constraints (Anastasiou, and Panayiotou, 2011).

KEYWORDS

Water Quality Management, TMDL, Regional Environmental Management Optimization, Watershed Management, Decision Support Model, Cyprus, Salt Lake

2 INTRODUCTION

The overall project targets the problem of ensuring the good ecological status of water bodies in Cyprus. In general, it aims to create the capacities and tools to facilitate the design and monitoring of cost efficient water quality management programmes and measures.

Water systems in Cyprus are facing increasing pressures both from human induced activity and natural weather / hydrological changes. Water availability has in recent years been the most pressing issue due to the ongoing drought. A significant portion of aquifers are facing depletion and/or water quality problems, with saline intrusion being a major concern. At the same time urban non-point pollution has been one of the main sources of pressure and, though the implementation of directive (C.D., 1991) will help to minimise urban pollution impacts, such pressures will likely continue to exist. Agriculture is a major contributor to non-point pollution regarding nutrients, BOD and biocides, while it is putting tremendous pressure on water availability. Measures for the control of non-point pollution such as the Code of Good Agricultural Practice help to reduce pressures from agricultural pollution. However, such measures concentrate on the implementation of prescribed pollutant control measures, usually homogeneously in applicable activities, and do not extend to wider policy level control. The severity of measures also is not directly liked to integrated impact of benefit analysis thus efficiency and cost effectiveness are not ensured (Anastasiou, and Panayiotou, 2011).

Measures stemming from legislation such as directive 91/271/EEC (C.D., 1991), the solid waste directive, the Nitrates directive, IPPC, EIA and SEA directives etc. are all contributing towards minimizing pollution. However, at present, each of these directives is treated individually and an integrated strategy that can guide the implementation of an efficient and cost effective integrated management plan is absent. Water abstraction, for example, is generally monitored and controlled. However, there are no technical tools to link abstraction rates to overall water availability (based on rainfall patterns) and water quality.

Water body management requirements stem from a variety of legislation, the Water Framework directive being the major driver for preparing river basin scale management plans. Despite the fact that a river basin management plan is currently under development in Cyprus, it is anticipated that a gap will remain concerning the integration of policies and measures directly related to environmental and biodiversity management. For example, EIAs, Biodiversity Management Plans, effluent emission permits, changes in agricultural crops all can place requirements on water bodies that will need to be incorporated in an integrated water quality management system.

One of the central themes of this effort is the introduction of the concept of the Total Maximum Daily Load (TMDLs) as a means of enhancing the procedures for water quality management. A TMDL is the maximum quantity of a pollutant, which a water body can receive, without jeopardizing its desired functions. TMDLs are currently used in the USA as a tool for alleviating environmental pressure on ecosystems that are already considered perturbed. A novelty of our work lies in the fact that we will use TMDLs as an umbrella tool that will assist the management of water quality by adopting a “top-down” approach, as opposed to a “bottom-up” approach, currently used, for all watersheds, regardless of their current condition. In this procedure, essential descriptors of an ecosystem, such as hydrologic parameters, water quantity inflow, are simultaneously considered with pollution source descriptors, such as key pollutants, pollution sources. These are coupled with ecosystem functions, when devising a management scenario (Anastasiou, 2002).

The actual development of TMDLs will be accomplished through the use of quantitative, optimization, models that can integrate pollution sources (river-basin users and uses) with ecosystem functions, as opposed to the traditional approach that isolates single pollutants and the respective ecosystem functions affected.

The decision models will have the capability of being used in the development and examination of water quality management scenarios for the area. Specifically, these models seek to assist the Department of the Environment of the Republic of Cyprus in the examination of Environmental Impact Assessments, as well as for the issue of licenses for possible new developments in an area. The once simplified scheme of issuing discharge licenses, for any given area in Cyprus, has evolved into an important and difficult task, if one is to consider new restrictions stemming from EU directives and procedures, as well as the coming-into-the-foreground of a broad spectrum of stakeholders. To this end, decision support tools have to be developed in order to assist such top management, or regulators, in taking the ‘best’ possible decisions.

The 'best' possible decision, or the 'optimum' decision, can be identified primarily with the use of optimization techniques. Optimization plays an essential role in modern world. Arising problems that involve minimizing treatment cost, minimizing the discharge of a specific pollutant, or, on the other hand, maximizing benefit (however this may be defined by the various stakeholders), seek for solutions in the optimization theory. Some of these problems can be expressed in the form of linear optimization problems with constraints and can be solved by the Simplex method (Rardin, 2009). The method was introduced by the American mathematician George Dantzig in 1947 (Dantzig, 1974) and its contribution in optimization theory has classified it as one of the top ten algorithms of the century (Dongarra & Sullivan, 2000 and Cipra, 2000). Other problems though possess additional complexity in the sense that they enjoy integer solutions or can only be expressed in terms of nonlinear expressions. To this end, several techniques have been developed to tackle these issues (Ruszczynski, 2006) but no unified methodology exists for finding unique solutions for all cases.

The main objective of this project refers to the formulation of a management (decision) model taking into account the BMP development based on different scenario analysis. To be more specific, this project is concerned with studying realistic pollutant source allocation scenarios which will incorporate the following topics: a) Existing and foreseen point and non-point sources, b) Estimation of pollutant release rates under various alternative policies concerning the issuance of permits and pollution prevention/control measures and c)Water management goals and constraints including socioeconomic parameters.

The specific objectives of this research are firstly to develop a formal quantifiable procedure (i.e. a mathematical optimization model) for generating and examine alternative strategies for managing water quality in a watershed/region (based on collective emissions of various pollutants over a region) and secondly to demonstrate the use of the decision support framework by applying it to a realistic case study (i.e. Kalo Horio Basin, Larnaca, Cyprus) to explore a range of management strategies.

Such mathematical optimization-based management (or decision) models have been reported in the literature for a variety of environmental problems. For example, Revelle and McGarity (1997) provide a compilation of several related applications in civil and environmental engineering topics. Our decision model is a mixed integer linear programming (MILP) which uses a standard mathematical programming-based search procedures that are commonly available for solving such as What's Best!.

The use of formal optimization is sometimes criticized because the optimal solution to a mathematical model is rarely the best solution to the real problem, as all the objectives and constraints of the real problem may not be included in the model (Liebman, 1976). This omission may be due to errors, unquantifiable nature of certain issues (e.g., political considerations), or issues that were not identified at the point of model formulation. Techniques have been developed to address this limitation. Modelling to Generate Alternatives (MGA) techniques (Brill, 1979; Brill et al., 1990; Chang et al., 1982; Hopkins et al., 1982) use optimization to generate a small set of very different solutions. The alternatives may perform differently with respect to unmodelled or unquantifiable issues (e.g., political considerations, perception of odour problems, public reactions), as well as provide new insights into the problem that may not have otherwise been considered. Results from recent and ongoing work (Harell and Ranjithan, 1997; Harell, 1998; Gillon, 1999; Loughlin et al., 1999; Loughlin and Ranjithan 1997; Solano et al., 2000), which investigates MGA techniques to generate a small set of efficient strategies, can be used to identify alternatives that are maximally different from each other. These techniques will be used at a later stage in this research to generate alternative strategies for basin water quality improvements.

All in all, the objective of the research team, for this project, is to introduce a new method to which state of the art analytical tools and supplementary decision support instruments (stakeholder participation, optimisation tools) are brought together to enhance the scientific base of water quality management. The paper is structured as follows: In section 2 the area, used as the case study for this work, alongside pressures and set objectives, is described. In section 3 the decision support framework is defined and the mathematical expressions calculating overall benefit for the watershed are derived. The optimization problem that minimizes cost subject to quality is presented and it is explained how this transforms to a mixed integer multi-objective problem. Further, model limitations and challenges are elaborated (Anastasiou, and Panayiotou, 2011). As regards the future work to be done, the decision model will be applied to solve a range of scenarios, including least-cost strategies to meet release targets for the different environmental pollutants, and optimal strategies that minimize the release of one pollutant within a specified budget limit. MGA techniques will also be applied to the case study.

3 STUDY AREA (CASE STYDY OF CYPRUS)

The selected study area (Kalo Horio catchment) drains into the Larnaca SaltLakes (**Figure 1**(a)). The two salt lakes of Larnaca are the second in size and importance in Cyprus after the salt lake of Akrotiri in Limassol. The area supports a large variety of extended and representative halophilous wetland habitat types while is host to more than 100 bird species and its important at National as well as international level. For these reasons the site is included in the Natura 2000 network and designated as a Ramsar site.

Despite its ecological importance the site is severely stressed by human activities. Industrial pollution from the Aradipou industrial zone, non-point pollution from agricultural and farming activity, the Larnaca airport and the Larnaca Sewerage Treatment Station all threaten the integrity of the ecosystem. Lastly, the lakes are recipients of surface rainwater runoff from the city of Larnaca. A further issue arises with the construction of the Larnaca storm water drainage system. At present a large part of the Larnaca Western area drains in the salt lakes. It thus appears that storm drainage management options can have a significant impact on the lakes. Disposal of the storm water at sea may have impacts of water availability and the duration each year during which the lake is flooded. This is vital aspect for the survival of many of the species hosted in the area. On the other hand, diverting the water to the lake may have other impacts from intensified peak flows due to a more efficient drainage regime than at present and increased inflow of urban area related pollutants (hydrogarbons, oils, particulate etc). Further concerns over water availability are caused by increasing demand for water diversion and abstraction within the catchment as well as the decreasing amounts of rainfall recorded over the last years.

Figure 1 (a)Satellite Image of the Study Area (Google Maps, February 2011), (b) Satellite Image of the Study area indicating the watershed and the 11 sub-watersheds of the Kalo Horio Catchment.

In order to achieve a better perspective for the study area, **Figure 1**(b) shows the watershed area which is divided into 11 sub-watersheds according to the river network. Sub-catchment 6 which is the outlet (final receptor) of the Kalo Horio Catchment represents the main body of the Larnaca Salt Lakes.

4 DECISION SUPPORT FRAMEWORK

In this section a thorough analysis of the water quality support framework, as developed for the Kalo Horio Watershed, is provided.

4.1 PROCEDURE OVERVIEW

The quantitative methodology, for the integrated management of water quality, at the watershed level, that is being developed, utilizes state-of-the-art software (ArcGIS), computer models (such as US EPA's HSPF and AQUATOX), and Decision-Support Optimization Models. With the initiation of this procedure, it is anticipated that the capacity for the development of scientifically-sound water quality management scenarios, based on quantitative procedures, will be provided and demonstrated.

Essentially, while the optimization procedures will empower decision-makers to examine a variety of management scenario, information that will feed into the optimization models will come from simulation models and from GIS, or other databases (**Figure 2**).

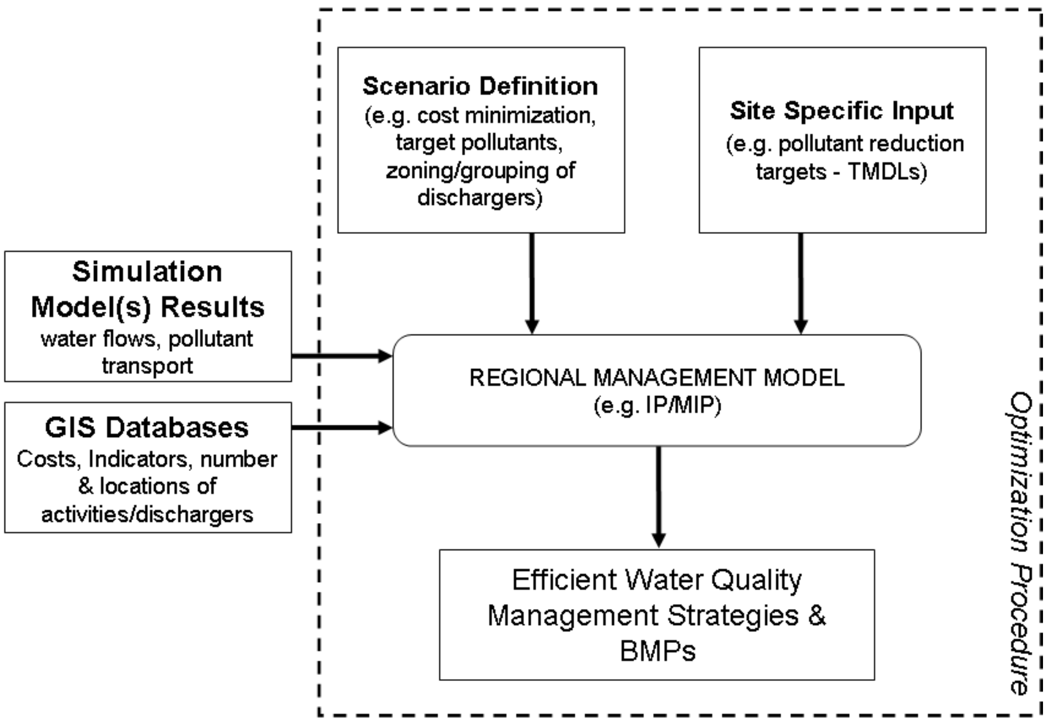

Figure 2 Overview of Decision Support Framework

4.2 MATHEMATICAL MODEL DEVELOPMENT

Optimization techniques are often used in producing solutions to problems involving multiple criteria. However, such tools are often controversial as results greatly depend on subjective opinions regarding criteria values and weights. In the course of the project, application of an optimization methodology aims indeed to demonstrate the sensitivity of decision making methods to criteria values as well as perceived opinions regarding the relative importance assigned to conflicting water use requirements.

A water quality decision support model for the Larnaca Salt lakes was developed following major stakeholders' contribution clarification. To enable robust elicitation process a focus group, representing academia, regulators (Department of Environment), and the consulting industry, has been formed. Engineers and scientists from different academic backgrounds, including biologists, environmental engineers, hydrologists, and economists, were represented in this group.

The fact that a number of different users are within the watershed of interest, complicates things, with regards to what weight one may place on any given use. For instance, it is not an easy matter for an activist group that wants to minimize any perturbation to the natural functions of the salt lakes to agree with an animal farmer who wants to implement yet another animal husbandry unit within the vicinity of the lakes.

In order to develop the optimization model concept, the functions of the Larnaca Salt Lakes that are considered essential to maintain were elicited. Further, the various activities/uses in the given watershed were elaborated. The decision variables chosen for the model were the area that could be devoted to a certain use/activity in the watershed. For example, a decision variable would be the area (i.e. hectares) for X crop to be cultivated, or the area for Y type of construction development (residential, commercial, etc.). Also, concerning animal farming, the Z number of animals to be housed in a new farm in the area constitutes a decision variable. Other uses, that are included as decision variables in the model include the number of new industrial plants that may be permitted within an area of interest, or any new tourist development that may be allowed. Each of these decision variables is related to a set of basic parameters (specifically, nutrients, BOD, salinity) that then map onto watershed functions that were chosen to be maintained (e.g. biodiversity, ecosystem productivity, aesthetic value) (Anastasiou, and Panayiotou, 2011).

However, since it is one of the goals of this effort to be able to assist decision-making by considering the "overall benefit" for the region, a scheme through which weights to each one of the main, possible, land uses and system functions (i.e. crop cultivation, animal farming, industrial activity, commercial and residential development, tourist development, biodiversity, productivity, etc.) for the area of interest was devised.

4.2.1 Optimization Model Concept

In brief, some general info about the concept supporting the optimization model should be given. As aforementioned, the Kalo Horio Catchment is divided into 11 different sub-catchments. Going further, an identification of the main polluters (point/non-point sources) in each sub-catchment has been succeeded. In addition a number of possible countermeasures have been prioritized for each existing polluter in each sub-catchment in order to maintain the current ecological status (water quality) of the study area not to mention the Salt Lakes area. However, apart from the existing polluters, attention should be paid to the fact that in all likelihood new licensing (i.e. new polluters), resulting in pollutant load increase might take place. That means establishment of new countermeasures. Each countermeasure has its own cost. Taking all the above into consideration, the great challenge is to find an optimum solution that gives the lowest possible cost of countermeasures establishment whilst maintain the current ecological status of the area.

Additionally to the above, it has to be noted that the main criteria pollutants concern the Kalo Horio Catchment were identified and are given in **Table 1**. Minimum and maximum values as well as the measurement units for each pollutant are provided.

Table 1 Information on Criteria Pollutants in the Kalo Horio Catchment

Pollutant name	Units	Min - Max	
DO	Mg/L	3.55	25.24
NH_4 – N	Mg/L	1.09	6.60
NO_3 – N	Mg/L	0.24	4.40
TP	Mg/L	0.04	1.25
F-Coli.	Count	0.00	0.00

In the following lines, an in detail analysis of the optimization model is attempted. In particular, every optimization problem has an objective function and some constraints.

4.2.2 Objective Function, Decision Variables and Constraints

An optimization procedure has mathematical expressions that describe the system and its response to the system inputs for various design parameters. These mathematical expressions include constraints to define the limits of the design variables, and objective functions for evaluating system performance (Larry, 2005). More precisely, every optimization problem is consisted of two essential parts: the objective function and the set of constraints.

To begin with, the objective function describes the performance criteria of the system (Larry, 2005). The main objective (Objective Function – **Equation 1**) of the problem describing in this paper is the minimization of the total cost taking into account all the possible countermeasures that might be implemented to each polluter in each sub-catchment in order to maintain the current environmental status. In this context, new possible licensing, may be given to a certain sub-watershed, are examined as well as the development of the appropriate countermeasures in order to maintain the pollution in an acceptable level.

Furthermore, the main objective function is composed by two other objective functions (see **Equation 1**): The first part of the objective function sums the unit cost of each possible countermeasure which is funded from the government whereas the second part sums the unit cost of each possible countermeasure which is funded by private investors. It has to be highlighted that the summations are done for the "P" possible polluters for the 11 sub-catchments. It is also noteworthy that the first variable of each part of the objective function is a Boolean variable by means of taking 1 on 0 values when a countermeasure is applied or not, respectively.

It is worth mentioning that the second term of each part of the objective function is calculated according to input data tables that are provided (see **Figure 4**). Thus, the decision variable of the optimization model would be the first term of each part of the main equation (i.e. the Boolean variables), which are the alternative technologies for load reduction.

It should also be noted that the unit cost variable is calculated based on a specific unit of measurement for each polluter. Particularly, an agricultural activity, for example, has a unit cost based on hectares whereas an animal farm has a unit cost based on the number of animals and so on.

$$Minimize\,Cost = \sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{Gov}} CounterGov_{m,p,a} \times Q_{p,a}\, UnitCostCM_{m,p,a}$$
$$+\sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{PI}} CounterPI_{m,p,a} \times \left(Q_{p,a} - Q^{o}_{p,a}\right) UnitCostCM_{m,p,a}$$

Equation 1 Objective Function of the Optimization Model

Where $a \in [1...11]$ are the sub-watersheds, $p \in [1...P]$ are the polluters (e.g. an industrial factory or an animal farm), $m \in Gov$ are the number of countermeasures which is funded by the Government whereas $m \in PI$ are the number of countermeasures which is funded by Private Investors. $CounterGov_{m,z,a}$ and $CounterPI_{m,z,a}$ are Boolean variables concerning the countermeasures that are funded by the government or by a private investor respectively. $Q_{a,p}$ represents all the licensing both previous and new ones, $Q^{o}_{a,p}$ represents the current licensing whereas the $Q_{a,p} - Q^{o}_{a,p}$ represents only the new licensing to be applied.

Moving on to the second essential part of the optimization problem, it has to be noted that constraints describe the process that is being analyzed, can be of two forms. The first form is the equality constraints whereas the second one the inequality constraints (Larry, 2005).

In the following lines, the first form (i.e. equality constraint) of our optimization model is being described where **Equation 2** and **Equation 3** represents the equality constraints.

When a countermeasure is applied to a certain polluter, a reduction percentage for the key pollutants takes place. The load removal percentage is an input variable as it is given by bibliography. In order to calculate the percentage remaining pollutant load for each criteria pollutant for each polluter in each sub-catchment, a multiplication is performed between the Boolean variable and the load reduction factor “Rd” is subtracting from 1 (**Equation 2**).

Hence, before proceeding to the constraints of the optimization model, the total pollutant load per pollutant (i) per sub-catchment (a), denoted by $I_{i.a,}$ is estimated by **Equation 2**. As it is illustrated, the first part of the equation refers to the pollutant load with regards to the governmental funding, whereas the second part of the equation refers to the funding from a private investor.

$$\sum_{p=1}^{P} \omega_{i,p} Q_{p,a} \left(1 - \sum_{m}^{M_{Gov}} CounterGov_{m,p,a} \times Rd_{m,p,a} \right) +$$
$$+ \sum_{p=1}^{P} \omega_{i,p} (Q_{p,a} - Q^{o}_{p,a}) \left(1 - \sum_{m}^{M_{PI}} CounterPI_{m,p,a} \times Rd_{m,p,a} \right) = I_{i,a}$$

Equation 2 (Equality Constraint 1)

Where $Rd_{m,p,a}$ refers to the percent removal of pollutant by each applied technology (i.e. countermeasure) in each sub-catchment.

Where the constant $\omega_{i,p}$ is accounting for the conversion of the licensing (i.e. $Q_{p,a}$) into pollutant units through the **Equation 3**.

$$I = \omega_{i,p} * Q_{p,a}$$

Equation 3 (Equality Constraint 2)

As aforementioned, the second form of the second part of the optimization model refers to the inequality constraints. In particular, these constraints are described below through **Equation 4**, **Equation 5** and **Equation 6**.

Each sub-catchment has a different pollutant load contribution (weighting factor) to the final receptor (i.e. Salt-Lakes). This is because the different characteristics of each sub-catchment which are the distance from the final receptor, the geology and topography as well, the human activities and so on. The weighting factor is denoted by "w" for each pollutant for each area. The summation of the load contribution over all areas should be between the min and max pollutant load (given in **Table 1**) which is expressed by **Equation 4**. The equation ensures the good ecological status of the study area, that is, the total pollutant load that results to the final receptor is within the appropriate range levels indicated in **Table 1**.

$$I_{i\,total}^{\min} \leq \sum_{a=1}^{11} w_{i,a} I_{i,a} \leq I_{i\,total}^{\max}$$

Equation 4 (Inequality Constraint 1)

Additionally, in order to facilitate the modelling procedure, it was convenient to make the following assumption: Only one countermeasure can be applied to each polluter. In case of having more than one countermeasure that should be applied, they can be considered as one. That is being expressed through **Equation 5**. Notice that variables of **Equation 5** are Boolean (i.e. 0 or 1), and hence in order to get a result equal or less than 1 (e.g. zero), at most one countermeasure should be applied to each polluter for each sub-catchment.

$$\sum_{m}^{M_{Gov}} CounterGov_{m,p,a} + \sum_{m}^{M_{PI}} CounterPI_{m,p,a} \leq 1, \quad \forall a, \forall p$$

Equation 5 (Inequality Constraint 2)

In case a new countermeasure is funded by a private investor, this countermeasure is obliged to be applied to every new licencing of a polluter with the same characteristics at any sub-catchment, expressed by **Equation 6**. This constraint ensures the principle of equality for every polluter with the same characteristics in the study area. Observe that this constraint refers only to the countermeasures funded by a private investor.

$$\left(Q_{a_i,z} - Q^{o}_{a_j,z}\right)\left(CounterPI_{m,z,a_i} - Counter_{m,z,a_j}\right) = 0$$

Equation 6 (Equality Constraint 3)

for i = 1,….,11 and j = 1,….,11

Taking all the above into consideration, the overall optimization problem takes the following form including the objective function and constraints:

Objective Function:

$$Minimize\,Cost = \sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{Gov}} CounterGov_{m,p,a} \times Q_{p,a}\,UnitCostCM_{m,p,a}$$
$$+ \sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{PI}} CounterPI_{m,p,a} \times \left(Q_{p,a} - Q^{o}_{p,a}\right) UnitCostCM_{m,p,a}$$

Equation 7 Objective Function of the Optimization Model

Subject to:

$$\sum_{p=1}^{P}\omega_{i,p}Q_{p,a}\left(1-\sum_{m}^{M_{Goc}} CounterGov_{m,p,a}\times Rd_{m,p,a}\right)+$$
$$+\sum_{p=1}^{P}\omega_{i,p}(Q_{p,a}-Q^{o}_{p,a})\left(1-\sum_{m}^{M_{PI}} CounterPI_{m,p,a}\times Rd_{m,p,a}\right)=I_{i,a}$$

Equation 8 (Equality Constraint 1)

$$I=\omega_{i,p}*Q_{p,a}$$

Equation 9 (Equality Constraint 2)

$$I^{\min}_{i\,total}\le\sum_{a=1}^{11}w_{i,a}I_{i,a}\le I^{\max}_{i\,total}$$

Equation 10 (Inequality Constraint 1)

$$\sum_{m}^{M_{Gov}} CounterGov_{m,p,a}+\sum_{m}^{M_{PI}} CounterPI_{m,p,a}\le 1,\quad \forall a,\ \forall p$$

Equation 11 (Inequality Constraint 2)

$$\left(Q_{a_i,z}-Q^{o}_{a_j,z}\right)\left(CounterPI_{m,z,a_i}-Counter_{m,z,a_j}\right)=0$$

Equation 12 (Equality Constraint 3)

Figure 3 and **Figure 4** are some print-screens which shed light on how does $DS_{S}LOM$ model looks like. More precisely, **Figure 3** illustrates the active worksheet where the final form of the objective functions and the constraints of the model are located. Keep on mind that **Figure 3**, as well as **Figure 4**, is only a part of the worksheet. It goes without saying that more tables are included in the certain worksheet.

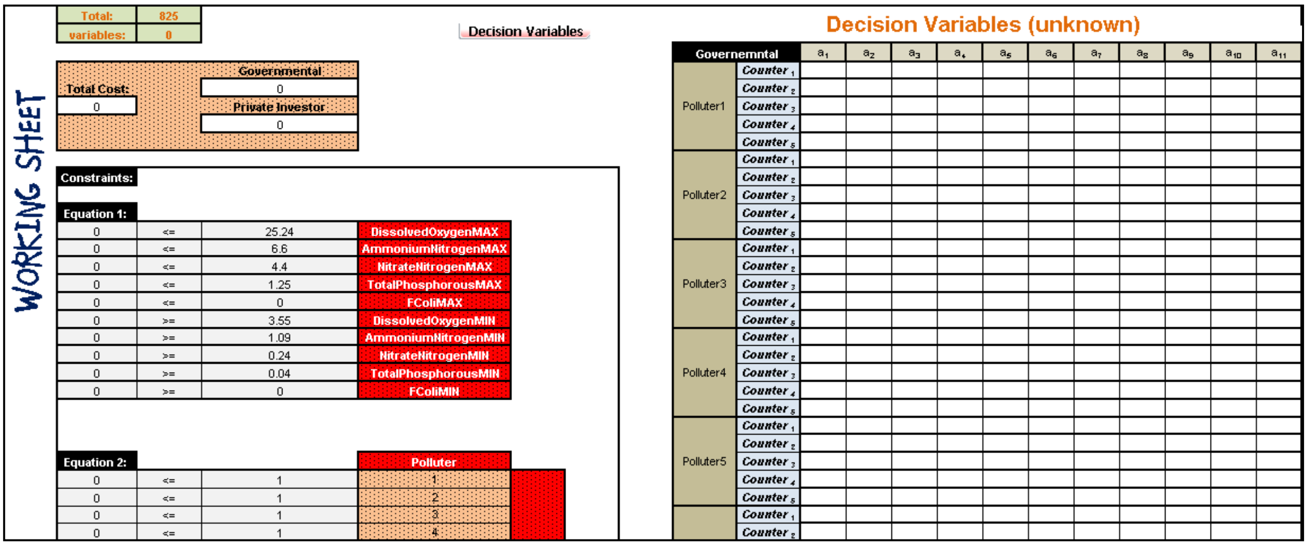

Figure 3 Print-Screen of the Actual Worksheet of the DS$_s$LOM model

Going further onto the **Figure 4**, is a representative example of the DS$_s$LOM input variables with regards to the alternative technologies, unit costs not to mention load removal percentages.

INPUT VARIABLE - COUNTERMEASURE (Governmental Funding) INFORMATION												Countermeasures
Governmental					Reduction Factor (Rd %)					Benefit	Social Acceptability
Zone	CounterMeasure	Unit	Unit Load	UnitControlCost	l_1	l_2	l_3	l_4	l_5		
Polluter1	CM1										
	CM2										
	CM3										
	CM4										
	CM5										
Polluter2	CM1										
	CM2										
	CM3										
	CM4										
	CM5										
Polluter3	CM1										
	CM2										
	CM3										
	CM4										
	CM5										

Figure 4 Print-Screen representative example of DS$_s$LOM input variables

As aforementioned, DS$_s$LOM model is an optimization model design in Excel Spread-sheet (Microsoft Office 2010). It's important to be said that DS$_s$LOM model is a mixed integer linear programming (MILP) problem which uses a standard mathematical programming-based search procedures that are commonly available for solving such as "What's Best!" (LINDO SYSTEMS INC.)

4.3 POSSIBLE SCENARIOS TO BE EXAMINE

Apart from the aforementioned optimization scenario (i.e. minimization of the total cost), important to be noted is that the model is flexible enough to be modified in order to examine different scenarios. Such example could be the following one.

In the first scenario (i.e. basic model) the total cost appears as the objective function. In this scenario, total cost would be the constraint. More precisely, in this case, the objective function change and the total cost is been replaced by the total load insert the Salt lake. In fact, we are trying to minimize the total load to the Salt Lake based on a certain total cost. The rest of the constraints would be remained the same.

This scenario is described mathematically in the following lines, where **Equation 13** represents the objective function, **Equation 14**, **Equation 15** and **Equation 18** represents the equality constraints whereas **Equation 17** represents the inequality constraints.

Objective Function:

$$Minimize\ Load = \sum_{a=1}^{11} w_{i,a} I_{i,a}$$

Equation 13 (Objective Function)

Subject to:

$$\sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{Gov}} CounterGov_{m,p,a} \times Q_{p,a}\ UnitCostCM_{m,p,a}$$
$$+\sum_{a=1}^{11}\sum_{p=1}^{P}\sum_{m=1}^{M_{PI}} CounterPI_{m,p,a} \times \left(Q_{p,a} - Q^{o}_{p,a}\right) UnitCostCM_{m,p,a} = Total\ Cost$$

Equation 14 (Equality Constraint 1)

$$I = \omega_{i,p} * Q_{p,a}$$

Equation 15 (Equality Constraint 2)

$$I_{k\,total}^{\min} \leq \sum_{a=1}^{11} w_{k,a} I_{k,a} \leq I_{k\,total}^{\max}$$

Equation 16 (Inequality Constraint 1)

for i ≠ k

$$\sum_{m}^{M_{Gov}} CounterGov_{m,p,a} + \sum_{m}^{M_{PI}} CounterPI_{m,p,a} \leq 1, \quad \forall a, \ \forall p$$

Equation 17 (Inequality Constraint 2)

$$\left(Q_{a_i,z} - Q_{a_j,z}^{o}\right)\left(CounterPI_{m,z,a_i} - Counter_{m,z,a_j}\right) = 0$$

Equation 18 (Equality Constraint 3)

Of course this is not the end of the possibilities. Further parameters and scenarios could be examined. For example, we could add specific constraints that could allowed the exclusion of specific countermeasures in specific regions (sub-watersheds). More alternative management scenarios as well as BMP's and management measures are scheduled to be examined in the coming deliverables.

Lust but not least, this capability of the model is especially important, considering that one of the main objectives of this work is to help develop TMDLs while examining, simultaneously, the overall benefit for the given region, and not individual objectives, which can be altered, based on a stakeholder category wants. The results expected from the implementation of the decision models, other than the management scenarios that will be developed, will include a set of trade-off curves, between the various objectives for the studied area (as these are identified by the various stakeholders) (Anastasiou, and Panayiotou, 2011).

4.4 MODEL CHALLENGES AND LIMITATIONS

From the development of a rudimentary form of a decision models, it proved to be exceptionally challenging to quantify the manner in which such things as biodiversity, or aesthetic value, can be influenced by basic factors such as nutrient and BOD inflows to the system. The decision variables of the model were defined to be the area of new development in the region (e.g. the land area to be devoted to agricultural activity), the number of animals to be permitted for the region (e.g. the number and size of animal farms to be allowed), or the number of new residential space that could be permitted in the region. These decision variables are connected to one another through a set of basic parameters that include water quantity flows in the watershed (affecting salinity regimes), inflow of basic macro-nutrients (Nitrogen and phosphorous) and BOD, as well as toxic substances such as heavy metals from industrial and other activities. Among objectives to be examined, reduction of treatment costs, maximization of economic profit, maximization of biodiversity (and/or biomass productivity), and minimization of aesthetic deterioration, are singled out. Among the constraints, environmental laws and regulations are imperative, as well as possible budget constraints, or town-planning zoning constraints (Anastasiou, and Panayiotou, 2011).

5 CONCLUSIONS

Operating in a complex environment such as the one that prevails today, where many uses in a given watershed often come into conflict with desired functions of a system, imposes the need for agile and vigilant regulation behaviour to minimize costs and deliver solutions that satisfy many different stakeholders. More importantly, such optimization frameworks can provide, not *the* optimal solution, but good starting points for discussion for stakeholders in focusing on the real issues without becoming entrenched in their respective positions. Further, it is essential that new management tools, such as the use of TMDLs, which we envision to introduce for Cyprus, are steeped in quantitative data that encapsulate whole concepts, as opposed to individual parameters that can often lead to sub-optimal directions. Aside from the management strategies developed through the proposed framework, alternative management approaches are currently used in other environmental fields.

For example, transferable (tradable) permits are an economic policy instrument under which rights to discharge pollutants or exploit resources can be exchanged through either a free or a controlled permit-market. Transferable permits could be excellent instruments to meet regional environmental goals while allowing more freedom to regulators in implementing watershed-use options, thus addressing equity concerns. Past implementations showed that transferable permits lead to cost-effective and equitable solutions for regions (Musole, 2009).

Notwithstanding the fact that significant work has been done concerning the optimization model formulation, the modeling effort is still in its infancy. Particularly, despite the fact that initial thoughts have been put to paper and the excel optimization model took a final form, it remains that the model is implemented, using data that is currently being collected / developed for the case study, on an optimization platform. Further, work that still can be undertaken under this project would be to run extensions of this model to examine a number of different management scenarios, as well as include alternative generation capabilities plus uncertainty analysis capabilities to the optimization framework.

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