OPTWASTEWATER: A COMPUTER PROGRAM FOR REGIONAL WASTEWATER SYSTEM PLANNING

J. A. Zeferino, M. C. Cunha and A. P. Antunes

ABSTRACT

OptWastewater, an easy-to-use computer program developed for regional wastewater system planning, is presented in this article. The regional planning of wastewater systems requires both the drainage of the wastewater generated by the population centers of a region and the meeting of the quality standards defined for the river. *OptWastewater* is designed to be a decision-aid tool. It incorporates a variety of optimization models aimed to find the best possible configuration of the system: single-objective optimization model; multi-objective optimization model; and robust optimization model. The type of results that can be obtained by applying *OptWastewater* are illustrated for three case studies.

1 INTRODUCTION

The wastewater generated in urban areas is one of the main sources of water pollution. The impact of wastewater is particularly hazardous when the discharges are made without any treatment. In Portugal around 30% of the population is not provided with any wastewater treatment system. This is one of the main reasons why none of the surface water quality measuring points installed around the country scored the highest classification last year, and 12% even had the worst level of the five water quality levels defined by the Portuguese National Information System of Water Resources (SNIRH). The aim to reach a good quality for all water bodies was revitalized by the European Union through the adoption of the Water Framework Directive. Anyhow, efficient wastewater systems are crucially important to the promotion of a sustainable development.

Since wastewater systems can be very expensive, they should be planned efficiently, taking into account not only the costs but also the quality of the receiving water bodies. The infrastructure for treating wastewater includes the following facilities: wastewater treatment plants (WWTP) to process the wastewater before it is discharged into rivers; sewer networks connecting the population centers with the WWTP; and pump stations to lift wastewater if it is unfeasible or uneconomic to drain it by gravity. Even though wastewater systems are often planned at local level, planning at a regional level can provide more economically and/or environmentally advantageous solutions. Because of the very large number of available configurations, it would usually be ineffective to evaluate each one individually to find an optimal solution. But this task is greatly facilitated and made efficient if decision-aid tools that make use of optimization models are employed.

OptWastewater, an easy-to-use computer program developed for regional wastewater system planning, is presented in this article. The computer code was written in Visual Basic, thereby offering all the user-friendliness of a typical Windows application. The article is organized as follows. In the next section the planning approach upon which *OptWastewater* is built is explained. Then the *OptWastewater* program is presented, including all the modules to input the data, solve the model, and output the results. Then an application of *OptWastewater* to some cases is described. Finally, in the closing section some concluding remarks are presented.

2 PLANNING APPROACH

The regional planning of wastewater systems requires both the drainage of the wastewater generated by the population centers of a region and the meeting of the quality standards defined for the river that receives the wastewater.

The aim of regional wastewater system planning is to determine an optimal solution for the layout of the sewer network, and for the location, type, and size of the pump stations and WWTP to include in the system. This search for the best regional wastewater system can only be efficient if pursued through optimization models, since the number of available configurations is far too large to enable individual evaluation. The first optimization model that initiated the present line of research pursued by the authors was introduced by Sousa et al. (2002) and consisted of a deterministic approach with a cost-minimization objective. An improved version of the wastewater system planning optimization model was developed and described by Cunha et al. (2009). In Zeferino et al. (2010) this model was extended to a multi-objective version to handle the presence of environmental objectives. Recently, a robust optimization model has been developed to consider the presence of uncertainty in the flow of the river or in the population centers of the region. The objective function of these models is subjected to different constraints to ensure that the sewer network will be sized according to hydraulic laws and regulations. Constraints to ensure that the treated wastewater discharged from each WWTP will not create environmental damage have also been considered. The water quality standards defined for the river can be evaluated according to environmental parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrogen (N), and phosphorus (P).

The *OptWastewater* program incorporates the latest optimization models developed in this line of research: a single-objective optimization model; a multi-objective optimization model; and a robust optimization model. This article introduces two important innovations that were not dealt with in the previous works about these optimization models. The first innovation is the possibility of considering the presence of one or more affluents to the main river. These affluents may be tributary streams or the discharge of an extra wastewater source, such as an industrial discharge or a WWTP of a complementary system. The other innovation is the ability to consider the presence of previously existing facilities. When the size of such facilities is equal to or larger than what is required in a considered solution, only the operating and maintenance cost is taken into account in the cost calculations. Otherwise, the expansion of pump stations and WWTP is allowed, subject to a certain partial capital cost.

3 THE OPTWASTEWATER PROGRAM

OptWastewater has been developed in the Windows environment, using the language Visual Basic. The program was designed in a modular way so that the code may easily be adapted to the needs of future improvements. The main modules correspond to the type of optimization model used, and define how the different modules and respective subroutines of the problem are related. Figure 1 shows these main modules on the left. The diagram on the right shows the different modules and how these are connected. The modules containing an inner hexagon refer to those that vary in some subroutines according to the main module used. In the subsections that follow the *OptWastewater* program and its modules are described for the application to a small example.
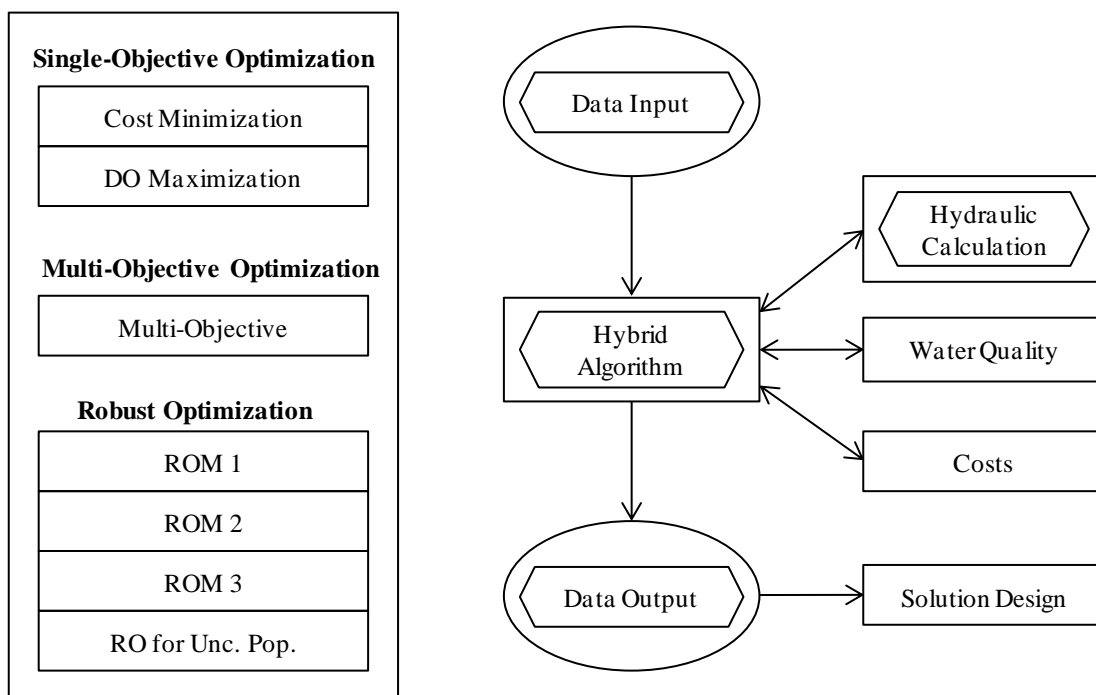
Fig. 1 The relation between OptWastewater modules

3.1 Example

A small example to mimic a real world situation is used in this article to show the application of the *OptWastewater* program. The region depicted in Figure 2 has a rectangular shape, with a length of 50 km along the main river and 25 km in the perpendicular direction. Different nodes are used to set a grid that represents the topography of the region according to local heights. Population centers are located in some nodes of the grid, while the sewers that collect the wastewater from these population centers can be connected from each node to one of the neighboring nodes. In this example, the maximum height is 200 m and the maximum population of a center is 50,000 inhabitants. The total population of the region is 150,000 inhabitants. The example considers the presence of a main river, with a flow of 3 m^3/s, and a tributary river, with a flow of 1 m^3/s. A previously existing system composed of three sewers and one WWTP is taken into consideration for searching for the minimum cost solution of the regional

wastewater system. The water quality of the river is restricted to having a minimum DO concentration of 7.5 mg/l.
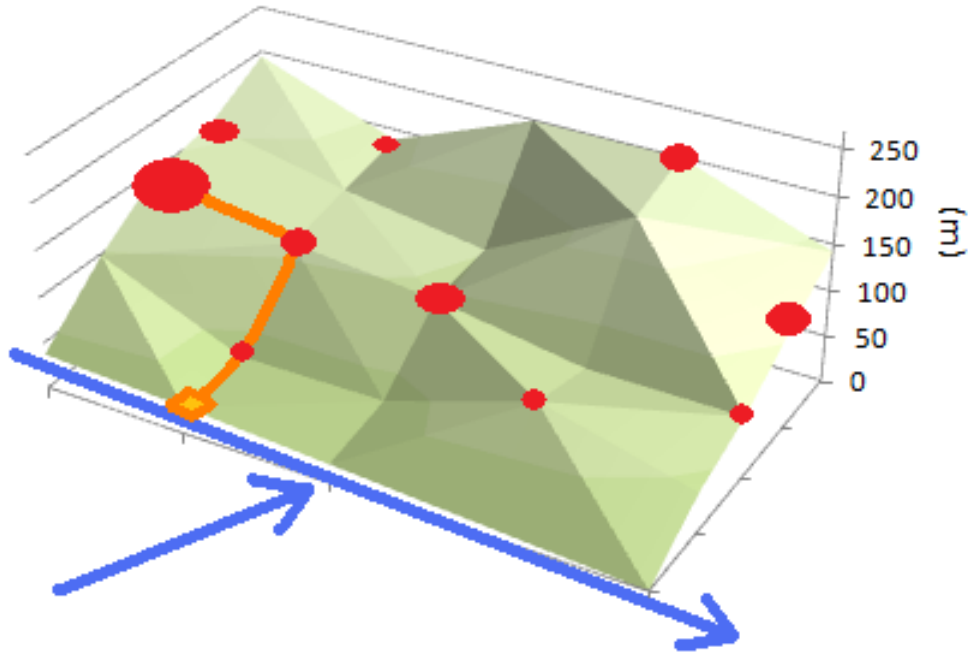
Fig. 2 Example

3.2 Entering and Main Modules

When opening the *OptWastewater* program file, the user is directed to an *Entrance Window* as shown in Figure 3. In this window there is the opportunity to select from three approaches, relating to the main modules presented in Figure 1. If the *Single-Objective Optimization* approach is selected the problem can be solved with an objective function of cost minimization or DO maximization. The *Multi-Objective Optimization* approach involves an objective function with three different objectives: minimization of capital cost; minimization of operating and maintenance costs; and maximization of DO. Here the user is allowed to define the weight given to each objective, since the model is solved through the weighting method. The *Robust Optimization* approach is used to deal with uncertainties in the problem, either in the flow of the river or in the population of the centers of the region. When the uncertainty in river flows is selected, the user can choose from 3 RO models: ROM1, ROM2, and ROM3.

Fig. 3 OptWastewater Entrance Window

In this article we will focus on the *Single-Objective Optimization* approach, since its optimization model is the most used and its interpretation is easiest to describe. After selecting the *Single-Objective Optimization* in the entrance window, a dialog box is presented to select either the objective function of cost minimization or DO maximization. When selecting cost minimization, which will be used in this presentation, the user is directed to the *Main Window,* shown in Figure 4.

The *Main Window* is composed of different boxes. When the window opens, the only enabled feature is the *Water Quality* group box, to choose whether the problem being studied will be analyzed considering/not considering the water quality in the river. After this selection, the *File* tab in the menu bar is enabled. This tab allows inputting data into the program, running the program, viewing the solution configuration, saving the results or simply quitting the program. The remaining elements in the window become enabled after the data input and program run are executed. The *Status* text list, on the left, displays the current status of the program. In the middle of the window there are two group boxes relating to the algorithms selected. In the *Algorithms* group box users can select which algorithms they want to use by means of check boxes. If the simulated annealing is elected, the *Simulated Annealing* group box becomes enabled, allowing definition of the parameters for the simulated annealing. When no algorithm is selected, the program run will present the results for the initial configuration given by the input data. Finally, the right text list shows the main results obtained while running the program, while a progress bar at the bottom of the window shows the progress of the optimization model.
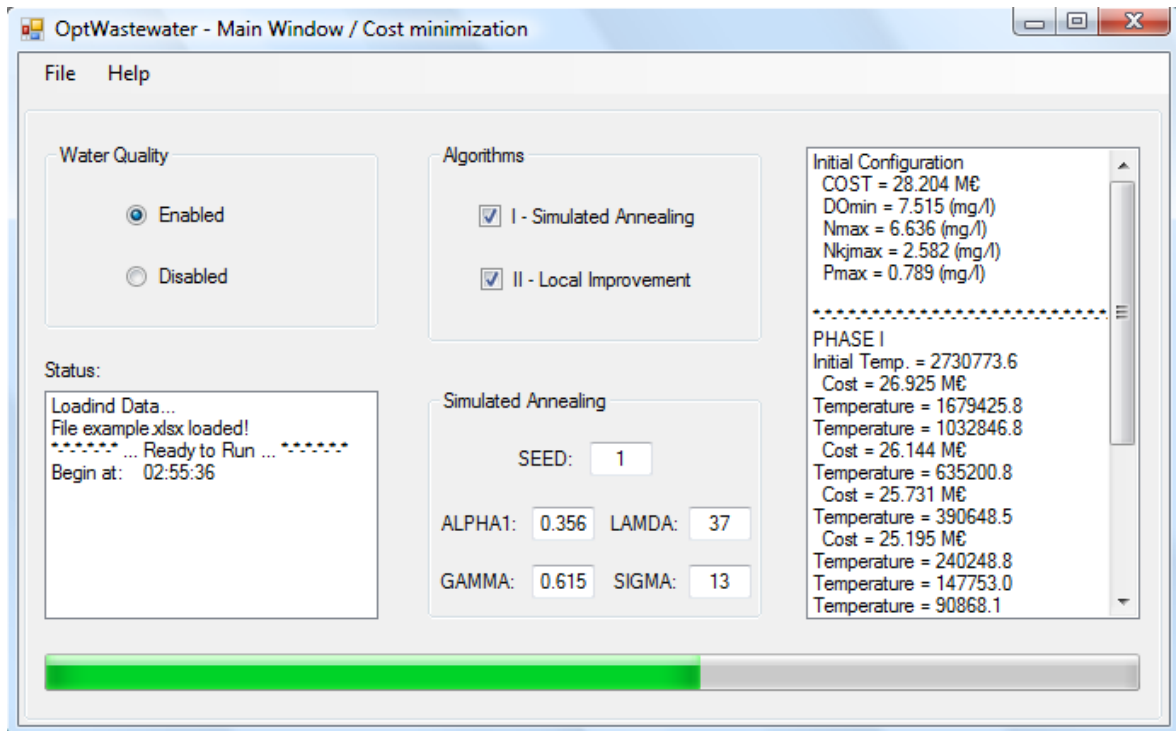
Fig. 4 Single-Objective Optimization – Main Window for Cost minimization

3.3 Input Description

The first step for solving a regional wastewater system is to collect all the required information about the problem. This is done through the use of an Excel workbook with four sheets, as shown in Figure 5. The first sheet (top left) has the information about each node. The first column contains the node enumeration, the second and third columns contain the coordinates of the nodes. Then there are columns with information about the elevation, population and respective per capita wastewater generation rate of each node. The last three columns contain information about the WWTP: if the node is of the WWTP type, the respective cell has value 1; if there is an existing WWTP in the node, the maximum capacity in terms of inhabitants is given in the next column; the last column contains the maximum capacity of a possible WWTP in the respective node, whether it is new or results from the expansion of an existing one. The maximum discharge in each plant is usually defined to guarantee the quality standards that must be met in the river. The second sheet (top right) contains the information about all the possible sewers between the nodes, with information about the starting node, the end node, and the length in meters. The third sheet (bottom left) contains the information about the initial solution. Start nodes and end nodes are specified, and there is a specific column to identify the Manning-Strickler coefficient of any possible sewer that starts in those nodes. Note that only one sewer can start in each node. The last two columns in this sheet relate to the diameter of possible existing sewers and the peak flow of any pump station existing in that node. The last sheet (bottom right) is used only when the water quality model in the river is enabled, and contains all the data on the river(s). The first rows contain information about the initial characteristics of the main river and tributaries, particularly relating to the water quality parameters and the flow of the main river. The rows underneath contain information about each river reach, such as the length, the number of elements considered, the respective node of the WWTP, temperature, transversal area, transversal width, slope, and flow of the

tributary that discharges in that reach. Then, the subsequent four rows define the minimum or maximum values for the water quality parameters: DO, total N, Kjeldahl nitrogen (NKj) and total P. The remaining rows define secondary parameters used in the water quality model.

After editing all the correct information in the Excel workbook, the data input module in the program can be executed using *File > Open* in the menu bar. A dialog box is presented to select the respective **.xls* or **.xlsx* file. This step enables *File > Configuration* in the menu bar to allow viewing the initial solution configuration, and also enables *File > Run* to allow the program run to be executed.

Nodes sheet — Nodes: 25

Node	x	y	Elev.	Pop.	Cap.	WWTP	WWTextP (pop)	MaxWWTP (pop)
1	50000	25000	141.7	0	0	0	0	0
2	33000	25000	200.0	15000	200	0	0	0
3	23000	25000	199.1	0	0	0	0	0
4	10000	25000	138.3	2500	200	0	0	0
5	0	25000	194.3	0	0	0	0	0
6	50000	20000	106.4	25000	200	0	0	0
7	33000	20000	181.3	0	0	0	0	0
8	23000	20000	101.0	0	0	0	0	0
9	10000	20000	124.2	0	0	0	0	0
10	0	20000	157.4	12500	200	0	0	0
11	50000	13000	66.8	2500	200	0	0	0
12	33000	13000	67.4	0	0	0	0	0
13	23000	13000	93.9	20000	200	0	0	0
14	10000	13000	109.9	10000	200	0	0	0
15	0	13000	144.6	50000	200	0	0	0
16	50000	6000	42.7	0	0	0	0	0
17	33000	6000	85.0	7500	200	0	0	0
18	23000	6000	34.1	0	0	0	0	0
19	10000	6000	32.8	5000	200	0	0	0
20	0	6000	97.9	0	0	0	0	0
21	50000	0	0.0	0	0	1	0	200000
22	33000	0	10.0	0	0	1	0	200000
23	23000	0	20.1	0	0	1	0	200000
24	10000	0	29.7	0	0	1	65000	200000
25	0	0	37.0	0	0	1	0	200000

total 150000

Links&Lengths sheet — Links: 123

Start	End	Length
1	2	17000.0
1	6	5000.0
1	7	17720.0
2	1	17000.0
2	3	10000.0
2	6	17720.0
2	7	5000.0
2	8	11180.3
3	2	10000.0
3	4	13000.0
3	7	11180.3
3	8	5000.0
3	9	13928.4
4	3	13000.0
4	5	10000.0
4	8	13928.4
4	9	5000.0
4	10	11180.3
5	4	10000.0
5	9	11180.3
5	10	5000.0
6	1	5000.0
6	2	17720.0
6	7	17000.0
6	11	7000.0

Sewers sheet — Sewers: 20

Sewer	Start	End	MS_Coef	SewExist (diam)	PSExist (Qp)
1	1	6	100	0	0
2	2	7	100	0	0
3	3	8	100	0	0
4	4	9	100	0	0
5	5	10	100	0	0
6	6	11	100	0	0
7	7	12	100	0	0
8	8	13	100	0	0
9	9	14	100	0	0
10	10	15	100	0	0
11	11	16	100	0	0
12	12	17	100	0	0
13	13	18	100	0	0
14	14	19	100	630	0
15	15	14	100	630	0
16	16	21	100	0	0
17	17	22	100	0	0
18	18	23	100	0	0
19	19	24	100	710	0
20	20	25	100	0	0

River sheet — Sects: 5

Q_0	L_0	CLA_0	N1_0	N2_0	N3_0	N4_0	P1_0	P2_0	DO_0
3	1.4	0.01	0.18	0.08	4	0.8	0.01	0.01	9
Extra	1.4	0.01	0.18	0.08	4	0.8	0.01	0.01	9

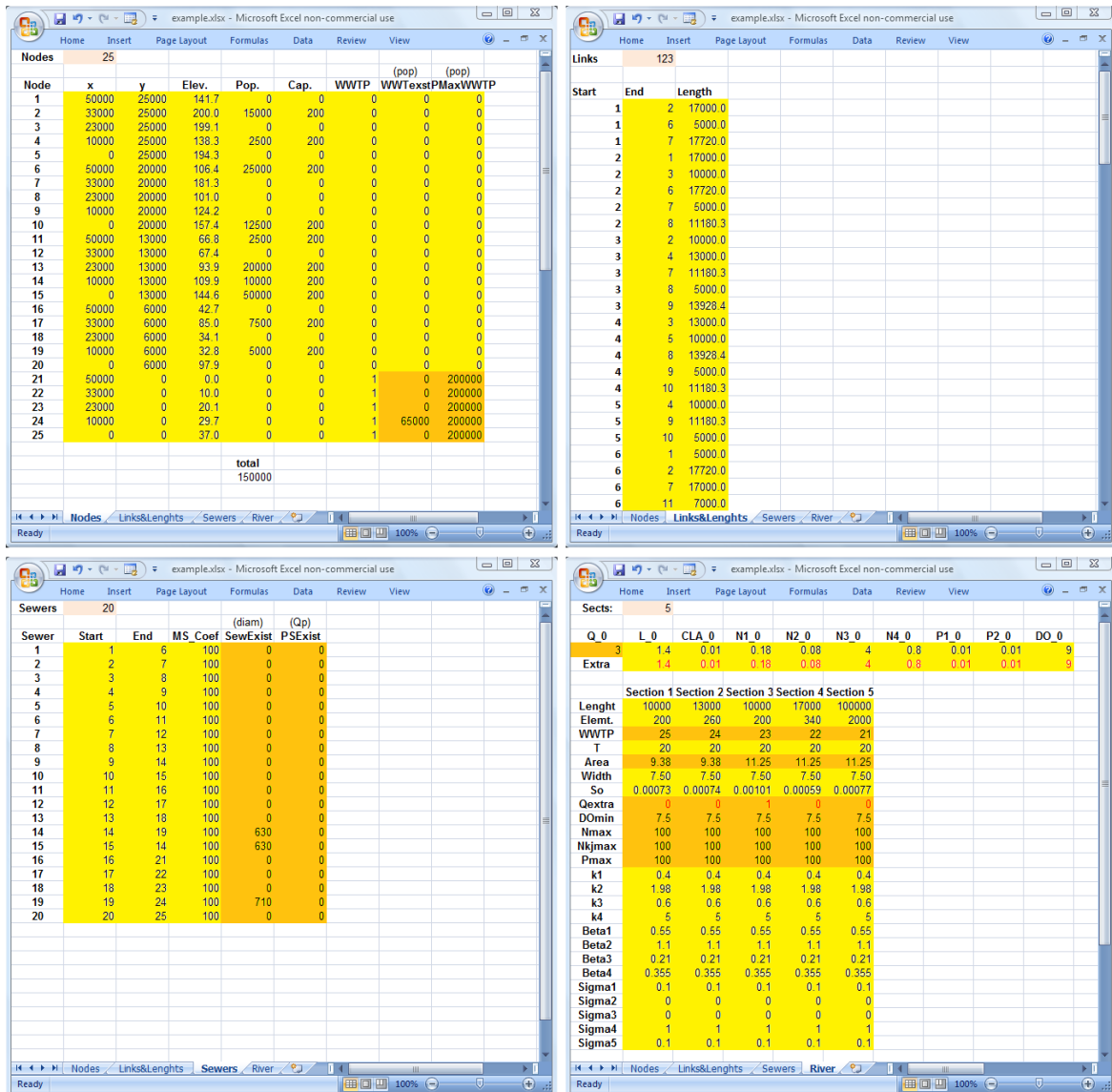|	Section 1	Section 2	Section 3	Section 4	Section 5
Lenght	10000	13000	10000	17000	100000
Elemt.	200	260	200	340	2000
WWTP	25	24	23	22	21
T	20	20	20	20	20
Area	9.38	9.38	11.25	11.25	11.25
Width	7.50	7.50	7.50	7.50	7.50
So	0.00073	0.00074	0.00101	0.00059	0.00077
Qextra	0	0	1	0	0
DOmin	7.5	7.5	7.5	7.5	7.5
Nmax	100	100	100	100	100
Nkjmax	100	100	100	100	100
Pmax	100	100	100	100	100
k1	0.4	0.4	0.4	0.4	0.4
k2	1.98	1.98	1.98	1.98	1.98
k3	0.6	0.6	0.6	0.6	0.6
k4	5	5	5	5	5
Beta1	0.55	0.55	0.55	0.55	0.55
Beta2	1.1	1.1	1.1	1.1	1.1
Beta3	0.21	0.21	0.21	0.21	0.21
Beta4	0.355	0.355	0.355	0.355	0.355
Sigma1	0.1	0.1	0.1	0.1	0.1
Sigma2	0	0	0	0	0
Sigma3	0	0	0	0	0
Sigma4	1	1	1	1	1
Sigma5	0.1	0.1	0.1	0.1	0.1

Fig. 5 Input - Excel Sheets

3.4 Model Solving

Wastewater system planning optimization models incorporate discrete variables and non-linear functions, and, due to the complexity involved in mixed-integer non-linear optimization, they require heuristic algorithms to solve them. A hybrid algorithm

composed of a combination of a simulated annealing algorithm (SA) and a local improvement procedure (LI) has been used as the solution method for these optimization models. More information about this algorithm and its implementation can be found in Kirkpatrick (1983) and Zeferino et al. (2009).

The hybrid algorithm is contained in the crucial model-solving module of the program. This module contains several sub-routines that are used according to the optimization model selected. The hybrid algorithm module is linked to three modules required to evaluate the solutions for each iteration of the algorithm: hydraulic calculation; water quality; and cost. The hydraulic calculation module is used to size sewers, possible pump stations and the WWTP, complying with all relevant regulations. The water quality module contains a specific model used to evaluate the effects of wastewater discharges in the river. This water quality model evaluates the water quality parameters of the river, taking into consideration the following factors: atmospheric reaeration, photosynthesis, respiration, sediment oxygen demand, carbonaceous organic matter oxidation, and nitrification. The cost module is used to calculate the capital costs and the discounted maintenance and operation costs of all facilities associated with the solution. The cost of the wastewater system facilities was taken from a sample of Portuguese case studies.

The program makes use of the model-solving modules to solve the optimization model selected and can be executed by selecting *File > Run* in the menu bar of the *Main Window*.

3.5 Output Description

After the program has been run and the best solution for the wastewater system is obtained, the user can check the main results in the text list on the right of the *Main Window*. The final configuration can then be viewed through *File > Configuration* in the menu bar, resulting in a *Solution Configuration Window* like that in Figure 6. When clicking the button *Design* in this window, a graphic image of the solution is shown, relating to the initial solution, the solution obtained from the SA algorithm or the final solution. If the user wants to have an idea of the terrain of the solution, the *Contour* button will provide it by drawing some points containing groups of elevation values according to the steps selected. These points can be connected in any graphics painting program to achieve the contour lines representing the land relief. The graphics image can be saved by clicking in the *Save* button, which shows a dialog box to select a name for the new **.bmp* or **.jpg* file.
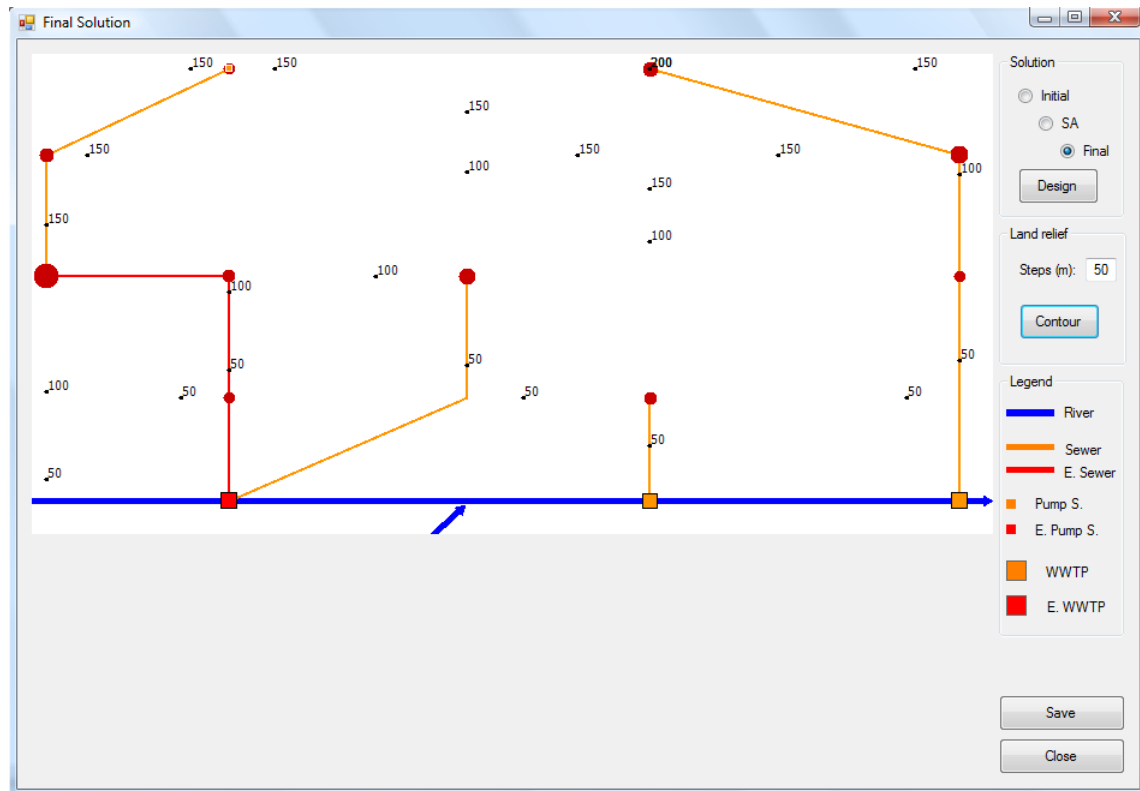
Fig. 6 Solution Configuration Window

All the information about the results is provided in an excel file that is stored in a single Excel workbook through the link *File > Save* in the menu bar of the *Main Window*. A dialog box requiring the name for the new *.xls* or *.xlsx* file to save is presented. The Excel workbook has three sheets: the first has the output for the initial solution, the second has the output for the final solution, and the third contains information about the parameters used and the time taken by the program to find the optimum solution. For the second sheet, describing the final solution (Figure 7 - left), the first group of lines show all the information on the resulting sewers: start node, end node, length, average flow, diameter of the sewer, Manning-Strickler coefficient, and diameter of the previously existing sewer. The rows below contain the cost of the different components of the system, and for the system as a whole. These costs are divided into capital costs, operating and maintenance costs, and total costs, for both the new and existing facilities.

When the water quality is enabled, a second Excel workbook is saved which contains information about the river. The first sheet of the file contains a summary of the input data. In the second sheet (Figure 7 - right) the river flow and the water quality characteristics are presented. In the first rows, for each river reach, the discharged flow (in l/s) of the respective WWTP is presented, as well as the minimum DO, and the maximum N, Nkj and P for that reach. The remaining rows give several water quality concentrations, and their number may be very high since they describe each element of each river reach. These values can be easily used in Excel to create a graphic representing the progress of these concentrations along the river.

All the obtained outputs can be readily adapted for use in any geographic information systems software, which is particularly useful since it allows a better interpretation of the results when dealing with real world situations.

results example.xlsx

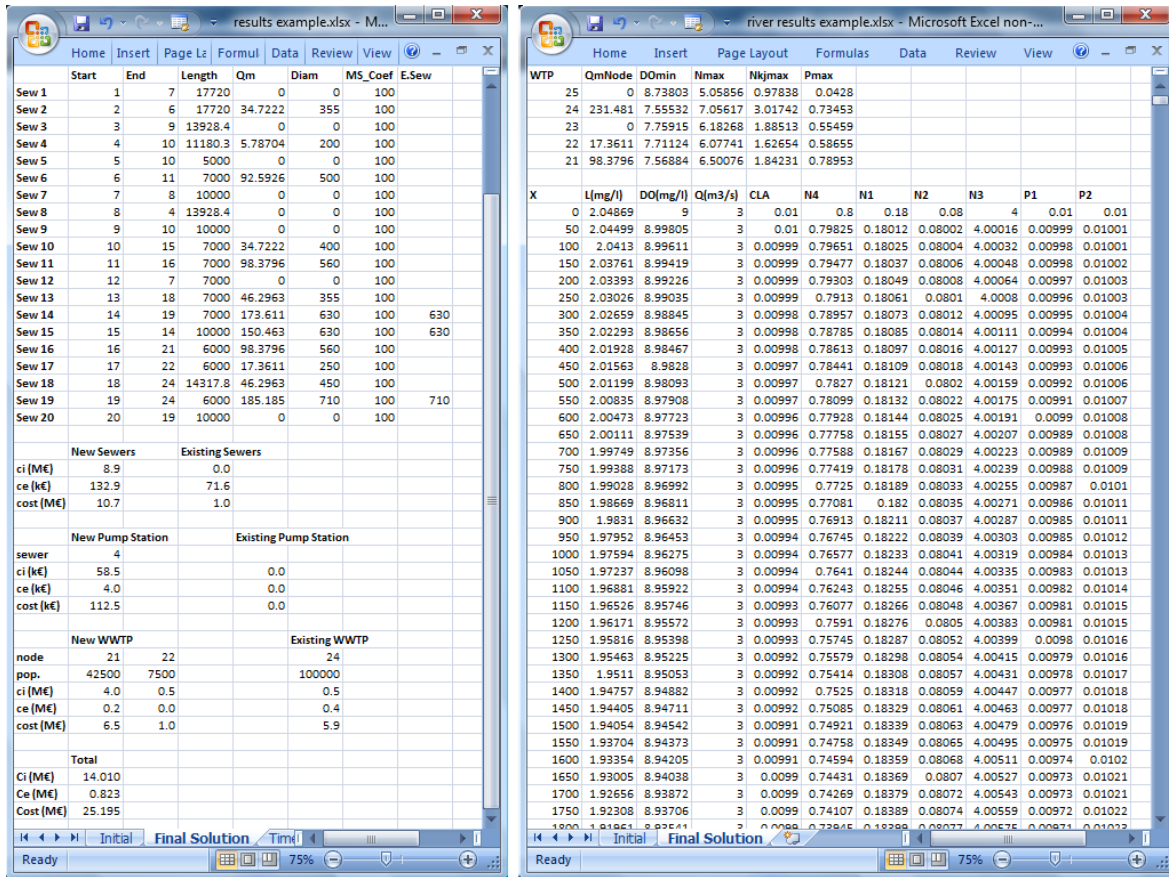|	Start	End	Length	Qm	Diam	MS_Coef	E.Sew
Sew 1	1	7	17720	0	0	100	
Sew 2	2	6	17720	34.7222	355	100	
Sew 3	3	9	13928.4	0	0	100	
Sew 4	4	10	11180.3	5.78704	200	100	
Sew 5	5	10	5000	0	0	100	
Sew 6	6	11	7000	92.5926	500	100	
Sew 7	7	8	10000	0	0	100	
Sew 8	8	4	13928.4	0	0	100	
Sew 9	9	10	10000	0	0	100	
Sew 10	10	15	7000	34.7222	400	100	
Sew 11	11	16	7000	98.3796	560	100	
Sew 12	12	7	7000	0	0	100	
Sew 13	13	18	7000	46.2963	355	100	
Sew 14	14	19	7000	173.611	630	100	630
Sew 15	15	14	10000	150.463	630	100	630
Sew 16	16	21	6000	98.3796	560	100	
Sew 17	17	22	6000	17.3611	250	100	
Sew 18	18	24	14317.8	46.2963	450	100	
Sew 19	19	24	6000	185.185	710	100	710
Sew 20	20	19	10000	0	0	100	

	New Sewers	Existing Sewers
ci (M€)	8.9	0.0
ce (k€)	132.9	71.6
cost (M€)	10.7	1.0

	New Pump Station	Existing Pump Station
sewer	4	
ci (k€)	58.5	0.0
ce (k€)	4.0	0.0
cost (k€)	112.5	0.0

	New WWTP		Existing WWTP
node	21	22	24
pop.	42500	7500	100000
ci (M€)	4.0	0.5	0.5
ce (M€)	0.2	0.0	0.4
cost (M€)	6.5	1.0	5.9

	Total
Ci (M€)	14.010
Ce (M€)	0.823
Cost (M€)	25.195

Initial / **Final Solution** / Tim...

river results example.xlsx - Microsoft Excel non-...

WTP	QmNode	DOmin	Nmax	Nkjmax	Pmax
25	0	8.73803	5.05856	0.97838	0.0428
24	231.481	7.55532	7.05617	3.01742	0.73453
23	0	7.75915	6.18268	1.88513	0.55459
22	17.3611	7.71124	6.07741	1.62654	0.58655
21	98.3796	7.56884	6.50076	1.84231	0.78953

X	L(mg/l)	DO(mg/l)	Q(m3/s)	CLA	N4	N1	N2	N3	P1	P2
0	2.04869	9	3	0.01	0.8	0.18	0.08	4	0.01	0.01
50	2.04499	8.99805	3	0.01	0.79825	0.18012	0.08002	4.00016	0.00999	0.01001
100	2.0413	8.99611	3	0.00999	0.79651	0.18025	0.08004	4.00032	0.00998	0.01001
150	2.03761	8.99419	3	0.00999	0.79477	0.18037	0.08006	4.00048	0.00998	0.01002
200	2.03393	8.99226	3	0.00999	0.79303	0.18049	0.08008	4.00064	0.00997	0.01003
250	2.03026	8.99035	3	0.00999	0.7913	0.18061	0.0801	4.0008	0.00996	0.01003
300	2.02659	8.98845	3	0.00998	0.78957	0.18073	0.08012	4.00095	0.00995	0.01004
350	2.02293	8.98656	3	0.00998	0.78785	0.18085	0.08014	4.00111	0.00994	0.01004
400	2.01928	8.98467	3	0.00998	0.78613	0.18097	0.08016	4.00127	0.00993	0.01005
450	2.01563	8.9828	3	0.00997	0.78441	0.18109	0.08018	4.00143	0.00993	0.01006
500	2.01199	8.98093	3	0.00997	0.7827	0.18121	0.0802	4.00159	0.00992	0.01006
550	2.00835	8.97908	3	0.00997	0.78099	0.18132	0.08022	4.00175	0.00991	0.01007
600	2.00473	8.97723	3	0.00996	0.77928	0.18144	0.08025	4.00191	0.0099	0.01008
650	2.00111	8.97539	3	0.00996	0.77758	0.18155	0.08027	4.00207	0.00989	0.01008
700	1.99749	8.97356	3	0.00996	0.77588	0.18167	0.08029	4.00223	0.00989	0.01009
750	1.99388	8.97174	3	0.00996	0.77419	0.18178	0.08031	4.00239	0.00988	0.01009
800	1.99028	8.96992	3	0.00995	0.7725	0.18189	0.08033	4.00255	0.00987	0.0101
850	1.98669	8.96811	3	0.00995	0.77081	0.182	0.08035	4.00271	0.00986	0.01011
900	1.9831	8.96632	3	0.00995	0.76913	0.18211	0.08037	4.00287	0.00985	0.01011
950	1.97952	8.96453	3	0.00994	0.76745	0.18222	0.08039	4.00303	0.00985	0.01012
1000	1.97594	8.96275	3	0.00994	0.76577	0.18233	0.08041	4.00319	0.00984	0.01013
1050	1.97237	8.96098	3	0.00994	0.7641	0.18244	0.08044	4.00335	0.00983	0.01013
1100	1.96881	8.95922	3	0.00994	0.76243	0.18255	0.08046	4.00351	0.00982	0.01014
1150	1.96526	8.95746	3	0.00993	0.76077	0.18266	0.08048	4.00367	0.00981	0.01015
1200	1.96171	8.95572	3	0.00993	0.7591	0.18276	0.0805	4.00383	0.00981	0.01015
1250	1.95816	8.95398	3	0.00993	0.75745	0.18287	0.08052	4.00399	0.0098	0.01016
1300	1.95463	8.95225	3	0.00992	0.75579	0.18298	0.08054	4.00415	0.00979	0.01016
1350	1.9511	8.95053	3	0.00992	0.75414	0.18308	0.08057	4.00431	0.00978	0.01017
1400	1.94757	8.94882	3	0.00992	0.7525	0.18318	0.08059	4.00447	0.00978	0.01018
1450	1.94405	8.94711	3	0.00992	0.75085	0.18329	0.08061	4.00463	0.00977	0.01018
1500	1.94054	8.94542	3	0.00991	0.74921	0.18339	0.08063	4.00479	0.00976	0.01019
1550	1.93704	8.94373	3	0.00991	0.74758	0.18349	0.08065	4.00495	0.00975	0.01019
1600	1.93354	8.94205	3	0.00991	0.74594	0.18359	0.08068	4.00511	0.00974	0.0102
1650	1.93005	8.94038	3	0.0099	0.74431	0.18369	0.0807	4.00527	0.00973	0.01021
1700	1.92656	8.93872	3	0.0099	0.74269	0.18379	0.08072	4.00543	0.00973	0.01021
1750	1.92308	8.93706	3	0.0099	0.74107	0.18389	0.08074	4.00559	0.00972	0.01022
1800	1.91961	8.93541	3	0.0099	0.73945	0.18399	0.08077	4.00575	0.00971	0.01023

Initial / **Final Solution**

Fig. 7 Output - Excel Sheets

4 OPTWASTEWATER: APPLICATION EXAMPLE

In order to illustrate the type of results that can be obtained by applying *OptWastewater*, the program was used for three examples. The three examples – case 1, case 2, and case 3 - are variations of the example given above and depicted in Figure 2. In case 1, the example is considered to have neither existing facilities nor a tributary river, resulting in a single main river with a flow of 4 m^3/s. In case 2 the flow of the main river is 3 m^3/s and contains the discharge of a tributary stream with a flow of 1 m^3/s, resulting in a total flow of 4 m^3/s ahead of the intersection. In case 3, in addition to the tributary stream the example also considers the presence of a previously existing system comprising three sewers and one WWTP, and thus it is the same to the example presented in section 3.1. The limit concentration for the DO in the main river is set at a minimum of 7.5 mg/l in all three cases.

The results obtained by applying *OptWastewater* to the three cases are presented in Figure 8. In terms of the total cost of the solutions, case 3 is the cheapest, 25.195 M€, derived from the exploitation of the existing system. In case 1, with the 4 m^3/s flow for the entire length of the main river, the solution does not require any adjustment to guarantee the minimum DO of 7.5 mg/l. But in case 2 the flow in the first reaches of the main river is 3 m^3/s, and the water quality restriction forces a larger discharge upstream of the tributary river intersection where the flow of the main river is greater. Therefore the cost of case 2, 28.630 M€, is higher than that of case 1, 27.725 M€. The solution configurations for the three cases are depicted in Figure 8 – left. Apart from the presence of existing facilities in case 3, the solutions are broadly similar, requiring the use of three WWTP. Cases 1 and 2

only differ in the transport of the wastewater from one population center. Figure 8 - right shows the DO concentration curves, where, as expected, the minimum DO does not fall below 7.5 in any case: 7.539 mg/l for case 1 and 7.555 mg/l for cases 2 and 3. The improvement of the DO concentration resulting from the flow increment given by the tributary stream is perceptible in the curves of cases 2 and 3. The time taken by the program to solve each case was around 5 minutes.
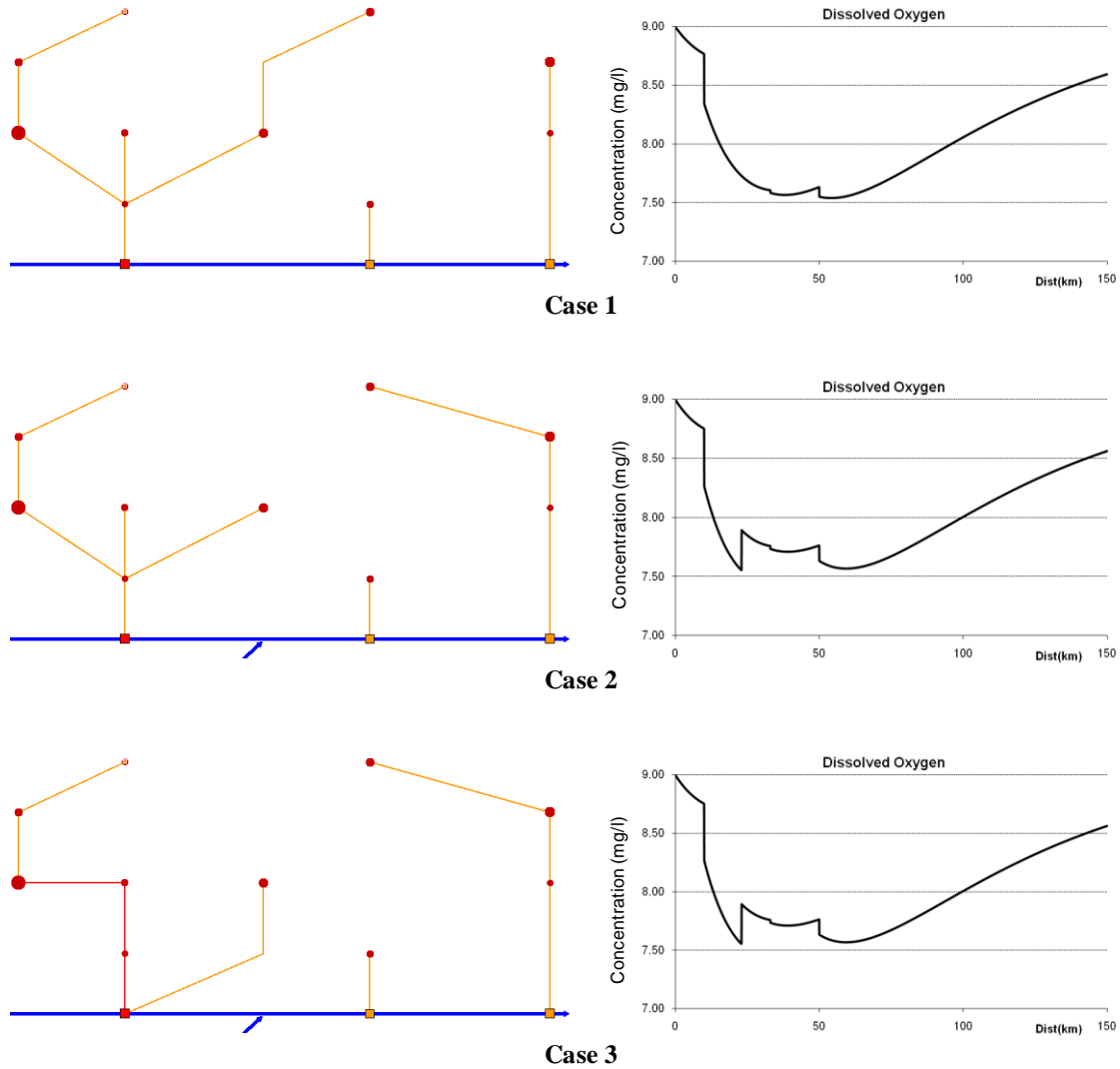

Case 1

Case 2

Case 3

Fig. 8 Solutions for the three cases

5 CONCLUSION

OptWastewater, an easy-to-use computer program developed for regional wastewater system planning, has been presented in this article. The program is aimed at helping to determine the best possible configuration for the layout of the sewer network, and for the location, type, and size of the pump stations and WWTP to include in the wastewater systems. This is done with the purpose of meeting the quality standards defined for the river, in terms of different water quality parameters: DO, N, Nkj and P. The search for the best regional wastewater system can only be efficient if pursued through optimization models. *OptWastewater* incorporates a variety of optimization models that have recently been developed by the authors: a single-objective optimization model; a multi-objective

optimization model; and a robust optimization model. The modular structure of the program allows several analyses involving different conditions to be carried out, and also allows the code to be easily adapted to the needs of future improvements. The nature of the results that can be obtained through the application of *OptWastewater* is illustrated in three examples – case 1, case 2, and case 3. The results obtained through the model demonstrate its potential usefulness in real-world applications.

6 AKNOWLEDGMENTS

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