- ORAL PRESENTATION -

PRACTICAL APPLICATIONS OF MATHEMATICAL MODELING FOR INTEGRATED WATER MANAGEMENT ON AN INDUSTRIAL PLATFORM

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Abstract

One of the main issues in the Water Framework Directive (see the portal EU-WFD, 2011) is the establishing of specific Action plans at the River Basins levels in EU. Building up such plans implies a thorough knowledge about all the processes, stakeholders, synergies, problems active in the area of a given River basin. The paper details a Project for integrating water management at VIROMET chemical platform. The mathematical models used are based upon water balances at the platform level, with details for each particular consumer (stakeholder). Sets of restrictions are developed for water flows, production capacities, and consumptions. Linear and non-linear programming are then used to answer specific scenarios: "what is the most favorable production structure in order to maximize the profit of the VIROMET system?", "what will be the production structure to fulfill the minimal requirements of the customers, whilst minimizing water consumption at the platform level", "given a specific need of a stakeholder, what will be the most profitable production profile?", etc.

Keywords: The Water Framework Directive, integrated water management, river basin management, eco-efficiency

THE SYSTEM UNDER SCRUTINY

The area included in building up an integrated model for water management includes:

1. the VIROMET – chemical platform in the Victoria City, Romania. The Platform produces methanol, formaldehyde, synthetic resins, plastic products, etc.
2. The PUROLITE factory – an important producer for ion exchangers and adsorbents
3. smaller companies, of local interest
4. communities around the industrial platform.

The mentioned components of the area studied constitute the VIROMET WATER SYSTEM (VWS) and are also the main stakeholders of the system considered. VIROMET is the manager of the water sources, located in 2 Counties (Sibiu, Brasov). It has a large capacity for water purification (including a module for de-ionization, for water used in the thermal system of the platform – boilers, heat exchangers and a module for potable water preparation) and all the facilities for distributing water to consumers. VIROMET also collects wastewater from adjacent consumers and purify it before sending it to the nearby river.

An illustration of the VWS under study is included in the following figure.1.

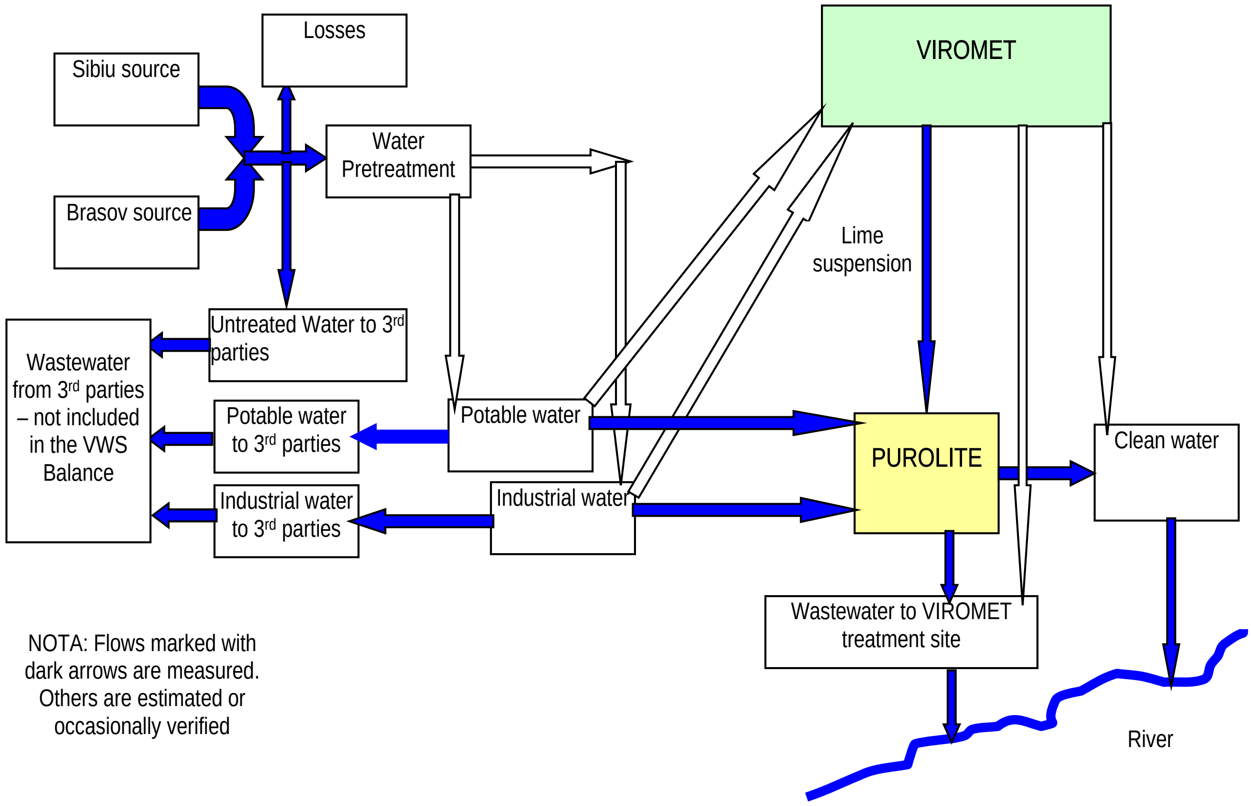

Fig. 1. The VWS main components and connections

The Mathematical Model

Model hypotheses used are detailed in the subsequent list:

a. Only VIROMET, PUROLITE, Smaller Companies (regarded as a single consumer) and adjacent communities are included in the analysis. They are connected to the VWS distribution and/or collecting system (in view of wastewater treatment).

b. Database used for setting up the parameters and the restrictions of the mathematical model covers the years 2007 – 2011. Yearly averages are used where other more detailed date is not available.

c. Potable water consumptions arise to max 2% of the total. It may be overlooked when building up scenarios for optimization of the VWS.

d. Seasonal indexes are built based upon the same 2007 – 2011 consumptions effectively recorded.

The mathematical model for optimization consists of an objective criterion (function) to be maximized / minimized, subject to a set o restrictions. In this way, the allocation and the optimization problem becomes a linear or non0linear programming model, with the attached set of restrictions.

Linear optimization is carried out using the classical SIMPLEX algorithm (LP, 2010) improved by Kharmakar (Dantzig and Thapa. 2003). In the case of non-linear criteria for optimization the Levenberg – Marquardt optimization algorithm (Rowais, 2011) is implemented in a computer program.

The number and type of restrictions are not limited. Restrictions may be linear, non-linear, inequalities or equalities. All variables are supposed non-negative (these variables are flows that physically cannot be negative).

The mathematical relations included in the model are summarized below for a maximization scenario.

The criterion to be maximized is of the form

$$\max_{P_i} \sum_{i=1}^{4} P_i \times c_i$$

Here, P_i are productions and c_i, associated costs.

The attached restrictions refers to minimal and maximal production capacities

$$P_{i,\min} \le P_i \le P_{i,\min};$$

Water consumptions vary between two limits, the minimal value (usually = 0) and a maximal level (imposed by the operating capacity of the sources, at a given moment or by the limited pre-treatment capacity at VIROMET)

Scenarios Analyzed

A large number of realistic scenarios have been tested, after discussions woth VWS management. Some scenarios are mentioned below:

1. maximize the production of various VIROMET modules, with a restricted consumption of water, imposed by all current contracts for water providing to PUROLITE or other third parties, including communities;
2. minimizing the water consumptions at VIROMET, whilst still covering the Contracts for providing water to adjacent consumers / communties and complying to quantities fo chemicals delivered to VIROMET consumers;
3. maximize the eco-efficiency: maximal production/1000 m^3 water consumed
4. minimize the water consumed / 1000 RON production
5. Minimize the wastewater quantity to be treated in the VIROMET treatment station.

The computer program results are illustrated in the following tables.

First, for the case of maximal productions at VIROMET, allowed by the level of water available and by the Contracts signed with 3rd parties to provide them industrial or potable water.

Table 1. Maximal production at VIROMET. (only relevant results were retained for reason of confidentiality).

Objective:				
Maximal Production, lei/an				
85816745				
Solution		**2. Restrictions**		
1. Productions, ton/yr	**value**	**Installation**	**Restrictions**	
Methanol	**71480.38**	Methanol	170000	Max
Research	**30.00**		30000	Min
Resins	**97745.15**	Resins	120000	Max
Plastics	**50.00**		50000	Min
		Plastics	50	Max
			3	Min
3.Water available, m3		Research	30	Min
Total	6400000		500	Max
Potable sold to communities	160000			
Industrial to PUROLITE	2900000			
Industrial to 3rd parties	750000			

Second, an eco-indicator is minimized (the water consumed for obtaining 1000 lei production at VWS)

Table 2. Ecoindicator minimization

Objective:				
Minimal Water consumption for 1000 RON production				
22.727				
Solution		**2.Restrictions**		
1. Productions, ton/yr	**value**	**Installation**	**Restrictions**	
Methanol	**30000**	Methanol	170000	Max
Research	**268.5**		30000	Min
Resins	**48000**	Resins	120000	Max
Plastics	**50.00**		50000	Min
		Plastics	50	Max
			3	Min
3.Water available, m3		Research	30	Min
Total	6400000		500	Max
Potable sold to communities	160000			
Industrial to PUROLITE	2900000			
Industrial to 3rd parties	750000			

Seasonal indexes for water consumption

The following figure illustrates the water consumptions at VWS and the associated moving averages profiles (with 2 or 4 values) that try to smooth the actual fluctuations.

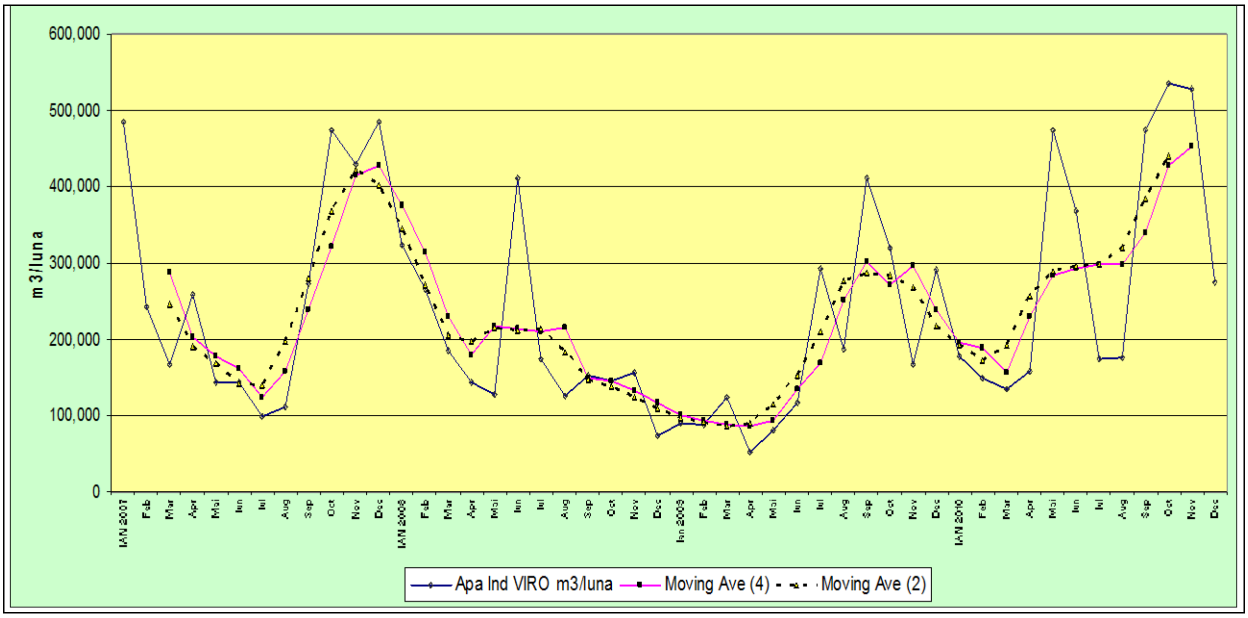

Fig. 2. Actual and smoothen water consumptions at VWS.

It is obvious that, for management purposes, a simple trendline prediction will not be accurate at all. The water managing unit needs a more powerful tool for predicting water consumptions as accurate as possible, in order to take the necessary measures to cover the demand, to comply to contracts, not entailing damaging consequences for the natural habitat.

Calculating a seasonal index for water consumptions leads to the following profile.

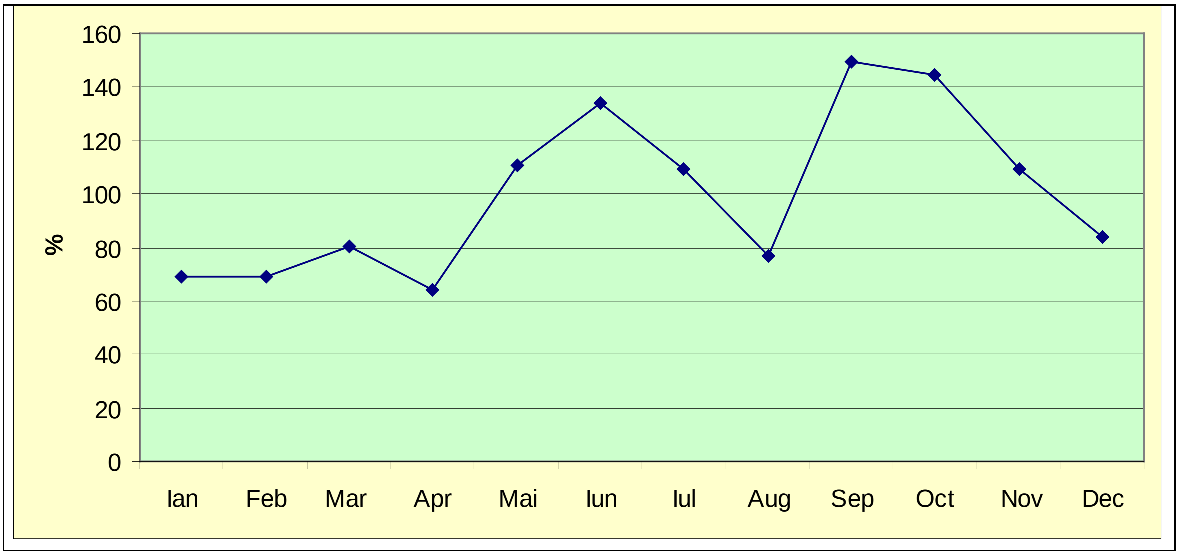

Fig. 3. Seasonal index for water consumption at VWS.

The following figure illustrates the seasonal index for the wastewater treatment station at VIROMET.

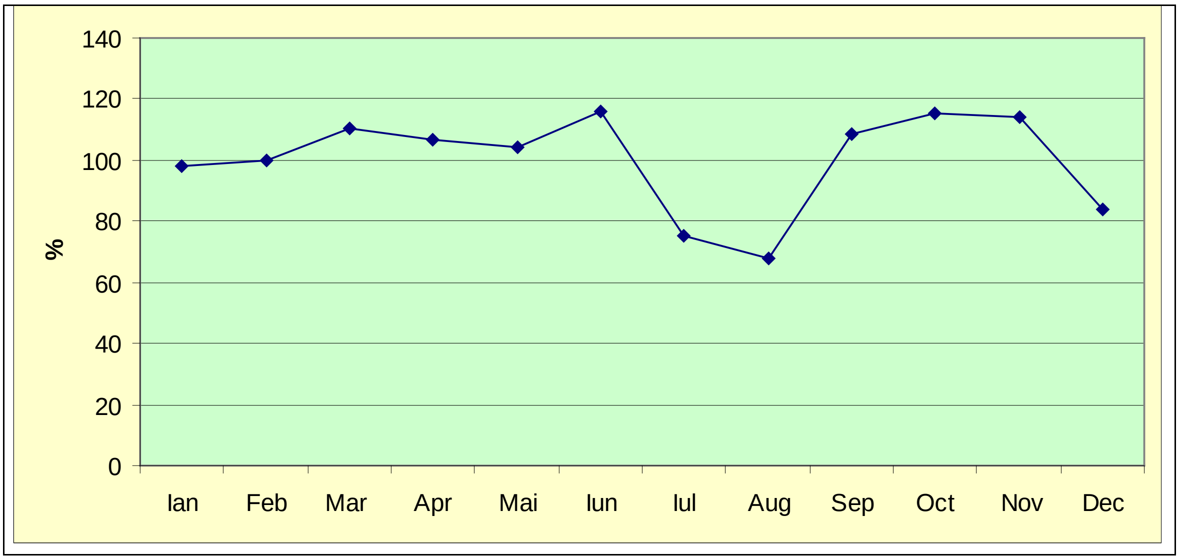

Fig. 4. Seasonal index for the wastewater reaching the treatment plant at VIROMET.

The following table illustrates the accuracy of the predictions.

Data used for devising the seasonal index (2007-2010) are used for predicting wastewater quantities in the first half of 2011.

Table 3. Accuracy of seasonal index prediction method

Month	Water effectively entering the treatment station, m^3	Values obtained by extrapolation, using seasonal indexes, m^3	Difference, m^3	Relative error, %
Jan 2011	105,672	114,091.00	-8,419	-7.38
Feb	107,696	113,637.00	-5,941	-5.23
Mar	118,487	124,225.00	-5,738	-4.62
Apr	114,587	121,675.00	-7,088	-5.83
May	112,175	122,339.00	-10,164	-8.31
Jun	124,466	121,953.00	2,513	2.06
TOTAL	683,082	717,920	-34,838	-4.85

As it can be seen, errors are well under 10%!

Conclusions

Extended studies were performed at and around a chemical platform for building up an integrated water management system.
The computer optimiztion program is used in various scenarios for production maximization, for water consumption minimization, for increasing the efficiency of teh system
Together with the seasonal index tool for predicting water flows in the system in a span of 3-6 months, the studies led to the generation of q powerful tool for water management. The study may be readily be expanded to include more consumers, more sources, more restrictions. In this way, the Water Framework Directive philosophy will be put in practice, with good results for the industry and communities.

References

1. EU-WFD (2011), http://ec.europa.eu/environment/water/water-framework/index_en.html , retrieved June 19, 2011
2. George B. Dantzig and Mukund N. Thapa. (2003). *Linear Programming 2: Theory and Extensions*. Springer-Verlag, Berlin 2003.
3. Rowais, Sam (2003), http://cs.nyu.edu/~roweis/notes/lm.pdf, retrieved, July 12, 2011