Water Stress Mitigation in the Vit River Basin Based on WEAP and MatLab Simulation

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Abstract

The presented study aims at the development of an approach, which will enable selection of optimal measures for mitigation of water stress. The approach is based on two software pillars – Water Evaluation and Planning System (WEAP) and MatLab, which are applied in combination. The approach has three main steps: 1) modeling of the river basin with WEAP software 2) selecting mitigation measures and preparation of intervention curves and 3) running of an optimization using MatLab to select the mitigation measures. The set of the applied mitigation measures includes: reducing urban water demand and supply, reducing water demand for irrigation, and rehabilitation of the irrigation system. The result of the performed optimization with objectives set as minimal investment and water abstraction shows that in the Vit River basin the best combination of mitigation measures are a change in irrigation practice as well as reducing leakage in the irrigation distribution network and in the municipal distribution network. The optimization results show that 36% of the abstracted water could be saved if 2.1 million EUR were invested. The approach which was developed and applied in this work proved its suitability for facilitating decision making for water stress management at a river basin level.

Keywords: Decision Support System (DSS); Matlab; Mitigation Measures; Optimization; Water Resources Management; Water Stress; WEAP.

1. Introduction

Sustainable water use, aimed at the long-term protection of available water resources is the main objective in a number of policy documents. Particular attention has been paid to the threats of water scarcity and desertification, which have recently cause water stress in many regions of the world and impose challenges to water ecosystems and social and economic activities. The policy requirement is that water stress should be halted or at least significantly reduced [1, 2]. Water stress and its mitigation have been addressed in a number of research studies. Different engineering, economic or participatory approaches have been reported, applied either as a single solution or in a combination [3-5]. In most studies the focus is on measures that are expected to achieve clear economic benefits, so as to minimize the potential damage and threat to water systems, human health, property, infrastructure and economic development [6]. The approach of increasing the capacity and number of intake facilities (like dams) is not seen as a sustainable nor in some cases as a possible solution [7-9].
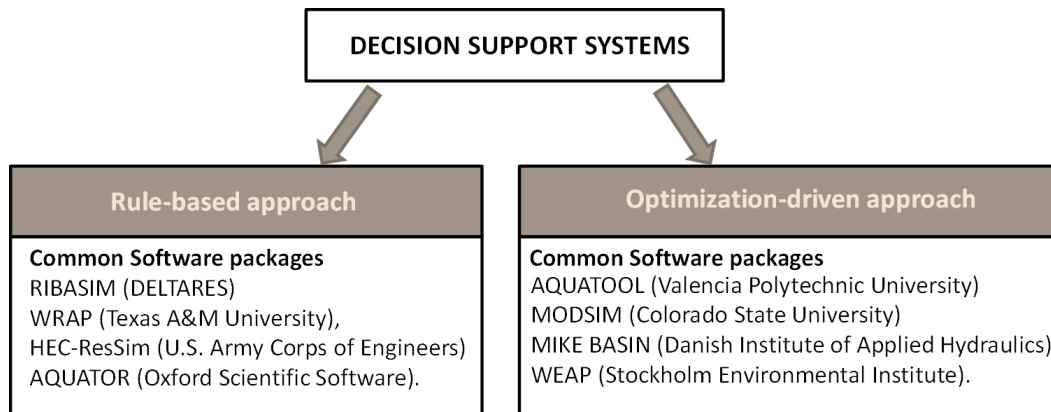
Most of the approaches to water stress mitigation address its complexity, taking into account the spatial and temporal characteristics of the water resources, as well as their important environmental and socio-economic role. In this regard, many studies use Decision Support Systems (DSSs), which allow simulation of the real problem by application of scientific knowledge, rather than thinking about the problem in a holistic manner [10]. According to Matrosov et al. [11] there are two main computational approaches used in a DSS, namely a rule based approach and an optimization-driven approach (Figure 1). The 'rule-based' approach is more suitable for modeling the system operating procedure, while the 'optimization-driven' simulation is suitable for predicting water trading, though the results based on this approach are not easy to replicate in practice.

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          ┌───────────────────────────┐   ┌───────────────────────────────┐
          │    Rule-based approach     │   │  Optimization-driven approach  │
          ├───────────────────────────┤   ├───────────────────────────────┤
          │ Common Software packages   │   │ Common Software packages       │
          │ RIBASIM (DELTARES)         │   │ AQUATOOL (Valencia Polytechnic │
          │ WRAP (Texas A&M University),│  │ University)                    │
          │ HEC-ResSim (U.S. Army Corps │   │ MODSIM (Colorado State         │
          │ of Engineers)              │   │ University)                    │
          │ AQUATOR (Oxford Scientific │   │ MIKE BASIN (Danish Institute of│
          │ Software).                 │   │ Applied Hydraulics)            │
          │                            │   │ WEAP (Stockholm Environmental  │
          │                            │   │ Institute).                    │
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Figure 1. Main computational approaches used in a DSS

There are a number of software packages supporting each of these approaches (Figure 1), though none of them is universally applicable. Sechi and Sulis [12] and Sulis and Sechi [13] carried out a useful comparison between the software packages AQUATOOL, MODSIM, RIBASIM, WARGI-SIM, WEAP and WARGI-SIM (University of Cagliari), simulating multi-reservoir and multi-use water systems. They conclude that the water allocation estimated using optimization models does not always reflect reality and cannot be applied in practice. To overcome such software shortcomings, some authors use a more sophisticated DSS by developing new or using combinations of existing software. Pallottino et al. [14] developed a DSS that performs scenario analysis for water system planning and management under conditions of climatic and hydrological uncertainty. They used identification of trends and essential features as background for robust decision policy. Ke et al. [15] used a DSS based on a linear optimization model with a "top-down" socio-economic mode and a "bottom-up" water quality control and water supply-demand component. Klein et al. [16] describe a DSS for determination of strategies for land management and apply a multi-objective spatial optimization aimed at maximizing agricultural productivity by minimizing environmental impacts including nutrient leaching, soil erosion and water utilization. Panagopoulos at al. [17] reported on the development of a DSS for water stress mitigation in a river basin with cotton fields. The proposed methodology uses a combination of MATLAB and the SWAT model to suggest optimization strategies for minimization of cost, irrigation water consumption and nitrate-nitrogen loads in the Pinios River Basin in Greece.

WEAP software has wide applications for different purposes, like analysis of current and future water demands [18], assessment of water supply–demand [19] or planning and systematic management of water resources [20]. WEAP is the preferred software when water allocation in catchments with urban water users is modeled [21, 22]. This is due to the fact that the model can be built on the basis of user types or spatial location providing different insights. Furthermore, it allows application of scenarios from "what if" type, like "what if urban leakages were reduced" or "what if water demand was increased".

WEAP can act as a standard "COM Automation Server" meaning that other programs through VBA can run and control it – changing data, calculating and exporting results. In this way WEAP can be set to run enormous number of simulations under different conditions whit only one click. Due to these characteristics it is used with other modelling tools, like MODFLOW [23] or Hydro-BID [24]. In our study, WEAP software was applied in combination with optimization module in MatLab. Similar applications have not been found in the literature reviewed.

The objective of this paper is to develop and test an optimization driven DSS for mitigation of the water stress in the Vit watershed in Bulgaria. Given the large volume of information to be processed and multi-disciplinary nature of the problem a combined approach (WEAP plus MatLab) is proposed that allows description of the characteristics of the hydrologic cycle and behavior of all water use sectors in the watershed.

The paper is organized in five sections. This introduction section is followed by Section 2 on research methodology, where the concept of the approach is presented together with description of the test river basin. Section 3 presents the results of the application of the developed approach. Section 4 discusses the results and compares them with similar studies. Finally, Section 5 presents the main conclusions.

2. Research Methodology

2.1. The Concept of the Approach

The combined approach is based on three main steps presented in Figure 2. The first step is modeling the watershed, giving the relationship between water users and the water cycle (WEAP software). The second step is the selection of mitigation measures and the development of intervention curves based on them. The curves are the decision variables in the optimization performed in the third step (MatLab software).
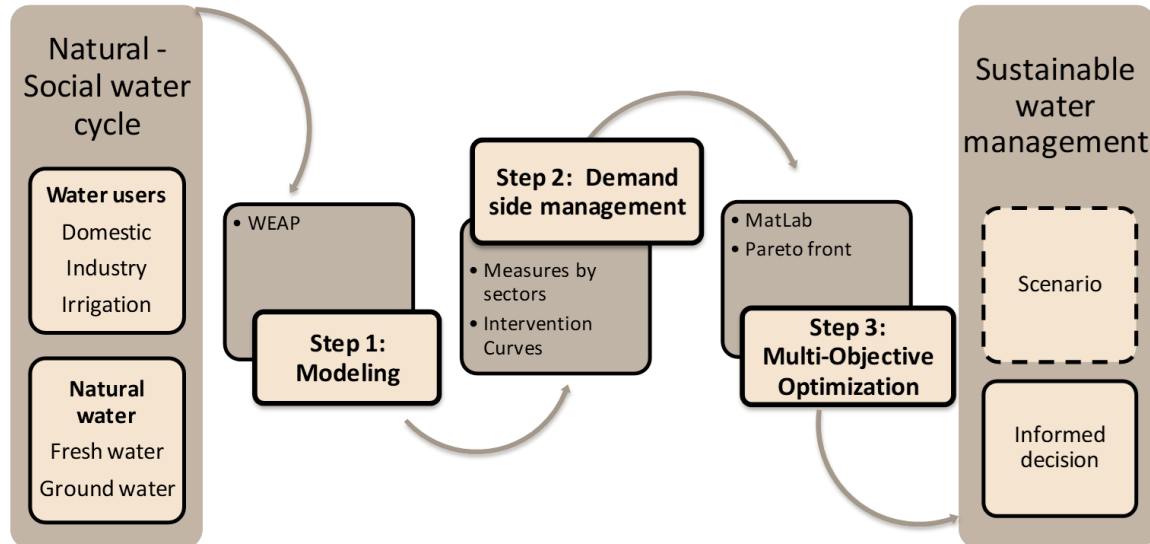

Figure 2. Concept of the DSS approach

The steps are described in detail below:

Step 1: Water Basin Modeling

The modeling describes the physical relationships between water users and natural water resources within the water basin area. The information that is required to run the model includes:

- Hydro meteorological– precipitation and streamflow;
- Irrigation system and irrigation – network, crops, irrigated areas, irrigation type and irrigation efficiency, reservoir and stored volumes;
- Potable water users, water user and used water;
- Industrial users;
- Ground water bodies.

The WEAP model, used in this step, was developed by the Stockholm Environment Institute's U.S. Centre (http://www.weap21.org/). WEAP maintains a water mass balance for every schematic node and link in the system on a monthly time step. In this research the Rainfall Runoff Method (FAO Crop requirement method) was used for hydrological modeling. The method determines evapotranspiration for irrigated and rain fed crops using crop coefficients. The remaining rainfall, not consumed by evapotranspiration, is proportioned among runoff to a river and flow to groundwater through via water basin interconnection links. The components of the systems are rainfall runoff, base flow, groundwater recharge, sectoral demand analyses, water conservation, allocation priorities, reservoir operations, hydropower generation and ecosystem requirements.

Step 2: Mitigation Measures

This step deals with demand side management – the water utilization in different sectors, the established shortcomings and opportunities for more efficient water use. The analysis develops, for a selection of mitigation measures, the corresponding intervention curves. In this study intervention curves are interpreted as the charts which represent the relationship between the cost and the effect of a water stress mitigation measure. The curves can be created for a single measure or for a group of measures. If the chosen measure is not affected by other measures it can be used to develop an intervention curve (e.g. reconstruction of water towers to reduce leaks). When measures mutually influence one another and/or have some technological sequence in their implementation, either for technical reasons or based on expert assessment, then they form a compound intervention curve (e.g. reduction in physical losses from a distribution network). For example, pressure management may be applied to a water distribution network,

followed by active leakage control (ALC). In this case a repair is made under ALC while the pressure in the network is maintained in an appropriate range to reduce the risk of new leakages in the pipework.

Step 3: Optimization

The goals of multi-objective optimization, carried out using evolutionary algorithms, are to find a set of solutions (called individuals) which lie on and are diverse enough to represent the entire range of the Pareto-optimal front [25]. The process runs multiple times; each time the best available solution from the previous run (generation) is used to create new generation, while the space of possible solutions is searched in detail. Searching is multidirectional, as it creates a population of potential solutions. The calculations continue until the best generation and introduced Pareto Front is reached (Figure 3).
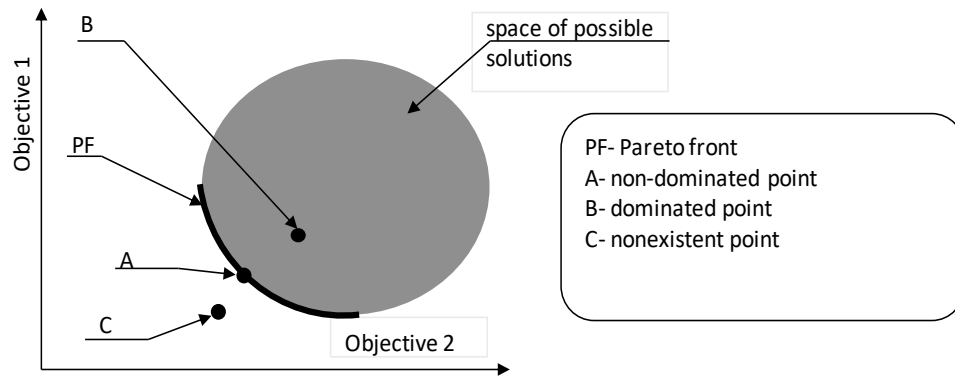

Figure 3. Pareto front with multi-objective optimization

The evolutionary algorithm NSGA-II was applied in this study, one of the five recommended for use in multi-objective genetic algorithm problems by the state-of-the-art overview by Van Veldhuizen and Lamont [26]. It is a fast and efficient multi-objective algorithm specifically designed to reduce computational complexity.

2.1. Combination of WEAP and MatLab

WEAP and MatLab were applied together in order to perform optimization. Both packages provide connectivity with other programs. WEAP can operate as an automatic server (COM Automation Server), so that other programs can manage and change parameters in it. Bespoke code handing the interaction between the two programs was developed in MatLab, using the COM-API module available in WEAP21. This interaction makes possible the bi-directional cooperation of both programs and makes possible the use of MatLab toolboxes.

Figure 4 shows the rationale of the simulation-optimization of programming code, summarized in the form of a flow chart. The main loop of the iterative process begins with the transformation of variables to an appropriate format readable by WEAP21, then opening the connection to WEAP through COM-API. WEAP21 reads the variables and calculates the results, which are then exported. The exported results are read by MatLab and the objective functions are calculated.
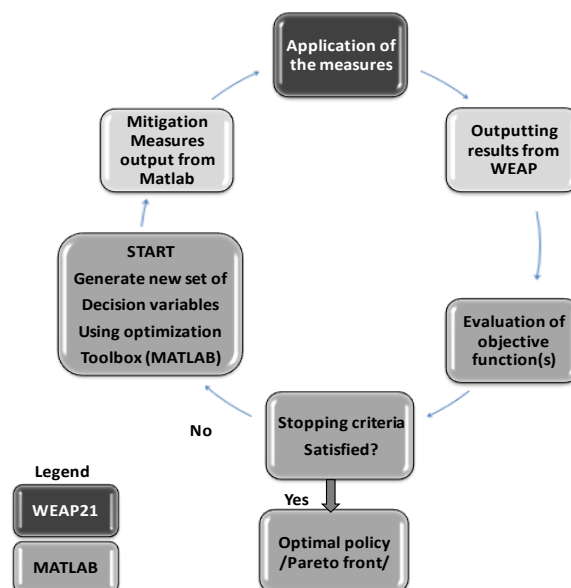

Figure 4. Flow Chart describing the methodology used for optimization
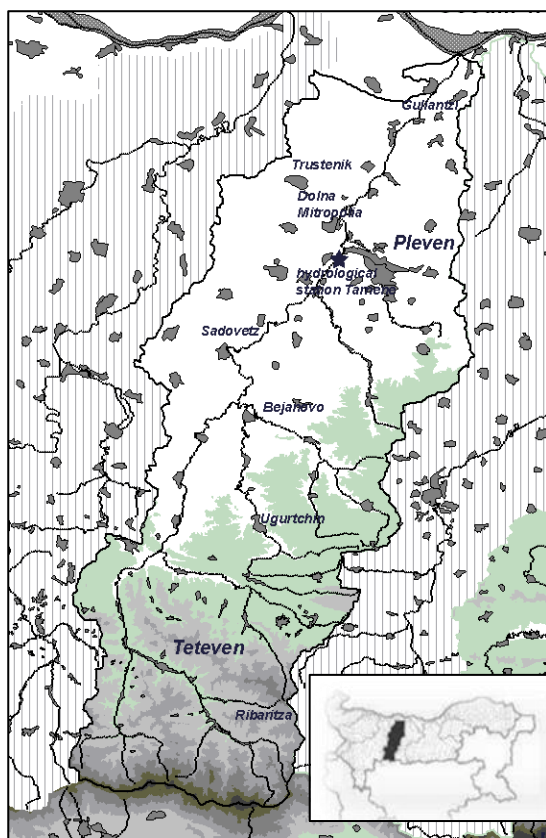
2.2. Test River Basin

The Vit River is a tributary of the Danube and runs through the central northern part of Bulgaria. The river is 189 km long with a catchment area of 3220 km² and an average altitude of 400 m (Figure 5a). The runoff has two maxima – a larger in March-May and a secondary, usually smaller one in October-November. Runoff is lowest at the end of summer (August-September), though some peaks can occur during this period due to storm rainfall. The average flow at the town of Teteven, situated less than 18 km from the source, is about 4.34 m³/s or (137 million m³/a) distributed over the year with 40% during the spring high flow period, 40 % during the autumn high flow period, and 20% over the remainder of the year [27].

The Vit catchment has a variety of water users unevenly distributed over the basin. There are 5 towns and 72 villages in the catchment, and the river is used for irrigation, recreation activities, industrial needs and household use. The irrigation network, in addition to providing irrigation water, is also used to transfer water for power plants and industrial water supply. Droughts are common in the region, and in severe cases impact on agriculture, industry, and the everyday life of citizens. Because the river cannot always meet demand, ground water, smaller streams and water transferred from neighboring basins are used as supplementary sources of water abstraction.
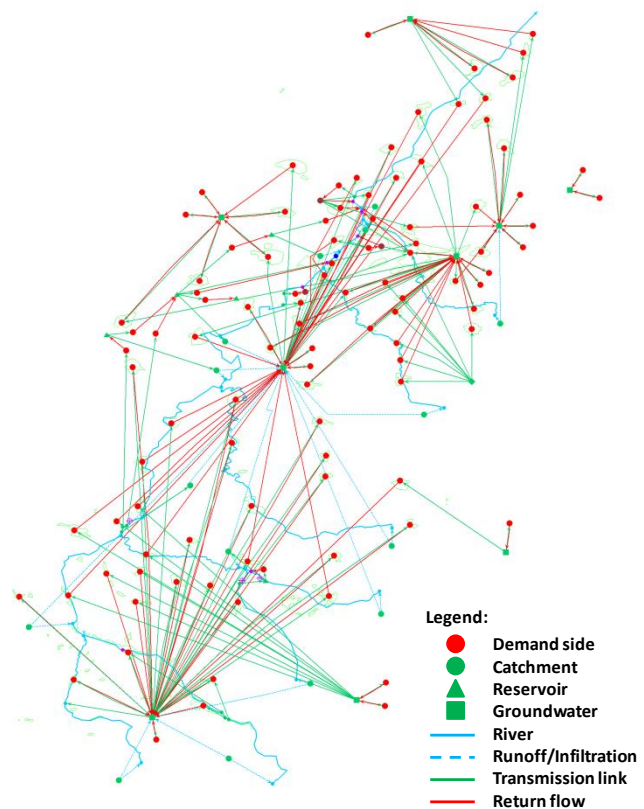
3. Results

3.1. Step 1: Modeling of the Catchment and Water Use

WEAP software was used to model the complicated Vit basin (15 sub-basins, 77 settlements, 8 groundwater bodies, 5 reservoirs, flow requirements and others). The catchment was initially processed by identifying: (1) the users - a unique node for each was created and (2) the physical links (i.e. water main trunks, irrigation channels, etc.) among them (Figure 5b).

| a) Geographical map (the small map presents location of Vit basin in Bulgaria) [28]. | b) Modelled scheme of the catchment of the Vit River, visualizing its complexity. |

Figure 5. Vit River basin

The years 2009 and 2011 were selected for the modeling, and the necessary data assembled. The year 2009 was used for calibration as a relatively "normal" hydrological year with annual rainfall of 676 mm (the value for the previous multi-annual period 1971-2008 is 645 mm). The year 2011 was used for validation, being a relatively dry year with 501 mm annual rainfall.

The calibration and validation are based on two components:

- Comparison between the streamflow calculated by the model and the values observed at the last gauged stations;

- Comparison between the simulated and stored volumes in the three largest reservoirs.

For the two years modelled, data on rainfall events, water use of different industrial users and settlements, agricultural land, irrigated areas, type of crops and types of irrigation, reservoir store volumes and streamflow were collected. Depending on their nature and availability, some data were monthly, others daily. The calculation step was a month.

The simulated and the measured values showed good correlation at an annual time scale. In the last hydrometric station, the difference between the simulated and the observed flows was 3% for the year 2009 (model calibration) and 1.8% for the year 2011 (model verification). The water volumes for the three largest reservoirs were in the range 0.45-6.0% for the year 2009 and 1.5-13.3% for the year 2011. Tsanov [29] provides further modelling details.

3.2. Step 2: Intervention Curves

Agriculture and potable water supply are the key water users in the Vit River basin. The preliminary rough analysis has shown that there is significant potential for water saving, through such investment as the replacement leaking pipes and irrigation channels, modernization of the irrigation system, and optimization of the potable water supply system. For this reason, intervention curves (i.e. cost-effective curves for water saving measures) have been set.

Urban Intervention Curves

Water saving measures have been considered for the town of Pleven, the largest town in the catchment, with a population of over 110 000. Pleven accounts for 70% of the total potable water needs in the basin. Two interventions to reduce the supplied potable water have been investigated:

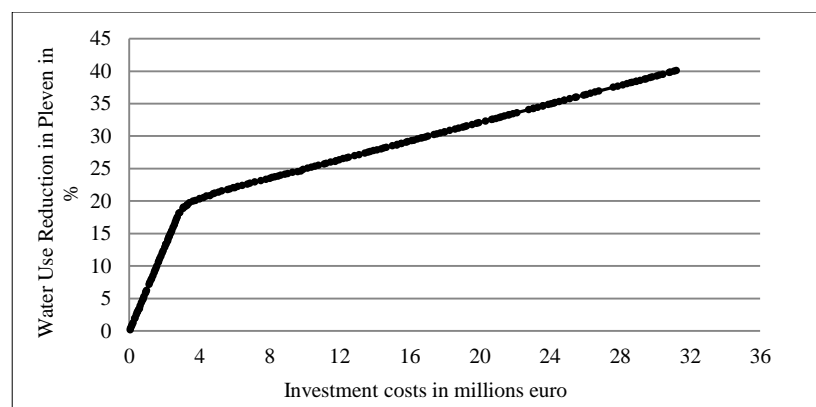*Intervention curve 1: Reducing urban water demand (UD parameter):*

To reduce urban water demand without lowering the level of provision, the use of modern water appliances has been considered by implementing two levels of retrofitting [30]:

- ***First Level Retrofitting (FLR)*** can be achieved by changing to more efficient showerheads (12 to 8 l/min) and more efficient taps (12 to 10 l/min). This can lead to a roughly 20-25% cost saving.

- ***Second Level Retrofitting (SLR)*** can be achieved by fixture changes such as water-efficient toilets (3/6 l dual flush), smaller baths and more efficient white goods (this is a marginal part of the saving, with high variability in cost saving). With such changes around 35-45% of water savings can be achieved as compared to the base case.

A MatLab model was created and optimization was performed to generate the urban water demand cost-effective curves. Two clusters of households (H1 and H2) were used in MatLab. The clusters are not predefined. Their number corresponds to the number of the measures applied (two in this case, FLR and SLR). During the optimization different sets of measures (***FLR*** or ***SLR***) are applied for each cluster. Although H1 and H2 vary at each calculation step, their sum always equals the total number of the households. The total number of decision variables in this optimization is six, as shown in Figure 6a. Figure 6b shows the relationship between the two objectives, the cost-effective curve and total investment cost. MatLab provides an additional table (not shown) with all optimization results for all six variables. The first part of the plotted line (with the steeper gradient) corresponds to the measure FLR, while the second part corresponds to the SLR.
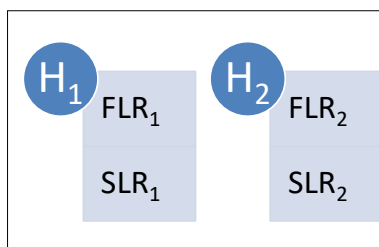
| a) Decision variables (H-households, FLR, SLR) | b) Cost-effective curves of water demand reducing measures for the town of Pleven (result of optimization with MatLab). |

**Figure 6. Optimization for UD parameter**

Figure 6 shows that First Level Retrofitting (FLR) achieves "faster" water saving, i.e. for relatively small invested money, the water saving potential is higher than for the measures from the SLR.

Intervention curve 2: Reducing urban water supply (UL parameter):

Non-revenue water losses in Pleven are around 53% in 2009 most of which are physical water losses. Three measures have been studied for achieving cost-effective reduction of physical losses, ranked by priority as: 1) Installation of Pressure Reducing Valves (PRV); 2) ALC measures and 3) Replacement of old pipework.

Pressure management is regarded as the first priority measure to reduce the losses of water through both detectable and undetectable leakages [31]. The practical experience in Bulgaria based on more than 40 settlements, in which 105 pressure regulators were installed, showed that this measure had reduced the leakages in the corresponding zones by 15-40% [32]. In this study a conservative leakage reduction of 10% is assumed because the measure will be applied to the whole town (Figure 7). The next priority is implementation of ALC measures in 4 steps for one year (37, 54, 65 and 72%). The application of the ALC in four steps for one year is based on the methodology, developed by Kalinkov et.al [33]. The four steps are considered since if fifth step was applied, the costs (for finding and repairing of the leakages) will be higher than the benefits (money saved). The first set of ALC measures is applied in the first month and reduces leakages with 30%. Considering that 10% of the initial losses has already been reduced by pressure management, this portion of 30% reduction will mean 30% of 90% (left losses) or 27%. So, the next critical dot in the intervention curve is 37% (10%+27%=37%). This measure has effect during the entire period of 12 months. The next set of ALC measures reduces leakages with another 30%, but it will be applied in the second moth, i.e. will have effect during 11 months. It means that the contribution of this set of ALC measures will be 30% out of 63% left (100%-37%) with coefficient 11/12 (11 months out of 12) or 17%. So, the next critical dot will be 37%+17%=54%. The logic behind determination of the last two critical dots 65% and 72% is similar.

Leak identification and repair will result in less water lost from the network and greater water pressure in the pipework. Assuming the first step has been already executed, pressure can be maintained at desired values so as to prevent an increase, with the risk of new leaks appearing. The third step is to replace old pipework (82%). Figure 7 presents the resulting compound cost-effective curve, which is developed based on expert estimation (i.e. mathematical optimization is not applied).
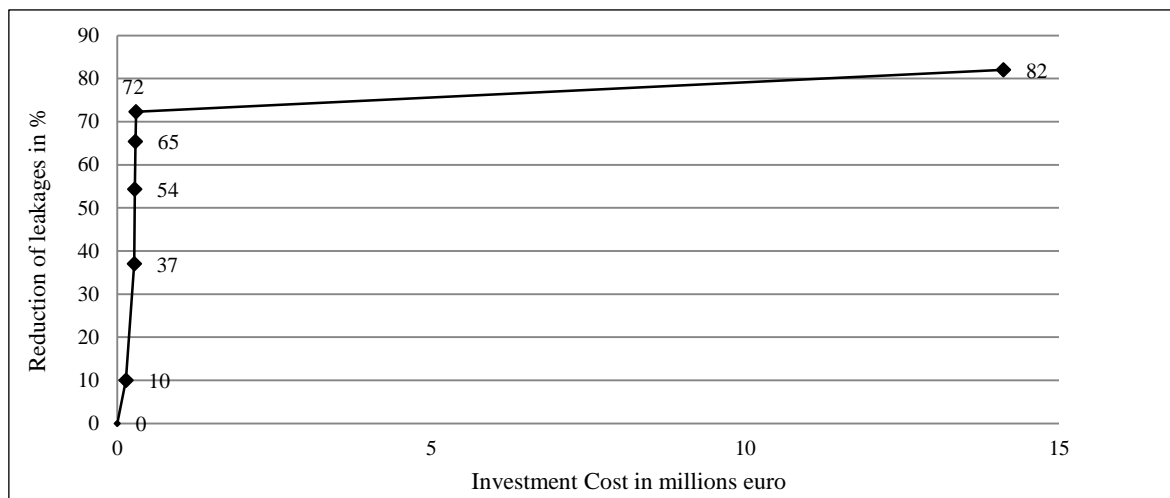
Figure 7. Compound cost-effective curve for water supply reducing measures

Irrigation Intervention Curves

The agricultural area in the Vit basin needing irrigation is 190.35 ha, unevenly distributed across the catchment. The main crops are vegetables/strawberries (129.34 ha), maize/sunflower (28.295 ha), melons (25.375 ha) and other fruit (0.54 ha). Irrigation is mostly by a sprinkler and furrow system with scope for significant improvement. Based on the information from the irrigation company for each crop area and type of irrigation, the overall irrigation efficiency was calculated as 76 % for the year 2009.

Two intervention curves have been analyzed for the reduction of irrigation water use.

Intervention curve 3: Reducing water demand for irrigation (AD parameter):

The cost-effective curve for irrigation estimates the optimum trade-off between three irrigation methods (drip, sprinkler and furrow) for the four main crops (vegetables/strawberries, maize/sunflower, melon and fruit). The approach is schematically described in Figure 8. Z1 to Z12 are the areas irrigated by a particular method. Z1 to Z3 are

areas, in which vegetables/strawberries are grown. Z4 to Z6 are areas, in which maize/sunflower are grown. Z7 to Z9 are areas, in which melons are grown. Z10 to Z12 are areas, in which fruits are grown. The initial values of Z1 to Z12 are the actual values in 2009 - the area with its corresponding irrigation method (drip, sprinkler or furrow). Each arrow in Figure 8 represents the decision variable that transfers an area from one irrigation method to another, and has different effectiveness and a different cost. The transfers included are only those which could improve efficiency (e.g. the case of moving from drip irrigation to sprinkler irrigation has not been considered), as presented in Figure 8.
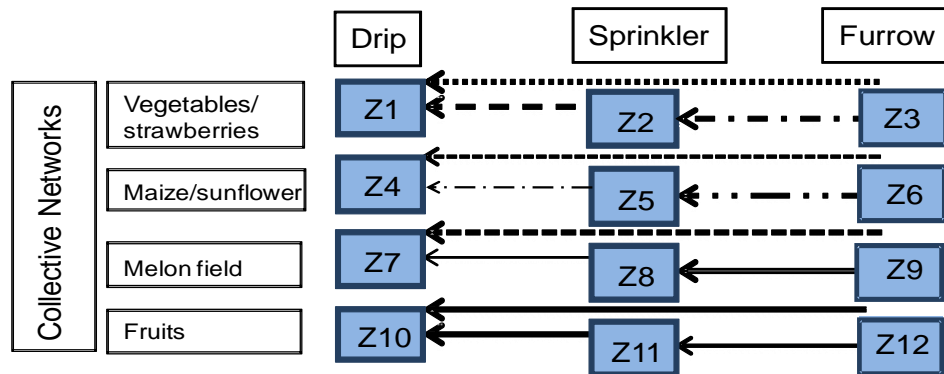
Figure 8. Schematic representation of optimization of cost-effectiveness

The area of wetted land could be reduced to as little as 30% by applying drip irrigation [34]. In this case study the wetted land is assumed to be 50% of the irrigated field, based on an irrigated area parameter of 50% of the irrigated field.

Figure 9 presents the cost-effective curve for irrigation efficiency and the corresponding relationship between equivalent irrigated area and irrigation efficiency. The „equivalent irrigated area" is the portion of the land with the crops, which gets wetted. Drip irrigation method has higher efficiency, because it smaller area gest wetted than, for example, the irrigation method with furrows. The results shown in Figure 9 were generated with the MatLab model, based on the concept, presented in Figure 8. The investment costs are based on executed projects in Bulgaria.
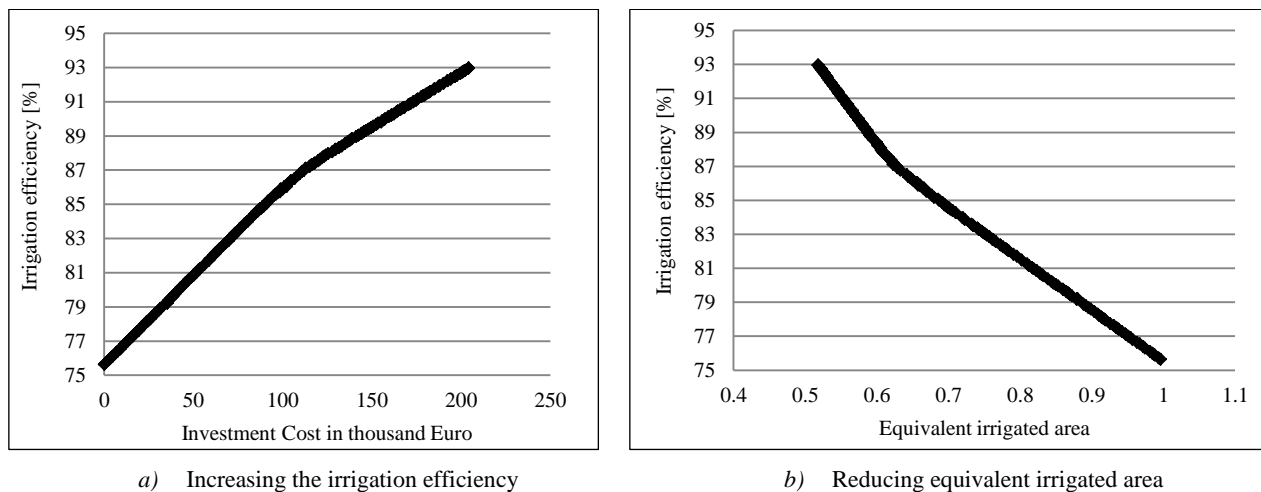
a)   Increasing the irrigation efficiency   *b)*   Reducing equivalent irrigated area

Figure 9. Cost-effective curves for reduction of irrigation water demand

Intervention curve 4: Rehabilitation of the irrigation system (AL parameter):

The irrigation network in the Vit basin is in poor condition with respect to its design functionality. Not all pumping stations function and the design (including trace) of the existing channels has been modified over time to deliver water by gravity. It is therefore very difficult to make an up-to-date evaluation of the investment needed to replace open channels with closed channels or pipes without carrying out a feasibility study outside the scope of this study. The necessary investment costs for reducing water losses from leakages in the irrigation system are based on expert evaluation by the company operating the irrigation system.

3.3. Step 3: Multi-objective Optimization

The cost-effective (intervention) curves have defined specific measures and the extent of their recommended application for the respective main water users within the Vit River basin. The purpose of the multi-objective optimization is to find measures which will minimize the optimization objectives at the scale of the river basin. In this

case each of these four cost-effective curves (CEC) shown in Figures 6b, 7 and 9 became a decision variable (i.e. 4 in total). The population size (number of individuals in generation) was set to 15 times the number of variables (the default optimal value in MatLab,), giving a total population size of 60. A larger population size results in a smoother Pareto front, though at the expense of longer computational time. Although the population size could be changed, the default value in MatLab of 15×number of variables provided good feedback in this study.

Figure 10 shows the optimization results (Pareto front) where the objective functions are cost and water abstraction minimization. The default situation (state in 2009) with zero investment cost corresponds to water abstraction equal to 143 million m^3. With relatively low investments (up to 2.1 million EUR) the corresponding amount of abstracted water could be reduced to 91.29 million m^3 (indicated as a red dot in Figure 10), resulting in a saving of 52 million m^3 or 36 % of the initial volume of the abstracted water. Figure 11 shows how the value of 91.29 m^3 could be reached.

The effect of further measures (Figure 10) is insignificant – from 91.29 million m^3 to 88 million m^3 abstracted water, achieved only with a significant increase in the investment costs (46 million EUR).

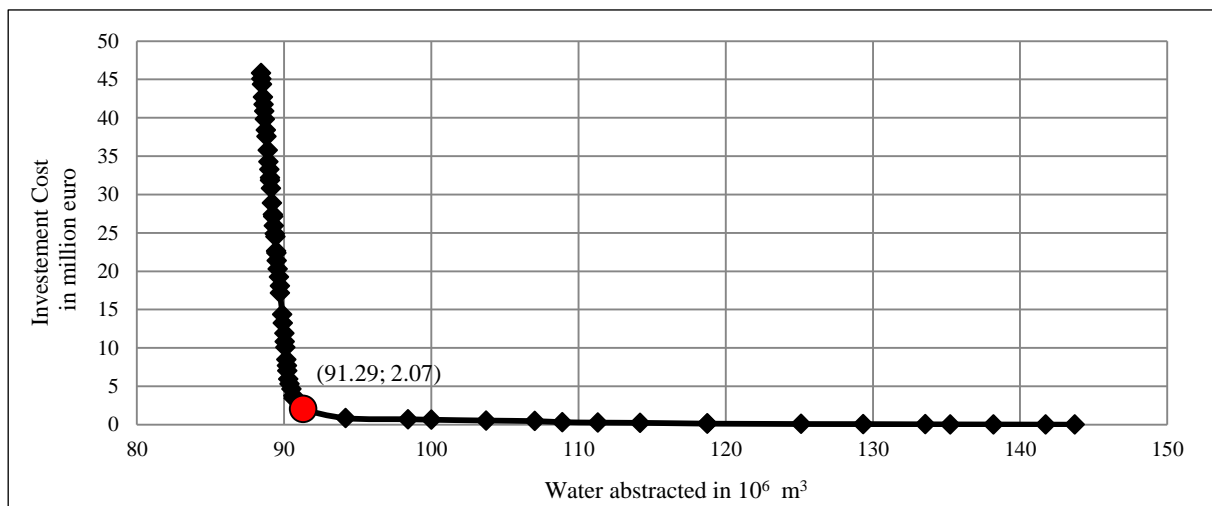**Figure 10. Pareto front of optimization of the Vit River basin for 2009**

Figure 11 provides additional information on how the value of 91.29 m^3 is reached through the four types of interventions. Figure 11 was developed on the basis of data, derived with the MatLab simulations. The figure shows that total the value of 91.29 m^3 abstracted water is due to 92,94% saved water through measure AD plus 72,20% saved water through measure UL plus 29,07% saved water through measure AL and 6,21% saved water through measure UD.
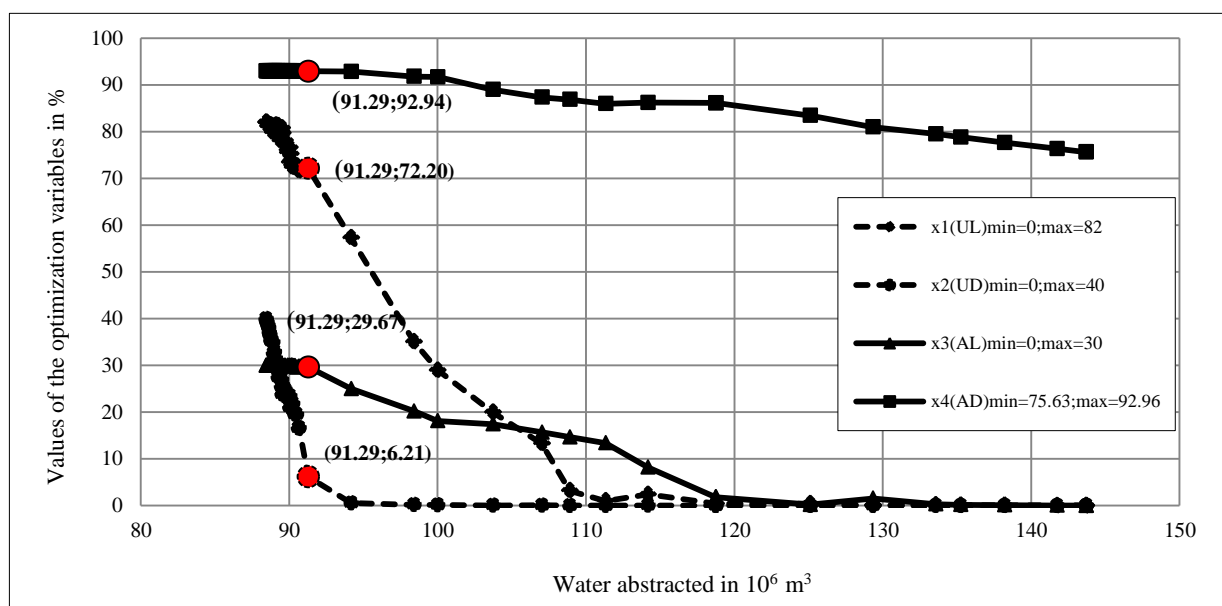

Figure 11. Values of the optimization variables for water abstracted in 2009
(UL - urban leakages, UD - urban demand, AL -agricultural leakages and AD - agricultural demand)

Table 1 shows which measures should be applied to reach the required % of reduction of the abstracted water.

Table 1. Optimal percent of decision variables and corresponding optimal measures

Parameter	UL%	UD %	AL %	AD %
Optimal value of variable	72.2	6.21	29.67	92.94
Corresponding measures	Pressure management; ALC	First level retrofitting FLR	Rehabilitation of the irrigation channels	Drip irrigation

According to Figure 10 (the red dot) and the corresponding value in Figure 11 (the red dot) and as shown in Table 1, the optimal percent for the set of measures associated with the UL parameter is 72.2. Figure 7 reveals that this reduction of leakages could be achieved by two measures "Pressure management" and ALC (as explained in the text above Figure 7).

Similarly, the optimal percent for the set of measures associated with the UD parameter is 6.21% which according to Figure 6b means that FLR should be partially applied. The optimal percent for the set of measures associated with the parameter AL is 29.67% which is practically the maximum value for that measure (30%, Table 1).

Finally, the optimal percent for the set of measures associated with the parameter AD is 92.94% which according to Figure 9 means that for all types of crop the irrigation should be changed to drip irrigation. Ineffective measures for the Vit River basin are replacement of old pipes and second level retrofitting in Pleven.

4. Discussion

The approach applied in this work was inspired by the work of Panagopoulos at al. [17], who applied a combination of MatLab and SWAT modeling to estimate optimal agricultural strategies for minimization of cost. In the more complicated case of the Vit River basin (with urban water use as well as agricultural water use) MatLab was combined with the WEAP modeling software. The application to the Vit River basin revealed that this modelling combination is possible and provides meaningful results. Connecting WEAP with MatLab allows application of a powerful optimization algorithm which considers the water needs of all the users and the natural conditions within the river basin and thus allows the application of the optimization measures in practice.

The SWAT model was replaced by WEAP model in this study, because: i) WEAP has a proven record of successful application in a variety of case studies including irrigation [35], steep mountainous regions with a contribution from glaciers [36], transferring water from well-endowed to more deficient areas [37], coastal zones [38] and ii) WEAP can be applied to model not only a variety of natural river basin systems but also economic based (municipal, urban and agricultural) systems, which was a critical requirement in our case.

Table 2. The use of the WEAP model has been widely reported in a number of recent studies

Catchment area, km^2	Application for urban water supply	Application for irrigation	Application for combination of water uses	Additional tools	Reference
1524		√		Combination between MODFLOW and WEAP	[23]
821.5	√	√	√	Hydro-BID and WEAP	[24]
8303	√	√	√		[18]
5460	√				[21]
991.6	√	√	√		[19]
43853	√	√	√		[40]
1306	√	√	√		[20]
	√				[22]
3220	√	√	√	MatLab	Our study

Despite the complexity or size of each catchment, all studies were able to successfully model the water availability and use. In our case study, WEAP model was successfully applied as well. However, our modelling process raised some specific issues with regard to urban water. WEAP considers the water losses in the urban network as a percent of the used water. This leads to incorrect conclusions when measures for reducing water use in households are applied, because the water losses are automatically reduced. To solve this issue, a second group of user was added (i.e virtual users), whose water use was equal to the water losses. After that the calculation of water consumption was also changed in order to reflect only the actual users. This issue was not identified in the reviewed papers.

In two of the reviewed recent studies, shown in the table above, WEAP was applied with another simulation tool. None of them combined WEAP with optimization tool, what our study does. At the optimization stage, our study showed that the limitation of NSGA-II algorithm used in MatLab to a maximum of three objectives was not a practical constraint, because for the Vit River basin only two objectives were defined, namely "investment cost" and "water abstracted". For cases with a greater number of optimization objectives, some model adjustments would be required. The computational time however may be a critical factor. From a computational perspective, with three objectives and a population of 200 individuals around 10% of the population is non-dominant but with ten objectives these percentages increase to up to 90%. Because of this, there is no room for new individuals to be introduced into the generation [25]. This means that a larger population would be needed and this would increase the computational time. Another problem is that the larger number of objectives would need a large-dimensional Pareto front which may be difficult for a decision maker. They are various techniques to tackle this problem. For example, only a part of the Pareto front could be investigated and redundant objectivities could be eliminated [25] or scalarizing functions and modification of Pareto dominance could be used. There are also different ways of representing the solutions, for example by reducing the objective space [39].

An important issue associated with any modeling work is the uncertainty in the results. For the Vit River basin, there are many factors, such as climate change (precipitation amount), demand patterns, changes in land use (including irrigated area and crop types) which could affect the mitigation measures and optimization results. The WEAP model was calibrated and verified for a relatively "normal" rainfall year and a relatively "dry" year. The simulated and measured values were close, providing confidence in having a reliable model of the catchment. Nevertheless, the optimization was done with data for the "normal" year 2009, so that all the results on optimal mitigation measures are based on the precondition of having "normal" climate conditions. To address the possible changes of the conditions (climate, demand patterns, etc.), a range of scenarios have been analysed and will be the subject of a forthcoming paper. Creation and analysis of scenarios is seen as a good alternative to the traditional stochastic approach often used to deal with uncertainty [14].

From a practical point of view, the optimization showed that the most effective measures for the Vit River basin are: rehabilitation of the irrigation system, reducing urban water supply through PRV and ALC measures and reducing water demand for irrigation through changing practice to drip irrigation. The message to the water company and the irrigation company should be to focus their efforts on reducing physical losses from their networks, while the farmer should be encouraged to adopt more efficient irrigation practices.

Another aspect of the suggested methodology is its applicability and usefulness as a DSS for water management at river catchment scale. The current management practice in the Vit catchment is not based on a DSS. The Ministry of Environment and Water issues long-term and monthly permits for water abstraction quota. For dry years, the water abstraction permits observe the following priorities: household, health care, irrigation, others (including industry) as stipulated in article 50 (4) of the Bulgarian Water Law. In international practice, sustainability of the abstraction rates over long term are assesses by the Water Exploitation Index (WEI), established by the European Environmental Agency. WEI is defined as "the mean annual total abstraction of fresh water divided by the long-term average freshwater resources". Water stressed is a region with a WEI between 20% and 40%. Although widely accepted, this indicator does not fully describe the level of the stress, because: i) "the total fresh water abstraction does not distinguish between abstracted water that is redirected after use (and after appropriate treatment) back to the water body or if it is used for irrigation purposes with inevitable evaporation" and ii) it is based on annual data and cannot account for seasonal variations in water availability and abstraction (http://ec.europa.eu/eurostat). The WEAP platform allows for a deeper analysis, calculating two indicators: 1) Unmet demand (the difference between the available resources and the demand in the corresponding month) and 2) Demand Site reliability (the % of satisfaction of the water demand). For the Vit River basin, in the year 2009 ("normal" in terms of rainfall) there is no water shortage. However, in year 2011 ("dry" in terms of rainfall) some months were identified as critical for some of the settlements. Figure 12 shows the results for the largest town, Pleven.
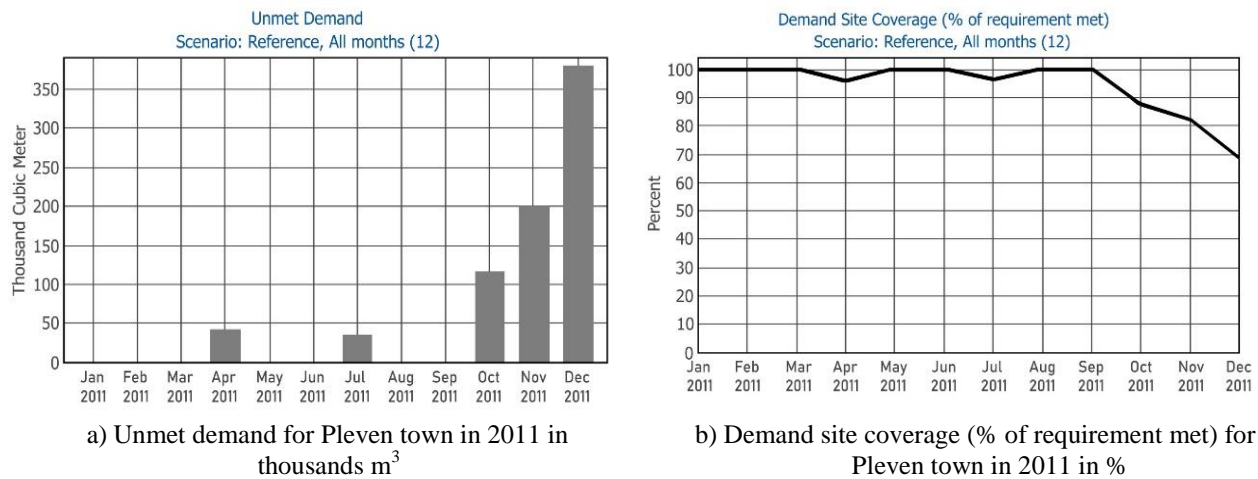
| a) Unmet demand for Pleven town in 2011 in thousands m³ | b) Demand site coverage (% of requirement met) for Pleven town in 2011 in % |

Figure 12. WEAP results for water shortage in Pleven town in 2011

The WEAP simulated results show that in 2011 there were five months in which the demand in Pleven exceeded the available water resources (April, July, October to December) (Figure 12a). The highest unmet demand was in December accounting for about 30% water shortage (Figure 12b). In reality, these months were managed by the water operator through regular cut offs of potable water. The calculations show that if the suggested optimization measures were applied, these unmet demands will disappear. This example demonstrates the power of the suggested methodology as a DSS. It is applicable not only for past periods (as studied here), but also for forecasting purposes (subject of incoming paper).

5. Conclusions

The methodology which was developed and applied in this work proved its suitability for facilitating decision making for water stress management at a river basin level. The most important findings in this respect are presented below:

- The WEAP modeling platform allows monthly identification of unmet water demand which enables the responsible institutions to plan ahead appropriate management measures.

- The optimization results for the Vit basin case study show that 36% of the abstracted water could be saved if 2.1 million EUR were invested. The greatest effect is achieved by a change in irrigation practice, followed by reducing the leakages in the irrigation distribution network and reducing the leakages in the municipal distribution network through PRV and ALC measures. The lowest effect is achieved by installing water saving appliances in domestic properties.

With regard to modeling and optimization knowledge, the most important finding emerging form this study are:

- The generation of reliable curves relating costs to water savings requires an extensive data base on the target object (water distribution network, irrigation system, etc.), on the effect of each measure, as well as up-to-date information on the operation, management and investment costs;

- When more than one measure is relevant for the same object (e.g water supply network, irrigation water network, etc.), depending on the mutual interrelations between the effects of these measures, two approaches are possible: 1) when the effects of the measures are interrelated, they should be prioritized by expert judgment; 2) if the application of one of the measures does not influence the effect of the application of the others, then MatLab global optimization, which incorporates the NSGA-II multi-objective algorithm is a useful tool for performing the prioritization analyses.

6. Funding

7. Conflicts of Interest

The authors declare no conflict of interest.

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