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Integrated modelling of a new dam: a case study from the "HELP" Mesta/Nestos River

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Abstract: New important dam projects and multipurpose water reservoirs are important parts of water resources management at the river basin scale in order to satisfy water needs in different sectors, such as hydroelectricity, water supply and agriculture. In an era of open market economy, investments for new dam projects are no longer covered by state budgets; so they need to attract private investment and thus should be able to demonstrate economic reliability and beneficial returns during their lifetime (usually 50 years).

Apart from economic considerations, water managers should also apply the main principles of integrated water resources management at the river catchment scale, which are included in new regulations for environmental protection, public participation and social equity. For example, the European Union Water Framework Directive (EU-WFD) stipulates that water resources management should combine economic issues together with technical reliability in order to meet environmental and social objectives.

In this paper, an integrated model for a new dam project which allows these objectives to be met is described. The model was applied in the case of the "Temenos" dam located in the Greek part of the transboundary river Mesta/Nestos. The basin covers 6,218 km^2 and is almost equally divided between Bulgaria and Greece. It flows from the North, where the headwaters are located in the Rila and Pirin mountains of Bulgaria, to the South East, where the river ends in a delta situated on the coast of the Aegean sea in Northern Greece. Currently, two hydroelectric power plants are located in the mountainous part of the Nestos basin in Greece: the Thissavros plant, with a reservoir capacity of 565 millions m^3, and further downstream the Platanovryssi dam, with a reservoir capacity of 11 millions m^3. Both dams were designed to operate in pump-storage mode for electricity generation. The future Temenos project is planned to be financed exclusively by private funds. Situated downstream of the other two dams, it is designed for electricity production, irrigation regulation and should contribute to increasing the total amount of power produced by the existing complex.

The integrated model of the Temenos project is based (1) on the MODSUR distributed hydrological model, (2) the HEC-ResSim tool for reservoir simulation, (3) the CLM regional climate model from the Max Planck Institute for Meteorology, Germany, and (4) the use of a special purpose economic tool based on the NPV (Net Present Value) rule.

Different climate scenarios were generated and used for testing the viability of the Temenos project, together with transboundary assumptions based on the execution of the flow treaty between Bulgaria and Greece on the sharing of the Mesta-Nestos waters. The economic rule has been extended to include the merging of economic elements (energy and water selling prices) with social benefits (compensation to farmers in case of lack of water) and the value of the environment (costs for restoration of good water status in case of failure to preserve a minimum environmental flow). It is argued that this integrated approach offers water managers and stakeholders a useful evaluation of the sustainability of water projects.

Keywords: *Integrated Water Resources Management (IWRM), hydrological modelling, climate change, dam project, environmental and social costs, Mesta/Nestos River.*

1. INTRODUCTION

UNESCO, in cooperation with the World Meteorological Organisation (WMO), initiated in 1999 under the International Hydrological Programme (IHP) a crosscutting programme named “HELP”: Hydrology for Environment, Life and Policy (http://www.unesco.org/water/ihp/help, Accessed 24 March 2009). The main aim of the programme was to promote the concept of Integrated Water Resources Management (IWRM) through a worldwide network of river basins, where the application of scientific approaches could be tested in depth in order to satisfy the needs of different socio-economic environments. After the pilot phase of the project (1999-2004) its operational phase (2004-2008) followed, during which the Mesta/Nestos transboundary river catchment joined the HELP network as a demonstration river basin. A strong bilateral and multinational cooperation between partners in the river basin has promoted the application of innovative scientific methodologies, such as advanced hydrological modelling, remote sensing, GIS, groundwater exploration and alternative conflict resolution techniques. For the third phase of HELP (2008-2013) emphasis has been placed on developing integrated modelling tools by aggregating technical, environmental, economic and social issues. The integration of these issues is crucial in order to apply the European Union Water Framework Directive (EU-WFD; EC Directive, 2000) in the river basin, where competing water uses are ever increasing, since Greece has built a series of hydro-electrical plants and Bulgaria now struggles for rapid economic growth in a market economy.

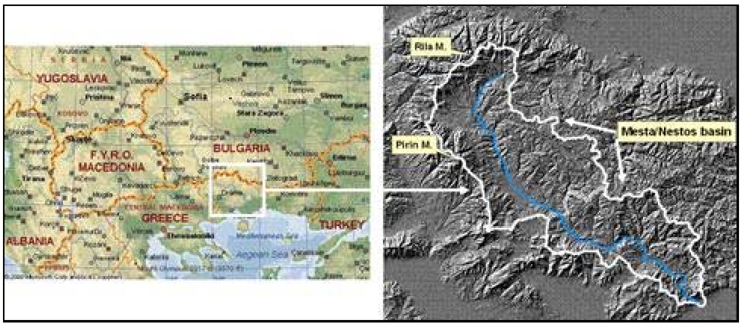

Figure 1 - Geographical location of the Mesta/Nestos river basin.

As shown in Figure 1, the Mesta/Nestos River basin is located in the Balkan peninsula, in South Eastern Europe and is shared between Bulgaria and Greece. The river flows some 255 km and its catchment area covers 6,218 km^2, of which 2,863 km^2 (46%) belong to Greece. From 1965-1990 the estimated mean runoff of the river was 20-30 m^3/s, the maximum discharge was rarely above 150 m^3/s, the minimum flow was often lower than 10 m^3/s and the annual discharge was 1,120 M m^3 (Moutafis, 1991; PPC/DAYE, 1994). The morphology of the area is mainly mountainous, except for the river delta area. Various recreational activities including skiing are of importance, mainly in the upper part of the river (Pirin and Rila mountains). Agriculture activities dominate the delta area and two large dams (Thissavros and Platanovrissi) are in operation in the Greek part for producing hydroelectricity and storing water for irrigation. In this paper the question of building a new dam (Temenos) is investigated by modelling the environmental and social costs of scenarios aiming to satisfy the conflicting demands for energy production and agricultural irrigation.

2. THE MODSUR HYDROLOGICAL MODEL

MODSUR is a distributed hydrological model, developed at the Ecole Nationale Supérieure des Mines de Paris (Ledoux et al., 1989) in order to simulate the spatial and temporal evolution of a river and the water table flows.

The model is based on a dense spatial grid (Figure 2) made of variably sized square cells. Characteristics of the surface domain (runoff directions, altitude, soil and land-use) are attached to each cell. The grid topology is based on the so-called 4 neighbours rule (4-connectivity). Each cell may only be connected to cells of the same dimension, or cells which are four times larger or four times smaller (Skoulikaris, 2009). The surface water is transferred through the runoff network or networks to the catchment outlet. The ensemble of connected cells builds a runoff network, which directs the flow down to the catchment outlet.

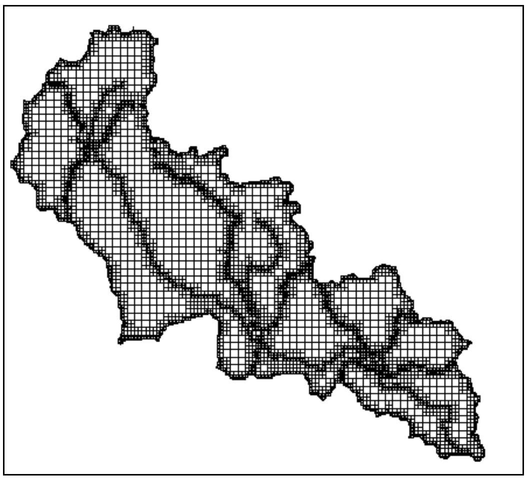

Figure 2 - Topology of the MODSUR grid in the Mesta/Nestos river basin.

A more advanced version known as MODSUR-NEIGE had to be used in order to account for the snow cover regime of the Rila and Pirin mountains of Bulgaria at the head of the basin.

From the past flow measurement sequences acquired at Temenos in the upper Nestos watershed over 30 years from 1966 until 1996 it appears that the maximum monthly flow ranges from 40 m^3/sec during dry years up to 200 m3/sec in exceptional precipitation conditions. Maximum flow happens during the spring with some rare peak events in the fall on the Mediterranean side of the basin. The minimum monthly flow is observed in late summer with average value of 6 m^3/sec with an exceptionally low flow of 1 m^3/sec observed in September 1994. The MODSUR-NEIGE has been calibrated form the period July 1991 until December 1995 which was the only period during which a uniform set of precipitation measurements were publicly available over both Bulgaria and Greece. The overall discrepancies between model and observations at the Temenos station show a bias of 0.25 m^3/sec and a standard deviation of 8 m^3/sec. Special care was applied to the fitting of low summer flows as these periods are essential to maintain sufficient irrigation. For the summer low flow periods the standard deviation is reduced to 1 m^3/sec. As the project was more interested in irrigation demand than flooding conditions, the higher standard deviation experienced during the other flow periods was taken as satisfactory.

3. EFFECT OF CLIMATE CHANGE

As far as climate change is concerned, various scenarios developed by the Intergovernmental Panel of Climate Change (IPCC) and published in the Special Report on Emissions Scenarios (SRES) revealed great climatic variations at a global scale (IPCC, 2001). More specifically, according to the output of the General Circulation Models (GCM) the average global surface temperature is predicted to increase by 1.4°C to 5.8°C from 1990 to 2100. Temperature increases will also result in an increased evaporation rate and precipitation fluctuations. Consequently, one of the sectors influenced by variations in climate is that of renewable technology, which relies completely on climate conditions. Moreover, the largest impact may be on hydropower generation as it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (Harrison et al. 2002).

In this study a regional climate model known as CLM has been used. The Climate version of the “Local Model” (CLM), is a non hydrostatic European region climate model which can be used for simulations on time scales up to centuries and spatial resolutions between 1 and 50 km (Kotlarski et al., 2005). The boundary conditions of the CLM are provided by the simulation results of the coupled atmosphere-ocean global climate model ECHAM5/MPIOM (Jungclaus et al., 2006) at 6 hourly intervals. More specifically, the regional climate model CLM, provides simulations of the SRES scenarios A1B and B1 over the period 2000 to 2100. They are referenced later in the text as CLM-A1B and CLM-B1.

In order to evaluate the impact of climate change by comparison with present climate conditions, artificial climate series were generated. They later referenced in the text as PC-SM which is simple duplication over 50 years of past climate measurements available over 25 years and RF-SM which is an artificial climate series generated by statistical methods in order to represent the “average” past climate conditions. By far, the later provides the most optimistic conditions as it is devoid from the exceptional drought events which have marked the local climate during the late eighties and early seventies. It is however close to the standard engineering practices used in past dam construction evaluation.

4. MODELLING THE NESTOS DAMS COMPLEX WITH THE HEC-RESSIM

The dams’ simulation was conducted using the HEC-ResSim (U.S. Army Corp of Engineers Hydrologic Engineering Center-Reservoir Simulation) tool, by taking into account the outputs of the hydrologic model (USACE, 2003; 2006). The water volume stored in the reservoir, the dam water discharge and the produced electricity was then evaluated for both the Thissavros and Temenos dams. The initial phase of the modelling concerns the tracing of the connected flow elements of the river watercourse between the Greek border and the Toxotes dam, where water is distributed between the irrigation networks and the last stretch of the Nestos down to the delta mouth. Apart from the main course, the modelling also includes the placement of inflow segments gathering the water drained from the various watersheds nourishing the Nestos River (Skoulikaris, 2009). A total of five watershed inflow stations were placed along the Nestos stream and named as follows Border, Thissavros, Platanovryssi, Temenos and Toxotes. All the necessary natural flow series which were fed into HEC-ResSim for each of these points were obtained from the results of the MODSUR basin simulation using the HEC-DSS program as a means of data transfer. Simulated flow at the Thissavros dam (Figure 3) in the case where the full flow of the Mesta waters is transferred to Greece demonstrates the long term effect of climate change scenarios.

Figure 3 - Comparison between CLM-B1 (blue) and CLM-A1B (green) 50 years HEC-ResSim results for the pool level (m) and inflow (cms) entering the Thissavros lake.

5. INTEGRATED MODELLING OF THE TEMENOS DAM PROJECT

In order to evaluate the socio-economic sustainability of the Temenos project, this work took into account the cost of possible “externalities”, both in terms of social and environmental impacts. Economists define externalities as being any loss of value the project might cause outside of its basic activities (Coase, 1960). These externalities classically evaluate the cost of cleaning and remediation when an industrial activity pollutes the environment.

In the present analysis, the externalities which have been considered are the cost of environmental repair if the minimum environmental flow of 6 m^3/s cannot be delivered to the main Nestos stream and compensation to farmers for lost crops if the amount of water available for irrigation is insufficient. On the other end, the activities bringing revenues to the project are the direct sale of electricity produced or the equivalent power value of the water back-pumped in the Platanovryssi pool, as well as the sale to farmers of water for irrigation. Thus, before performing the sustainability evaluation it is necessary to assess various factors influencing key parameters, such as the price of electricity, the value and nature of the crops produced in the irrigated fields and the environmental constraints which need to be met along the Nestos River channel.

5.1. Agricultural activities in the Nestos delta

In order to have a complete view of the current agricultural production in the Nestos delta region, agricultural survey data aggregated by municipality were obtained from the National Statistic Service of Greece for the years 1999-2003. The collected data were stored in the ArcGIS project database and contain the aggregated field areas by town district for the ten main products of the region: soft wheat, durum (hard) wheat, sugar beet, cotton, rice, barley, maize, asparagus, alfalfa and tobacco. These production statistics show a distinct difference in crops and farmer revenues between the irrigated areas on the right (west) bank of the Nestos and the non-irrigated areas on the left (east) bank around the town of Xanthi (Figure 4).

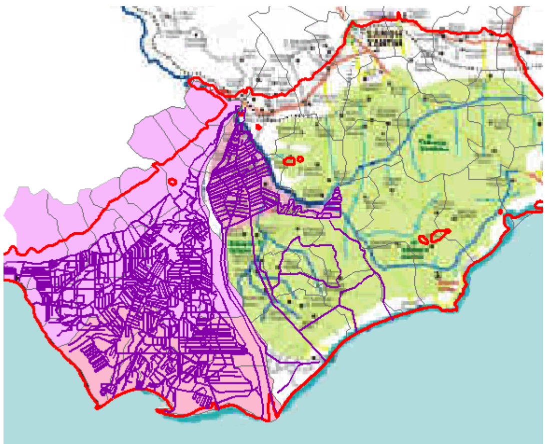

Figure 4 - Irrigation networks at the Nestos River delta.

Evaluation of the income increase between irrigated and dry agriculture has been conducted using the agro-economic model produced by the Common Agricultural Policy for Regional Impact also known as CAPRI model (Heckelei et al., 1999). The model was used in order to determine the average income from the two types of farms (Table 1) for three EU Common Agriculture Policy (CAP) scenarios: the reference conditions of 2001, the Agenda 2000 and the Mid-Term Review (MTR) 2003 measures.

Aggregated revenue terms	**Reference 2001 (in Euros/ha)**	**Agenda 2000 (in Euros/ha)**	**MTR 2003 (in Euros/ha)**
Irrigated	1899	1755	1822
Non-irrigated	908	818	864
Income differential	991	937	958

Table 1 – Evaluation of farm average income for irrigated and non-irrigated areas using the CAPRI system under various EU CAP policy scenarios

The benefits of the Temenos project were evaluated using an expected average income increase (idem, marginal benefit) of 950 Euros/hectare (in Euro value of year 2001) when farms will be irrigated. This number is used in order to evaluate the “Lost Crop” term in the situations when the Temenos irrigation system is unable to provide enough water to the farmers of the Xanthi area

5.2. Valuing the environment

The evaluation is based on the number of days over a year for which a complete loss of ecological flow would be observed in the main stream. The predicted effects on the natural environment are loss of fish and mammal species, a drastic reduction in bird migration, loss of riparian forests including the Nestos Gorge and Kotza Orman, a drastic increase in coastal erosion of the delta mouth and loss of sea fish spawning grounds due to over salinisation. In the long tern there would be side effects on human activities linked to the environment such as an impact on coastal fisheries, a reduction in recreational activities both along the shore, due to the loss of sandy beaches, and inland, in the Nestos Gorges, where rafting would no longer be possible, and the closure of the nature park and related educational activities in the delta.

Environmental economists classify environmental values by the type of human usage (Barbier, 1994). In the Nestos case the first term is the “Direct Use Value” which corresponds to economic activities which can be quantified monetarily, such as fishing, tourism, and rafting. The second term is the “Indirect Use Value” which comes from the indirect benefits such as: nutrient source for species, shallow groundwater recharge to sustain the riparian vegetation, shoreline stabilization. The third is the “Option value” which relates to the future benefits of the today usage such as: education activities in wetlands or future park developments. Finally, the “existence value” is a non usage value which anyone, being a local resident or not, is willing to attach to the very existence of the Nestos River as an historic symbol or as an archetype of one of the few natural wetlands left in the Balkans.

The “Direct Use Value” and the “Indirect Value” have been evaluated in monetary terms using the economic statistics available for the region of Eastern Macedonia and Thrace. The two other terms are not directly accessible and must be estimated by expert panels by surveying the near-by population by questionnaires. Such a survey has been recently conducted in the area (Pavlikakis et al., 2006) and involved a sample of 1600 inhabitants of the Thrace region who expressed a “willingness to pay” an average of 36.15 Euros per person in order to maintain the Nestos Delta natural environmental status (idem, “the existence value”). On the other hand an older environmental study was also conducted in order to evaluate the expected damages (idem, externalities) caused by the operation nuisance caused by Thissavros and Platanovryssi dams along with the impacts of overflowing of their reservoirs (Kollas et al., 2002). In this case, the authors estimated the “Total Environmental Value” loss at 3.7 million Euros per year. In the light of these results the various terms of the environmental value of the Nestos River flow downstream of the Temenos project were estimated in Table 2.

Direct Use Value		**Indirect Use Value**		**Option Value**		**Non Use Value**	
Fishing	2	Birds and mammals	1	Education	0.5	Existence	0.45
Tourism	4	Coastline	2	Parks	0.5		
Rafting	0.5	Forest	2				

Table 2 - Proposed repartition of ecological values for a year of maintained environmental flow in the Nestos (Values in million Euros)

5.3. The discounted cumulative cash flow

The discounted cumulative cash flow (DCCF) over the life cycle of a project is one of the most commonly used tools for project financing evaluation and decision (Bénichou et al., 1996). It can be represented graphically and offer a clear view of when the project’s Net Present Value (NPV) is at its minimum level, following the money draw-down during the construction phase, when it reaches the break-even point, when it starts to be positive and how much it will be at the end of the project.

The project cost is spread among several items which are: CAPEX, OPEX, “Lost Crop” and “Eco Repair”. The capital expenditure (CAPEX) covers the construction of the Temenos dam and its plant including the renewal of the equipment after 25 years. It does not include the investment cost of the irrigation system in the Xanthi plain. The operational expenditure (OPEX) relates to the maintenance of the Temenos plant and the irrigation system of the Xanthi plain. The “Lost Crop” term is the value of the crops lost if irrigation demands are not met and the “Eco Repair” term is the amount of damage done to the environment if the minimal ecological flow is not maintained

The CAPEX and OPEX terms for the Temenos plant are derived from the corresponding terms published by the Public Power Corporation (PPC) in the original tender for the Nestos dam complex in the 1990s. The only change made to the original figures is their conversion from drachmas to Euros (year 2001). Furthermore, the cost of replacing the mechanical equipment (because of wear) after half of the project’s lifetime has been evaluated at 22.5 million Euros. As for the operational expenditures (OPEX), an estimated amount of 100,000 Euros per year is needed to cover the operational needs and salaries. The OPEX part related to the maintenance of the Xanthi irrigation network is covered by the revenue from water sold to farmers in the Xanthi plain. The “Lost Crop” term is evaluated from any water deficit arising from the difference between the demand for water for irrigation and the actual flow sent to the irrigation channels from the Toxotes dam into the Xanthi plain. This last term is extracted from the results of HEC-ResSim. It is expected that in case of loss of irrigation water, the farmers of the Xanthi plain would ultimately revert to their old dry crop practices and would therefore only be compensated for the revenue increase when going from dry crops to irrigated crop (see, Section 5.1). The amount of compensation is evaluated in proportion to the water deficit simulated by HEC-ResSim. “Eco Repair” computation is based on an annual total environmental value of the delta ecosystem at 12 million Euros (see Table 2). The HEC-ResSim model simulates the daily water volume discharged from the Toxotes dam to the river outlet and the sequence of data is extracted in order to define the number of days when a water deficiency occurs, i.e. the discharged water volume is less than the environmental flow of 6 m^3/sec. The yearly “Eco Repair” cost is then computed in proportion to the number of deficit days per year.

6. EVALUATION OF THE TEMENOS PROJECT SUSTAINABILITY

According to the NPV formula the result of incomes minus outgoings is divided by the discount rate which is augmented with time. For the Temenos project, the discount rate R which is tested is the value that was adopted by the MICHANIKI tender report, and is equal to R = 7.35%.

An ad hoc software using Microsoft Excel facilitates the extraction and display (Figure 5) of the yearly sequence of the accumulated NPV of the whole project (DCCF) along with the income from electricity production and agriculture as well as the evolution of the CAPEX. The other DCCF terms may also be extracted from the Microsoft Excel sheet.

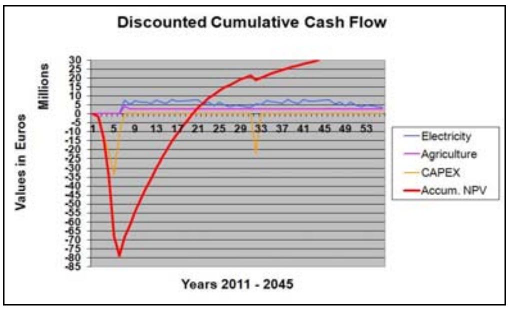

Figure 5 – Time variation of NPV as compared with electricity (in blue) and agriculture (in magenta) benefits and the CAPEX investments (in orange)

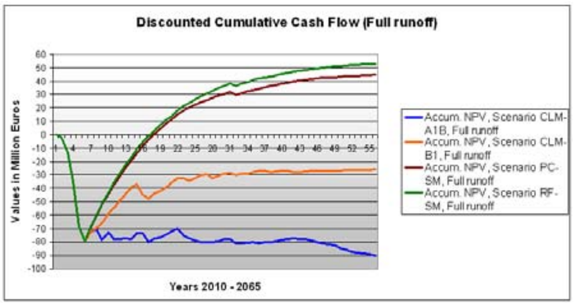

Figure 6 – Comparison between Temenos project NPV evolutions under different climate change IPCC scenarios**.**

When different climate scenarios are taken into account (Figure 6), the results show that under an hypothesis of prolonged present climate (cases PC-SM and RF-SM), the project starts to be profitable after 19 years of operation and finally peak at a return on investment ranging from 45 to 55 millions Euros. However, if climate change scenarios are considered, either IPCC B1 or A1B, the project never reaches profitability over a period of 50 years. It is even diving into an abyssal deficit for the A1B case. In the case of scenario B1, the accumulated deficit is split evenly between the terms of environmental repair, loss of electric production and value of “lost crop”. But in the case of scenario A1B, the “lost crop” value dominates at 60% with 30% for the lost electric power and 10% for the eco-repair. Thus one may consider that the main reason for the lack of sustainability in case of climate change comes from the fact that too much farming crops are lost and that the farmers are repeatedly compensated for these losses year after year.

7. DISCUSSION AND CONCLUSIONS

Overall, the comparison of DCCT curves for all climate scenarios (Figure 6) gives an idea of the range of impacts that these scenarios might have on the sustainability of the project. It is important to note here that the full temporal simulation of all the natural and technical factors (rain, hydrology, hydropower, irrigation, agriculture, ecological flow) is the only way to produce a realistic vision of how the Temenos project might function over its 50 years of life.

In this paper the variability study has been deliberately limited to the factor of climate change. However, the method developed can easily be applied to the study of other factors such as transboundary water flow management, the way the dams are operated, the variation in price of electricity and crop products as well as other irrigation scenarios.

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