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Hydrodynamic Numerical Simulation and Flood Risk Assessment in a Natural River

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***Abstract*—The current research work presents one-dimensional numerical simulation results of water surface elevation along a natural river, in order to investigate an accurate operation of three existing dams, with flat and arched gates, for flood protection. The study reports an extensive numerical simulation procedure of four different operations of the dam gates, including all gates opened, all gates closed, only flat gates opened and only arched gates opened, for flood risk estimation through the studied river reach. The one-dimensional hydrodynamic numerical simulation procedure of water surface profile variation, under steady flow conditions, through the natural river, was performed for available maximum inflow discharges of 5, 25 and 100 year flood period.**

All numerical results are graphically presented and comparisons between different gate operations provide an accurate investigation of a safe dam handling in order to prevent the surrounding river area against flood events. The applied hydrodynamic numerical model, "HEC-RAS" model, is a useful and accurate methodology for flood risk assessment in a natural river area, with complicate geometries and different hydraulic constructions.

***Index Terms*—Hydrodynamic Numerical Simulation, Flood Risk Estimation, Gate Operation**

I. Introduction

In river control engineering works an accurate and reliable quantitative estimation of water surface variation is of paramount importance for a safe river design and flood protection procedure. The foundation of hydraulic constructions along alluvial channels produce a non-uniform flow pattern and underestimation of flow depth may led to flood risk while overestimation provides unnecessary construction cost. Significant advances have been made in numerical simulation models, applied to free-surface flows in natural rivers, as the flow pattern of the aforementioned regions is highly complex. Several numerical simulation methodologies have been developed with the aim of simulation detailed information about the flood extent, flood water depth, how the flow affects several structures and other flood characteristics which are necessary in flood risk management.

Free-surface variation and flood characteristics simulation with flood risk evaluation are often determined using several one-dimensional and two-dimensional hydrodynamic models as Miller and Chaudhry (1989), Bousmar, Scherer and Zech (1998), Horritt and Bates (2002), Farsirotou, Soulis and Dermissis (2002) and Bradford and Sanders (2002). The application of a one-dimensional (1D) or a two-dimensional (2D) hydraulic flood propagation model for flood hazard and risk assessment makes a focus on how well can predict the spatial-dynamic characteristics of floods and how the model results can be transformed into a flood risk assessment. Furthermore, Ahmad and Simonovic (1999) compared free surface variation results on a natural river area using 1D and 2D hydrodynamic modeling approaches. Capart, Eldho, Huang, Young and Zech (2003) developed a one-dimensional finite volume algorithm for the treatment of irregular bathymetry of open channel flow and performed a simulation of a severe flood through a complex river system. Comparison between 1D/1D and 1D/2D Coupled (Sewer/Surface) hydraulic models for urban flood simulation from Leandro, Chen, Djordjevij and Savij (2009) shows that flow over the terrain is better modeled by 2D models, whereas in confined channels 1D models provide a good approximation with less computational effort. Farsirotou, Klonidis and Soulis (2013) performed a three-dimensional numerical simulation of supercritical flow in an expansion channel and Farsirotou and Kotsopoulos (2015) focus on the effect of abrupt changes in river topography on free surface flow variation performing experimental and one-dimensional numerical simulation analysis and the results were satisfactorily compared.

The main purpose of the current research work is to numerical simulate water surface variation along a natural river, with different hydraulic constructions, and to investigate an accurate and safe operation of three dams in the river reach in order to prevent flood risk in the studied area and control the potential risk of flood. Four different scenarios of dam gate openings are numerically simulated and comparisons of free surface flow elevation from each estimation are graphically presented.

A. *One-dimensional water surface numerical simulation*

The Hydrologic Engineering Center's River Analysis System, "HEC-RAS" (2010) numerical model was used in order to perform one-dimensional water surface profile calculations for steady flow through a natural river, Enipeas river reach.

Water surface profiles are computed from one cross section to the next by solving the energy equation to a body of water enclosed by two cross sections at locations 1 and 2, presented in Fig 1., as:

$$Y_2 + Z_2 + \frac{a_2 V_2^3}{2g} = Y_1 + Z_1 + \frac{a_1 V_1^3}{2g} + h_e \qquad (1)$$

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where Y is the water depth at cross sections, Z is the elevation of the main channel inverts, V is the average velocity, α is velocity weighting coefficient, g is the gravitational acceleration and h_e is the energy head loss.

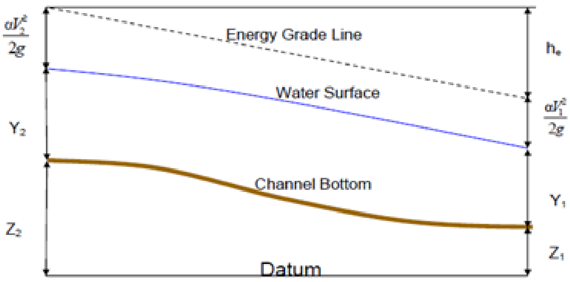


Figure 1: Representation of terms in the energy equation

The energy head loss between two cross sections is comprised of friction losses and contraction and expansion losses as:

$$h_e = LS_f + C\left(\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right) \quad (2)$$

where L is the distance between cross section 1 and 2 along the direction of the flow, S_f is the friction slope between two cross sections, which is computed using Manning's equation as:

$$Q = \frac{1}{n} AR^{2/3} S_f^{1/2} \quad (3)$$

where Q is the flow discharge, n is the Manning roughness coefficient, A is the flow area, R is the hydraulic radius (area/wetted perimeter) and C is expansion or contraction loss coefficient.

The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniform distributed. The approach used in "HEC-RAS" model is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision, as presented in Fig.2. Conveyance is calculated within each subdivision from the form of Manning's equation. The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and the right overbank. The main channel conveyance is normally computed as single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, main channel, and right).

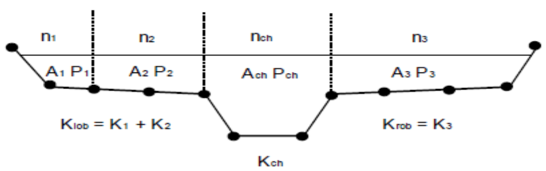


Figure 2. Conveyance subdivision method

The program assumes that a contraction is occurring whenever the velocity head downstream is greater than the velocity head upstream. When the change in river cross section is small and the flow is subcritical, the contraction and expansion coefficient are equal to 0.1 and 0.3, respectively. In more abrupt change, such as these occurring at bridges, the used values are 0.3 and 0.5, respectively.

In the one-dimensional water surface profiles simulation program, only a single water surface and therefore a single mean energy are computed at each cross section. For a given water surface elevation, the mean energy is obtained by computing a flow weighted energy from three subsections of a cross section (left overbank, main channel and a right overbank). Figure 3 shows how the mean energy would be obtained for a cross section with a main channel and only a right overbank area.

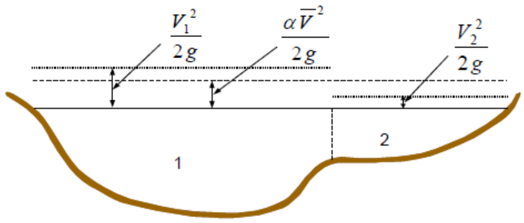


Figure 3. Mean energy numerical simulation

B. *Research area*

Enipeas river is a tributary of Pinios river in Thessaly region in Greece. The total length of the River Enipeas reaches 85 km with a catchment area of 1.140,55 km^2 consisting of 25 sub-basins. The part of the river studied in this project starts from the kilometric position 48+250 to the kilometer position 32+740 and is presented in Fig. 4. The study area is located in a water catchment area of $32km^2$. Along the studied river reach there are three dams. The dams are constructed in locations named "Mega Evudrio", "Purgakia" and "Ypereia" (Fig. 4) for irrigation purposes, as well as for enrichment of the underground aquifer and during flood events are operating with gates and without overtopping. "Mega Evudrio" dam has two arched and five flat gates. "Purgakia" dam has two arched and two flat gates and "Ypereia" dam has two arched and four flat gates. The flat gates are designed to be either completely open or completely closed.

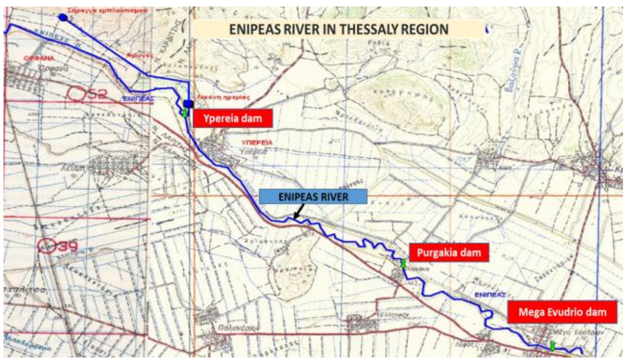


Figure 4: Research area (scale 1:50.000)

The lifting of the gates should be quick and easy to avoid the risk of their stay in flood periods. The height and width of the gate openings are related to technical and economic data for achieving a practical and optimum solution. Such constructions cause serious disturbances in water surface elevation, during flood events, and this is why this study attempts to numerical simulate their operation in order to provide a useful tool for an adequate and validate flood risk assessment.

C. Hydrodynamic conditions

The one-dimensional hydrodynamic numerical simulation of water surface profile variation, under steady flow conditions, through the natural river, Enipeas river reach, was performed for the maximum inflow discharges of 5, 25 and 100 year flood period obtained from YDRETME (1990). Moreover, the one-dimensional analysis, under mixed flow regime conditions, requires both upstream and downstream boundary conditions. For upstream and downstream boundary conditions, the normal depth was used, which is the river bottom slope at the inlet and outlet of Enipeas river reach, respectively. All the necessary hydraulic conditions are given in Table 1.

Table 1. Hydraulic conditions

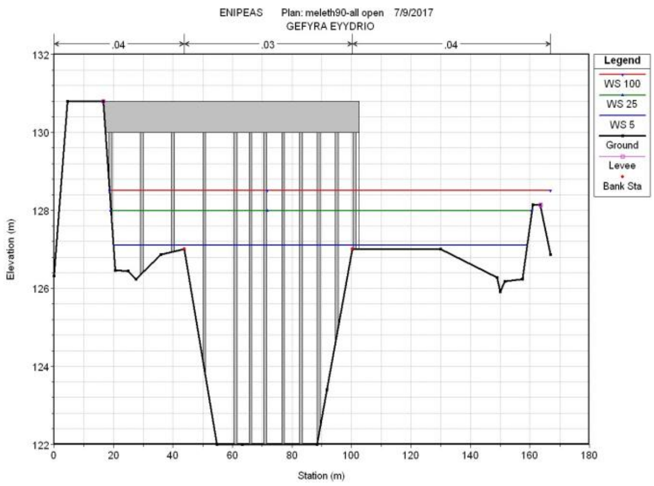
a/a	Flood period (year)	Water inflow discharge (m^3/s)	Upstream normal depth	Downstream normal depth
1	5	632	0.23	0.12
2	25	905	0.23	0.12
3	100	1100	0.23	0.12

For the numerical simulation procedure the Manning roughness coefficient, n, was estimated equal to 0.04 for the left and right overbank areas and equal to 0.03 for the main channel of the Enipeas river reach, for all cross sections.

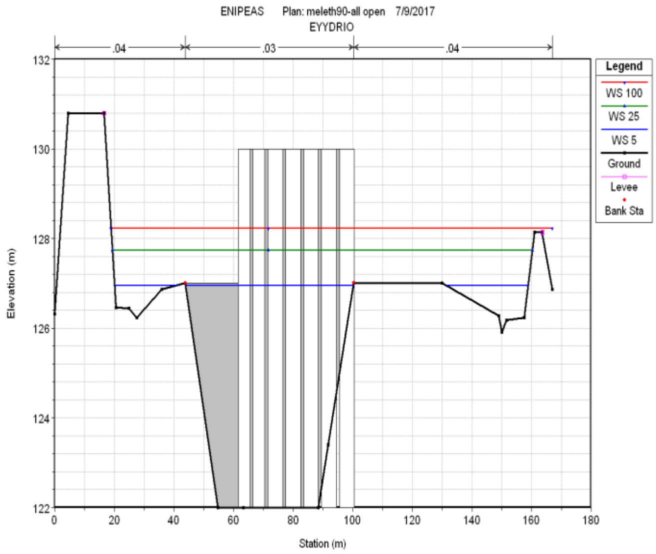
In the one-dimensional hydrodynamic numerical simulation procedure four different operations of the gates are investigated and numerically simulated, including all gates opened, all gates closed, only flat gates opened and only arched gates opened, for the flood risk evaluation through the studied river reach.

II. NUMERICAL SIMULATION RESULTS

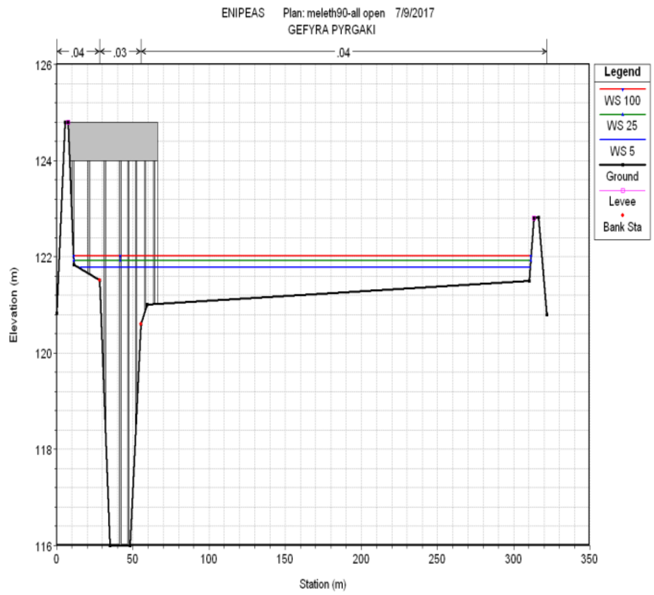
Numerical simulation results of free-surface variation, at six different cross sections, along the natural river Enipeas are given in Fig. 5, for the maximum inflow discharges of 5, 25 and 100 year flood period and for all gates opened. The selected cross sections are the cross sections of the three dams and of the three bridges at the region of each dam, as the main purpose of the current research work is to investigate the optimum operation of the gates for protection against floods. Numerical simulation results of water surface variation, at the same cross sections, along the natural river Enipeas and for the same maximum inflow discharges, for all gates closed, for flat gates opened and for arched gates opened are presented in Figs. 6, 7 and 8, respectively.



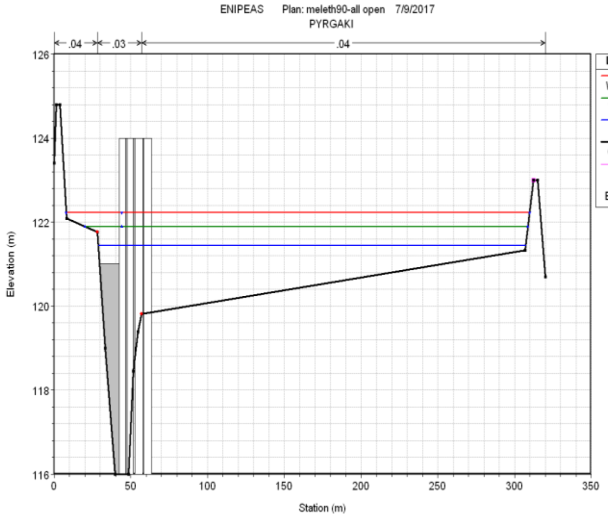
(a) “Mega Evudrio” bridge



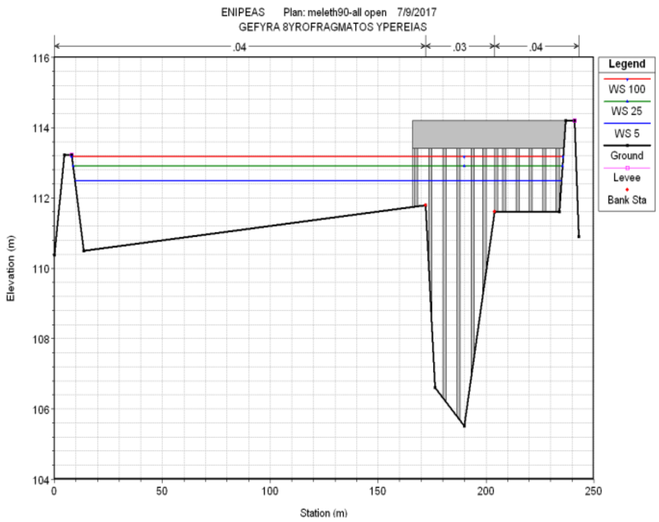
(b) “Mega Evudrio” dam



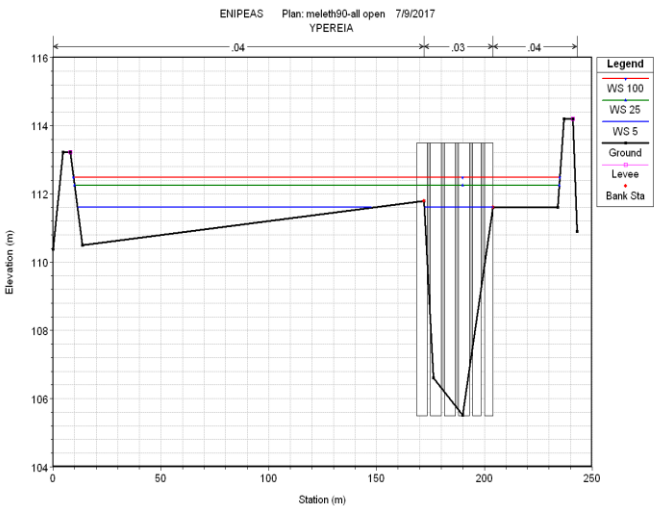
(c) “Purgakia” bridge



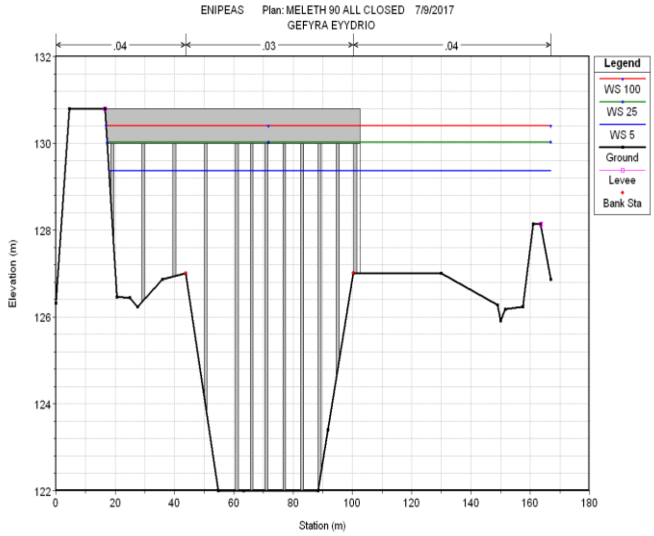
(d) “Purgakia” dam



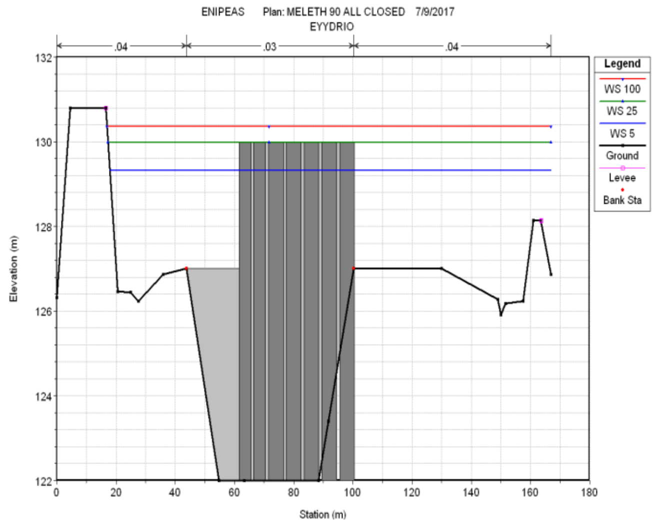
(e) “Ypereia” bridge



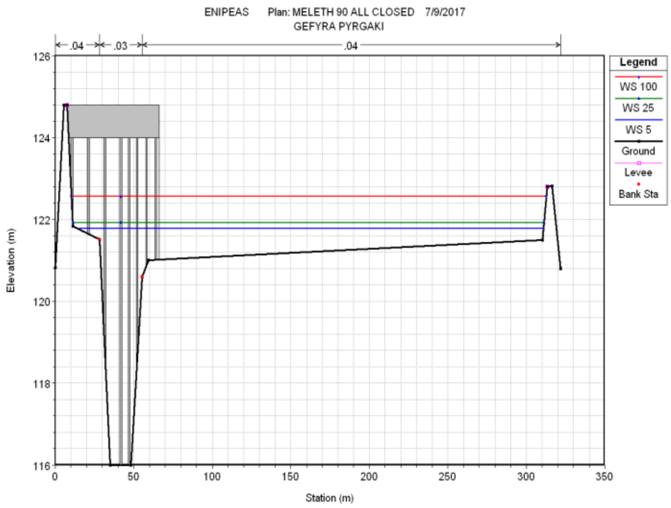
(f) “Ypereia” dam



(a) “Mega Evudrio” bridge

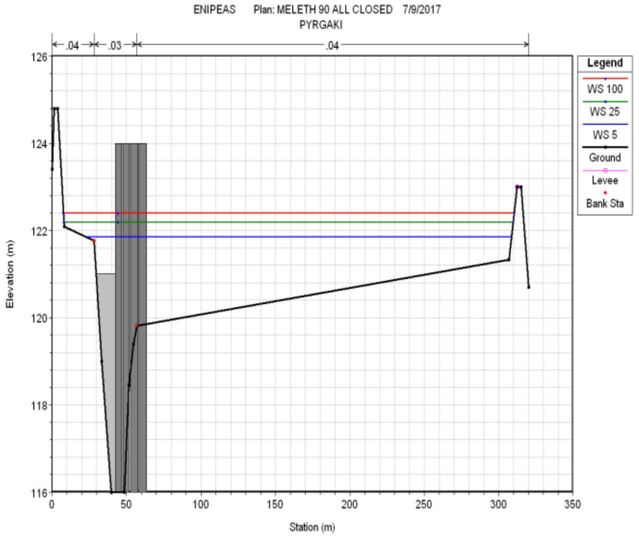


(b) “Mega Evudrio” dam

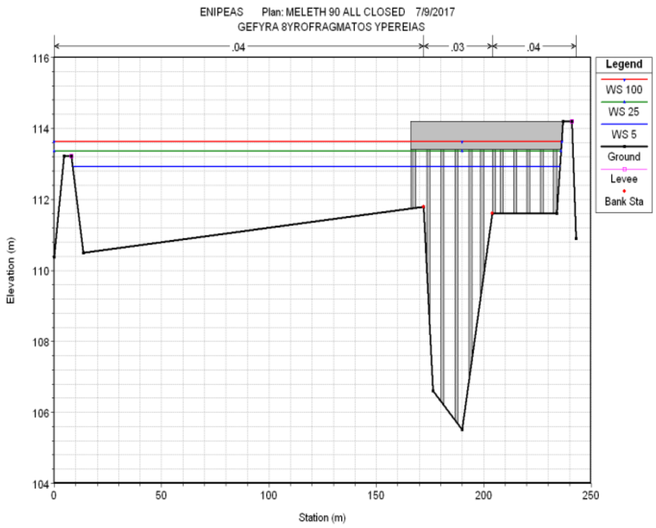


(c) “Purgakia” bridge

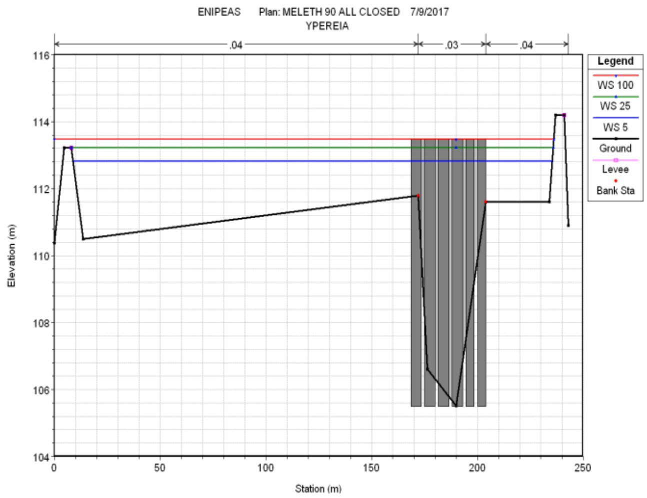
Figure 5: Water surface variation for the operation of all gates opened and for the maximum inflow discharges of 5, 25 and 100 year flood period, at different cross sections



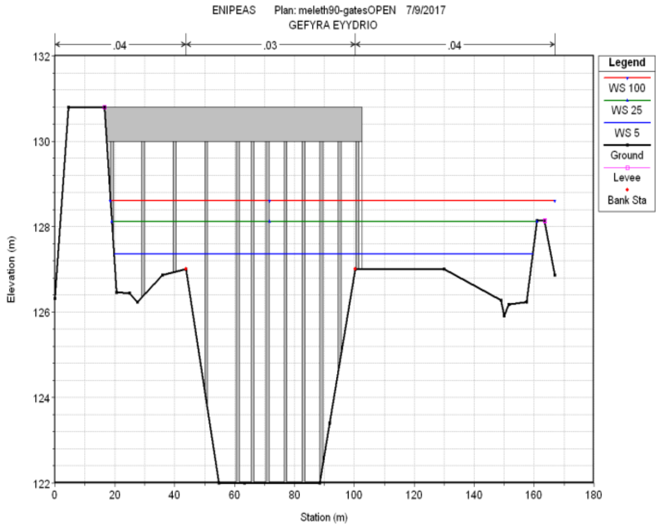
(d) "Purgakia" dam



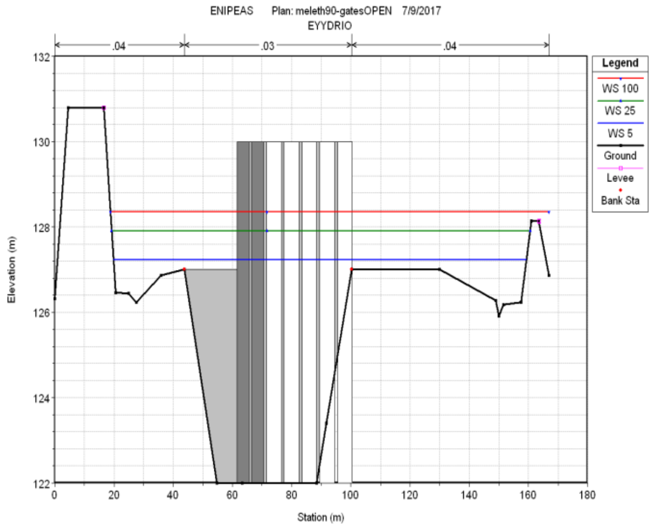
(e) "Ypereia" bridge



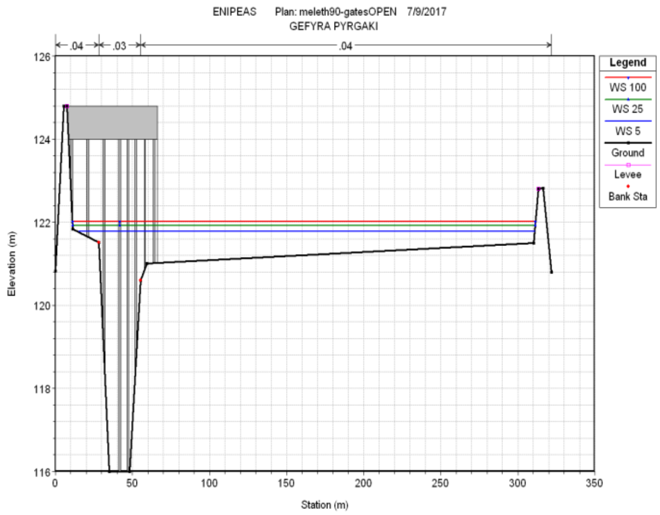
(f) "Ypereia" dam



(a) "Mega Evudrio" bridge

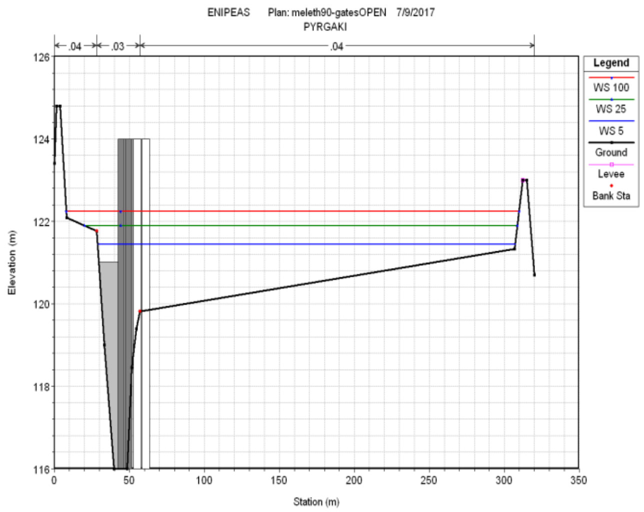


(b) "Mega Evudrio" dam

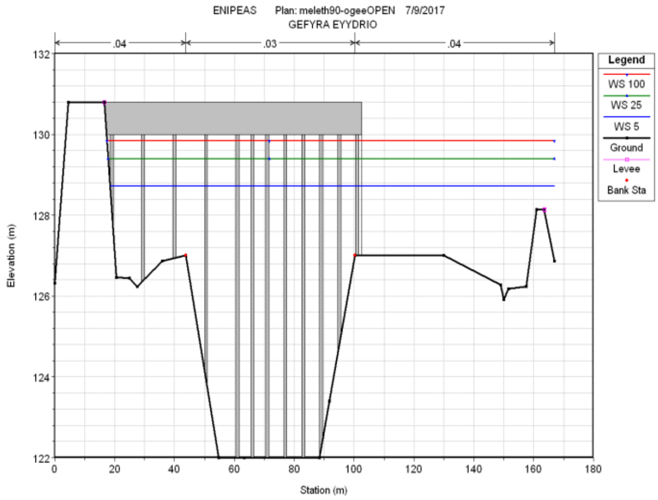


(c) "Purgakia" bridge

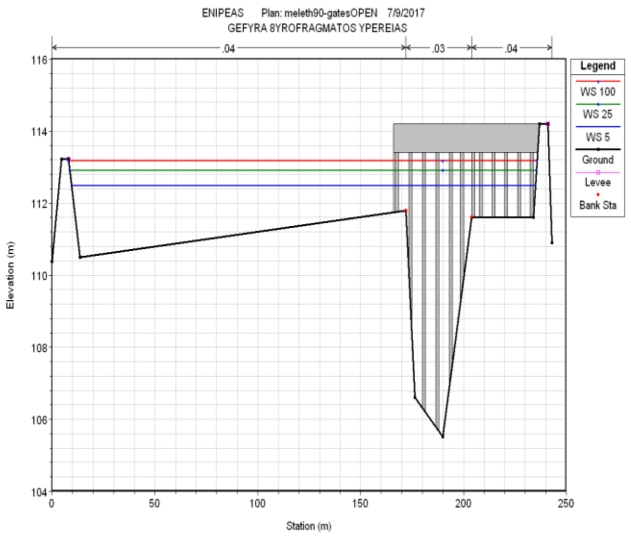
Figure 6: Water surface variation for the operation of all gates closed and for the maximum inflow discharges of 5, 25 and 100 year flood period, at different cross sections



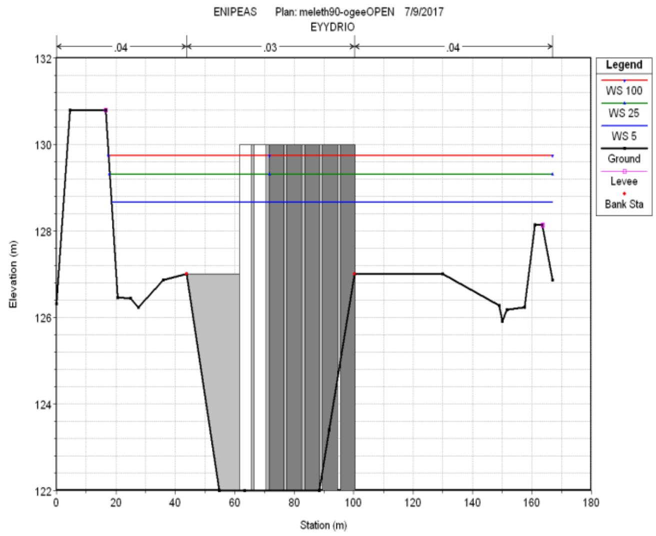
(d) "Purgakia" dam



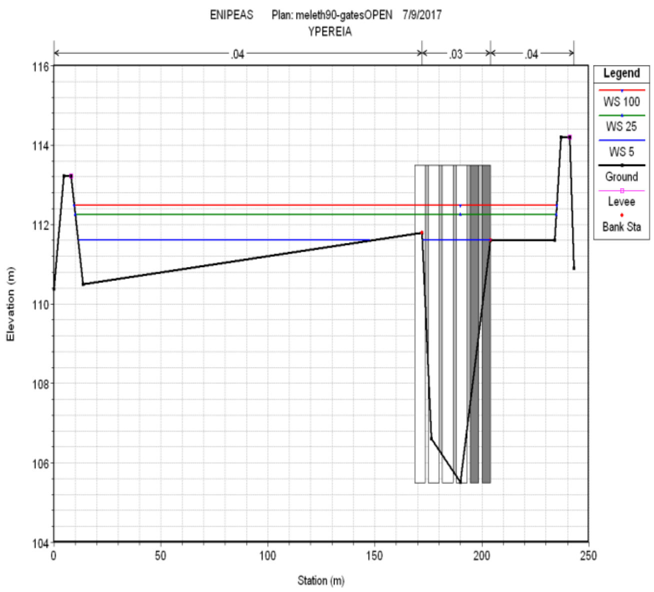
(a) "Mega Evudrio" bridge



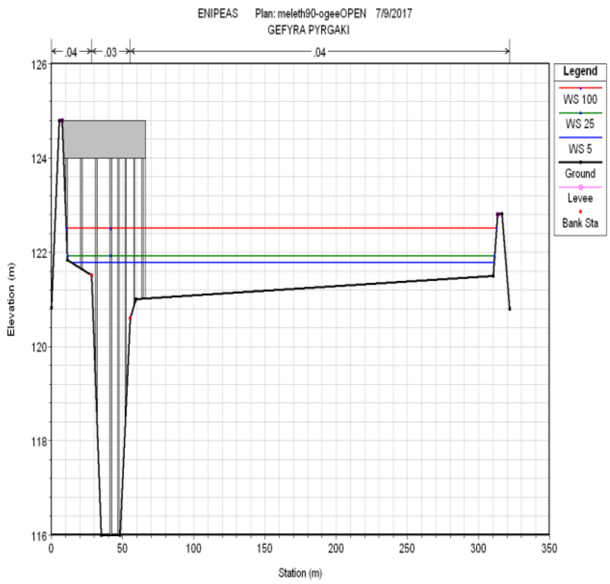
(e) "Ypereia" bridge



(b) "Mega Evudrio" dam

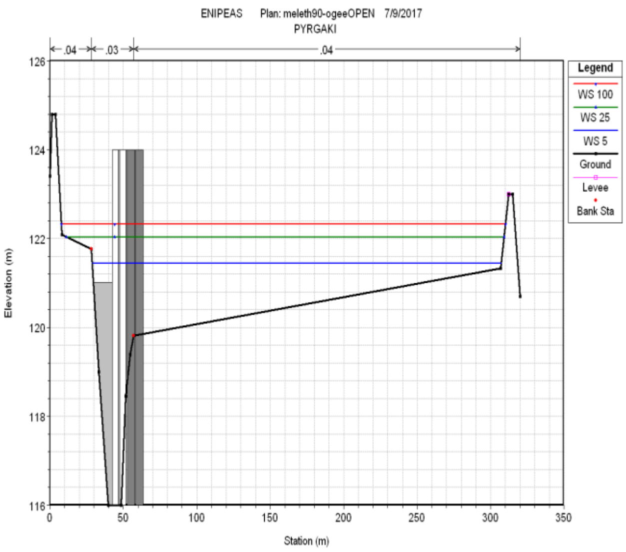


(f) "Ypereia" dam

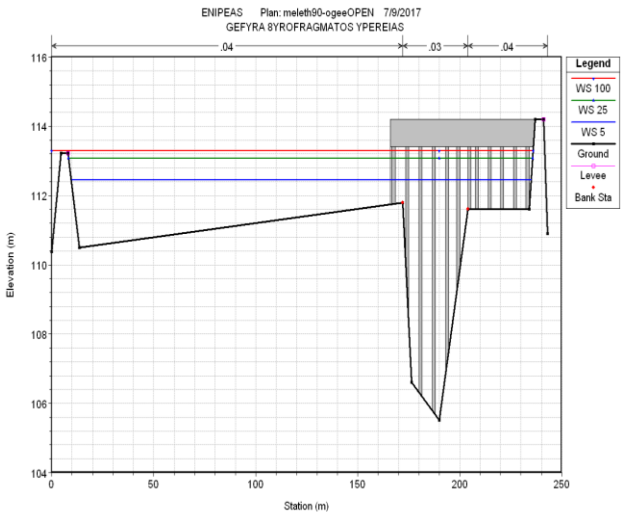


(c) "Purgakia" bridge

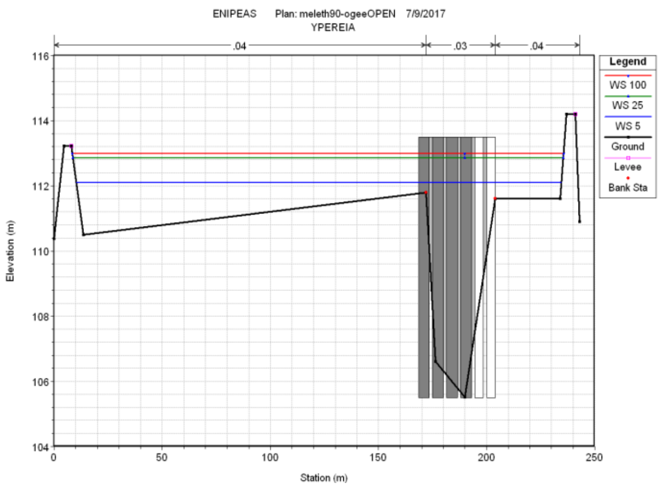
Figure 7: Water surface variation for the operation of only flat gates opened and for the maximum inflow discharges of 5, 25 and 100 year flood period, at different cross sections



(d) "Purgakia" dam



(e) "Ypereia" bridge



(f) "Ypereia" dam

Figure 8: Water surface variation for the operation of only arched gates opened and for the maximum inflow discharges of 5, 25 and 100 year flood period, at different cross sections

From all the above numerical simulation results it is obviously that the worst operation is when all gates are closed, and only in the region of "Purgakia" dam there is no flood risk for the maximum inflow discharge. When all the gates are opened a flood risk evaluation exists in the region of "Mega Evudrio" dam, even with the minimum inflow discharge. When only the flat gates are opened there also exists a flood risk estimation in the same region, for the maximum inflow discharge. In this region an appropriate elevation of existing embakments can prevent flood events. Furthermore, with only the arched gates opened the total operation causes higher water surface elevations, along the river reach, comparing with the operation when the flat gates are opened.

III. Conclusion

The results of one-dimensional water surface profile calculations, for steady flow through a natural river, Enipeas river reach and for the maximum inflow discharges of 5, 25 and 100 year flood period are graphically presented. The studied river reach area is a flood prone area and from the engineering view point, an accurate quantitative estimation of water surface variation is necessary for the prevention of severe environmental problems and for a safe river design. Along the studied river reach there are three dams constructed in locations named "Mega Evudrio", "Purgakia" and "Ypereia" for irrigation and enrichment of the underground aquifer purposes and during flood events are operating with flat and arched gates, without overtopping. Dam constructions cause serious disturbances in water surface elevation, during flood events, and a safe and optimum operation of the dam gates is numerically investigated. The applied hydrodynamic numerical model is a useful, reliable and accurate methodology in order to provide an adequate and validate flood risk assessment in a natural river area with complicated geometries and different hydraulic constructions.

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- Farsirotou E.D., Soulis J.V. and Dermissis V.D. (2002), ¨A Numerical Method for Two-Dimensional Bed Morphology Calculations¨, *International Journal of Computational Fluid Dynamics, 2002, Vol. 16 (3), pp. 187-200.*
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- Evangelia D. Farsirotou, ¨Two-Dimensional numerical simulation of bed level variation around vertical wall abutments¨, *International Journal of Engineering Research and Science, ISSN: 2395-6992, vol 4(11), 2018, pp. 1-9.*

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