Extended abstract

1. Introduction

A very important variable in hydrology is discharge and it is useful in many cases, such as in the water management or in the statistical analysis of floods. However, its data acquisition is a very expensive and difficult task, in comparison to the data acquisition of precipitation or stage.

Generally, there are several methods for the measurement of the flow, such as measured in the solution process, the estimation by floats, the acoustic Doppler current profiler, the estimation using hydraulic flow formulas in triangular section etc. For areas that are difficult to access or is difficult to measure the flow, some methods have been developed using remote sensing (Bjerklie *et al*., 2003, 2005). Of course, such methods have other errors and difficulties, like the presence of ice (Shiklomanov *et al*., 2006). Unfortunately, most of these methods don't permit to have continuous and direct measurements of discharge, so a common practice to deal with this problem is to convert stage data, which is easy to provide, into discharge. For this purpose, it is used the rating curves, which is a relationship between stage and discharge. The mathematical expression of rating curves is the well-known equation (Herschy, 1978, 1995· Rantz *et al*., 1982b· ISO, 1998):

$$Q=C(h\text{-}\alpha)^N \tag{1}$$

where h is the stage, C and N are parameters and α is the stage for the zero discharge. These parameters are calibrated by a best fit method or a graphical method using pears of simultaneous (Q,h) measurements (Koutsoyiannis and Xanthopoulos, 1999, p. 331). The most common practice to take these measurements is the velocity-area method. In order to estimate the rating curve, it is necessary to take measurements frequently, but due to some difficulties, such as the cost, the measurements performed with a weekly frequency or fortnight.

The European Directive ISO EN Rule 748 (1997) provides guidelines for the proper conduct of hydrometric measurements. It states that in order to calculate the velocity, the section should be divided into a number of vertical segments. If the cross section exceeds 10 m, the section should be divided into at least 20 parts to measure the velocity, while the separation of the sections must be in a way so that each section will have less than 5% of the total discharge. Also, the number and the distance of the velocity measurements, along each vertical, should be selected so that the difference in readings between two adjacent points will not be more than 20% of the higher value. Once the velocity readings at each vertical are integrated to the depth, the area of the velocity curve gives the rate flow per unit width along this vertical. The mean value of two adjacent measurement gives the flow per unit width of the portion enclosed by the two verticals. Eventually, the river flow $Q(x,t)$ results integrating all discharges in each segment.

Based on these rating curves and using continuous data of stage, obtained from staff gages, gage houses or digital devices, we can estimate discharge any time of the day depending on the frequency of stage measurements. The asset of this method is the feasible conversion of stage measurements into discharge through the rating curves.

For constructing the rating curve, the directive ISO 1100-2 (ISO, 1998) proposes the use of at least 12-15 pairs of (Q,h) uniformly distributed throughout the range of a curve. It is very common that a curve does not cover the full range of stage values, so there is no information for very small and very large level, which affects the water resources management and flood management respectively.

The first step for constructing a rating curve is to depict the pairs (Q,h) on logarithmic axes. The use of logarithmic axes offers some benefits which are:

1. The easy identification of outliers, which may be erroneous measurements.
2. It is feasible to identify if the curve should be separated into segments and the range of each segment.
3. It is achieved the homoscedasticity of residuals.

The logarithmic transformation is preferred in regression because it achieves the homoscedasticity of residuals. In this way, the percentage errors are about the same at high and low stages (Koutsoyiannis and Xanthopoulos, 1999, p. 333). Also, when we have heteroscedasticity, the estimators can unbiased and consistent but they are not efficient. So, the hypothesis testing and confidence intervals are invalid (Chatzinikolaou, 2002, p. 358). The mathematical expression of logarithmic transformation for an one-segment rating curve is the following equation.

$$\log Q=\log C+N\log(h-\alpha) \tag{2}$$

In order to identify the heteroscedasticity or the homoscedasticity, we have to depict the estimation error w relation to the value of variable in a diagram. If the points are randomly distributed around the line w=0, then we have homoscedasticity; while in the case that a "trumpet" shape is generated, we have heteroscedasticity. This heteroscedasticity proves the inappropriateness of the regression model (Koutsoyiannis, 1997, p. 219· Petersen-Overleir, 2003). It is obvious that the more the points the more visible the result. In Fig. 1, it is obvious that logarithmic transformation achieves the homoscedasticity which proves that this transformation is efficient.

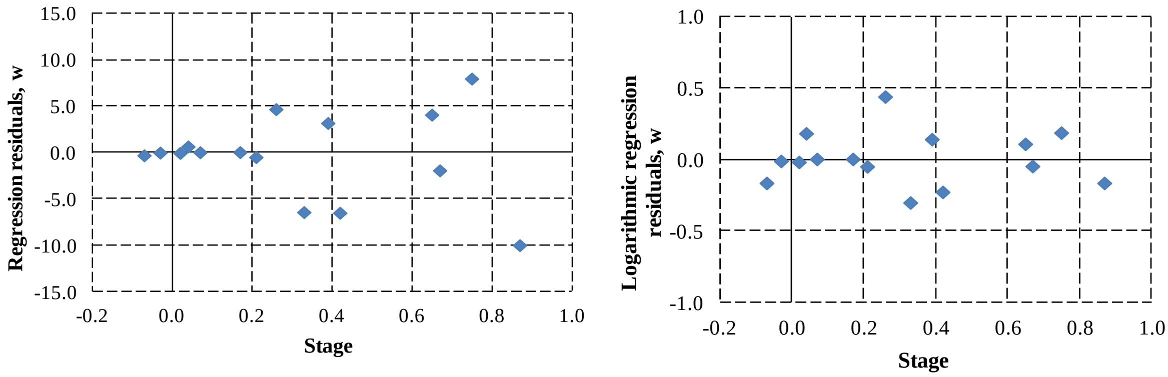

Figure 1. Diagram of the regression residuals w of discharge relation to the value of stage for the third period (left). Diagram of the regression residuals w of the logarithm of discharge relation to the logarithm of stage (right).

Despite the utility of rating curves, they are entail a large amount of uncertainty, as many sources of errors affect them and they are rarely taken into consideration. Actually, relation between stage and discharge is not stable neither spatially nor in time. The main factors which affect this relation in a specific cross section are (Herschy, 1995· Rantz *et al.*, 1982b· Mimikou and Baltas, 2012, p. 165):

a) Erosion and deposition of sediments

b) Hysteresis in unsteady flow

c) Growth or decay of vegetation

d) Accumulation of logs and other items

e) Subcritical and supercritical flow

f) Ice

Commenting the second factor, which plays the most important role and is examined in this thesis, we can say that in the unsteady flow, there is no a one-to-one relationship between discharge and stage. This means that the rising and falling branch don’t coincide neither each other nor with the corresponding curve of uniform flow.

Also, comparing the hydrograph of steady and unsteady rating curves (Fig. 2), there are two important conclusions. Firstly, the steady rating curve seems to underestimate the peak flow. The magnitude of underestimation depends on some factors, such as the slope of the bed, the extend of the flood and the Manning coefficient. The second conclusion is that the peak flow occurs before the estimation given by the steady rating curve.

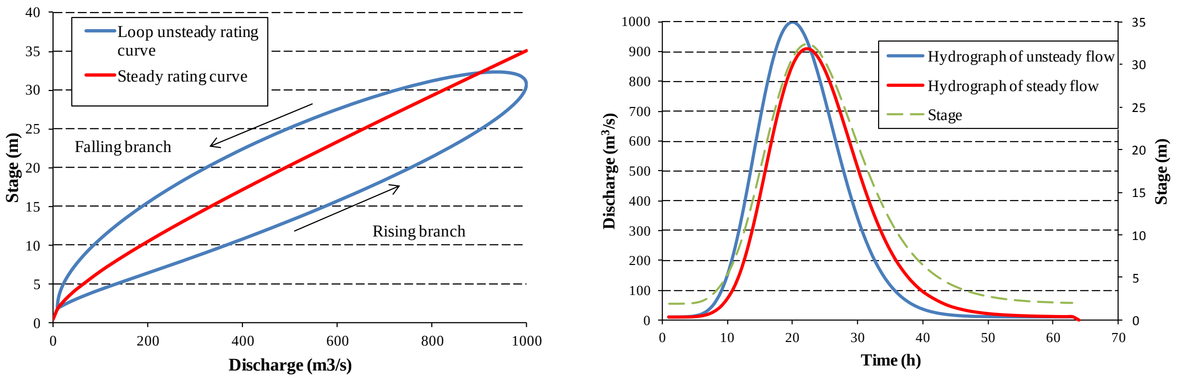

Figure 2: Comparison of steady rating curve with loop unsteady rating curve (left). Comparison of hydrographs given by steady (red) and unsteady (blue) rating curve for the same stage (green) (right).

The study of this phenomenon is complicated and there are rarely available measurements (e.g. with simultaneous measurements of stage upstream and downstream of a gage station), so hysteresis is not taken into consideration and it is used the one-to-one relationship between stage and discharge for flood events. The error is negligible for steep slope but in mild river the error is high (Koutsoyiannis and Xanthopoulos, 1999, p. 336).

During the hydrometric measurements, the presence of unsteady flow is likely to cause errors in the rating curve if it is not clarified whether the measurement belongs to the rising or the falling branch. So, it may be considered that dispersion of measurements is caused by errors in measurements or other sources and, in fact, is caused by the presence of hysteresis. Some scholars choose to adapt one curve for the rısing branch and one another for the falling branch, but this is wrong because the hysteresis loop is not stable for a cross section and varies with the flood, as shown in Fig. 3 (Fread, 1975).

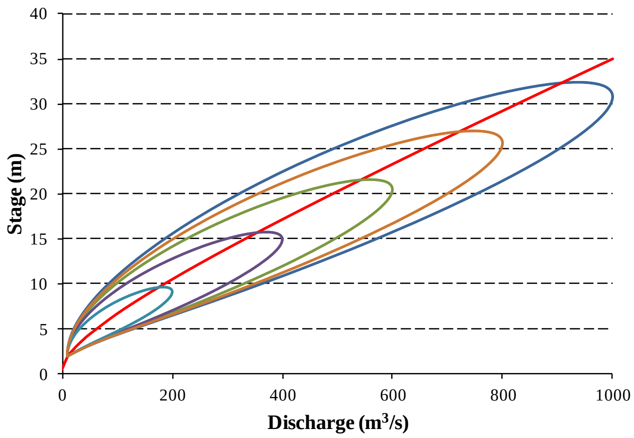

Figure 3: Loop rating curves for different floods.

Another source of uncertainty in rating curves is the extrapolation. There are no usually hydrometric measurements in high values of stage due to the risk of the process. In order to deal with this problem, it is very common to extrapolate rating curve using hydraulic formulas, such as Manning and Chezy formulas, if it is known the geometry of the cross section, the roughness and the slope. Also, it is common to use statistical methods, graphical extrapolation in logarithmic axes and hydraulic programs, like HEC-RAS. For any cases, Rantz *et al.* (1982b) suggest that extrapolation should not exceed twice the largest measured discharge.

In order to examine better the phenomenon of unsteady flow, three standard channels were designed with the same width but with different length in hydraulic model HEC-RAS. The study was done for different values of bed slope, from mild to steep slope, for different values of Manning coefficient, which correspond to those of natural rivers, and for different hydrographs. The aim was to study the difference between the steady rating curve with the unsteady rating curve. In particular, it was investigated the underestimation of the peak flow, when we use the steady rating curve, and the uncertainty around the steady curve due to the loop curve of unsteady flow. Also, it was examined the effect of the shape of hydrograph in uncertainty between unsteady and steady flow and the use of the Manning and Chezy formulas in extrapolation of rating curves, which is a common practice.

The study area was the Evinos River and in particular the section between the Poros Reganiou gauge and the Bania Bridge gauge. Initially, we will perform: (1) the construction of the stage-discharge relations; (2) the calibration of HEC-RAS for the section between the two stations; (3) the estimate of the error in extrapolation curve constructed with hydraulic methods and with extrapolating the curves; (4) the estimation of the standard deviation of residual errors of the interpolation when constructing the curves in order to calculate the 95% confidence interval using Monte Carlo analysis.

Finally, it was examined the impact of uncertainty in the process of calibration. To this end, it was used the conceptual model Zygos in daily time step in the subbasin of Poros. Firstly, it was calibrated in accordance with the discharge stem from rating curves and secondly with the same values including uncertainty. The aim was to investigated if the use of uncertainty plays role in the process of calibration. In other words, whether allowing the model to be more flexible, as it doesn't try to decrease the difference with a value (Q_{obs}) but to be inside of a range of values, it will provide more robust solutions.

2. Standard channels

2.1 Introduction

For the best study of unsteady flow, standard channels were designed in hydraulic model HEC-RAS, in order to consider how the slope, the Manning coefficient and the hydrograph affect in uncertainty between steady and unsteady flow. The use of a simple geometry, such as a rectangular section, permits the study of phenomenon without additional sources of uncertainty, as it would be in a natural river where both slope and Manning coefficient have uncertainty in their estimations.

Rectangular cross section often can describe natural rivers and many scholars admit that the examinee river can be considered as rectangular, as the examination and the equations are simpler. Three standard channels were designed with a width of 30 m and length of 10 km (short length), 25 km (middle length) and 50 km (long). The reason why we didn't use only the long channel and examine the intermediate positions is that the flood routing will decrease the flood peak in downstream positions, while it was desirable the comparison of similar hydrograph. Finally, the lengths of the channels don't describe only the distance from the estuary but the distance from a place which provokes hysteresis. This place can be a reservoir or a lake.

In order to estimate the input hydrograph, the equation of Dottori *et al*. (2009) was used.

$$Q(t) = Q_\mathrm{b} + (Q_\mathrm{p} - Q_\mathrm{b})\left[\frac{t}{T_\mathrm{p}}\exp\left(1-\frac{t}{T_\mathrm{p}}\right)\right]^{\gamma} \tag{3}$$

where Q_b is base flow discharge (equal to 10 m^3/s), T_p the time to peak flow (equal to 24 h), Q_p the peak discharge and γ a coefficient, which was assumed to be equal to 16.

Regarding the peak flow, when it was studied the effect only of the slope and manning coefficient, the hydrograph was considered constant with peak flow equal to 1000 m^3/s, while when it was studied the effect of the peak flow in relation to the slope, with a constant value of manning coefficient (0.035), the examinee values of the peak flow were equal to 50, 100, 200, 400, 600, 800 and 1000 m^3/s. In these cases, the time to peak flow and the base flow remained constant. Also, we examined the impact of the shape of hydrograph in uncertainty between steady and unsteady flow, by decreasing the time to peak flow to 15 h.

2.2 Methodology

For calculating the underestimation of peak flow and the error between steady and unsteady flow, the model HEC-RAS was used. For each case, depending the variables we wanted to study, we computed the steady rating curve for each slope and the corresponding unsteady curve for a specific hydrograph, considered it as the correct solution because the software solves the full Saint-Venant equation for the unsteady scheme.

Firstly, regarding the methodology used to calculate the underestimation of peak flow, the HEC-RAS calculates the stage and the flow per hour in the exported data for unsteady flow. For this value of stage, we estimated the discharge for steady flow using the corresponding rating curve constructed from the software. So two hydrographs were arising, one for steady and one for unsteady flow. Then, we compared the peak flows and the resulting percentage error.

The estimate of the error between the two curves was done by calculating the stage value that gives the steady rating curve for a given flow rate (total of 24 flow rates). Then, for the same value of stage, we calculated the corresponding value for the unsteady flow and thus we calculated the error between them. In other words, when in fact, using the curves that describe the steady flow in order to estimate the discharge for a measured stage, then we want to estimate how much the uncertainty round of this estimate is. For these calculations, neither equations nor interpolation were used, as this introduces the error of interpolation. Instead, the code *interpolate* in the visual basic of excel, built by Koutsoyiannis and Efstratiadis for the course of Management of Water Resources, was used. Because the data was enough dense, the error of the non-alignment of the curves can be considered negligible.

Finally, as about the boundary conditions, in the implementation of steady flow, the program used mixed flow with upstream and downstream boundary conditions the slope of the bed, while in unsteady flow, the slope of the bed was used as downstream boundary condition again.

2.3 Results

Examining the standard channels we can extract the following results:

- Studying the three standard channels (with constant width 30 m and length 10, 25 and 50 km) and assuming the same input hydrograph (peak flow 1000 m^3/s), it seems that as the slope increases, the phenomenon of hysteresis decreases, while as the Manning coefficient increases, the underestimation increases and therefore the unsteady flow has a greater effect. Also, the longer channel causes greater underestimation of the peak flow, especially for small slopes and high values of the Manning coefficient the underestimation can reach the value of 90%. Putting as threshold the underestimation of peak 10% , we conclude that ignoring the Manning coefficient, for a length of 10 km it should be taken into account the unsteady flow for slopes less than 0.075%, while for length 25 km and above for slopes less than 0.1%. Considering the value of Manning coefficient, these limits will be moved to milder slopes. Depicting in diagrams the underestimation of the peak flow relative to the Manning coefficient for each slope and for each standard channel, it was found that the mild slopes described by logarithmic curves, while the steeper slopes by linear relationships. Finally, it was found that for the longest channel, the slope separating logarithmic and linear correlation moves to steeper slopes.

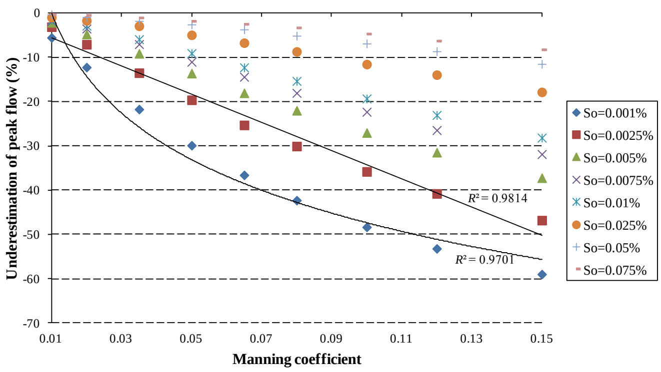

Figure 4: Depiction of Manning coefficient with the percentage of underestimation of peak flow for each slope for the middle channel (25 km).

- Studying the underestimation of peak flow, assuming constant Manning coefficient (0.035) and changing the input hydrographs (total 7 hydrographs with peaks from 50-

1000 m^3/s), it was found that the size of the input hydrograph does not significantly affect the relative underestimation of the peak flow. Also, when it was depicted the percentage of the underestimation of peak flow in relation to the peak flow of hydrographs, it was inferred that the percentage stabilizes after a specific value of discharge. This value was about 400 m^3/s for all three channels.

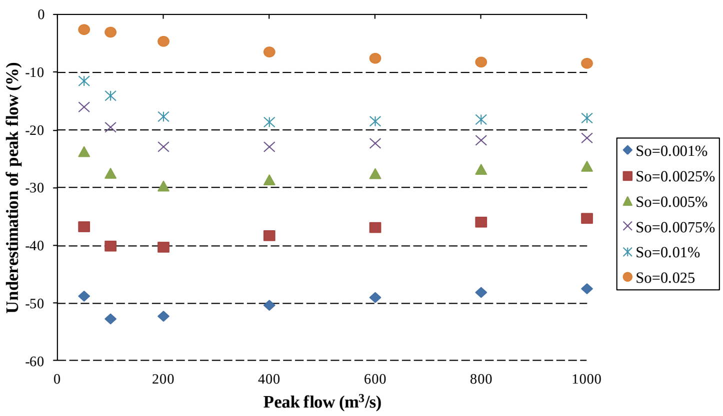

Figure 5: Depiction of peak flow with the percentage of underestimation of peak flow (for middle channel)

- Studying the percentage error between steady and unsteady rating curve for each slope and each Manning coefficient, with the same input hydrograph (peak flow 1000 m^3/s), it was deduced that the percentage error is large enough and it can overcome the value of 300% for small slopes, while they were affected mainly the intermediate flow rates. The larger the values of Manning coefficient, the higher the increase of the percentage error. Moreover, it seems that the middle and the large channel do not show too much difference. The large percentage error for flow rates of 10 and 20 m^3/s is due to the fact that although the absolute error is small, the small denominator increases the percentage.

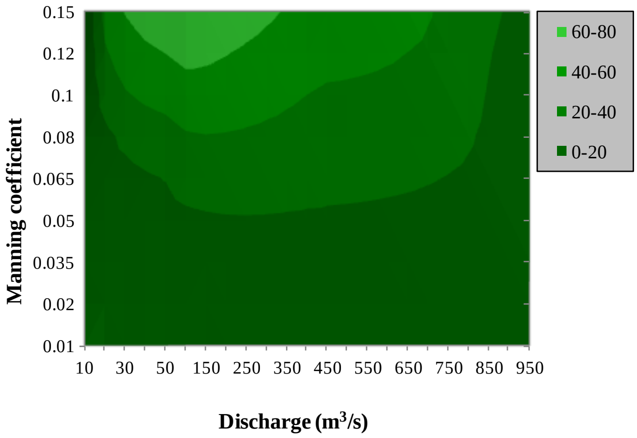

Figure 6: Percentage error between steady and unsteady rating curve for the middle channel and for bed slope 0.05%.

- Considering again the error between steady and unsteady curve for constant Manning coefficient (0.035) and using the 7 hydrographs, it was observed that the maximum error values are for intermediate flow rates where the loop is wider. Also, the percentage errors decrease for smaller hydrographs, which is associated with the smaller loop. For small slopes, the error exceeded 200% in intermediate flow rates.

- Decreasing the time to peak flow from 24 h at 15 h (peak flow 1000 m^3/s), it was proved that for mild slopes less than 0.025%, the difference is noticeable, while for higher slopes both looped curves are almost identical, so the shape of hydrograph is not important. Indeed, it seems that the rising branch of rating curve is not affected by the change of hydrograph, relative to the falling branch, where the wider hydrograph causes larger loop. Finally, it was checked whether the different looped curve will have a serious impact on the underestimation of peak flow. Again it seems that for slopes less than 0.025%, the difference is significant, while for steeper slopes, the difference is negligible. The study was done for the long channel.
- Finally, it was examined the use of hydraulic formulas of Manning and Chezy for extrapolating the rating curves. It was found that for rectangular channel and for any slope, the two equations are almost identical to the values given by HEC-RAS for steady flow. The maximum percentage error was about for Manning formula 0.15% and for Chezy formula 0.1%, while generally, the Chezy formula was almost identical with the steady flow of HEC-RAS. In trapezoidal channel with slope of 1:1, it was deduced that the two formulas give smaller values of discharge in comparison the values given by HEC for steady flow. Specifically, for flow rates from 10-1000 m^3/s, they seem to underestimate the values given by HEC for steady flow from -4.2 to -13.6% for slope 0.001% and from -1 to -8% for slope 0.5% respectively. In conclusion, it is obvious the inadequacy of the two formulas in extrapolation of rating curves as they ignore the unsteady flow, while in trapezoidal channels they underestimate even the discharge given by the steady curves.

3. The case of Evinos River

3.1 Introduction

The application of this thesis was in the gauging station of Poros Reganiou in Evinos River. The reasons for the selection of the specific area related to the adequacy of data in two gauging stations (Poros Reganiou and Bania Bridge), the topography of the river that meets the constraints set by the 1-D model HEC-RAS, while the area of the Evinos is very important because it contains a reservoir connected to the hydrosystem for the water supply of Athens.

The construction of rating curves made for the position of Poros Reganiou in Evinos river. There were data available of hydrometric measurements (a total of 98 pairs (Q,h)) for a ten-year period, whilst the data were approximately per month. Also, daily data of stage and periodic data of stages for flood events were available.

Initially, we had to split up the data in periods so that each curve can describe the new section and converts the values of stage into discharge. A common practice is to select the beginning of a new period after a great flood, which provokes significant change of the geometry of cross section and of the curves, as well. This threshold of flood level was defined equal to 4.5 m. Also, each curve should contain at least 12 pairs of (Q,h), in order to be consistent with the guidelines of ISO 1100-2, and should have hydrometric measurements for the widest possible range level. Totally, three periods were created, while the curves obtained from the equation 2. The rating curves were multisegments and the program Hydrognomon was used to separate the curves into segments.

Having drawn the curves, it was tested if the logarithmic transformation eliminated the heteroscedasticity of residuals. This seems to have been achieved in accordance with the Fig. 1.

Having ensured the homoscedasticity of the residuals, the next step was to draw the extrapolation of rating curve. As mentioned in Chapter 2, the extrapolation of curves for large values tend to converge into one curve and for this reason, it was considered that only one extrapolation curve can describe adequately the discharge for high level. The threshold of 2.8 m was used because there wasn't a hydrometric measurement for a stage above of this threshold. As about the extrapolation curve, we used the curve resulting from HEC-RAS.

The aim of this study was to investigate the uncertainty in the rating curves, with emphasis on flood discharge. For this purpose it was constructed the hydraulic model HEC-RAS and then it was calibrated the section between the two gauging stations.

In order to construct the hydraulic model and create the cross sections, the Digital Terrain Model (DTM) with resolution of pixel 5.5 m and 20 orthophoto maps were used. The DTM was supplied free by the NATIONAL CADASTRE AND MAPPING AGENCY S.A. and the geodetic reference system was the European Terrestrial Reference System 1989 (ETRS89), which was converted into the GGRS '87.

When the river was digitalized, it was found that the longitudinal profile was quite abnormal with fluctuations about 1-5 meters, due to the errors of raw DTM and the size of pixel. For this purpose, the DTM was reconstructed using the digitalized line of river and filling the sinks. Moreover, it was used the toolbox HEC-GeoRAS for drawing the cross sections in ArcGIS. Totally, 762 cross sections were drawn from DTM.

Finally, we designed the two bridges of Poros Reganiou and Bania using aerial photos so as to approximate, as closely as possible, the width of the bridges and of the piers.

For calibrating the model, it was selected a particular flood event took place on 10-14 January 1997, with a maximum estimated discharge for the site of Poros Reganiou equal to 460 m^3/s and a maximum stage of 5.07 m. During the calibration process, only the Manning coefficient was changing, varying between 0.025 and 0.15 $m^{-1/3}s$ for the main channel and between 0.035 and 0.16 $m^{-1/3}s$ for the banks. These values are in accordance with the values proposed by Chow (1959). The calibration of the model was based on the recorded level values at downstream section, while the recorded level hydrograph at upstream section was used as the input hydrograph. Also, since HEC-RAS needs stage data per hour and the measured data were sparse, we interpolated them in hourly time step (Fig.5.21). The length of the river between the two bridges is about 9 km and in this section the basin is quite narrow, so it was assumed that there is no lateral inflow.

Since emphasis is given on estimation of uncertainty in flood discharge, we will estimate the error between the rating curve of HEC-RAS with the extrapolation curve constructed with hydraulic methods by Efstratiadis *et al*. (2000) and with the graphical extrapolation of rating curves drawn from hydrometric measurements.

The uncertainty will be expressed as a percentage error to the estimated discharge, given by model HEC-RAS, which is used as the benchmark. The uncertainty will be described by the following equation

$$\varepsilon = \left(\frac{Q'(h) - Q_{\mathrm{HEC}}(h)}{Q_{\mathrm{HEC}}(h)} \right) \cdot 100 \tag{4}$$

where $Q_{HEC}(h)$ is the discharge given by the model, $Q'(h)$ the discharge estimated by the rating curves constructed for the site of Poros Reganiou. The calculations will be done for all three periods for which we constructed the separate curves.

3.2 Results

As we mentioned, the calibration was done for the flood event took place on 10-14 January 1997. The only variable that was changing during the calibration was the Manning coefficient. After each run, it was compared the estimated levels from the model with the measured levels, using the method of minimizing the squared errors in order to find the optimal solution. The optimal values of Manning coefficient were 0.037 $m^{-1/3}s$ for the channel and 0.08 $m^{-1/3}s$ for the banks. Fig. 7 depicts the result of calibration and it is obvious the satisfactory adjustment of the model.

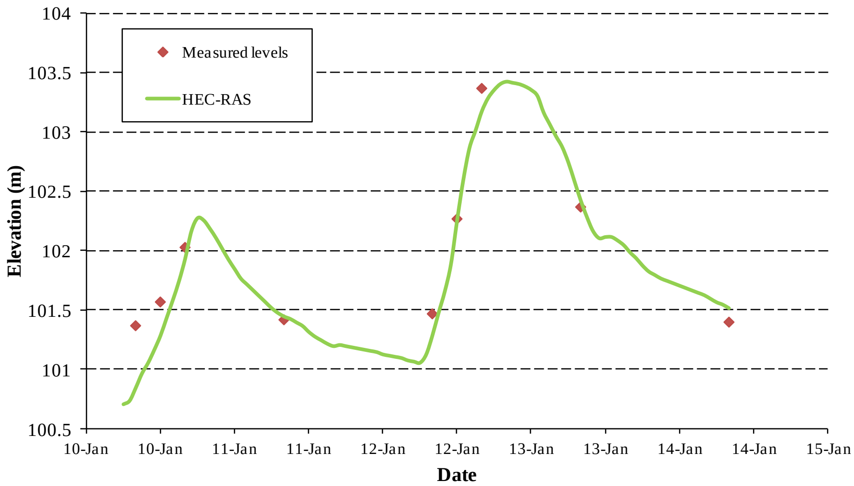

Figure 7: Comparison of estimated levels with the measured ones.

Assessing the extrapolation curve, constructed by Efstratiadis *et al*. (2000), it seems that it overestimates the flow up to 40%, but as the level increases the percent overestimation decreases. Assessing the other three extrapolating curves, stem from graphical extrapolation, it seems that the first two curves underestimate the flow from 5% to 40%, while the third period overestimates up to 100%. Regarding the third period, the error is due to the fact that the highest hydrometric measured is for level equal to 1.5 m, so the extrapolation curve creates a large error.

Conclusevily, extrapolating curves using graphical methods in logarithmic axes or using hydraulic formulas, such as Manning or Chezy equation, are inappropriate methods and it is proposed the use of hydraulic models.

4. Impact of uncertainty in calibration process

4.1 Introduction

Generally in the literature, there are many studies that quantify the uncertainty of the rating curves (Domeneghetti *et al*., 2001· Di Baldassarre and Montanari, 2009· Clarke, 1999· Jalbert *et al*., 2011). However, there are only a few works that investigate how uncertainty affects the process of calibration of a hydrological model, which uses flow data as output (McMillan *et al*., 2010). So the aim is the use of the estimated flow as stochastic variable and the comparative analysis of different methods in calibration.

Calibration is a very popular technique among scientists and engineers as it helps them in many applications. Giving a general definition of calibration, we could say that it is a systematic process for estimating parameter values of a model, so that the outputs or responses of the model y_i', with respect to a set of observed inputs x_i, to adapt as best as possible to a corresponding set (eg. observed) responses y_i, of a physical or a mathematical system that represents the model.

The deviation $e_i=y_i'-y_i$ called error of the model or residual. The sum of the errors indicates whether the model is biased or not. In this second case, it reproduces the mean observed outputs (Efstratiadis and Makropoulos, 2011).

Generally, there are many criteria for best fit, such as the determination coefficient, the least square methods and the Nash and Sutcliffe coefficient. All these criteria for best fit require that we know the correct value of the calculated outputs and we try to create a model that can represent the system. Especially in nature where uncertainty is an inherent feature of information how correct this practice is? Did we force the model ultimately to reach wrong values in order to improve some criterion of best fit resulting that parameters do not correspond to the natural system? We presented previously that steady rating curves underestimate the peak flow. If we calibrated a model without introducing some uncertainty, but this model showed a good fit to some criteria, we could say that the model is able to represent the system?

The uncertainty is contained in the entire manufacturing process of rating curves and therefore it should be taken into consideration in all the processes that it will be used, such as the calibration of models, the construction of rainfall-runoff models, the flood protection, the flood hazard maps, the hydrologic studies of dams etc. Even when R^2 is quite large during the construction of the curves, we should not have the illusion that the error is small. Often in a deterministic environment, such as that of the rating curves, the output data have been extracted by relationships which have been built without any reference to random variation. This implies that for a given input value and the same initial and boundary conditions, the result will always be the same as the uncertainty is not taken into account. In these cases the uncertainty assessment is done indirectly and creates the illusion that the reduction of uncertainty will be achieved by improving deterministic models (Montanari and Koutsoyiannis, 2012). That’s the reason why the flow should be treated as a stochastic variable and taken into account the uncertainty.

4.2 Methodology

The purpose of the last chapter is to study the effect of uncertainty in the calibration of a hydrological model. In particular, we will study the effect of uncertainty in the rating curves in the subbasin of Poros Reganiou. For the outlet of the subbasin, we have drawn the rating curves and we have estimated the typical error. To study the effect of this uncertainty in the calibration of a hydrological model, it was used the model Zygos.

The model Zygos, constructed by the research group "ITIA", is a conceptual model which represents the conversion of precipitation into outflow, evapotranspiration and percolation to the aquifer. This model will "run" in daily time step in the environment of R and it uses seven parameters for the presentation of surface processes and three for the presentation of underground processes. Finally, it uses the efficiency coefficient of Nash and Sutcliffe (1970) as a best fit criterion, whereas in order to solve the multicriteria problem of parameters’ optimization, it uses an evolutionary annealing-simplex algorithm (Efstratiadis, 2001· Efstratiadis and Koutsoyiannis, 2002· Rozos *et al.*, 2004· Efstratiadis, 2008). The model requires as input data the temperature of the basin, the rainfall and the evapotranspiration, all measured in equivalent amount of water.

Regarding the precipitation data, 6 rain gauges stations were used and after the homogeneity test of double mass diagram, the Thiessen method was implemented in order to obtain the spatially integrated time series of precipitation. Also, it was necessary to reduce it to the mean elevation of subbasin.

For constructing the temperature time series, it was used the station at Lidoriki, which had only a few missing values. The reduction of temperature to the mean elevation of the subbasin was done using the values *c* given by Giandotti for Mediterranean catchments beneath the 45^{th} parallel were used.

As about the evapotranspiration data, it was used the parametric model for potential evapotranspiration estimation based on a simplified formulation of the Penman-Monteith equation proposed by Tegos *et al*. (2013). This model permits to estimate the evapotranspiration for a nearby area, where they are disposable data for temperature, wind velocity, sunshine and relation humidity for calibrating the parameters of the model. Using the calibrated parameters and the temperature of the mean elevation of the subbasin, we estimated the potential evapotranspiration.

The outflow, which was used in calibration, was estimated by the drawn rating curves in daily time step. The metric system of estimated outflow was in m^3/s, so it was divided by the area of the subbasin and multiplied by 86400 in order to convert it into mm.

As about the calibration process, initially, the model was calibrated based on the estimated flow from the rating curves on the outlet of subbasin, while in the second phase, the model was calibrated based on the value of the flow counted the estimated uncertainty for the period from November 1992 to May 1995.

In the first two studies, we implemented the calibration process using Nash and Sutcliffe coefficient, as the best fit criterion (Case study 1), and the mean square error, as the best fit criterion (Case study 2) avoiding the uncertainty.

In the third case study, two curves were calculated for 95% confidence interval ($Q_{\max95}$, $Q_{\min95}$) around the estimated outflow. In the objective function, it was assumed that if the modeled outflow is within the range of two curves, then the weighted coefficient of the square of the difference (α) is equal to one, whereas if the modeled outflow is outside the range, the weight gets a penalty which is equal to the absolute value of the distance from the nearest curve.

This methodology avoids the occurrence of discontinuity at the position of the two curves. Generally, the problem is defined as follows:

Let $\boldsymbol{\theta}=(\theta_1, \ldots, \theta_n)$ be the unknown parameters of the model. The function of the global error measure $f(e)$ is:

$$f(e) = f\left(a(Q_{\text{sim}}(t) - Q_{\text{obs}}(t))^2\right) \tag{5}$$

It is defined the feasible space of parameters Θ, introducing upper and lower limits ($\boldsymbol{\theta}_{\min} \leq \boldsymbol{\theta} \leq \boldsymbol{\theta}_{\max}$).

Finally, the definition of the problem is (Efstratiadis and Makropoulos, 2011):

$$\text{minimize}\, f(e) = f\left(\theta\right), \boldsymbol{\theta} \in \Theta \tag{6}$$

4.3 Results

Comparing the three case studies, firstly we can observe that the optimized parameters are different for each case, whereas despite the fact that the parameters of the first two studies (deterministic theory) are different, the result and the errors are quite similar. This means that the choice of a best fit criterion has a minor impact to the result. Also, commenting the Fig. 8, we can say that the errors for the third study case (stochastic theory) are smaller for high and low values of outflow. However, the large values in the modeled outflow are out of the range of uncertainty (Fig. 9.) which is caused to the use of the daily time step. Specifically, in the daily time step it was introduced the total daily rainfall whereas. reagarding the runoff, it was used the estimated, by the level, outflow at 8 am, and thus the model often does not reach the peak.

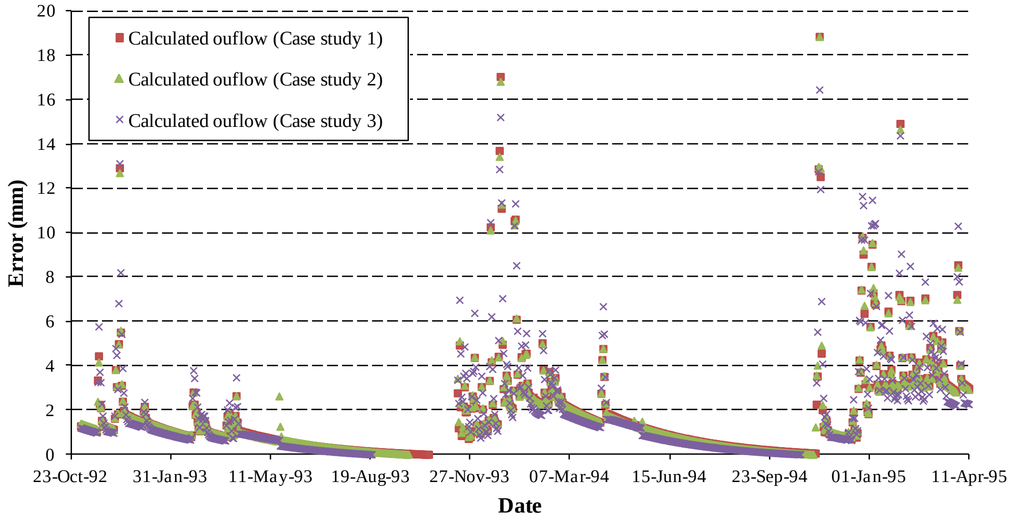

Figure 8: Depicting the errors of the calculated outflow for each case study.

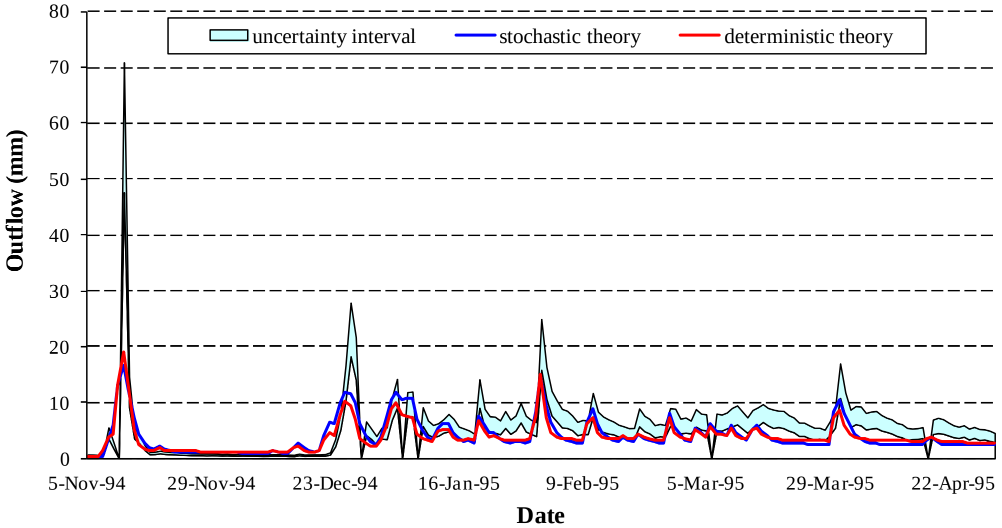

Figure 9: Comparison between stochastic and deterministic (Case study 2) theories compared with the uncertainty interval.