

# Modeling of water flows through a designed dry dam using the HEC-RAS program

Lukasz Gruss<sup>1,\*</sup>, Robert Głowski<sup>1</sup>, and Mirosław Wiatkowski<sup>1</sup>

<sup>1</sup> Institute of Environmental Engineering, Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24, 50-363 Wrocław, Poland

**Abstract.** In the designing water reservoirs, information on flood control it's necessary to make the right technical decisions related to the safe use of reservoirs, human life and the natural environment in the areas below the reservoirs. The hydrological data of a given river profile (stages and discharges) is important for the planning, hydraulic modeling of the reservoir and its exploitation. In the last years of the twentieth and twenty-first century in Central Europe, many floods of different intensity and extent have occurred on the Odra River and its tributaries. Therefore, the increasing extreme natural phenomena, like a violent floods and long droughts, mean that the importance of hydrotechnical constructions increases. One of the planned investments, which is to minimize the effects of the flood by collecting a flood wave on the Osobłoga River is the dry dam named Raclawice Śląskie. According to Polish law, model researches are required for the 1<sup>st</sup> and 2<sup>nd</sup> class of hydrotechnical constructions. Considering research models, not only physical models are used, but also hydroinformatic programs for the numeric model, like HEC-RAS. These programs enable modeling based on hydrometric measurements of rivers. The aim of the work is to model the discharges using the HEC-RAS program after analysis of the hydrological data. Analyzes and modeling were made of the planned reservoir – the dry dam across the Osobłoga River, Raclawice Śląskie profil in the Opolskie Province, in Poland.

## 1 Introduction

The hydrological data (stage and discharge) of a river is important for water resources planning, reservoir operation [1, 2, 3], sediment handling as well as hydrologic modeling [3]. In surface hydrology exists a relation between stage and the corresponding discharge at river cross-section. This relation is termed a stage-discharge relationship or rating curve [4, 6]. The stage-discharge relationship is a very important tool in hydrology [3]. A graphical rating curve helps in representation the relationship and to transform stages to discharges [3, 4, 5, 6, 7]. The extreme discharges and water levels are the most relevant hydrologic river data about the floods [8, 9, 10]. The floods cause a calamitous impact for the people, economy, and environment every year. They happen all over the world. With the increasing effects of climate change on the hydrological cycle, the planning of infrastructures within the floodplain zone is more and more important. The study of floodplain, especially floodplain mapping, is becoming a key tool in the water management [11]. Considering the flood control standards for reservoir engineering, it should be taken into account safety of

reservoirs, the lives, properties and ecological environment in the areas downstream. The economic issues, like directly influences the cost and completion time of projects are important as well from technical decision – making for the design of reservoirs [12].

In the twentieth century and the beginning of the 21<sup>st</sup> century many floods of different intensity and extent have occurred on the Polish Odra River and its tributaries. However, hazardous floods were not only those that covered the whole upper and middle Odra River basin [13]. In 1997 the Osobłoga River, one of the Odra River tributary, caused the flood wave overlap on the Odra River. The extreme flood was caused by the heavy rainfall, that fell down on the territory of the Czech Republic [14, 15] and Poland [14]. It should be mentioned that historical, extreme floods in the Osobłoga River catchment took place in the following years: 1854, 1903, 1907, 1913 [16] and in 2010. Ciepeliowski [17] includes this catchment like a high flood risk area. In the upper and middle basin of the Odra, in Opolskie Province following localities were classified to flooded areas: valleys of the Odra and Nysa Kłodzka rivers, valleys of the border (polish-czech) rivers of the mountain and foothill areas, including the

\* Corresponding author: [lukasz.gruss@upwr.edu.pl](mailto:lukasz.gruss@upwr.edu.pl)

Osobłoga River [18]. Therefore, the increasing extreme natural phenomena, like a violent floods and long droughts, increase the importance of hydrotechnical constructions [19]. Especially that global climate change might affect water resources and the environment at both global and local or regional levels [20]. One of the planned investments, which might minimize the effects of the flood by collecting a flood wave on the Osobłoga River is the dry dam, named Raclawice Śląskie. It will be a second class hydrotechnical construction [21]. According to the Polish water law for the 1<sup>st</sup> and 2<sup>nd</sup> class of hydrotechnical constructions, the capacity and shapes of hydrotechnical sluice structures and devices for dissipating hydropower should be checked using model research [22]. The water floods modeling during floods allows the physical and hydraulic description of the movement of fluids in open channels (rivers, streams, ditches). The flow area can be described by means of cross-sections of a watercourse or valley. Then, the position of the cross-sections should be entered using a rectangular coordinate system on the watercourse entered into the model. The coordinates marked on the x-axis determine the mileage of the trough's route [23]. River network cross-sections required for numerical modeling can also be obtained from very detailed digital elevation models by QGIS [24] and the numerical terrain model prepared in ArcGIS [11]. The modeling of discharges in the main channel and in river valley together with complex engineering structures (bridges, culverts, weirs) uses one-dimensional hydroinformatics programs such as HEC-RAS [25, 26] and MIKE 11 [26]. In addition, these programs enable modeling based on hydrometric measurements of rivers [25]. The program for two-dimensional modeling in flood mapping research is MIKE 21 [27]. The advantage of one-dimensional models compared to two-dimensional models is higher resolution that allows capturing all bathymetric channel properties [28, 29].

The aim of the work is to model the discharges using the hydroinformatic HEC-RAS program after analysis of the hydrological data. Analyzes and modeling were made for the planned reservoir – the dry dam across the Osobłoga River in the Opolskie Province, in Poland.

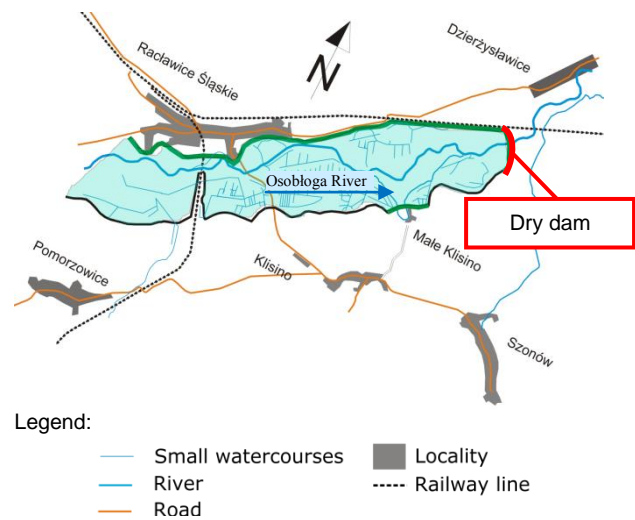
## 2 Material and methods

### 2.1 Study area

The planning dry dam across the Osobłoga River will be located in Opolskie Province, in Poland near the border with the Czech Republic, in Central Europe (figure 1). It will be situated between the following localities (50.19°N, 17.49°E): Dzierżysławice, Raclawice Śląskie, Pomorzowice, Małe Klisino and Klisino (figure 2) at 26.400 kilometer of the Osobłoga River. Designed dam is constructed of earth materials (embankment dam) with section of concrete. The concrete section have a four flood gates (radial with a diameter 1.0 m) and one gravity dam spillway (deck width 36.0 m). The dam crown elevation is 204.00 m a. s. l. (with about 11 m height from the riverbed).



**Fig. 1.** Osobłoga River with planning dry dam on the background of the Odra River basin (Own work based on [30, 31]).



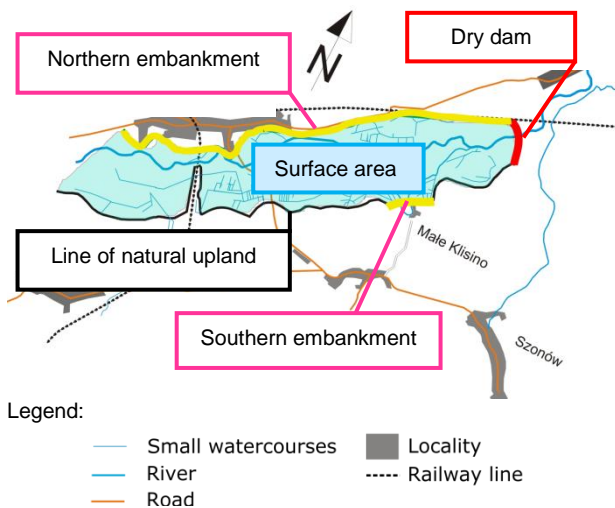
**Fig. 2.** Location of the planned dry dam with surface area (Own work based on [32]).

**Table 1.** Selected parameters of the surface area of the designed dry dam.

Parameters	Value
Length of the dry dam	550 m
Length of the side embankment	6200 m
Normal Pool Elevation in the reservoir	195.00 m a.s.l.
Maximum Pool Elevation in the reservoir	202.50 m a.s.l.
Surface area at Normal Pool Level in the reservoir	about 94 ha
Surface area at Maximum Pool Level in the reservoir	about 450 ha
Normal Pool Capacity	1.0 mln m <sup>3</sup>
Maximum Pool Capacity	22.0 mln m <sup>3</sup>
Engineering Classification	II

(own work based on [32])

Due to the existing localities, roads and railway infrastructure in the Osobłoga River valley, the dry dam can not be located across the entire valley. Therefore, apart from the dry dam, the side embankment have been designed. The side embankment with a length of 5650 m will be located on the north side. From the southern side there is a line of natural upland. The only place where the side embankment is planned will be the area of Małe Klisino locality (length of the side embankment have 550 meters) (figure 3).



**Fig. 3.** Dry dam location with side embankment (Own work based on [32]).

The hydrological parameters of the designed flood retention dam are as follows:

- 1) outflow through the flood gates will not exceed  $Q = 12,76 \text{ m}^3 \cdot \text{s}^{-1}$ ,
- 2) outflow through the flood gates and spillway will not exceed  $Q = 40,26 \text{ m}^3 \cdot \text{s}^{-1}$
- 3) Environmental flow is  $Q = 1,78 \text{ m}^3 \cdot \text{s}^{-1}$ .

The main function the designed dry dam is flood prevention of Raclawice Śląskie and the areas downstream. The secondary function can be recreation when the water level could not be lower than 195.00 m a. s. l. [32]. Then the flood gates should be equipped with sluice gates.

The Osobłoga River catchment is located in the middle basin of the Odra, in the southern part of Poland, in the Opolskie Province and in the Czech Republic in the Moravian-Silesian Region [30, 33]. The total area of the Osobłoga River catchment is 991.34 km<sup>2</sup> whereas the catchment area in Poland is 737.77 km<sup>2</sup> [30]. The catchment area in the cross-section of the planned dry dam is 498.4 km<sup>2</sup> and it is used agriculturally. The highest elevation in the catchment is Biskupia Kopa (890.00 m a. s. l.) and the lowest place is located in the estuary section of the Osobłoga River in the Krapkowice town (157.76 m a. s. l.). Sources of the Osobłoga River are located on the slopes of Kutna Krych (866 m a. s. l.). Osobłoga River is a left – bank tributary of the Odra River [34]. The Osobłoga River catchment is controlled. The Gauging station is located downstream Raclawice Śląskie at kilometer 27.400 of the Osobłoga River (figure 4).



**Fig. 4.** Gauging station at kilometer 29.850 of the Osobłoga River, Raclawice Śląskie profile (fot. L. Gruss).

In terms of climatic conditions, Woś [35] includes the discussed part of the catchment to the Lower Silesian Region of the South. The average annual precipitation for Głogówek, from the multi-year period of 1966 – 2006, is 663 mm. However, the average annual precipitation from 1961 – 2000 in the Czech Republic ( $H = 200 - 866\text{m}$ ) is 925 mm [36].

## 2.2 Inventory of the Osobłoga River valley

The inventory of the Osobłoga River valley was performed based on the method of mapping according to Gutra-Korycka and Werner-Więckowska guidelines [37]. The mapping were made twice (in spring and autumn) in 2010. The work have been begun from the inventory of the Osobłoga River and its tributaries. In addition, an inventory of hydrotechnical and communication structures (bridges and culverts), as well as irrigation and drainage structures has been made.

## 2.3 Stage-discharge rating curve for the Osobłoga River in the Raclawice Śląskie profile

Hydrological data that were used for the numerical model were previously prepared on the basis of the rating curve. The rating curve was prepared for the Osobłoga River based on data from the gauging station from the period 1971 – 2010.

Data preparation and determination of the rating curve were made according to the guidelines given by Michalec et al. [1], Yadav et al. [3], Byczkowski [4], Guide [5], Rantz [7], Kiciński et al. [38], Wałęga et al. [39]. The equation of the rating curve was determined from the general equation (Harlacher equation):

$$Q = a(H - H_0)^n \quad (1)$$

where:

- $Q$  – discharge ( $\text{m}^3 \cdot \text{s}^{-1}$ ),
- $a, n$  – calibration parameter,
- $H$  – stage (m),

$H_0$  – stage corresponding to zero discharge, called the  $H_0$  – constant (m).

The  $H_0$  – constant was determined by the Głuszkow method. For this purpose, on the graph, plotted on arithmetic scale, were marked the states ( $H$ ) on the Y axis, and the discharges ( $Q$ ) on the X axis. The points on the graph have been aligned with the least squares line by graphical method. Two coordinate points were selected on the curve  $A=(H_1, Q_1)$ ,  $B=(H_2, Q_2)$ . Points A and B have been maximally spaced from each other. These points involve to the main river bed. On the basis of the equation (2), the discharge ( $Q_3$ ) was calculated which allowed the state ( $H_3$ ) to be read from the graph:

$$Q_3 = \sqrt{Q_1 - Q_2} \quad (2)$$

$H_0$  – constant was determined by the Głuszkow equation:

$$H_0 = \frac{H_3^2 - H_1 \cdot H_2}{2H_3 - H_1 - H_2} \quad (3)$$

In order to determine the calibration parameters ( $\alpha$ ) and ( $n$ ), the theoretical depth of flow in the analyzed cross-section of the river ( $T$ ) was calculated according to the formula (4):

$$T = H - H_0 \quad (4)$$

where:

$T$  – the theoretical depth of flow in the analyzed cross-section of the river (m),

$H$  – stage (m),

$H_0$  – the  $H_0$  – constant.

( $T$ ) and ( $Q$ ) values were plotted on the graph. Values ( $T$ ) were plotted on the Y axis (on arithmetic scale) and values ( $Q$ ) on the X axis (being the logarithmic scale). The points on the graph have been aligned with the least squares line by graphical method. Parameter ( $\alpha$ ) was read from the graph ( $\alpha = Q_1$ ). In order to determine the parameter ( $n$ ), the point with the appropriate coordinates was selected on the line. The coordinates of this point corresponded to the maximum flow from the multi-year period ( $Q_2, T_2$ ). The read data ( $\alpha$ ), ( $Q_2$ ), ( $T_2$ ) was substituted for the rating curve equation (5) to calculate the parameter ( $n$ ):

$$Q = \alpha \cdot T^n \quad (5)$$

The values of the parameters ( $\alpha$ ), ( $n$ ), ( $H$ ), ( $H_0$ ) were substituted for the curve equation (1) to obtain the rating curve equation. Based on the rating curve equation (1) for ( $H$ ) data, ( $Q$ ) was calculated. The results are summarized on a graph (theoretical rating curve).

## 2.4 Modeling procedure using the hydroinformatic HEC – RAS program

The planned dry dam with surface area across the Osobłoga River was made in the hydroinformatic HEC – RAS program based on the guidelines named HEC – RAS Hydraulic Reference Manual [40] and User's

Manual [41]. The numerical model was made in the following stages: implementation of the Osobłoga River valley model, calibration of the model, construction of the reservoir dam and simulation of the water surface in the steady flow. The SI is agreed system of measurements in Poland therefore, calculations were made in this system. The first stage of modeling was the creation of the Osobłoga River route. In the calculation procedure used in HEC – RAS it is important that the river route is created in the direction of water flow. Then, valley cross-sections were introduced on the section from kilometer 26.100 to 33.000 of the Osobłoga River. A total of 44 cross – sections were introduced. Manning's ( $n$ ) coefficients have been introduced (one for the main channel and one for the right floodplain terrace and the left floodplain terrace) as well as contraction and expansion coefficients. After the numerical model of the valley area has been made, three existing bridges, two weirs and levees were introduced to the model. It was necessary to complement the model with additional cross-sections, near to the engineering buildings – two on the upstream and analogously on the downstream at the distances specified in the instructions for the program. The addition of cross-sections allowed the correct calculation of flow through engineering buildings. The second stage of modeling was the preliminary calibration of Manning's ( $n$ ) coefficients using the values of ( $H$ ) and ( $Q$ ) read from the rating curve 4 (RC4). The stages have been changed to the water elevations (m a.s.l.) based on the elevation of the Zero Water Level. The results of the water elevations simulation were compared with historical data, in particular on the basis of the water elevations from the flood from July 1997. After the preliminary calibration, the dry dam model was performed. All steady flow analysis were performed in mixed flow regimes. The surface area of the dry dam will have variable flow conditions.

Because the water levels will be above some bridges, the energy equation method was chosen. The gates of the dry dam are open to perform of steady flow simulation (There are boundary conditions for the dry dam).

In all calculations, the HEC – RAS program included the rating curve 4.

The following steady flow boundary conditions were applied:

1. Normal Depth was used as a downstream boundary condition. As the slope of the energy grade line was accepted the average slope of the river bed  $I=0.0018$ .
2. The rating curve 4 (RC4) was used as a upstream boundary condition

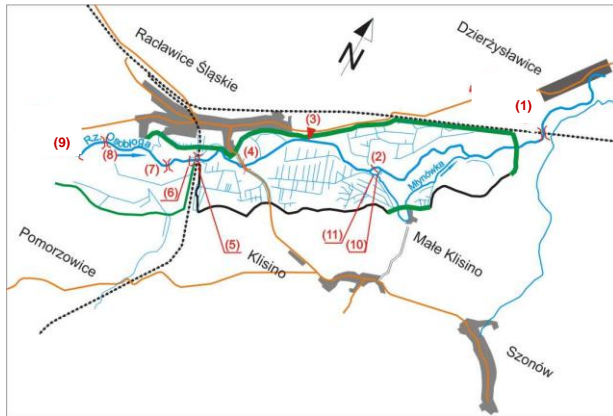
The results of the calculations were read from:

- profile plot of the Osobłoga River valley with the dry dam,
- profile output table containing the values of discharges, water surface elevations.

### 3 Results and discussion

#### 3.1 Inventory of the Osobłoga River valley

The Osobłoga River valley was inventoried from the Dzierżysław cross section (from the railway bridge located at 25.813 km of this river) to the Raclawice Śląskie cross-section (to the weir located at 33.643 km of this river). On the basis of the mapping, the map of inventoried objects was made (figure 4).



#### LEGEND:

- Small watercourses
- River
- Road
- Locality
- Railway line

- (1) – Railway bridge at km 25.813 of the Osobłoga River;
- (2) – Weir (equipped with a siphon) at kilometer 28,834 of the Osobłoga River (Width of the weir is 30.0m and height is 2.8m)
- (3) – Gauging station at km 29.850 of the Osobłoga River
- (4) – Road bridge at km 30.900 of the Osobłoga River
- (5) – The railway bridge at km 31.732 of the Osobłoga River
- (6) – Weir at km 31.812 of the Osobłoga River (Width of the weir is 50.0m and height is 2.5m)
- (7) – Road bridge at km 32.200 of the Osobłoga River
- (8) – Road bridge at km 33.150 of the Osobłoga River
- (9) – Weir at km 33.643 of the Osobłoga River
- (10) – Small hydro at km 0.090 of the Młynówka Canal
- (11) – Weir at km 0.140 of the Młynówka Canal

**Fig. 4.** The map of inventoried objects on the Osobłoga River (Geoportal.gov.pl 2012, oprac. własne).

The following watercourses have been located on the inventoried section of the Osobłoga River valley:

- The first Młynówka Canal flows into the Osobłoga River at km 27.050. Młynówka Canal has a length  $L = 2.5$  km and flows from Osobłoga in km 28.900,

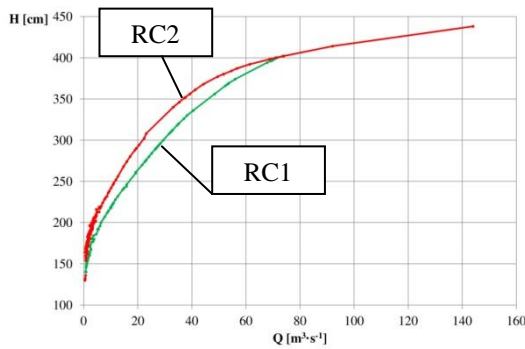
- The second Młynówka Canal flows into the Osobłoga River at km 28.700. This is a canal derivation with a length of 100m,
- from km 25.813 to km 27.250 of the Osobłoga River, on the left side of the river, there is a network of ditches,
- from km.28,840 to 30.880 of the Osobłoga River, on the right side of the river, there is an irrigation of grassland,
- from km 30.880 to km 33.643 of the Osobłoga River, on the right side of the river, there is a system of irrigation and drainage ditches.

The inventory made it possible to identify the area of the planning flood protection investment and was helpful in performing the mapping and numerical model of the reservoir. Thakali et al. [11] are of a similar opinion. They report that flooding mapping helps planning infrastructure in the flood zone. In addition, as stated by Banasiak and Krzyżanowski [8], the inventory can enable hydrological services to find the right cross – section for measurements, especially during the flood.

#### 3.2 Rating curve for the Osobłoga River in the Raclawice Śląskie profile

The analysis in period (1971 – 2010) (figure 5) showed, that there were changes in the depth of the channel, which were affected by filling of the bed. This took place in July 1997 during the flood of the millennium. Thus, in the rating curve, the points are arranged along two different curves, with a larger spread in the low states zone. Therefore, points were approximated by two rating curves. Also Michalec and others [1] in order to correctly determine the relationship of stages and discharges, in a given gauge section of the Dłubnia river, took into account the impact of changing the bottom and the weir water damming up. As they wrote, if these factors are not included into analysis, it would result in determining the inflated capacity of the Dłubnia river bed near the gauging station. As Yadav and others [3] inform that the spread of points on the rating curve is often caused by changes due to vegetation growth or bed movement. However, Krekeler and Siwale [25] report that the comparison of historical results with the results measured for the Ngwerere River in the Republic of Zambia indicates a modification of the weir.

The rating curve 1 (RC1) was prepared based on data from the period from 01.01.1971 to 5.07.1997. The rating curve 2 (RC2) was made based on data from the period from 6.07.1997 to 31.12.2010. Both curves (called empirically generated stage-discharge rating curve) were plotted on the graph (figure 5).



**Fig. 5.** Empirically generated stage-discharge rating curve of the Osobłoga River, Raclawice Śląskie profil.

The lowest recorded stage on RC1 was  $H = 136\text{cm}$  (date: September 1992), while on RC2 it reached  $H = 124\text{cm}$  (date: October 1997). Analyzing both rating curves (RC1 and RC2), it was found that with the same discharges there are different stages.

After determining the data ( $H_0$ ), ( $\alpha$ ) and ( $n$ ), they were substituted for the Harlacher equation (1) to obtain the following rating curve equations:

- equation of the rating curve 1 (RC1):

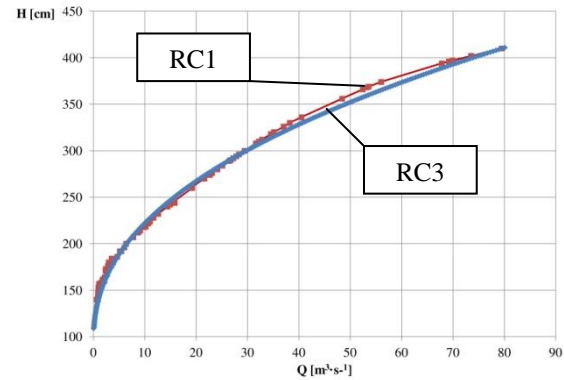
$$Q = 6(H - 1,01)^{2,29} \quad (6)$$

- equation of the rating curve 2 (RC2):

$$Q = 0,2(H - 0,31)^{4,70} \quad (7)$$

Yadav et al. [3] used the same equation (1) to determine the  $H - Q$  relationship of the rating curve for the Perennial River profile in Sikkim (India) for the period from 27.08.2011 to 29.11.2011. Krekeler and Siwale [25] did the same determining the rating curves for the following rivers: Chalimbana, Chilongolo, Chongwe, Chunga, Kapwelyomba, Mwembeshi, Ngwerere and Laughing Waters Spring located in the Republic of Zambia. Based on the rating curve equation (6), ( $Q$ ) was calculated for the ( $H$ ) data, resulting in rating curve 3 (RC3) (figure 6).

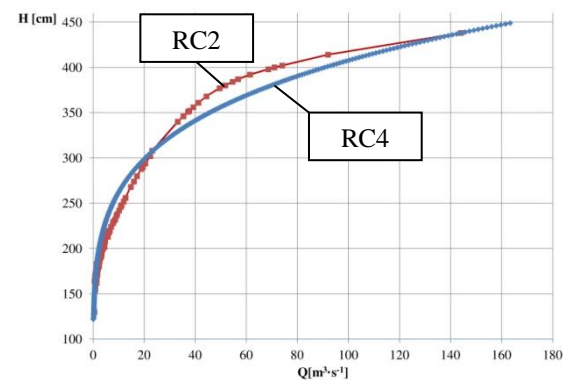
Analyzing the rating curves: empirically RC1 and theoretical RC3 for the needs of the numerical model, in terms of flows shaping the flood, it was found that the maximum stage ( $H_{\max}$ ) recorded in the analyzed period reached the value  $H_{\max} = 410\text{cm}$ , and the corresponding flow was  $Q_{\max} = 79.5 \text{ m}^3 \cdot \text{s}^{-1}$ . For  $H_{\max} = 410\text{cm}$  read from the RC3, the flow was  $Q = 79.5 \text{ m}^3 \cdot \text{s}^{-1}$ . The value of the maximum flow from the RC3 is similar to the flow  $Q_{\max}$  recorded in this period. Both curves overlap except for the interval from  $Q = 35 \text{ m}^3 \cdot \text{s}^{-1}$  to  $Q = 75 \text{ m}^3 \cdot \text{s}^{-1}$ , where the stages for the RC1 are slightly higher than on the rating curve 3.



**Fig. 6.** Empirically rating curve 1 (RC1) and theoretical rating curve 3 (RC3) of the Osobłoga River, Raclawice Śląskie profil, period from 01.01.1971 to 5.07.1997.

Based on the equation of rating curve (7), ( $Q$ ) was calculated for the ( $H$ ) data, resulting in theoretical rating curve 4 (RC4) (figure 7). Maximum stage ( $H_{\max}$ ) recorded in the period from 6.07.1997 to 31.12.2010 achieved the value  $H_{\max} = 438\text{cm}$ , and the corresponding discharge was  $Q_{\max} = 144 \text{ m}^3 \cdot \text{s}^{-1}$ . For the maximum stage  $H_{\max} = 438\text{cm}$  read from the RC4, the flow was also  $Q_{\max} = 144 \text{ m}^3 \cdot \text{s}^{-1}$ . Because the revised theoretical RC4 included the current period as opposed to the RC3, it was introduced to the HEC – RAS program, to the numerical model of the Osobłoga River valley covered by the basin of the reservoir.

These data were used to calibrate the model. Also Reistad et al. [10] used rating curves to calibrate the model indicating that it gives good results at maximum stage.

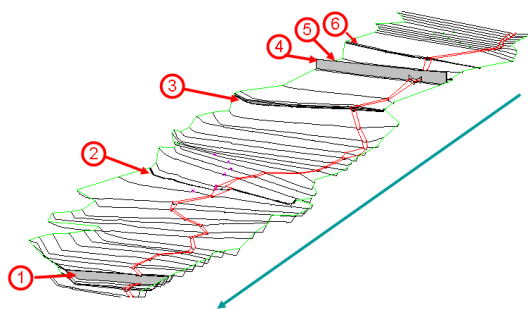


**Fig. 7.** Empirically rating curve 2 (RC2) and theoretical rating curve 4 (RC4) of the Osobłoga River, Raclawice Śląskie profil, period from 6.07.1997 to 31.12.2010.

### 3.3 The dry dam across the Osobłoga River valley in the hydroinformatic HEC – RAS program

In the model of the designed dry dam across the Osobłoga River valley (figure 8) the following data was introduced: the geometry data of the fragment of the Osobłoga River valley, existing engineering constructions, designed dry dam with side embankment

as well as boundary conditions, for which a steady flow calculation was performed.

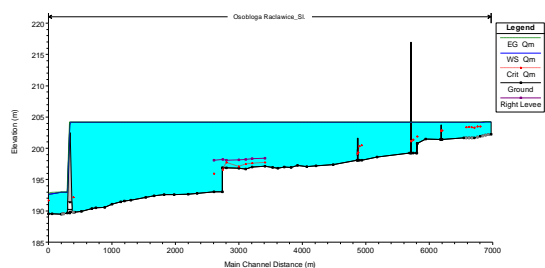


Legend:

- 1 – dry dam (at km 26.400 of the Osobłoga River),
- 2 – weir and small hydro (at km 28.834),
- 3 – road bridge (at km 30,900),
- 4 – railway bridge (at km 31,732),
- 5 – weir (at km 31,829),
- 6 – road bridge (at km 32,200).

**Fig. 8.** The numerical model of a dry dam across the Osobłoga River valley made in the HEC – RAS program.

In the numerical model of the Osobłoga River valley with the planned dry dam with surface area (of the section from km 26.100 to 33.000), there was performed the computations of the steady flow data in order water surface elevation During the steady flow computation with the maximum discharge ( $Q_{max}$ ) the Maximum Pool Elevation of the numerical model of dry dam has been reached. It is shown in figure 9.



**Fig. 9.** Profile plot of the Osobłoga River valley with the dry dam during the Maximum Pool Elevation.

The analysis of the profile allowed to determine the differences in water surface elevation in many parts of the reservoir. Therefore 4 surface areas of the reservoir were separated during its filling:

- 1) the first located on the section from the dry dam cross-section (1) to the road bridge cross - section (3) has a filling value of 204.13 m a.s.l. at the Maximum Pool Elevation;
- 2) the second located from the road bridge (3) to the railway bridge (4) has a filling value of 204.15 m a.s.l. at the Maximum Pool Elevation;
- 3) the third located between the railway bridge (4) and the cross-sections at km 32.690 of the Osobłoga River has a filling value of 204.18 m a.s.l. at the Maximum Pool Elevation;
- 4) the fourth located between the sections in km 32.690 – 33,000 of the Osobłogi river has a filling value from

204.18 to 204.24 m a.s.l. at the Maximum Pool Elevation.

## 4 Conclusion

1. The field inventory allows to create a numerical model of a dry dam. In addition, it is important to determine the location of field measurements and structures located in the area of the designed reservoir.
2. An important stage in the modeling process is proper analysis of hydrological data, including stage – discharge rating curve. The rating curve may change the course due to various reasons such as scour and fill bed channel and the impact of a hydrotechnical construction. The rating curve prepared should be compensated by determining its equation.
3. The theoretical rating curve can be used in the preliminary calibration of the numerical model of the valley.
4. On the basis of theoretical rating curve the water surface elevation for the designed reservoir at the given flow have been determined.
5. The analysis of the profile plot allowed to state that the water surface elevation is different in different parts of the reservoir. Therefore, for these parts four surface areas of the reservoir were separated during its operation.

## Acknowledgements

Acknowledgments for the Institute of Meteorology and Water Management – National Research Institute for making available the stages and discharges of the Osobłoga River in the Raclawice Śląskie profile in multi-year from 1971 to 2010 and the precipitation for the Głogów station in period 1966 – 2006. The Institute of Meteorology and Water Management – National Research Institute is the source of data Data of the Institute of Meteorology and Water Management – National Research Institute have been processed.

## References

1. B. Michalec, A. Wałęga, A. Cupak, A. Michalec, A. Połoska-Wróbel, *Acta Sci.Pol. Form. Cir.* **15**, 1, 113–124 (2016)
2. M. Wiatkowski, *Acta Sci. Pol. Form. Cir.* **14**, 3, 191–203 (2015)
3. S. R. Yadav, H. D. Singh, J. Panda, *Journal of Agroecology and Natural Resource Management* **4**, 3, 238-242 (2017)
4. A. Byczkowski, *Hydrologia* (Tom I, Wydawnictwo SGGW, Warszawa, 1999)
5. *Guide to Hydrological Practices Volume I Hydrology – From Measurement to Hydrological Information* (Sixth edition, WMO-No. 168, Last visited : 06th of July, 2018, [www.wmo.int/pages/prog/hwrrp/publications/guide/english/168\\_Vol\\_I\\_en.pdf](http://www.wmo.int/pages/prog/hwrrp/publications/guide/english/168_Vol_I_en.pdf),2008)

6. *Training module # SWDP - 29. How to establish stage discharge rating curve* (Hydrology Project. Technical Assistance, World Bank & Government of The Netherlands funded, New Delhi, CSMRS Building, 4th Floor, Olof Palme Marg, Hauz Khas, New Delhi – 11 00 16 India, DHV Consultants BV & DELFT HYDRAULICS with HALCROW, TAHAL, CES, ORG & JPS, November 1999, Last visited : 05th of July, 2018, <http://www.mahahp.gov.in/pdfFiles/resource/modules/29howtoestablishstagedischargecurve.pdf>)
7. S. E. Rantz et al., *Measurement and computation of streamflow, Volume 2, Computation of Discharge* (USGS Geological Survey Water Supply Paper 2175, U. S. Government Printing Office, Washington, 1982)
8. R. Banasiak, M. Krzyżanowski, *Meteorol. Hydrol. Water Manage.* **1**, 3 (2015)
9. K. Banasik, L. Hejduk, D. E. Woodward, J. Banasik, *Annual Set The Environment Protection* **18**, 201-212 (2016)
10. S. K. Reistad, A. Petersen-Øverleir, L. J. Bogetveit, *J. Nor. Water Assoc.* **3**, 20–30 (2007)
11. R. Thakali, R. Bhandari, G. A. Arif-Deen Kandissounon, A. Kalra, S. Ahmad, *Flood Risk Assessment Using the Updated FEMA Floodplain Standard in the Ellicott City, Maryland, United States* (World Environmental and Water Resources Congress 2017: Hydraulics and Waterways and Water Distribution Systems Analysis, 280-291, 2017)
12. M. Ren, X. He, G. Kan, F. Wang, H. Zhang, H. Li, D. Cao, H. Wang, D. Sun, X. Jiang, G. Wang, Z. Zhang, *Water* **9**, 3, 152 (2017)
13. A. Dubicki, J. Malinowska-Mąlek, K. Strońska, *Limnologia* **35**, 3, 123-131 (2005)
14. A. Dubicki, H. Słota, J. Zieliński, *Dorzecze Odry. Monografia powódź lipiec 1997* (Wyd. IMGW, Warszawa, 1999)
15. B. Lojkásek, S. Lusk, K. Halačka, V. Lusková, P. Drozd, *Hydrobiologia* **548**, 1, 11-22 (2005)
16. S. Bednarczyk, T. Jarzębińska, S. Mackiewicz, E. Wołoszyn, *Vademecum ochrony przeciwpowodziowej* (Krajowy Zarząd Gospodarki Wodnej, Gdańsk, 2006, Last visited : 14<sup>th</sup> of May, 2012, <http://www.kzgw.gov.pl/pl/Vademecum-ochrony-przeciwpowodziowej.html>, 2006)
17. A. Ciepiewski, *Podstawy gospodarowania wodą* (Wydawnictwo SGGW, Warszawa, 1999)
18. R. Głowski, R. Kasperk, W. Parzonka, *Infrastructure and Ecology of Rural Areas PAN Kraków* **8**, 2 (2010)
19. M. Wiatkowski, Ł. Gruss, *Ann. Warsaw Univ. of Life Sci. – SGGW, Land Reclam.* **49**, 3, 153–166 (2017)
20. L. Kuchar, S. Iwański, L. Jelonek, W. Szalińska, *Meteorol. Hydrol. Water Manage.* **2**, 2, 49-63 (2014)
21. *Program budowy zbiorników małej retencji w województwie opolskim* (EMPEKO, Poznań, 2007)
22. *Rozporządzenie Ministra Środowiska z dnia 20 kwietnia 2007 r. w sprawie warunków technicznych, jakim powinny odpowiadać budowle hydrotechniczne i ich usytuowanie* (Dz. U. 2007 nr 86 poz. 579)
23. L. Radczuk, R. Szymkiewicz, J. Jełowicki, W. Żyszkowska, B. Jean-François, *Ograniczanie skutków powodzi w skali lokalnej. Wyznaczenie stref zagrożenia powodziowego* (Biuro Koordynacji Projektu Banku Światowego, 2001)
24. H. Aksoy, V. S. Ozgur Kirca, H. I. Burgan, D. Kellecioglu, *IAHS-AISH Proceedings and Reports* **373**, 137-141 (2016)
25. T. Krekeler, Ch. Siwale, *Development of a Groundwater Information & Management Program for the Lusaka Groundwater Systems Technical Note NO.7. Discharge Measurements and Rating Curves of the Rivers Chalimbana, Chilongolo, Chongwe, Chunga, Kapwelyomba, Mwembeshi, Ngwerere and Laughing Waters Spring* (Hannover and Lusaka 2012, Republic of Zambia Ministry of Mines, Energy and Water Development and Federal Republic of Germany Federal Institute for Geosciences and Natural Resources, Last visited : 05th of July, 2018, [https://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Zambia/lu\\_techn\\_note\\_7.pdf?\\_\\_blob=publicationFile&v=2](https://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Zambia/lu_techn_note_7.pdf?__blob=publicationFile&v=2))
26. L. Książek, M. Wyrębek, M. Strutyński, A. Strużyński, J. Florek, W. Bartnik, *Infrastructure and Ecology of Rural Areas PAN Kraków* **8**, 1, 29-37 (2010)
27. P. Singh, V. S. P. Sinha, A. Vijhani, N. Pahuja, *International Journal of Disaster Risk Reduction* **28**, 237-250 (2018)
28. R. Ahmadian, R. A. Falconer, J. Wicks, *Journal of Flood Risk Management* **11**, S314-S328 (2018)
29. M.G.F. Werner, *Phys. Chem. Earth (B)* **26**, 7-8, 517–522 (2001)
30. *Mapa Podziału Hydrograficznego Polski* (Krajowy Zarząd Gospodarki Wodnej. iMap GISPartner [online], 2017, Last visited : 01st of June, 2017, <http://geoportal.kzgw.gov.pl/imap/>)
31. *Vodopis České republiky* (Last visited 11th of May, 2012, [http://www.trasovnik.cz/k\\_ainfcr/vodopis/vodopis.asp](http://www.trasovnik.cz/k_ainfcr/vodopis/vodopis.asp))
32. *Koncepcja budowy zbiornika Raclawice Śląskie* (PRO AQUA, 2008)
33. *Dorzecze Osobłogi* (P.P.H. ZAPOL spółka jawna Szczecin, Prudnik, 2003)
34. *Rzeki i potoki dorzecza Osobłogi* (Wyd. Stowarzyszenie Rozwoju Dorzecza Osobłogi Rynek-Ratusz, Prudnik, 2005)
35. A. Woś, *Klimat Polski* (PWN, Warszawa, 1999)
36. *Atlas podnebí Česka* (Wydawnictwo Praha: Český hydrometeorologický ústav, Olomouc: Univerzita Palackého v Olomouci, 2007)
37. M. Gutra-Korycka, H. Werner-Więckowska, *Przewodnik do hydrograficznych badań terenowych* (Wydawnictwa Naukowe PWN, Warszawa, 1996)



38. T. Kiciński, A. Byczkowski, J. Skrzynecka, M. Wicher, *Materiały do ćwiczeń z hydrologii* (Wydawnictwo SGGW, Warszawa, 1994)
39. A. Wałęga, A. Górka, A. Cupak, B. Michalec, *Acta Sci. Pol. Form. Cir.* **15**, 3, 177–186 (2016)
40. *Hydraulic Reference Manual. Version 5.0. HEC-RAS River Analysis System* (US Army Corps of Engineers, 2016)
41. *User's Manual. Version 5.0. HEC-RAS River Analysis System* (US Army Corps of Engineers, 2016)