Hydrological conditions of the Pietraszki water reservoir designed for the River Sufraganiec (Kielce)

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Abstract: The Pietraszki water reservoir is designed for the lower part of the River Sufraganiec catchment (61.43 sq km), in the area of Kielce. In those conditions water volume is designed to be about 1.4 hm$^3$, and the reservoir’s maximum depth, 4.2 m. The hydrological characteristics of the ungauged catchment of the River Sufraganiec are based upon the results of stationary field observations held in the cross-section located in the same place as the designed dam head. In the present analysis GIS techniques were also used, based on data obtained from the city’s Spatial Information System and WIOS in Kielce. Based on the Digital Elevation Model done with Airborne Laser Scanning, the reservoir area has been designated and its bathymetric and volume curves calculated. The mean annual values of specific runoff (8.8 l s$^{-1}$ km$^{-2}$), runoff coefficient (39%), runoff volume (17.2 hm$^3$), specific discharge and the filling time have been determined. The analysis also took into account the annual cycle characteristics including minimum in-stream flow calculated with the use of a number of methods. The performed analysis shows that the River Sufraganiec water resources are enough for the fast filling of the Pietraszki reservoir (depending on the season – from 22 to 114 days), even when applying the most restrictive criteria in minimum in-stream flow calculations. The ecological quality of the River Sufraganiec water in 2014 did show any significant environmental threats. The analysis shows that the quantity and quality of the River Sufraganiec water is enough for the proper functioning of the planned reservoir.

Key words: water reservoir, water resources, river, Kielce

Introduction

In the area of large cities, where natural water reservoirs do not exist, there is often a need for building such reservoirs for recreation purposes (Suligowski et al. 2014). There are two basic questions that one should answer at the stage of water reservoir design, namely whether the water resources are sufficient to use the reservoir during the whole year and whether the ecological quality of water is acceptable (Biernat et al. 2009). The issue of natural and anthropogenic water reservoirs functioning in urbanized areas is the subject of many publications (i.a. Kudelska 1992; Rzętała 2000, 2008; Ciupa 2003; Jaguś and Rzętała 2003; Bok et al. 2004; Machowski et al. 2005; Choiriński 2007; Wiśniewski 2007). Also the ecological quality of water bodies located in whole or in part within the boundaries of cities is analysed (i.a. Gutowski et al. 1982; Grochowska et al. 2004; Marszelewski and Sokalska 2014; Szymański et al. 2014).

The aim of the present paper is to analyse the hydrological conditions of the designed water reservoir, planned for recreational purposes and partially for flood defence, located at the mouth of the River Sufraganiec on the outskirts of Kielce.

The construction of a water reservoir in the area of Kielce with almost 200 thousand inhabitants is justified from the social point of view. In the city area there is a lack of reservoirs performing the above mentioned functions.

Study area

The designed Pietraszki water reservoir is situated within the administrative borders of Kielce (Suligowski et al. 2014), in the lower part of the River Sufraganiec catchment, which is a left tributary of the River Bobrza in the River Nida basin (Fig. 1). The River Sufraganiec (V order stream), is 16.13 km long, its average slope is 8.3%, and it drains a forest-rural catchment...
The total catchment area of the River Sufraganiec covers 61.98 sq km, and the catchment area reaching the planned dam, 61.43 sq km. The two-wing dam head will be situated in the breakthrough zone between Marmurek Mountain and Machnowica, at 0+450 m of the river course. It will be 1162 m long and will reach 244.8 m above sea level. In normal water level conditions (NWL) the water level will cover 68.92 hectares, which will allow the water reservoir to hold around 1.4 hm$^3$ of water. Its deepest part will be located next to the dam – in the north-western part of its head – and will amount to 4.2 m (Suligowski et al. 2014; Ciupa et al. 2015).

In the geological bedrock of the Pietraszki reservoir, there can be found lower triassic rocks and upper Permian (sandstones and mud stones with interbeds of clay stones, and conglomerates), and in the southern part of the investment, karsted Middle Devonian limestones (Filonowicz 1973) with the infiltration index from $1\times10^{-4}$ to $1\times10^{-5}$ m$^3$ s$^{-1}$. Within them the main reservoir of the underground waters GZWP 417-Kielce has been sectioned off and has been intensively exploited by the city of 200 thousand inhabitants (Prażak 2012). The analysis of hydrogeological conditions indicates that the waters from the basin can infiltrate and flow into the municipal groundwater intakes. On the surface there are quaternary rocks and sediments formed from glacial and fluvio-glacial sandy deposits (mean filtration index around $1\times10^{-3}$ m$^3$ s$^{-1}$), and underneath one can find fluvial and fluvio-glacial silt and sands (filtration index – below $1\times10^{-6}$ m$^3$ s$^{-1}$) deeply (40 m) filling in the excavation valley cut into the old base and documented with geophysical studies. In the head of the suggested water reservoir there are also organic deposits with the thickness reaching several dozen centimetres, where peat-muck soils can be discerned.

The agricultural use value of this area is low whereas the rank of its natural values is high, which is proven by the fact that almost all the area is protected in different ways (Checiny-Kielce Landscape Park, Kielce Area of Protected Landscape and Special Area of Conservation Bobrza Valley).

The water reservoir will be fed with the waters of the River Sufraganiec, which flows mostly in the northern-west part of Kielce suburbs. It receives several no name watercourses and two left-bank tributaries: the Sufraganick Stream and a stream from Czarnów. The latter receives water from 4 canal reception basins which function within the storm sewer system of the city. Their importance increases in the summer when there is more rain water outflowing through the sewer system and in the spring when the snow melts on the roads, parking sites, built-up areas, etc.

**Methods**

The River Sufraganiec has never been controlled hydrometrically by the Institute of Meteorology and Water Management (IMGW). In its mouth section, surface water monitoring functioned in the years 1998-2003 for the purpose of flood control in Kielce. In the scope of this project, stationary field observations were conducted, which included water level observations (water gauge, limnigraph), discharge measurements and rainfall measurements using a rain gauge (one day period) and a pluviograph (one hour period). Furthermore, in this period, about 90 measuring series were performed, leading to the determination of the chemical composition of water.

The location of the measuring point in the mouth of the River Sufraganiec proved to be the right decision both from the cognitive and practical point of view, because it responds to the location of the designed water reservoir dam head. Results obtained from the surface water monitoring were used for the
preliminary concept of the location of the Pietraszki water reservoir. The full 6-year series of daily discharge measurements provides valuable hydrological information enabling hydrological regime analysis, which is impossible in the case of calculation methods used for ungauged rivers. It makes it easier to calculate important hydrological characteristics such as specific runoff, runoff coefficient, runoff volume, specific discharge, minimum in-stream flow and the reservoir filling time.

Data from the city’s spatial information system and GIS technology have also been used in the analysis. On the basis of the Airborne Laser Scanning Digital Elevation Model (DEM), the reservoir area has been designated, followed by calculations of its parameters including bathymetric and volume curves.

Results

In the years 1998-2003 mean annual specific runoff (SSq) in the River Sufraganiec catchment area reaching the Pietraszki cross-section amounted to 8.8 l s⁻¹ km⁻² (Table 1). In the same period mean annual specific runoff from the Bobrza catchment area (the recipient of the River Sufraganiec) up to the Słowik cross-section (A= 307.5 km²) was lower by 24.5%. Maximum annual specific runoff (WWq) in the River Sufraganiec catchment area reaching the Pietraszki section was 250 l s⁻¹ km⁻².

The analysis of the course of maximum annual specific runoff on consecutive days of the year is also interesting as it allows its range of variation to be traced as well as the frequency and timing of occurrence of certain values. A value of 200 l s⁻¹ km⁻² was exceeded in the Pietraszki section 5 times. In the cross-section of the mouth of the River Sufraganiec, in comparison to the upper sections of this river, during the summer flood period the amount of this runoff clearly increased. It is a hydrologic effect of a large increase in the proportion of impervious land (urban sprawl) in the catchment area towards the mouth of the river (Ciupa 2009a, Ciupa 2009c, Ciupa 2009d).

The mean runoff coefficient during the study period (1998-2003) (α,) in the catchment area of the Sufraganiec amounted to 39.0% and in the catchment area of the River Bobrza reaching the Słowik section, 29.2%. The size of the runoff coefficient in the catchment area of the River Sufraganiec is comparable to the value obtained for the catchment area of the River Belnianka (38.9%) dewatering the southern part of the Łysogóry mountain range (Suligowski et al. 2009). The monthly runoff coefficient (α_m) showed high variability in time. The highest value was reached in March – 83.9% – during the spring thaw, and the lowest in July (16.7%). A similar rhythm of runoff coefficient (of slightly lower values) is observed in the River Bobrza catchment area (at Słowik).

Another important characteristic, taken into account in the design calculations for reservoirs, is the runoff volume reaching the cross-section of the streambed at a certain time. The mean annual runoff volume in the Pietraszki cross-section in the period 1998-2003 amounted to 17.22 hm³. In the winter season (November to April) the mean was 10.93 hm³ and in the summer (May-October), 6.29 hm³. The maximum mean monthly runoff volume in the annual cycle occurred in April – 2.63 hm³ – and the minimum in September, 0.62 hm³. It is worth noting that in 1999, the total documented runoff reached 22.7 hm³ in the analysed cross-section, while in 2003 only 10.9 hm³.

For the analysis of the discharge regime and assessment of water resources the values of characteristic discharges are used. In the study period, the mean annual discharge (SSQ) in the Pietraszki cross-section amounted to 0.544 m³ s⁻¹, the lowest – 0.057 m³ s⁻¹, and the highest - 15.53 m³ s⁻¹ (Table 1). The discharge regime of the River Sufraganiec can be described as complex, with two peaks during the year. The maximum mean monthly discharge of SSQ in the Pietraszki cross-section occurred in April (1.016 m³ s⁻¹) (Fig. 2). This was due to the spring thaw and simultaneous high precipitation accompanied by relatively high moisture content. The second maximum discharge SSQ occurred in June (0.655 m³ s⁻¹).

In July, when vegetation was fully developed, the mean discharge decreased to 0.523 m³ s⁻¹. The lowest mean discharge (0.239 m³ s⁻¹) was observed in September due to the low precipitation (48.4 mm) and still relatively high temperatures (12.4°C), which
caused evaporation. The maximum daily discharge (WWQ) occurred on a monthly basis in April (15.53 m$^3$ s$^{-1}$), and was a little lower in July (15.34 m$^3$ s$^{-1}$). It can be expected that further development of urbanization in the lower part of the catchment (west districts of Kielce) will contribute to the growth in extremely high discharges caused by heavy storm rains during the summer months (Ciupa 2009a).

Another characteristic, valuable from the point of view of the functioning of a small water reservoir, is to know the size of the regularity coefficient in mean annual discharges ($\lambda_r = WSQ_r/NSQ_r$). It defines, in an indirect way, the dynamics of variability of water resources in dry and wet years in a multi-year period. In the period 1998-2003 it amounted to $\lambda_r = 2.07$.

The proper functioning of a flow-through water reservoir requires the minimum in-stream flow to be preserved, for the maintenance of organic life in the watercourse and in the ecosystems related to the course below the dam. This flow is discriminated by different methods (Witowski et al., 2001) i.a.: through the multi-criteria Kostrzewa method, the Stochliński method (the Malopolska method), and the method of the National Fund for Environmental Protection and Water Management. In the present work, the minimum in-stream flow discerned with the use of the Kostrzewa method (Kostrzewa 1977) was calculated according to three criteria: hydro-biological, fishing and the protection of natural objects. According to the first criterion – recommended by the Regulation of the Director of the Regional Water Management Board in Krakow of 16 January 2014 (RZGW 2014) – the minimum in-stream flow ($Q_{n_h}$) is calculated with the following formula:

$$Q_{n_h} = k \cdot SNQ, \text{ where } Q_{n_h} > NNQ \quad (1)$$

where:

- $Q_{n_h}$ – minimum in-stream flow according to the hydro-biological criterion (m$^3$ s$^{-1}$),
- $SNQ$ – mean low discharge (m$^3$ s$^{-1}$),
- $NNQ$ – the lowest discharge (m$^3$ s$^{-1}$),
- $k$ – the coefficient depending on the river regime and the surface of the catchment area; $k=1.27$ was adopted (hydro-biological river type: transitional and submountain; catchment area smaller than 500 km$^2$).

The mean annual discharge according to the hydro-biological criterion is 0.268 m$^3$ s$^{-1}$ (Table 2). In particular months it was subject to slight fluctuations from 0.205 (September) to 0.382 m$^3$ s$^{-1}$ (April).

The minimum in-stream flow that takes into account the requirements of fishing (fish survival) results from assigning the river to one of the two ichthiological types (rivers with salmonids and lowland fish). Depending on the ichthiological type of a river, characteristic periods of the fish life cycle are determined – the period of spawning and breeding, the period of growth of juvenile fish and feeding, and the wintering period. The River Sufraganiec is a habitat for salmonid fish and their spawning period falls in March-April or September-November, the period of growth in May.
Hydrological conditions of the Pietraszki water reservoir designed for the River Sufraganiec (Kielce) and August, and the wintering covers the months from December to February. For these periods, the mean monthly low discharges were compared and the lowest of them selected:

\[ Q_{n-rw} = \min\{SNQ_1, SNQ_2, \ldots, SNQ_k\} \]  

where:

\( Q_{n-rw} \) – minimum in-stream flow according to the fishing criterion (for the period related to a particular phase of the fish life cycle: spawning and reproduction, growth and wintering) \( (m^3 s^{-1}) \),

\( SNQ_1, SNQ_2, \ldots, SNQ_k \) – mean low discharge in particular months of the studied fish life period \( (m^3 s^{-1}) \),

Therefore, on the basis of this criterion, not one but several of the minimum in-stream flow values are calculated in the characteristic periods distinguished. According to this criterion, in the particular periods, the minimum in-stream flow amounts to the following values: spawning and reproduction (March-April or September-November) – 0.193 \( m^3 s^{-1} \); feeding and juvenile growth (May-August) – 0.177 \( m^3 s^{-1} \); and wintering (December-February) – 0.164 \( m^3 s^{-1} \) (Table 3).

Due to the fact that the designed reservoir is located in a landscaped park and in the Natura 2000 site, it is advisable to recognize the size of the minimum in-stream flow according to the criterion of nature conservation \( (Q_{n-op}) \). This discharge is usually the subject of individual studies. Frequently it includes the protection against areas drying out. Because of the need to take into account the seasonal water flow fluctuations in rivers and their impact on the water plant habitat areas, the issue is analysed in particular hydrological seasons: winter (December-February), spring (March-April), summer (May-August), autumn (September-November). In each of these seasons, two discharge values are determined – the upper limit of the discharge of soil origin identified with \( WNQ \) and lower discharges \( (NNQ) \). The minimum in-stream flow in different seasons must be higher than \( NNQ \) (Table 4).

### Table 2. Minimum in-stream flow according to the hydro-biological criterion of the Kostrzewa method \( (Q_{n-h}) \) and the Małopolska method \( (Q_{n-m}) \)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Month</th>
<th>XI</th>
<th>XII</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kostrzewa method – ( Q_{n-h} ) [m^3 s^{-1}]</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hydro-biological criterion</td>
<td></td>
<td>0.287</td>
<td>0.208</td>
<td>0.240</td>
<td>0.305</td>
<td>0.370</td>
<td>0.382</td>
<td>0.246</td>
<td>0.251</td>
<td>0.225</td>
<td>0.231</td>
<td>0.205</td>
<td>0.266</td>
<td>0.268</td>
</tr>
<tr>
<td>Małopolska method – ( Q_{n-m} ) [m^3 s^{-1}]</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>complex ecological state of the stream</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>good*</td>
<td></td>
<td>0.226</td>
<td>0.164</td>
<td>0.189</td>
<td>0.240</td>
<td>0.291</td>
<td>0.301</td>
<td>0.193</td>
<td>0.198</td>
<td>0.177</td>
<td>0.182</td>
<td>0.161</td>
<td>0.209</td>
<td>0.211</td>
</tr>
<tr>
<td>moderate*</td>
<td></td>
<td>0.146</td>
<td>0.115</td>
<td>0.169</td>
<td>0.187</td>
<td>0.213</td>
<td>0.263</td>
<td>0.137</td>
<td>0.140</td>
<td>0.117</td>
<td>0.119</td>
<td>0.109</td>
<td>0.156</td>
<td>0.134</td>
</tr>
</tbody>
</table>

* good = \( SNQ \); **moderate = \( NNQ + \frac{SNQ - NNQ}{2} \)

and August, and the wintering covers the months from December to February. For these periods, the mean monthly low discharges were compared and the lowest of them selected:

\[ Q_{n-rw} = \min\{SNQ_1, SNQ_2, \ldots, SNQ_k\} \]  

Table 3. Minimum in-stream flow \( Q_{n-rw} \) \( (m^3 s^{-1}) \) according to the fishing criterion

<table>
<thead>
<tr>
<th>Spawning and reproduction</th>
<th>Winter</th>
<th>Feeding and juvenile growth</th>
<th>Summer</th>
<th>Wintering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period ( III-IV )</td>
<td>0.193</td>
<td></td>
<td>V-VIII</td>
<td>0.177</td>
</tr>
<tr>
<td>IX-XI</td>
<td>0.209</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Małopolska method assumes that the value of the minimum in-stream flow, which is intended to provide adequate living conditions for fish, should be calculated separately for each month and be based on the hydro-biological flow. Its value depends on the assumed ecological state of the course, referred to as
good or moderate (Table 2). The minimum in-stream flow calculated by the National Foundation for Environmental Protection and Water Management is equated with the mean low discharge (SNQ), and at the same time reflects the values of the minimum in-stream flow with a good ecological status of the river determined with the use of the Małopolska method (Table 5). In the following parts of this paper, the results of calculations of minimum in-stream flow were adopted at the most restrictive level, i.e. according to the Małopolska method.

The bathymetric curve was made on the basis of the digital elevation model, after its preprocessing including terrain smoothing, for two levels of the reservoir fill – normal (244.0 m a.s.l.) and maximal (244.4 m a.s.l.). Finally, a bathymetric map was drawn (Fig. 3). To allow clear representation, isobaths were drawn only with 0.5 m intervals (NWL). For the curve creation an area calculation between isobaths with 5 cm intervals was made. The deepest part of the reservoir (-4.2 m) is situated next to the dam head in the SW part of the reservoir. In this zone there are many areas with depths exceeding -3.5 m (15% of the reservoir’s NWL area and 20% of the reservoir’s MWL area). The upstream part of the reservoir is shallow, where depths do not exceed -1 m.

The bathymetric curve allowed the area of the designed reservoir to be calculated for every fill level (Fig. 4). The water body area during NWL conditions is 68.92 hectares, during MWL conditions, 74.37 hectares, while the shoreline is almost identical in both cases.

As the next step, a water volume curve was drawn, and the reservoir’s water volume was calculated for both water levels (NWL 1 373.7 dam$^3$ and MWL 1 668.3 dam$^3$). The results indicate that the reservoir’s flood reserve will amount to nearly 300 dam$^3$, which would take up a whole large flood wave. A high flood volume (267 dam$^3$) was observed between 15th and 17th July 1999 in the cross-section closing the River Sufraganiec catchment area. It was caused by a 4-hour storm with 45.4 mm of rainfall. The analysis shows that the functioning of the reservoir in this area would help to avoid the overlapping of high flood waves of the River Silnica, downstream the River Bobrza (where there is no flood control reservoir) and of the River Sufraganiec, which would reduce the risk of flooding in the district of Bialogon and in the area of the sewage treatment plant “Sitkówka” (Ciupa and

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>XI</th>
<th>XII</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSQ [m$^3$s$^{-1}$]</td>
<td>0.376</td>
<td>0.456</td>
<td>0.614</td>
<td>0.754</td>
<td>0.933</td>
<td>1.016</td>
<td>0.379</td>
<td>0.655</td>
<td>0.523</td>
<td>0.295</td>
<td>0.239</td>
<td>0.284</td>
</tr>
<tr>
<td>SNQ [m$^3$s$^{-1}$]</td>
<td>0.226</td>
<td>0.164</td>
<td>0.189</td>
<td>0.240</td>
<td>0.291</td>
<td>0.301</td>
<td>0.193</td>
<td>0.198</td>
<td>0.177</td>
<td>0.182</td>
<td>0.161</td>
<td>0.209</td>
</tr>
<tr>
<td>$\Delta Q = SSQ - SNQ$ [m$^3$s$^{-1}$]</td>
<td>0.150</td>
<td>0.292</td>
<td>0.425</td>
<td>0.514</td>
<td>0.642</td>
<td>0.715</td>
<td>0.186</td>
<td>0.457</td>
<td>0.346</td>
<td>0.113</td>
<td>0.078</td>
<td>0.075</td>
</tr>
<tr>
<td>$\Delta M = \Delta Q \times t$ [m$^3$ d$^{-1}$]</td>
<td>12960</td>
<td>25229</td>
<td>36720</td>
<td>44410</td>
<td>55469</td>
<td>61776</td>
<td>16070</td>
<td>39485</td>
<td>29894</td>
<td>9763</td>
<td>6739</td>
<td>6480</td>
</tr>
</tbody>
</table>

$\Delta M$ = the number of seconds per day
The time of filling the reservoir was determined on the basis of monthly mean and minimum in-stream flow. It made it possible to designate disposable discharge (ΔQ) followed by dispositional resources (ΔM) to be used when filling the reservoir (Table 5).

The presented hydrological analysis shows that it would be the most profitable to start filling the Pietraszki reservoir in the spring months. The theoretical time to fill the reservoir to its normal water level conditions (NWL) would take 25 days in March and 22 days in April. Assuming that the reservoir began to be filled on 1st June, it would take 36 days (until 6th July). On the other hand, it would be advisable to avoid this kind of works in the autumn: if started on 1st September the filling would last until the 24th December. The above calculation does not take into account the results of the initial losses associated with infiltration and evaporation from the free, enlarging water surface. The estimated time of filling the designed reservoir, even in the worst period, is still relatively short. Extensions of this time of up to one month do not make much difference from the point of view of its functioning. The documented water resources of the River Sufraganiec are therefore sufficient for the reservoir to be able to function here. At the stage of the concept development of the location of the reservoir, it is of key importance to identify and analyse the quality of its supplying waters, as well as any potential threats to the aquatic environment in the whole catchment area. It is also important to determine the type and amount of pollutants transported by the river and the pollution limits from the point of view of preserving the ability of the environment to self-purify.

Fig. 4. Bathymetric curve (A) and capacity curve (B) of the designed Pietraszki Reservoir
The results of the study performed under the local monitoring of water quality in the city of Kielce, the River Sufraganiec included, in the years 1998-2003 indicate that its condition worsened towards the river mouth. Among 45 water quality measurement series in the mouth cross-section of the River Sufraganiec, the first class of water quality was recorded twice, and unclassified waters as many as 20 times, while above the designed reservoir in the Niewachłow cross section, 6 times, and 15 times respectively. The cause of lower water quality in the analysed measurement series was mainly due to water quality standards being exceeded in the case of nitrates, phosphorus and phosphates. Water quality was also lowered by high phenol concentrations, and in a number of observations, heavy metals including zinc and lead (Ciupa 2006a,b; 2009a,b).

The current water quality classification system applies to separate sections of rivers called uniform parts of water bodies (MŚ 2004). In 2010 the upstream part of the River Sufraganiec – Podgórze hydro-metrical cross-section (PLRW200062164869) – was distinguished as a uniform water body. However, in this period, chemical and ecological properties of the water were not analysed. The assessment of chemical and biological water quality of the Sufraganiec in 2012 and 2013 showed that it belonged to the third class in terms of biological criteria and to the second class in terms of physiochemical criteria (WIOŚ 2013). The status and ecological potential have been defined here as moderate. It should be noted, however, that at the same time the adjacent rivers were characterized by a weak (River Silnica) and a bad (River Bobrza) status and ecological potential.

The above mentioned pollutant concentrations in the River Sufraganiec waters could periodically worsen the quality of water in the designed reservoir. The main pollutants are nitrogen, phosphorus and chloride compounds. Biogenic substances could enhance intensive phytoplankton growth and overgrowing of the coastal zone. In 2014 a significant improvement in the River Sufraganiec water quality state was recorded. It was then classified as first class in terms of physio-chemical properties (physical state, oxygen content, salinity, acidification, biogenic substances), as second class in terms of hydro-morphological criteria, and as third class in terms of biological criteria. The ecological status and potential were described as moderate and the chemical as poor (WIOŚ 2015).

Conclusions

In the lower part of the River Sufraganiec catchment (in the city of Kielce) the Pietraszki flood water reservoir is being designed covering an area of 68.92 hectares and with a capacity of 1.4 million m³ of water. Within the designed reservoir there is a large diversity of depths, the largest being 4.2 metres.

A detailed hydrological analysis of the River Sufraganiec catchment area of 61.43 km² (reaching the cross-section of the dam), made on the basis of stationary field research conducted in the years 1998-2003, identified the following characteristics:

1. Mean annual discharge reached 0.544 m³ s⁻¹, the lowest was 0.057 m³ s⁻¹, and the highest, 15.53 m³ s⁻¹.
2. Mean annual specific runoff amounted to 8.8 l s⁻¹ km⁻² (maximum – 250 l s⁻¹ km⁻²), runoff coefficient was 39%, and runoff volume, 17.2 hm³.
3. The discharge regime of the River Sufraganiec can be described as complex, with two maxima within the year (spring: March-April and summer: June). During summer freshets high runoff was observed, which was the hydrological result of a rapid increase in impermeable areas in western parts of the city.
4. Minimum in-stream flow, calculated with the use of different methods, clearly indicates sufficient water resources during a whole year to sustain aquatic life in the River Sufraganiec below the designed reservoir at the time of its functioning. Taking into account the most restrictive criterion of the Małopolska method calculated for a good state of ecosystem functioning, mean annual minimum in-stream flow is – 0.211 m³ s⁻¹, and monthly flow from 0.161 m³ s⁻¹ (September) to 0.301 m³ s⁻¹ (April).
5. The time needed to fill the reservoir, in terms of preserving the minimum in-stream flow, will reach from the shortest 22 day period in spring to 114 days in autumn.
6. The flood reserve, within the designed reservoir’s parameters, will reach almost 300 thousand m³, which will allow a whole flood wave caused by a few hours’ rainfall reaching up to 45 mm to be captured. It could reduce flood risk in the Białogon district and in the area of “Sitkówka” sewage treatment plant.
7. Water quality of the River Sufraganiec in 2014 was significantly improved in comparison to previous years, reaching the first class in terms of physico-
chemical criteria, the second class in terms of hydro-morphological criteria and the third class in terms of biological criteria. The ecological state and potential were determined as moderate.

To sum up, the resources of waters flowing in the catchment area of the River Sufraganiec are sufficient for the designed reservoir to function properly and their current quality status does not indicate that there exist any significant environmental threats.

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