The functioning of drainage canal near barrage “Brzeg Dolny” on the Odra River in 1971–2009

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Abstract

The paper analyses the amount of water flowing into the drainage canal in comparison to the levels of the Odra waters in the Brzeg Dolny – Wały cross section (upper water in the barrage). The results of the measurement of the flow intensity in the canal in 1971–2009 provided the basis for the evaluation.

The analysis led to the conclusion that with the same ordinate of damming in the barrage the average yearly flow in the canal in the Warzyna section decreased from 196 m³·s⁻¹ to about 80 dm³·s⁻¹ as the Odra’s riverbed and the area between the embankments became tighter. The flow into the canal changes in time and depends on the difference between water levels in the Odra and in the canal. The paper presents the dynamics of changes in the water flow into the canal in relation to 1 m of difference between the level of water in the Odra and the drainage canal. It was shown that in a similar location, ground and water conditions as well as similar damming levels, the value of the drained water can be estimated to be about 35–40 dm³·s⁻¹·km⁻¹ for 1 meter of difference of the water level in the river and the canal.

Key words: barrage, damming, drainage canal, percolating water, water flow

INTRODUCTION

The building of the barrage in Brzeg Dolny in 1958 changed the Odra’s character in relation to the adjoining areas, above the barrage the Odra became the infiltrating river [PŁYWACZYK 1988; 1997; SZYMAŃSKI, PŁYWACZYK 1988]. After the barrage was build, shallow draining ditches were dug, yet part of the area was still flooded and hence could not be used for agricultural purposes. Between 1958 and 1960 the Jeziorka River was regulated so as to drain the areas threatened with flooding. The water level in the Jeziorka decreased by about 1 meter, yet during summer the riverbed was overgrown by plants and the draining system didn’t function properly [OLSZEWSKA 1988; PŁYWACZYK 1988]. In 1967 deep drainage canal was dug along the side dike of the reservoir. The paper presents the results of amount of water flowing into the drainage canal in the Warzyna section in relation to the level of water in the Odra River in upper water section in the Brzeg Dolny barrage.

Recognition of factors affecting the development of water relation forming in the river valley, in conditions of damming and free-flowing river, is essentials in designing, execution and exploitation of land-improvement systems [CHALFEN et al. 2005; 2010].

STUDY AREA

The barrage “Brzeg Dolny” is located on 281.77 km of the Odra River, about 21 km below the barrage “Rędzin” and about 3 km up the river from the town
Brzeg Dolny itself. According to regulations from the Minister for Environmental Protection, Natural Resources and Forestry Regulation of December 20, 1996 on technical conditions to which water management buildings and their location should adhere (OJL 2007, item 86, point 579), the main buildings of barrage “Brzeg Dolny” should be classified as hydro-technical buildings of 2nd class of importance. The barrage closes the basin of the area of 263,811 km². It is located in the section Brzeg Dolny, situated about 500 m below the weir. The particular appliances of the barrage have the following discharge capacity [MOKWA 2002]:
- water power plant: 4 x 60 = 240 m³·s⁻¹;
- fish ladder: 4.30 m³·s⁻¹;
- canal lock during locking: 21.66 m³·s⁻¹;
- weir when water is flowing above the gates and damming elevation up to 108.00 m a.s.l. (normal water level): 330 m³·s⁻¹;
- weir when the water is flowing under the gate valves and damming elevation up to 108.00 m a.s.l. (normal water level) when the valve is raised to: 1.5 m – 710 m³·s⁻¹; 2.0 m – 865 m³·s⁻¹; 3.0 m – 1120 m³·s⁻¹; 4.0 m – 1300 m³·s⁻¹; 5.0 m – 1420 m³·s⁻¹ (all spans in operation).

After building the barrage in Brzeg Dolny the Regional Board of Water Management in Wrocław established the elevation on the weir on 107.00 m. In 1960 this elevation was raised to 108.00 m a.s.l. In 1980 this elevation was raised to 108.00 m and such value is valid until today [AR Wroc. 1971–2012]. The measurements of water levels in the Odra above the barrage are conducted in upper part of the barrage.

The damming by the barrage Brzeg Dolny by about 5.8 m changed the way in which the river affects the adjoining areas. Building of the barrage changed the Odra’s character in relation to the adjoining areas – above the barrage it became infiltrating river, below the barrage Odra is still draining river [OLSZEWSKA et al. 2012].

The leakage from the water reservoir began to infiltrate into the left bank areas and the raising of groundwater table made it difficult to keep the existing way of using the area. The water and ground conditions in this part of the Odra valley foster the infiltration to adjoining areas. Under the shallow layer of alluvial soils, consisting of clays, there are easily permeable layers of sands, gravel and sand and gravel mix, constituting the water bearing layer. The infiltration coefficient is between 1.0·10⁻³ to about 1.6·10⁻¹ cm·s⁻¹ [PLYWACZYK 1988].

After the barrage “Brzeg Dolny” was built, when the level of water in the Odra was high enough, the water began to infiltrate the valley, the groundwater table rose and pressure conditions were created in part of the area. The flooding and swamping of the agricultural grounds were unacceptable, therefore the actions aiming at draining the area between the Odra and the Jeziorka were undertaken. The first attempt to protect the left-bank areas was the project from 1955–1959, which relied on strengthening the embankment from the water side and designing shallow banding ditches, which were supposed to catch the excess water. This solution proved to be ineffective [HAMADI 1989; LENCZEWSKI 1982].

The next attempt was regulating the Jeziorka stream, which was finished in 1960, and which was supposed to catch the percolating waters. The riverbed was broadened and deepened. After this, the level of water in the Jeziorka decreased by about 1 m. Yet the improvement was only temporary, because during the vegetation period the riverbed was overgrown by the water plants and the attempts to control it were ineffective in the long run. Later there were many ideas of how to channel the percolating waters, but they were not accepted for various reasons such as difficulties in introducing them, high costs and little effectiveness. The project of channeling the percolating waters by gravity below the barrage in Brzeg Dolny using deep drainage canal was the first one which seemed to offer the possibility of success. In 1967 the drainage canal of the following parameters was put into operation:
- length: 5.5 km,
- average depth: 2.2 m,
- the bottom width: 0.5–2.5 m,
- elongated slope: 0.4‰,
- average distance from left bank embankments: 80 m.

Reference sketch of the construction is presented in Figure 1.

The researches conducted directly after digging the canal showed that the water flow into it depends mostly on the hydrogeological conditions, the elevation of water in the Odra and technical parameters of this canal [NAWALANY, PŁYWACZYK 1988a, b; PŁYWACZYK 1997; PŁYWACZYK et al. 1992].

**MATERIAL AND METHODS**

The aim of this paper is to analyze the amount of water flowing into the drainage canal in the Warzyna section in relation to the level of water in the Odra in upper water section in the Brzeg Dolny barrage. A number of periods were analyzed: 1971–1972.
The functioning of drainage canal near barrage “Brzeg Dolny” on the Odra River in 1971–2009


- daily observations of water level in the Odra in the Brzeg Dolny section – upper water in barrage,
- daily observations of water levels in drainage canal in the Warzyna section,
- regular (on average, twice a month) measurements of flow rate of water in the drainage canal in the Warzyna section and in the junction connecting the canal with the Jeziorka stream. The details concerning the junction of the drainage canal with the Jeziorka are shown in Figure 2.

The measurements and observations of everyday water levels provide the basis to draw the appropriate flow rate curves. Using the curves drawn for every year, as well as the water levels and the seasonal coefficient of level reduction (used because of plants overgrowing the canal) daily, average monthly and periodical flow rates were determined [AR Wroclaw 1971–2009]. Since 2003 the flow rate measurements were conducted in the junction (situated about 400 m below the section in Warzyna) connecting the drainage canal with the ditch channeling water into the Jeziorka. When the water level in the Odra is high (and the reflexive valve in the embankment opening is closed) and with the appropriate steering of water gates in the junction, the water from the canal is channeled to the Jeziorka.

The flow rate in drainage canal \( Q \), depending of the direction of water flow in the ditch connecting drainage canal with the Jeziorka, was calculated according to the following formula: \( Q = Q_w \pm Q_r \), where:

- “+” – when the water is flowing to the Jeziorka,
- “−” – the water from the Jeziorka flows into drainage canal,

\( Q_w \) – the flow rate in the canal in the junction,
\( Q_r \) – the flow rate in the ditch.

RESULTS AND DISCUSSION

Table 1 presents semiannual, annual and monthly average water levels in the Odra in upper water section in the barrage Brzeg Dolny in the analyzed periods, whereas Table 2 presents appropriate values of average monthly, semiannual and annual flow rates in drainage canal in the Warzyna section.

Table 1. Average monthly, semiannual and annual water levels (cm) in the Odra River on the barrage Brzeg Dolny – upper water on the barrage

<table>
<thead>
<tr>
<th>Years</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>XI–IV</th>
<th>V–X</th>
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<tr>
<td>1981–1982</td>
<td>765</td>
<td>745</td>
<td>723</td>
<td>728</td>
<td>777</td>
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<td>774</td>
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<td>774</td>
<td>776</td>
<td>769</td>
<td>767</td>
<td>754</td>
<td>772</td>
<td>763</td>
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<tr>
<td>1986–1988</td>
<td>771</td>
<td>772</td>
<td>732</td>
<td>734</td>
<td>754</td>
<td>770</td>
<td>756</td>
<td>754</td>
<td>754</td>
<td>768</td>
<td>771</td>
<td>761</td>
<td>752</td>
<td>761</td>
<td>756</td>
</tr>
<tr>
<td>2003–2004</td>
<td>733</td>
<td>741</td>
<td>759</td>
<td>744</td>
<td>714</td>
<td>730</td>
<td>735</td>
<td>723</td>
<td>716</td>
<td>735</td>
<td>733</td>
<td>735</td>
<td>737</td>
<td>730</td>
<td>733</td>
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<td>2007–2009</td>
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<td>724</td>
<td>728</td>
<td>711</td>
<td>706</td>
<td>718</td>
<td>724</td>
<td>720</td>
<td>690</td>
<td>713</td>
<td>716</td>
<td>726</td>
<td>718</td>
<td>715</td>
<td>717</td>
</tr>
</tbody>
</table>

Source: own study.

Table 2. Average monthly, semiannual, annual values of the flow rates (dm³·s⁻¹) in the drainage canal in the Warzyna section

<table>
<thead>
<tr>
<th>Years</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>XI–IV</th>
<th>V–X</th>
<th>XI–X</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971–1972</td>
<td>205</td>
<td>184</td>
<td>177</td>
<td>183</td>
<td>191</td>
<td>210</td>
<td>203</td>
<td>211</td>
<td>195</td>
<td>197</td>
<td>193</td>
<td>201</td>
<td>192</td>
<td>200</td>
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<tr>
<td>1986–1988</td>
<td>208</td>
<td>218</td>
<td>190</td>
<td>190</td>
<td>178</td>
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<td>195</td>
<td>227</td>
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<td>188</td>
<td>171</td>
<td>172</td>
<td>200</td>
<td>189</td>
<td>194</td>
</tr>
<tr>
<td>1995–1996</td>
<td>152</td>
<td>123</td>
<td>95</td>
<td>92</td>
<td>127</td>
<td>171</td>
<td>173</td>
<td>171</td>
<td>120</td>
<td>152</td>
<td>166</td>
<td>182</td>
<td>127</td>
<td>161</td>
<td>144</td>
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<td>1998–1999</td>
<td>193</td>
<td>194</td>
<td>197</td>
<td>189</td>
<td>224</td>
<td>158</td>
<td>165</td>
<td>157</td>
<td>120</td>
<td>98</td>
<td>125</td>
<td>120</td>
<td>193</td>
<td>131</td>
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<td>2003–2004</td>
<td>94</td>
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<td>108</td>
<td>97</td>
<td>80</td>
<td>73</td>
<td>61</td>
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<td>52</td>
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<td>57</td>
<td>93</td>
<td>92</td>
<td>66</td>
<td>79</td>
</tr>
<tr>
<td>2007–2009</td>
<td>63</td>
<td>55</td>
<td>93</td>
<td>108</td>
<td>90</td>
<td>98</td>
<td>74</td>
<td>77</td>
<td>90</td>
<td>91</td>
<td>69</td>
<td>56</td>
<td>85</td>
<td>76</td>
<td>80</td>
</tr>
</tbody>
</table>

Source: own study.
The water levels in upper part of barrage in Brzeg Dolny during the analyzed periods varied, which was the effect of both different flow rates in the Odra, and also exploitation conditions of the barrage resulting from different elevation in subsequent periods. Average monthly elevation in upper water in the Odra between 1971–1972 (while elevation was established at 107.00 m a.s.l.) assumed values between 660–696 cm. After raising the elevation to 108 m a.s.l. in 1980 the average monthly water level in the Odra amounted to 723–772 cm between 1981–1982, and to 732–772 cm in 1986–1988. During next analyzed periods (after establishing the elevation at 107.50 m a.s.l.), the respective levels of upper water amounted to 705–741 cm between 1995–1996, 670–743 cm between 1998–1999, 714–759 cm between 2003–2004 and 690–728 cm between 2007–2009.

The flow of percolating waters from the reservoir into the drainage canal during the whole year is steady and depends mainly on the water levels in the Odra. After putting the canal into operation (1971–1972) the average monthly flow rates amounted to 177 to 211 m³·s⁻¹, average annual flow rate was 196 m³·s⁻¹. Until the flood in June 1997 the decreasing of percolating waters flow into the canal was observed. Between 1995–1997 the average monthly flow rates were between 92 to 182 m³·s⁻¹. After the flood in 1997 in subsequent months of 1998 and between November 1998 and April 1999 the average monthly flow rates observed were higher, 142–231 dm³·s⁻¹ and 142–276 dm³·s⁻¹ respectively. The average yearly flow rate in 1998 amounted to 173 dm³·s⁻¹ [OLSZEWSKA 1998; YWACZYK 1997].

The average monthly flow rates in the canal in the Warzyna section between 2003–2004 fluctuated from 52 to 108 dm³·s⁻¹, average annual flow rate was 71 dm³·s⁻¹, and in the next analyzed period (2007–2009) it reached values ranging from 55 to 108 dm³·s⁻¹.

Figure 3 presents the decreasing flow into the canal for different elevation levels in the barrage Brzeg Dolny. As the water level in the Odra is rising, the water flow into the drainage canal is rising too, however due to the process of the Odra’s riverbed and the area between embankments becoming more impermeable it is observed that the percolation values are decreasing in subsequent periods at the same elevation in the weir.

The data concerning daily flow rates in the drainage canal QK and water levels in the Odra in the Brzeg Dolny HO section allowed to determine the relationship between those values. Table 3 presents the collation of equations of relationship between the flow in the drainage canal and the water level in the Odra in the upper water section in the barrage. The critical value of correlation coefficient with the assumed significance level α = 0.01 equaled 0.56. Figure 4 presents the determined linear correlation between flow rate in the drainage canal in the Warzyna section and upper water level in the Odra in the Brzeg Dolny barrage within the analyzed period between 1971 and 2009.

Table 3. Equations showing relationship between flow rate Q in the drainage canal in the Warzyna section and upper water levels HO in the Odra in the Brzeg Dolny barrage

<table>
<thead>
<tr>
<th>Years</th>
<th>Equation</th>
<th>Correlation Coefficient</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971–1972</td>
<td>Q = 92.800HO – 9716</td>
<td>0.99</td>
<td>4</td>
</tr>
<tr>
<td>1981–1982</td>
<td>Q = 94.390HO – 9948</td>
<td>0.97</td>
<td>16</td>
</tr>
<tr>
<td>1987–1988</td>
<td>Q = 94.270HO – 9944</td>
<td>0.89</td>
<td>44</td>
</tr>
<tr>
<td>1995–1996</td>
<td>Q = 98.040HO – 10370</td>
<td>0.92</td>
<td>23</td>
</tr>
<tr>
<td>1998–1999</td>
<td>Q = 72.544HO – 7625</td>
<td>0.70</td>
<td>16</td>
</tr>
<tr>
<td>2003–2004</td>
<td>Q = 62.110HO – 6590</td>
<td>0.77</td>
<td>18</td>
</tr>
<tr>
<td>2007–2009</td>
<td>Q = 48.926HO – 5160</td>
<td>0.81</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: own study.

During summer the drainage canal becomes overgrown with hydrophilic plants and is cleaned only sporadically. Therefore the values of percolation into the canal were presented in relation to the difference of dammed water elevation in the Odra HO and water elevation in the canal HK [OLSZEWSKA 1998; OLSZEWSKA, PŁYWACZYK 2010]. These values QP
were determined per 1 m of difference in water levels in the Odra and the canal (\(H_O - H_K\)). The results are presented in Table 4.

<table>
<thead>
<tr>
<th>Years</th>
<th>(Q) (\text{dm}^3\text{s}^{-1})</th>
<th>(H_O - H_K) m</th>
<th>(Q_e) (\text{dm}^3\text{s}^{-1}\text{km}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971–1972</td>
<td>196</td>
<td>3.02</td>
<td>37</td>
</tr>
<tr>
<td>1981–1982</td>
<td>277</td>
<td>3.84</td>
<td>36</td>
</tr>
<tr>
<td>1987–1988</td>
<td>194</td>
<td>3.75</td>
<td>30</td>
</tr>
<tr>
<td>1995–1996</td>
<td>144</td>
<td>3.38</td>
<td>24</td>
</tr>
<tr>
<td>1998–1999</td>
<td>162</td>
<td>3.32</td>
<td>28</td>
</tr>
<tr>
<td>2003–2004</td>
<td>79</td>
<td>3.21</td>
<td>12</td>
</tr>
<tr>
<td>2007–2009</td>
<td>80</td>
<td>3.12</td>
<td>18</td>
</tr>
</tbody>
</table>

Source: own study.

The value of infiltration in the Odra valley direction in the initial years of canal exploitation (1971–1982) equaled between 36–37 \(\text{dm}^3\text{s}^{-1}\text{km}^{-1}\), after 10 years (1995–1999) between 24–30 \(\text{dm}^3\text{s}^{-1}\text{km}^{-1}\) and after 30 years of barrage exploitation (2003–2009) between 12–18 \(\text{dm}^3\text{s}^{-1}\text{km}^{-1}\).

**CONCLUSIONS**

1. The valley areas adjoining the damming, near the barrages on water routes should be equipped with appropriate draining systems in order to preserve proper water relationships for the given area usage.

2. The analysis of flow rates in the drainage canal in the areas adjoining to the Brzeg Dolny barrage and functioning within pressure conditions between 1971–2009 showed that the flow rate in the canal depends on the difference between water elevation in dammed river and draining device and it decreases with time as a result of water bearing system becoming more impermeable.

3. Direct, lasting over 35 years, measurement of flow rates show that in the similar water and ground conditions as well as similar location and differences between dammed water level and water level in the canal, the percolating waters flow rate between 35–40 \(\text{dm}^3\text{s}^{-1}\text{km}^{-1}\) per 1 m difference in water level in the Odra and in the canal. These values can be used as the basis for calculating the dimensions for basic draining devices.

**REFERENCES**


Beata OLSZEWSKA, Leszek PŁYWACZYK, Wojciech ŁYCZKO

Funkcjonowanie kanału odwadniającego w rejonie stopnia wodnego na Odrze w Brzegu Dolnym w latach 1971–2009

STRESZCZENIE

Słowa kluczowe: kanał odwadniający, piętrzenie, przepływ, stopień wodny, wody przesiąkowe

W pracy dokonano analizy ilości wody dopływającej do kanału odwadniającego na tle stanów wody w Odrze w przekroju Brzeg Dolny – Wały (górna woda na stopniu). Podstawę oceny stanowiły prowadzone przez Instytut Kształtowania i Ochrony Środowiska Uniwersytetu Przyrodniczego we Wrocławiu bezpośrednie pomiary natężenia przepływu w kanale w przekroju Warzyna w okresie 1971–2009. Analiza wyników, na tle stanów wody w Odrze, wykazała, że z upływem czasu, w warunkach tej samej rzędnej piętrzenia na jazie, obserwuje się coraz mniejsze wartości natężenia przepływu w kanale. Jest to spowodowane procesami uszczelniania się koryta Odry i terenów międzywodnych. W latach 1971–2009 średnie roczne natężenie przepływu w kanale w przekroju Warzyna zmniejszyło się ze 196 dm³·s⁻¹ do około 80 dm³·s⁻¹. Badania wykazały, że ilość wody dopływającej do kanału jest zmieniona w czasie i zależy od różnicy rzędnych zwierciadła wody w Odrze i kanale. W pracy przedstawiono dynamiczne zmiany dopływu wody do kanału w przeliczeniu na metr różnicy poziomów zwierciadła wody w Odrze i kanale odwadniającym. Na podstawie przeprowadzonych analiz wykazano, że w podobnych warunkach lokalizacyjnych, gruntowo-wodnych i zbliżonych wysokościach piętrzenia do określa-

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