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BARRAGE BARTOSZOWICE-OPATOWICE INFLUENCE ON GROUNDWATER STATE IN ADJACENT AREAS IN 1997

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The main idea of this study was to analyze an influence of altering water level, by the barrage Bartoszowice – Opatowice, on the groundwater in adjacent areas. In this paper a physiographic characteristic of the Big Island and characteristics of barrages are presented. A simulation of the influence of a flood wave passing in 1997 on water level in the study area was presented. The simulation included: period before the flood, period of flood wave passing through Wrocław and period after the flood. To carry out model testing previously collected physiographic data and data regarding water levels in 1997. The test were carried out using mathematical model FIZ, that allows modeling of groundwater flow. For hydrotechnical engineers influence of structures altering water level on groundwater is an important issue, because it can disturb foundations of existing structures, adjacent buildings or other objects in close proximity of groundwater influence. It is worth to predict the influence of a hydrotechnical structure on groundwater.

Keywords: ground water, earth water, barrages, computer modelling, water level increase, Big Island, Odra River

1. INTRODUCTION

Hydrographic conditions in the areas adjacent to watercourses and water reservoirs are formed depending on geology, surface water level and groundwater supply conditions. Location of the water table is closely connected with surface water. Groundwater can be recharged by surface water (losing stream) or recharge surface water (gaining stream). Periodic changes from gaining to losing stream are connected with fluctuation of water level in the stream. The Big Island was created by rivers and channels, separating it from the rest of Wrocław. These rivers and channels are: Inundation Channel and

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Shipping Channel from the Northeast, Odra riverbed from the south side and Old Odra River from the west side. In the area of the Big Island are weirs: Bartoszowice, Szczytniki, Opatowice and Psie Pole. A task of these hydrotechnical structures is to alter water level in order to maintain a constant water level in the river. The weirs are also part of the flood control system (Wrocław Power Plant I). Significant fluctuations of water table can be observed in vicinity of weirs. Particular situation can be observed in the area of canalized part of the Odra River in Wrocław (WWW), including the Big Island with quarters: Zacisze, Dąbie, Biskupin, Sępolno, Szczytniki and Bartoszowice.

2. AREA OF RESEARCH

The Big Island in Wroclaw is located in the eastern part of the city by Odra River. It contains housing estates: Bartoszowice, Biskupin, Dąbie, Zacisze, Sępolno and Zalesie, Szczytniki and Sępolno. The name: Big Island was given in 1980 by professor Wanda Kononowicz. For a long time it was an unofficial name, nowadays it is used also by Wrocław City Council. The lands belonging to the Island except Zacisze were located on the left bank of Odra River (in the area between Odra and Oława) until the 16th century. In the following years the construction began, involving digging the riverbed. These settlements lien now on the opposite bank of the Orda river (which were separated by oxbow lakes). There is, however, a connection with the left bank and with the Wrocław city center – bridges: Szczytnicki and Zwierzyniecki. The Big Island has an individual protection – Natural –Landscape Complex being a part of Szczytnicki Natural-Landscape Complex [1], [2], [3], [4], [5].

Barrage Bartoszowice – Opatowice

Barrage Bartoszowice – Opatowice is situated at km 245 + 035 of Odra River. This barrage consists of: weir Bartoszowice, lock Bartoszowice, weir Opatowice, Navigation Channel Opatowice, upper and lower outer harbors of lock Bartoszowice, residential buildings, magazines and outbuildings. It is connected with Navigation Channel Bartoszowice – Zacisze – Różanka, Flood Control Channel, dykes, polders: Blizanowice, Trestno and Oławka and with spillway to Widawa. That barrage has a great significance for the whole Wrocław Water Junction, especially with regard for flood control in the city. The barrage intercepts water flowing to the city and controls its flow.

- ***Weir Bartoszowice*** was built in 1913-1917. It is a weir with a segmental closing. It was built to be a part of Bartoszowice Barrage. Weir Bartoszowice alter water levels of Odra River in upper course. It is situated 0,45 km from the flood control channel. In is a three-span structure of dimensions: 2 x 30,00 [m], 1 x 40,00 [m]. The clear span of the weir is 100,00 m and its length is 108,40 m.

Slope for NPP [m] equals 4,49. Threshold crown in weir Bartoszowice: 117,60 mamsl. Ordinate ”0” of water gauge: 111,188 mamsl.

The weir regulates water level together with the weir Opatowice:

- level of upstream water for lock Bartoszowice and lock Opatowice,
- level of downstream water for lock Janowice.

Fig. 1. Weir Bartoszowice from downstream side – view from left bank

Fig. 2. Weir Bartoszowice from upstream side – view from left bank

- ***Weir Opatowice*** was built in 1977-1985. It is a weir with a sectional closing. The weir consists of: abutment with control room on the right bank, abutment with a fish ladder on the left bank, two piers, threshold with sectional chamber and a passage. The structure made of concrete is a casing for three main steel sectors 2,70 m high and 32,00 m long. Weir Opatowice has a hydraulic system to control these sectors, a defrosting installation that allows its exploitation during the whole year, and washing, draining and ventilation systems. Span lengths are: 3 x 32,00 [m]. The clear span of the weir is 96,00 m and its length is 103,70 m.

Above the weir there is a footbridge that allows also privileged cars to get to the Opatowicka Island. The riverbed below the weir Opatowice is an artificial bump, protected by a riprap lying on a slab mattress of thickness of 1,0 m. Scarps of the riverbed are protected by concrete slabs, supported by a riprap lying on a fascine mattress. The embankment on the right bank is protected by steel sheet piling and on the left bank – by a groin.

The weir regulates water level together with the weir Bartoszowice:

- level of upstream water for lock Opatowice and lock Bartoszowice,
- level of downstream water for lock Janowice.

Fig. 3. Weir Opatowice – view from right bank

Fig. 4. Weir Opatowice – view from left bank

3. NUMERICAL MODEL AND BASIC HYPOTHESES

FIZ software – used in the engineering practice to determine influence of the designed hydrotechnical structures on hydrographic conditions in the adjacent area. FIZ software allows modeling of the groundwater flow and contaminants flow. Basic formula in FIZ software is Boussinesq equation:

$$\frac{\partial}{\partial x}\cdot\left(T_x\cdot\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\cdot\left(T_y\cdot\frac{\partial H}{\partial y}\right)+W=\mu\frac{\partial H}{\partial t} \tag{1}$$

where:
x, y – spatial variable $(x, y)\ \varepsilon\ \Omega$, Ω – filtration area, t – time,
μ – coefficient of gravity drainage capacity, H – piezometric height,
T_x – hydraulic diffusivity in direction of OX axis, $T_x = k_x (H – a)$,
T_y – hydraulic diffusivity in direction of OY axis, $T_y = k_y (H – a)$,
k_x, k_y – coefficient of hydraulic diffusivity on direction , respectively, OX and OY,
a – ordinate of the bottom of layer,
W – source function.

That is used to describe an unstable groundwater flow in saturated area. In order to solve the equation for unstable filtration it is necessary to specify initial conditions and boundary conditions. Initial conditions indicates distribution of piezometric heights at the present moment (t = 0). Piezometric height values in nodes for the initial moment can be determined on the basis of performed measurements or calculations for steady state [15].

Boundary conditions [16]:

- First-type condition (Dirichlet Boundary Condition) – by piezometric height, it occurs when the values of the function h (x,y,t) are given on the filtration area borders:

$$h = F_1(x, y, t) \tag{2}$$

- Second-type condition (Neumann Boundary Condition) – by intensity of the flow, it occurs when on the border the values of a derivative normal to the border are given, which means that boundary conditions depend on the value of the flow on the borders:

$$Q_n = \int_{C_f} q_n \cdot ds = \int_{C_f} k \frac{\partial h}{\partial n} \cdot ds \tag{3}$$

- Third-type condition (mixed) – it occurs when on the border a linear combination of the values of the function h and its derivative is given:

$$h + A \frac{\partial h}{\partial n} = F_3(x, y, t) \tag{4}$$

4. RESULTS FROM MODEL TESTING

Model testing for the Big Island

In model testing an influence of surface water on groundwater in adjacent area was determined. The influence of water level of Odra River in 1997 on rise of water level was tested. Mathematical model was used for testing the influence of the flood in 1997 on groundwater level. The studies allowed to determinate changes of water levels when the flood wave was coming, during the flood wave culmination and after the flood wave and estimation of reach of reach of the influence of altering water levels and duration of elevated groundwater level.

Discretization of the selected area

On the study area a triangular finite element mesh was generated. To each element, which is located in the area covered by the study, coordinates of nodes (x,y) were assigned. These nodes are linked together and they allow to solve the assignment problems. Division of the area into smaller elements allows to obtain more accurate calculation results. In my studies the applied mesh is uniform, the triangles are equilateral or similar to equilateral triangles.

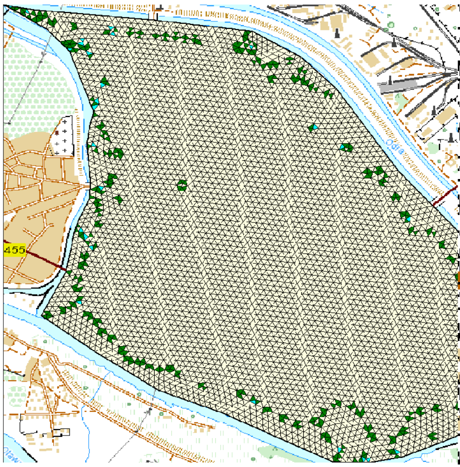


Fig. 5. Discretization mesh

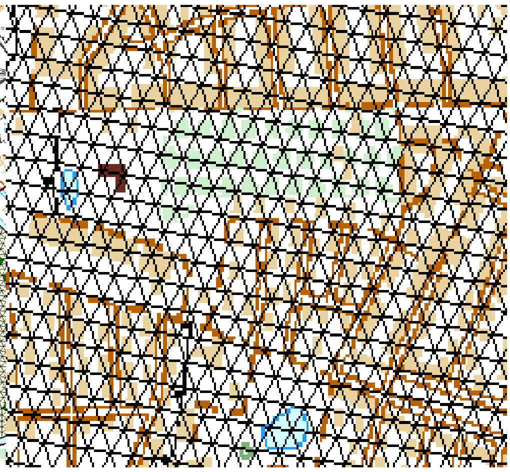


Fig. 6. Part of the mesh

The mesh consists of 4686 nodes and 9091 triangles. The triangles are described with subsequent numbers of nodes. The maximum angle should not exceed a value of 70 degrees. The mesh accuracy is 0.05 %, which means that only 0.05% of triangles are obtuse triangles (marked with red color), in which calculation errors may occur. In the test there is one such triangle, located on northwest.

Theoretical studies have shown that if the triangles are close to equilateral, results of the model testing are more accurate. Blue triangles are similar to right triangles, which angle exceed 80 degrees but not exceed the maximum value of 90 degrees. In the test there are several quasi-right triangles, located on the east side of the study area. Other triangles are similar to equilateral, they are marked with yellow color (angles smaller than 70 degrees) and green color (angles between 70 and 80 degrees) – these triangles give the most accurate results.

Parameters preparation

To each node several values were assigned:

- filtration coefficient along x and y axis – for the study area a mean value of the coefficient k = 10 m/d was assumed (filtration coefficient for medium sand),
- coefficient of gravity drainage capacity μ = 0,16 – calculated using the Bieciński formula

$$\mu = 0{,}117\sqrt[7]{k} \tag{5}$$

where:

k – filtration coefficient [m/d]

[5]

- altitudes of the top and the bottom and the ground level, the top altitude is 118 mamsl and the bottom altitude is 112 mamsl [16], [8], [7], [17], [4].

In the model it was assumed that the average rainfall equal to 600 mm/year is equal to evaporation on the study area. Therefore it was assumed that charging by rainwater is equal to 0 mm/day.

Determination of boundary conditions

In the studies the first-type boundary condition (Dirichlet Boundary Condition) was used, on the borders of the filtration area a value of the function h(x,y,t) was assumed:

$$h = F_1(x, y, t) \tag{6}$$

Groundwater level was determined on the border of the area in accordance with water altitudes in the watercourse. In the paper second-type and third-type conditions were not used.

Influence of the barrages on groundwater levels in 1997

The study of the influence of surface water on groundwater in the Big Island in 1997 area was carried out. The research began two months before the culmination of the flood wave – on May 18, 1997, to estimate a distribution of water table rise for groundwater in the study area before the flood, during the flood and after the flood.

May 18, 1997

Simulation studies for period before the flood (May – June, 1997)

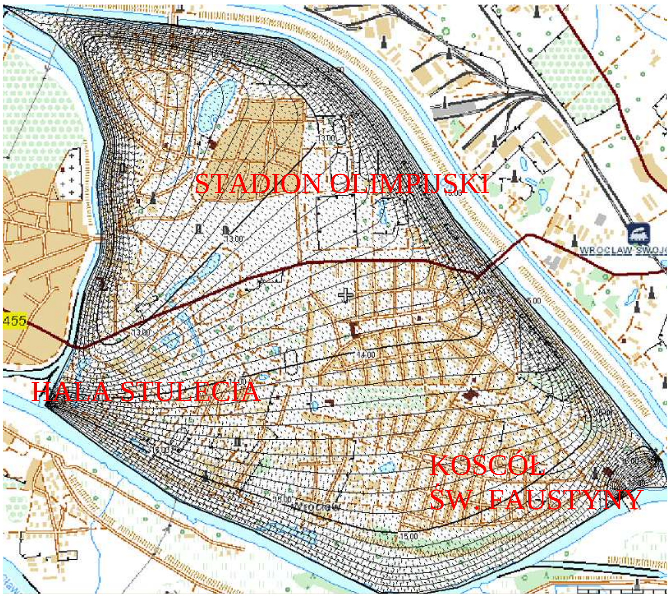


Fig. 7. Hydroisohips and velocity field of 18 May, 1997

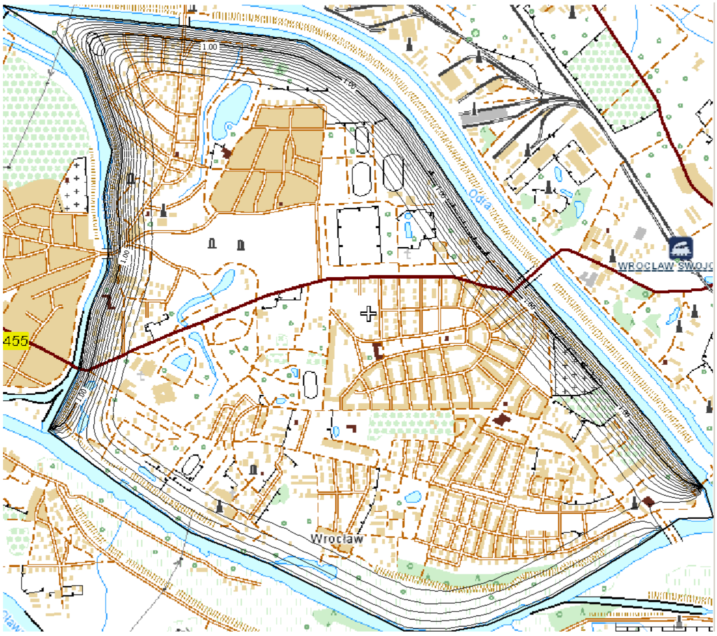


Fig. 8. Rise of groundwater level of 18 May, 1997

June 18, 1997

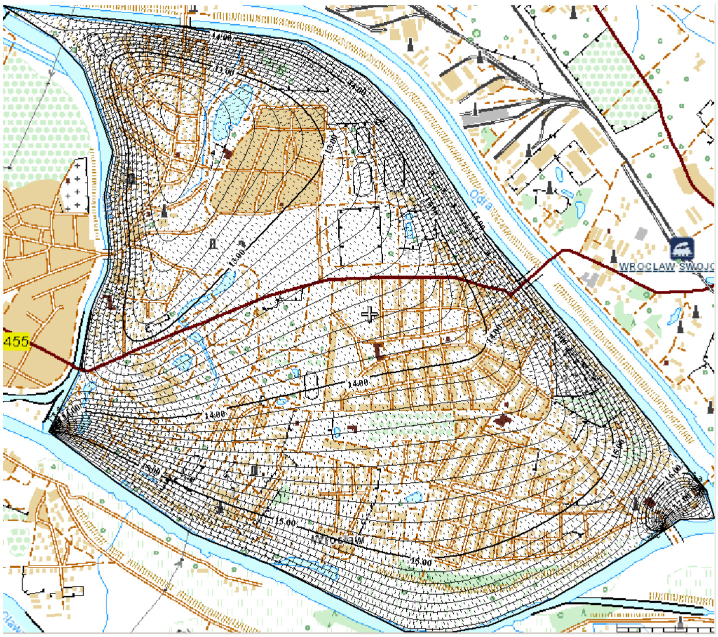


Fig. 9. Hydroisohips and velocity field of 18 June, 1997

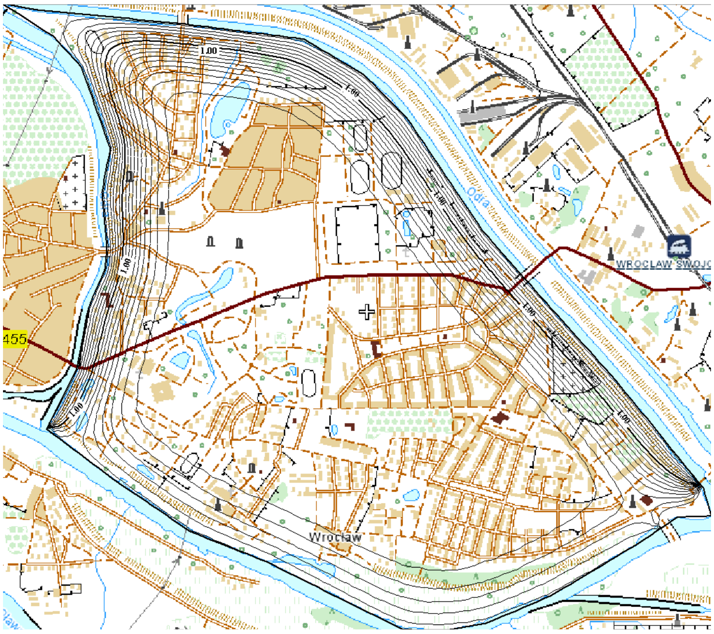


Fig. 10. Rise of groundwater level of 18 June, 1997

July 12, 1997

Simulation studies for period during the flood (July 1997)

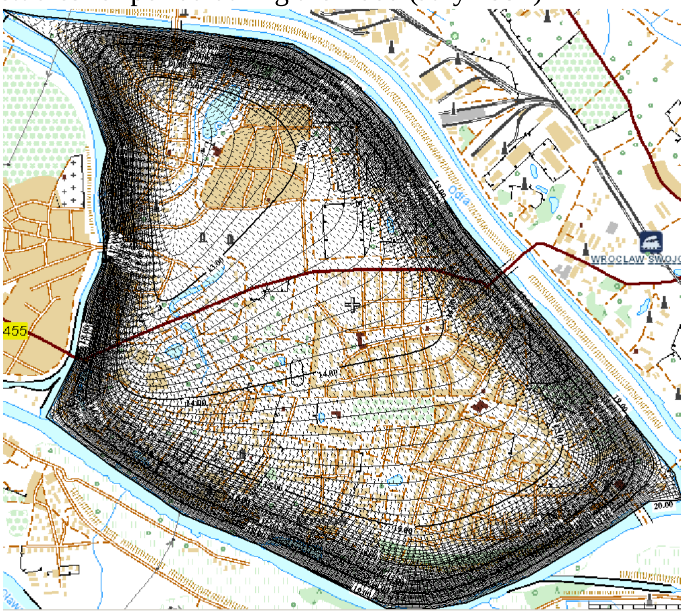
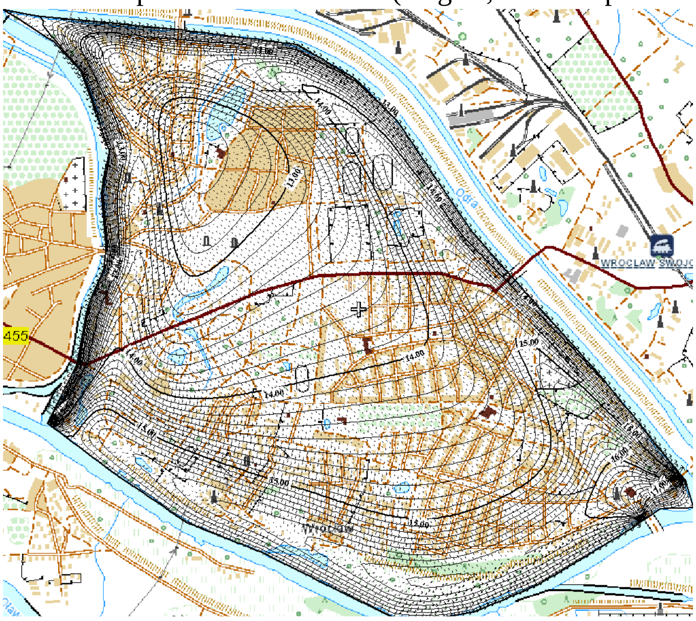


Fig. 11. Hydroisohips and velocity field of 12 July, 1997

Fig. 12. Rise of groundwater level of 12 July, 1997

August 12, 1997

Simulation studies for period after the flood (August, 1997 - April 1998)



Rys. 13. Hydroisohips and velocity field of 12 August, 1997

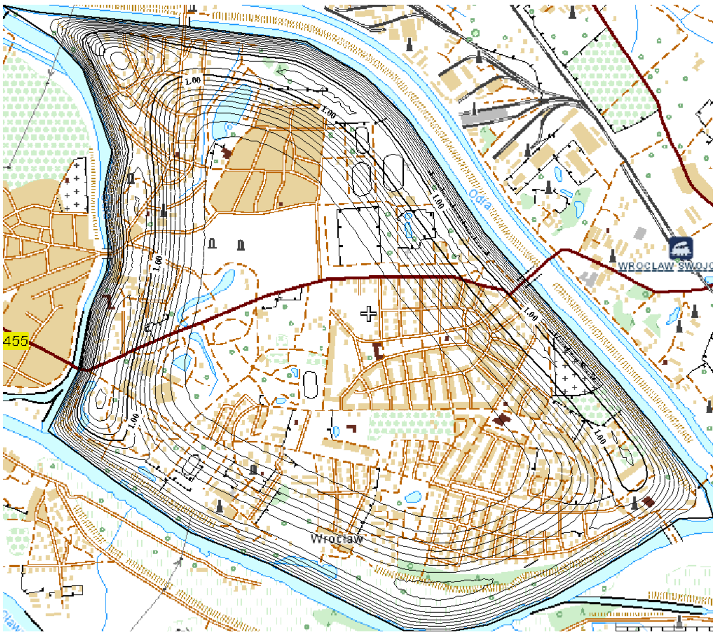


Fig. 14. Rise of groundwater level of 12 August, 1997

October 12, 1997

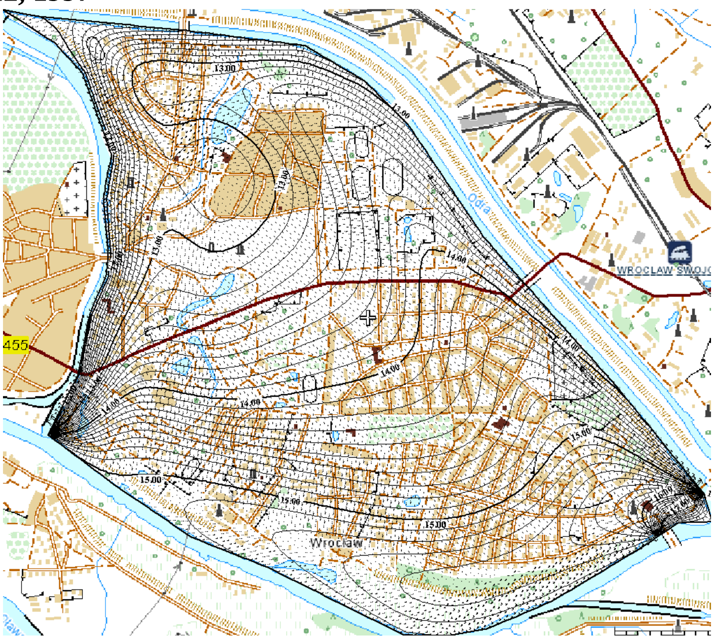


Fig. 15. Hydroisohips and velocity field of 12 October, 1997

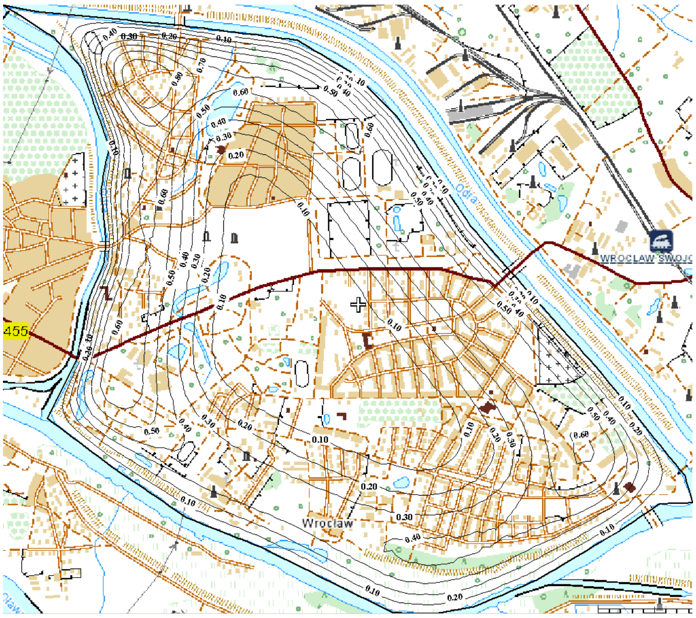


Fig. 16. Hydroisohips and velocity field of 12 October, 1997

April 12, 1998

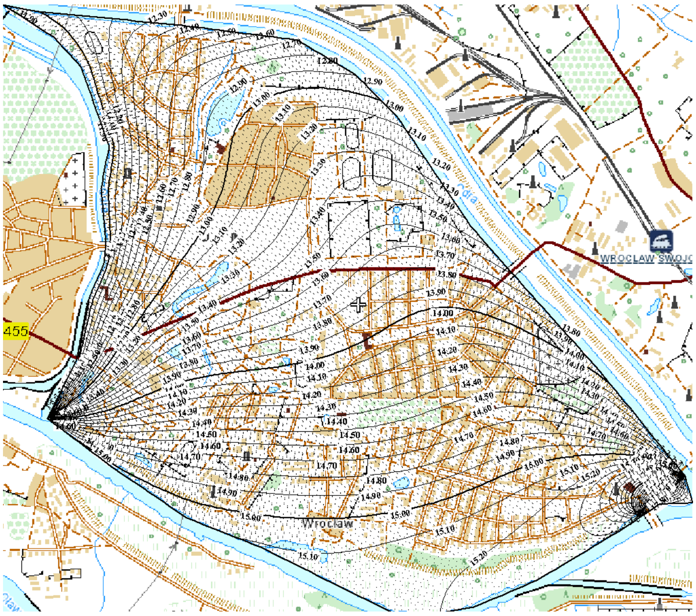


Fig. 17. Hydroisohips and velocity field of 12 April, 1998

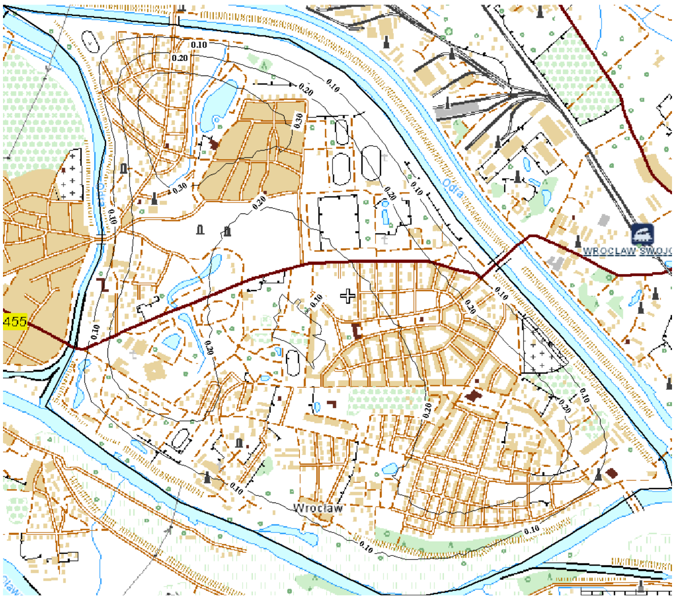


Fig. 18. Hydroisohips and velocity field of 12 April, 1998

5. MODEL TESTING RESULTS ANALYSIS

The simulation was carried out for the period from 18th May, 1997 to 12th April, 1998. The largest area of the influence of surface water on groundwater is located in the north and northeast part if the Big Island, between the Old Odra and the flood control channel, near the weir Psie Pole. Isoline of an increase equal to 0.1 m was located along Józefa Mianowskiego Street, Jana Głogowczyka Street on the east side and to Morskie Oko on the west side. Range of influence of surface water on water table in the Big Island area was about 150 metres from the Odra River toward the center of the study area. The largest rise of the groundwater level occurred near Odra River and it was about 1.5 – 1.8 m.

After thirty days of observation a larger range of the water table rise of 0.1 m was observed, which reached a quarter Zalesie in the northern part of the area and it was distributed proportionally to the whole area from Odra River towards the city center at a distance of about 450 m from watercourses. From the side of a quarter Sępolno an isoline of level rise 0.1 m was located near Piotra Wysockiego Street. In the southern part of the island rise of water levels was equal to 0.5 m and in other areas – between 1.5 and 1.8 m [Fig. 9 – 10].

On the day of culmination of the flood wave (July 12, 1997) groundwater level significantly increased. The maximum increase was in the area of the Old Odra and near the flood control channel. Isoline of level rise 0.1 m was located near Spółdzielcza Street [Fig. 11 – 12].

A month after the culmination of flood wave rises of water levels in the vicinity of the Odra River were significantly reduced. The biggest values of the rises were observed in the zone of 280 m from the Odra River toward the Island center (from Bartoszowice, Sępolno, Zalesie and Szczytniki). However, the range of isoline level rise 0.1 m was moved toward the center of the Big Island, about 800 m from the watercourses [Fig. 13 – 14].

In October in the vicinity of the Odra River water level increase equaled about 0.3 m and in the area situated about 300 m farther from the river toward the center the increase equaled 0.5 m. The range of the area of water level increase was enlarged at 0.1 m. Isoline 0.1 m ran in the proximity of Ludomira Różyckiego Avenue, Walerego Sławika Avenue, Karola Olszewskiego Avenue, reaching Banacha Street and Zaleskiego Bridge [Fig. 15 – 16].

Nine months after the start of the study (12th April 1998) water levels were back to normal levels – before the flood. Near Odra increases from 0.1 to 0.2 m were observed. In the Big Island center the area of groundwater level increase covered also Adama Mickiewicza Street. As can be observed in the following analyses, the flood of 1997 had a huge influence on groundwater level in the area of the Big Island. Even nine months after the flood increased level of groundwater could be observed.

6. SUMMARY AND CONCLUSIONS

In the paper the influence of altering water levels by the barrage Bartoszowice – Opatowice and cooperating weirs Szczytniki and Psie Pole on groundwater in adjacent area during the flood of 1997 was analyzed. The study was carried out using mathematical model FIZ, which allows modeling of the groundwater flow. For model testing previously obtained physiographic data for the Big Island area were used together with data regarding water levels in 1997. After preparation and elaboration all input data they were introduced into the mathematical model. A simulation of the influence of the flood wave in 1997 on water table in the area of the Big Island was carried out. The simulation covered the period before the flood, period of flood duration in Wrocław and period after the flood.

- Performed model test have showed the huge influence of the flood wave on groundwater level in the area of the Big Island. During the Millennium Flood many places in the area of the Big Island were inundated. The cause of the rise were two flood waves that occurred one after the other in a very short time period, caused by high intensity of rainfall. The rises remained constant in the closest vicinity to the Odra River. The highest surface water levels (reaching a value of 120.00 mamsl) were observed on the weirs Bartoszowice, Opatowice and Różanka on 12th July, 1997. That level remained constant for three days. After culmination the flood wave started to subside to 20th July when water level on the weir reached 118.50 mamsl. At the time when flood wave was subsiding, heavy rainfall occurred and caused the second flood wave with a water level of 119.00 mamsl. The range of the influence of surface water on groundwater significantly increased. Isoline of the water level rise equal to 0.1 m covered the area of Adama Mickiwicza Street. Even four months after the culmination of flood wave an increase of the range of influence of isoline 0.5 m in the center of the Big Island was observed. Only in April 1998 values of the groundwater isolines increase came back to pre-flood conditions.

- After the flood in 1997 most of the dikes have been rebuilt and modernized. The dikes surrounding the Big Island have been sealed up. Hydrotechnical structures and devices have been modernized and rebuilt.
- Performed model tests have shown in which areas of the Big Island the largest increase of water table caused by high water level during and after the flood may occur. Obtained data allow to indicate the areas endangered by flooding. In these areas appropriate damp insulation should be applied to building foundation.

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ODDZIAŁYWANIE STOPNIA WODNEGO BARTOSZOWICE – OPATOWICE NA SATNY WÓD PODZIEMNYCH TERENÓW PRZYLEGŁYCH W 1997 ROKU

S t r e s z c z e n i e

Główną ideą pracy była analiza wpływu piętrzenia stopnia wodnego Bartoszowice – Opatowice na wody podziemne terenów przyległych. W niniejszej pracy przedstawiono charakterystykę fizjograficzną Wielkiej Wyspy wraz z charakterystyką stopni wodnych. Zamieszczono symulację oddziaływania przejścia fali powodziowej w 1997r. na kształtowanie się zwierciadła wody na terenie objętym badaniem. Symulacje obejmowały: okres przed wystąpieniem powodzi, okres przejścia fali przez Wrocław i okres po powodzi. Do wykonania badań modelowych posłużyły wcześniej zgromadzone dane fizjograficzne oraz dane dotyczące stanów wody w latach 1997. Badania wykonano przy zastosowaniu modelu matematycznego FIZ, który umożliwia modelowanie przepływu wód podziemnych. Dla inżynierów hydrotechników kwestia wpływu budowli piętrzących na wody podziemne odgrywa istotną rolę, ponieważ może zaburzyć posadowienie istniejących konstrukcji, przyległych budynków, jak i innych elementów w bliskim otoczeniu oddziaływania wód gruntowych, dlatego warto przewidywać, jaki wpływ będzie miała budowla hydrotechniczna na wody podziemne.

Słowa kluczowe: wody podziemne, wody gruntowe, stopnie piętrzące, modelowanie komputerowe, przyrosty stanów wód, Wielka Wyspa, rzeka Odra