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THE BAGRY RESERVOIR – PART 4. THE APPLICATION OF ACOUSTIC SONAR LOWRENCE MARK-4 IN THOROUGH INVENTORY OF A DIFFICULT-TO-ACCESS WATERBODY

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Abstract

Geomorphological and ecological examination of waterbodies facilitates efficient action aimed at their correct management and attributing proper functions to them or their parts. For years there have been many concepts of the management of numerous post-mining water bodies in Cracow, within the Local Site Development Plan (*Miejscowy Plan Zagospodarowania Przestrzennego*). Within the borders of the city of Cracow there are several water bodies important and valuable in environmental, landscape, economic and recreational aspect. One of them is the Bagry Reservoir called Bagry Wielkie (the Great Bagry). Nowadays it consists of two parts separated with a dike: the bigger of the area 30.03 ha, fulfilling the function of sports and recreation as well as economic function (Special Fishery „Wspólnota”, managed by the Regional Board of the Polish Angling Association – Zarząd Okręgowego Polskiego Związku Wędkarskiego Z.O. PZW Kraków/Cracow) and the smaller one – 0.57 ha, for many years being a breeding site of several protected species of birds and fish. The knowledge of the geometry of the water basin, characteristics of the bottom (type of the surface, mud) and location of water vegetation, makes base and component of reliable assessment of the state of water environment as well as making proper decisions in the area of the protection of natural resources or revitalization of the water body. This article presents the possibilities of measurement system Lowrence Mark-4, which, apart from hydrographical data, due to specialist algorithm of the interpretation of the return signal, provides numerical information on the hardness of the bottom and the thickness of the vegetation mass on its surface. Measurements made with the application of remote-controlled Smart-Sonar-Boat equipped with sonar Lowrence Mark-4 and GPS R8s Trimble provided important data giving basis to initial assessment of the condition and natural value of this difficult-to-access part of Bagry Reservoir.

ZALEW BAGRY – CZĘŚĆ 4. ZASTOSOWANIE SONDY AKUSTYCZNEJ LOWRENCE MARK-4 W SZCZEGÓŁOWEJ INWENTARYZACJI TRUDNODOSTĘPNEGO OBSZARU WODNEGO

Słowa kluczowe: Zalew Bagry, pomiary hydrograficzne, zastosowanie hydrodronów

Streszczenie

Rozpoznanie geomorfologiczne oraz przyrodnicze akwenu pozwala na prowadzenie skutecznych działań zmierzających do właściwego zagospodarowania zbiornika lub jego części oraz przypisanie mu właściwej funkcji. Od lat w Krakowie istnieje szereg koncepcji zagospodarowania wielu akwenów pogórnicych w ramach Miejscowych Planów Zagospodarowania Przestrzennego. W granicach miasta Krakowa zlokalizowanych jest kilka ważnych i wartościowych pod względem przyrodniczo-krajo-

brazowym, gospodarczym oraz rekreacyjnym akwenów wodnych. Jednym z nich jest Zalew Bagry zwany Bagrami Wielkimi. Obecnie składa się on z dwóch rozdzielonych wąską groblą części: większej o powierzchni 30,03 ha pełniące funkcję rekreacyjno-sportową i gospodarczą (Łowisko Specjalne „Wspólnota” będące pod opieką Zarządu Okręgowego Polskiego Związku Wędkarskiego Z.O. PZW Kraków) oraz mniejszej o powierzchni 0,57 ha, która stanowi od lat miejsce lęgowe kilku chronionych gatunków ptaków oraz tarlisko ryb. Znajomość geometrii misy zbiornika, charakterystyki powierzchni dna (rodzaj powierzchni, zamulnie) oraz lokalizacji roślinności wodnej, stanowi podstawę i składową wiarygodnej oceny stanu środowiska wodnego oraz podjęcie właściwych decyzji w zakresie ochrony zasobów przyrodniczych lub rewitalizacji akwenu. W artykule przedstawiono możliwości systemu pomiarowego Lawrence Mark-4, który poza danymi hydrograficznymi, dzięki specjalistycznym algorytmom interpretacyjnym sygnału powrotnego, dostarcza ponadto informacje w formie liczbowej o twardości dna oraz miąższości masy roślinnej zalegającej na jego powierzchni. Pomiary wykonane przy wykorzystaniu zdalnie sterowanej jednostki pływającej Smart-Sonar-Boat wyposażonej w sonar Lawrence Mark-4 oraz odbiornika GPS R8s Trimble’a dostarczyły istotnych danych, które dają podstawę wstępnej oceny kondycji oraz wartości przyrodniczej trudnodostępnej części Zalewu Bagry.

INTRODUCTION

Post-mining bodies of standing water, i.e.: Bagry Wielkie, Staw Płaszowski, Zakrzówek belong to the most interesting objects in Cracow, from the point of view of landscape and nature. Moreover, they make a very delicate ecosystem, reacting to all the weather changes and human activities. The Bagry Reservoir is one of many typical objects, making a relic of mining. At the moment of the end of exploitation the excavation was already filled with ground waters of relatively steady level of the water table. Relative stability of the water table is a characteristic feature of anthropogenic water bodies arising after exploited deposits of sand, gravel and clay. The Bagry Reservoir, called Bagry Wielkie (situated in Cracow-Płaszów), nowadays consists of two parts separated with a narrow dike: the big-

ger, of the area 30.03 ha, fulfilling functions related to recreation and sports, economic function (Special Fishery „Wspólnota”, managed by the Regional Board of the Polish Angling Association – Zarząd Okręgowego Polskiego Związku Wędkarskiego Z.O. PZW Kraków/ Cracow) and the smaller one, of the area 0.57 ha, which for years has been a breeding place of several protected bird species and spawning ground for fish. Thus to keep economic function of the smaller part (spawning grounds and the area of angling), it is important to raise the level of waters and keeping it stable (technically difficult) or at least slight lowering the crown of the dike that divides both parts of the Bagry dike to keep hydrological connection of both water basins (in the space between water table and the surface of the dike – figure 1).

The knowledge of the basin’s geometry, characteristics of the bottom (the type of the surface, mudding) and

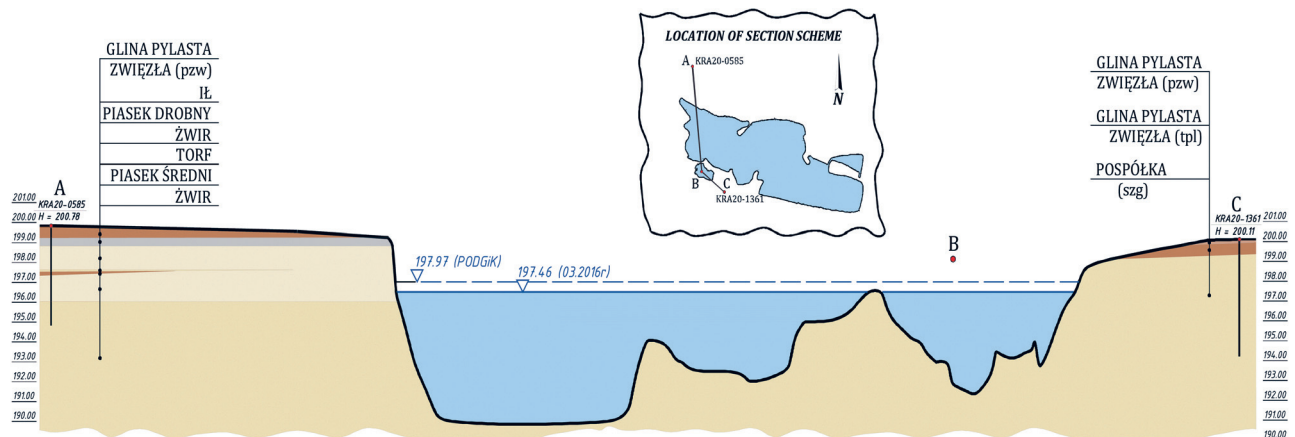


Fig. 1. Cross-section through water basins of both parts of the Bagry Reservoir and the dike facilitating direct exchange of waters
Rys. 1. Przekrój przez misy jeziorne obu części Zalewu Bagry oraz próg rozdzielający uniemożliwiający bezpośrednią wymianę wód

the localization of water vegetation, makes base and component of reliable assessment of the state of water environment and proper decision-making, referring to the protection of natural resources or the revitalisation of the water body. The analysed in this article, smaller part of the water body, localised in its south-west part, according to the Study of Site Development (*Studium Zagospodarowania Przestrzennego*) for the city of Cracow, 0.75% of the area known as Bagry, i.e. 2 water bodies with the adjacent areas – 75.79 ha in total. Linking the possibilities to interpret acoustic signals of sonar Lowrence Mark-4 and informatic tools facilitated full documentation of water environment in the bottom zone of this small water body.

1. ENVIRONMENTAL CHANGES IN THE SOUTH-WEST PART OF THE BAGRY OVER THE HISTORY

Permanent transformation of landscape in the south-west part, in the form of hollows of various depth and elaborated shoreline by spontaneous filling with ground and precipitation waters, without human intervention, became the start of its evolution (Pietrzyk-Sokulska E., 2010). Also the function of this place converted from industrial (mining) into ecological (habitats for birds and amphibians, as well as spawning grounds for fish) and economic function (angling).

Inflowing water and the succession of vegetation in this part of Bagry (the Prokocim shore) formed an area of exceptional landscape and habitat value, presenting an example of an anthropogenic and yet semi-natural habitat in a cultural landscape. Thus this small fragment of Bagry today is a historic mining area, as well as the area including three ecosystems, i.e. water, meadow and anthropogenic ecosystem, the combination of which formed unusual local ecological peculiarity. According to Kudłek J., et al. (2005) this area in category „ranks of the landscape and ecological value” was classified on 2nd level, while according to criterion of threat it was also 2nd level.

This part of the water body surrounds meadows of humid character, today being permanent spontaneous ruderal greenery (Trzaskowska E., 2011), typical for post-industrial or railway areas, where the plants protected by law were documented. Already in 2005, the south-west part was defined as an area of high natural

and cultural values (Budnik A., et al. 2013), where it was assumed that the construction of large buildings will be banned as well as all the changes threatening the ecological substance of the area. There was permission to built paths for pedestrians and cyclists as well as devices connected with the use of the water body (Bzowski M., et al. 2005). The discussed isolated fragment of the Bagry Reservoir with the adjacent area (the area of its catchment to the border of the railway restricted area), according to Enclosure No. 4 – Załącznik nr 4 (2006) and the Study of Site Conditions... – Studium uwarunkowań... (2014), belongs to the areas of „Areas of Natural Unorganized Greenery” and „Areas of Protective Screening and Landscape Greenery” (abbreviation – ZO), situated in the zone of the local airing corridor (the area of air exchange) – figure 2.

The shore zone and litoral zone are covered by a high reed bed, represented by such plant species as: the common reed (*Phragmites australis*) and broadleaf cattail (*Typha latifolia*). Hydrographical measurements showed very differentiated bottom morphology with distinct shallow and wide litoral belt, strongly insolated and overgrown by reed and broadleaf cattail (reed-mace) to the depth of about 1.5 m (figure 2). They make monotonous aggregations in a form of one-species clusters in a litoral zone. According to Bieroński J. (2005), the majority of small water bodies show macroscopic features of strong eutrophication, which means that in the summer period water transparency diminishes and the water body gets overgrown with aquatic vegetation and accelerates the process of its mudding. Thus this part of Bagry is rich in bottom sediments responsible for mudding, which in practice makes the water body shallower. Due to the endorheic character of the basin and intensive vegetation growth at the shore and bottom, one can suppose that the main mass of the silt is of autochthonic origin from dead plants, subdued to permanent decomposition processes.

Protection of small water bodies, regardless their origin and their morphometric parameters, requires inventory and ecological parameterization (characteristics). Particularly sensitive to environmental changes are water bodies of the area below 1 ha, which usually fulfil only one function – ecological one (Jakubiak M., Panek E., 2017). In practice, granting small post-mining water bodies a status of ecological sites (ecological utilities – in Polish: *użytki ekologiczne*) is widely applied form of their protection (Rzętała M., 2000).

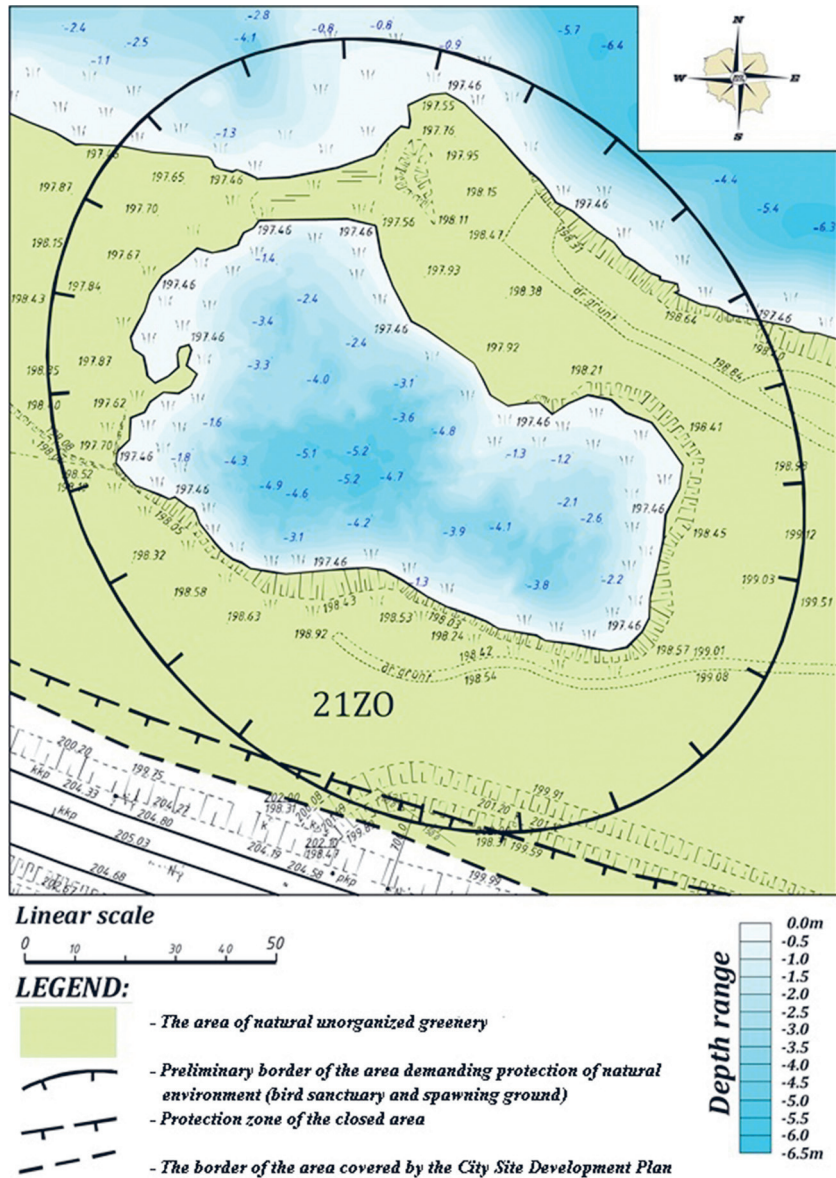


Fig. 2. Borders of zones: protection of natural environment (bird sanctuary and spawning ground), protection of the railway closed area the area covered by the City Site Development Plan in the difficult-to-access part of the Bagry Reservoir (by R. Gawalkiewicz)
Rys. 2. Granice stref: ochrony środowiska przyrodniczego (ostoja ptactwa i tarliska ryb), ochrony kolejowego terenu zamkniętego oraz obszaru objętego MPZP w obszarze trudnodostępnej części Zalewu Bagry (opracowanie: R. Gawalkiewicz)

Ecological significance of objects of small retention is differentiated and usually grows at the moment of appearing shore and litoral vegetation. Shores usually get fully overgrown with vegetation in the period of several years from the moment when the mining finishes. The necessary conditions to get such status are:

- Stabilization of hydrological conditions by spontaneous filling the excavation with ground and

precipitation waters, assuming small fluctuations in the water table in time;

- lack of negative activities of the owner or manager of the water objects and the adjacent area (removal of vegetation during reclamation works).

According to the assumptions of MPZP, the analysed water zone with the catchment area is supposed to gain the status of ecological utility in the future (Kudłek J.,

et al. 2005) to protect the remnants of this ecosystem – preserving biodiversity, according to art. 42 of the Law on Environmental Protection (2004). This means that this area will be a key element of a so-called zone of the formation of ecological system of the city, the system of greenery and river parks for the protection of precious ecological values of the water body, mainly spawning grounds for fish and breeding places for birds, especially in the south-west part (Gawałkiewicz R., 2017).

Pro-ecological activities and protection of water bodies, both natural and artificial, permanent, temporary or ephemeral, regardless their origin, morphometric parameters and function, should be based on thorough examination of the water body. Thus it is important to build a geo-base containing detail descriptive information, photographic and cartographic (geodetic and geological) documentation and morphometric description. This data should be contained in the inventory card, constantly updated.

2. ANALYSIS OF THE WATER TABLE LEVEL

Geological characteristic of the study area stimulates the retention of precipitation waters and ground waters in post-exploitation pit of Bagry. The Bagry and the nearby Staw Płaszowski are in the zone, where the Vistula River (Vistula Terrace) has a draining character and the underground waters to both water bodies inflow through the whole thickness of the water-bearing horizon (the layer of sands, gravel and aggregates). In case of closed water bodies of this type (standing waters), precipitation is the main source of water inflow and keeping a proper balance of water resources, providing the renewal of surface waters and ground waters (Mańkowska-Wróbel L., 2014). Their common feature is relatively constant level of the water table. In urbanized and industrialized areas, which surround the Bagry Reservoir and Staw Płaszowski, maintenance and retention of waters from rain and melting snow is a very important element for sustainable development of this part of the city. Thus these waters should be protected from pollution as well as managed and used in the place of their origin. In urban areas disturbances in natural hydrological cycle in atmosphere, biosphere and lithosphere are common. This is caused by urban development on the surface (increase of the impermeable areas: roads, squares, buildings, etc.), which diminishes

retention and infiltration abilities of precipitation waters to the ground. Another significant factor of human creative activities in the city is the growth of number of residential building in the vicinity of the water body. Uncontrolled investment (cheap deep draining wells, trenches – instead of expensive sealed walls), can lead to the limitation of the inflow of precipitation waters to water-bearing horizon directly empowering water bodies. An example of such situation, by hydro-geologists defined as ecological catastrophe was the formation of local depression funnel in the region of Staw Płaszowski in the first 3 months of 2016. Building several draining wells caused lowering the water table by nearly 1.0 m, and consequently, making the water body significantly shallower, as well as caused rapid growth of algae and litoral vegetation diminishing ecological and economic values.

From the moment when the officials of the City of Cracow announced the state of environmental disaster in the region of Staw Płaszowski in March 2016, caused by building industry, levelling measurements of water tables have been carried out in the areas of: Bagry Wielkie and Staw Płaszowski (Gawałkiewicz R., 2018). The results of measurements allowed us to define the magnitude of water level oscillations of both water bodies separated by a piece of ground (figure 3). They show that the liquidation of illegal draining wells in the vicinity of Staw Płaszowski caused the increase of the level of the water table; while in the Bagry reservoir a steady, although slow decrease of water level (maximal ordinate value of 202 mm) is observed, which is probably connected with extensive construction projects (residential buildings) in the region of streets: Grochowa, Kozia, Lipska, Bagrowa, forming a local depression funnel limiting the inflow of precipitation waters and ground waters to the water bearing horizon filling the reservoir (negative water balance). Conclusions about the influence of human activities on the decrease of water were based on information of the Institute of Meteorology and Water Management (IMGW), can be drawn that the period from March 2016 to January 2018 was characterized with very stable atmospheric conditions. Moreover, no extreme phenomena were recorded that time (long and intensive precipitation „urban floods”, weeks-lasting heat-waves responsible for hydrological droughts), which could particularly affect water resources of the Bagry Reservoir. The amount of water body resources, is shown in the graph of the ordinate

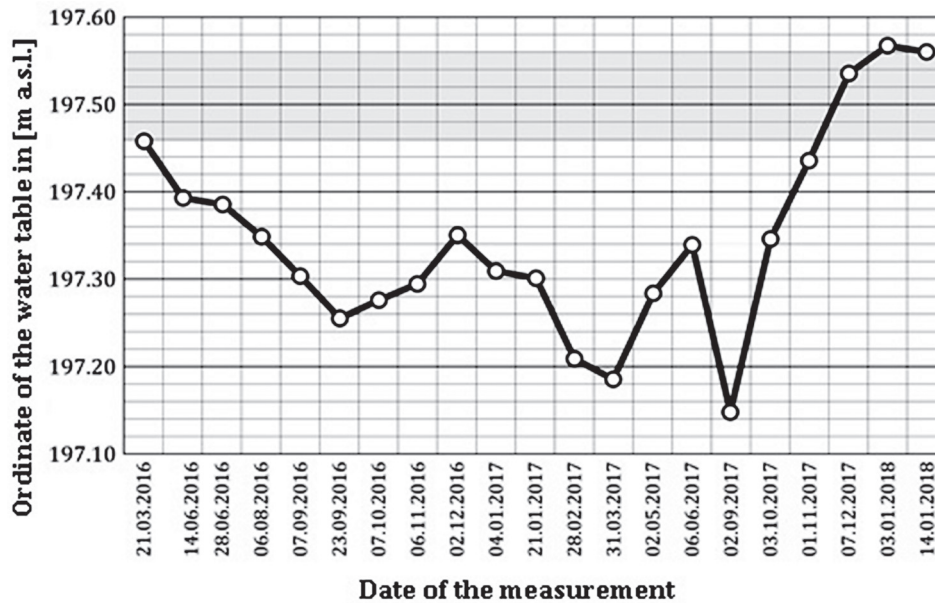


Fig. 3. The graph of the ordinate water table Bagry Reservoir (measurement: R. Gawalkiewicz)

Rys. 3. Wykres rzędnej zwierciadła wody Zalewu Bagry (pomiar: R. Gawalkiewicz)

of the water table marked with the method of geometric levelling in the period: March 2016 – January 2018 (figure 3).

3. MEASUREMENT INSTRUMENTS

Nowadays the market of measurement instruments applied on water was dominated by sonars of company Garmin and Lowrance (so-called angling and sailing sets), the range the measurement reaches 300 metres – sonar Lowrance Mark-4 – 305 m; source: www.echosonda.pl/product_info.php?product_id=1535 – access March 2018). These are devices integrated with satellite navigation of GIS accuracy (in motion), thus the accuracy given by mean situation error of point $m_p \leq \pm 2.7m$ (Gawalkiewicz R., Madusiok D., 2018). Thus the growth of positioning accuracy is obtained by the application of GNSS receivers functioning in NAWGEO system, guaranteeing the highest possible accuracy $\pm 1cm$. A detail analysis of the signal echo, by the application of advanced interpreters described in Valley R., (2014), facilitates the generation of information on the bottom hardness, the presence and thickness of bottom vegetation defined by Biovolume coefficient. Biovolume index can make the main parameter of the utility value assessment of the water body for

recreational and sports purposes (the assessment of the nuisance of water vegetation) or ecological purposes (introduction of fish).

4. THE ANALYSIS OF THE BOTTOM HARDNESS IN THE RESERVOIR AND THE ENVIRONMENTAL ASSESSMENT OF THE MINI WATER BODY

One of significant indicators of the state of natural environment in the areas of inland waters (standing or flowing) is the parameter of the bottom hardness. It defines the characteristic of the bottom area by marking the hardness index. The value of this parameter is determined by the zone of mean or large mudding of the bottom, which unfavourably influence the condition of flora and fauna and the state of the retained water. The loss of hydraulic connection with water-bearing horizons of the Quaternary or deeper layers due to the colmatation of the basin by the accumulation of bottom sediments and slime (acting as isolator), makes a water body „a sealed tub” (Wiehle D. et al. 2016). Lack of the possibility of the exchange waters or its limitation slows down or halts the process of the self-purification of the resources of standing waters.

Modern acoustic systems, apart from the measurement of depth allow the assessment and identification of the type of the bottom and sediments covering the bottom. The appearance of the echo depends on the intensity of the reflection of impulse (Osadczyk A., 2007). The power of the return signal to the receiving system shapes the value of hardness coefficient, following the rule shaping the value of the hardness coefficient, following the rule that a hard bottom (hard rock, intact deposit of sand and gravel) well reflects acoustic impulse, while a soft bottom (fine sand freshly provided, silt, silted sand, mud) strongly disperse the signal (absorption of impulse energy). According to Orłowski A. (1984), the coefficient of the reflection of sound is reversely proportional to porosity of sediments, which means the finer particles of the sediment – the weaker their reflective properties are.

The analysis of the reflection strength of the acoustic beam from the surface of the bottom, according to the calculation algorithm contained in Valley R., (2014), allows us to determine the hardness of the bottom based on the definition of the index in the measurement point. Thus, applying sonar Lawrence Mark-4, the type of the bottom is defined by the intervals of the hardness coefficient (Navico Inc. 2014), i.e.:

- 0.00 ÷ 0.25 – soft bottom;
- 0.25 ÷ 0.40 – medium-hard bottom;
- 0.40 ÷ 0.50 – hard bottom.

The highest coefficients of hardness were recorded in the zones of sudden depth increase (1.7% of the water body area), which means local discovery of unexploited sand and gravel (high density). The greatest areas cover

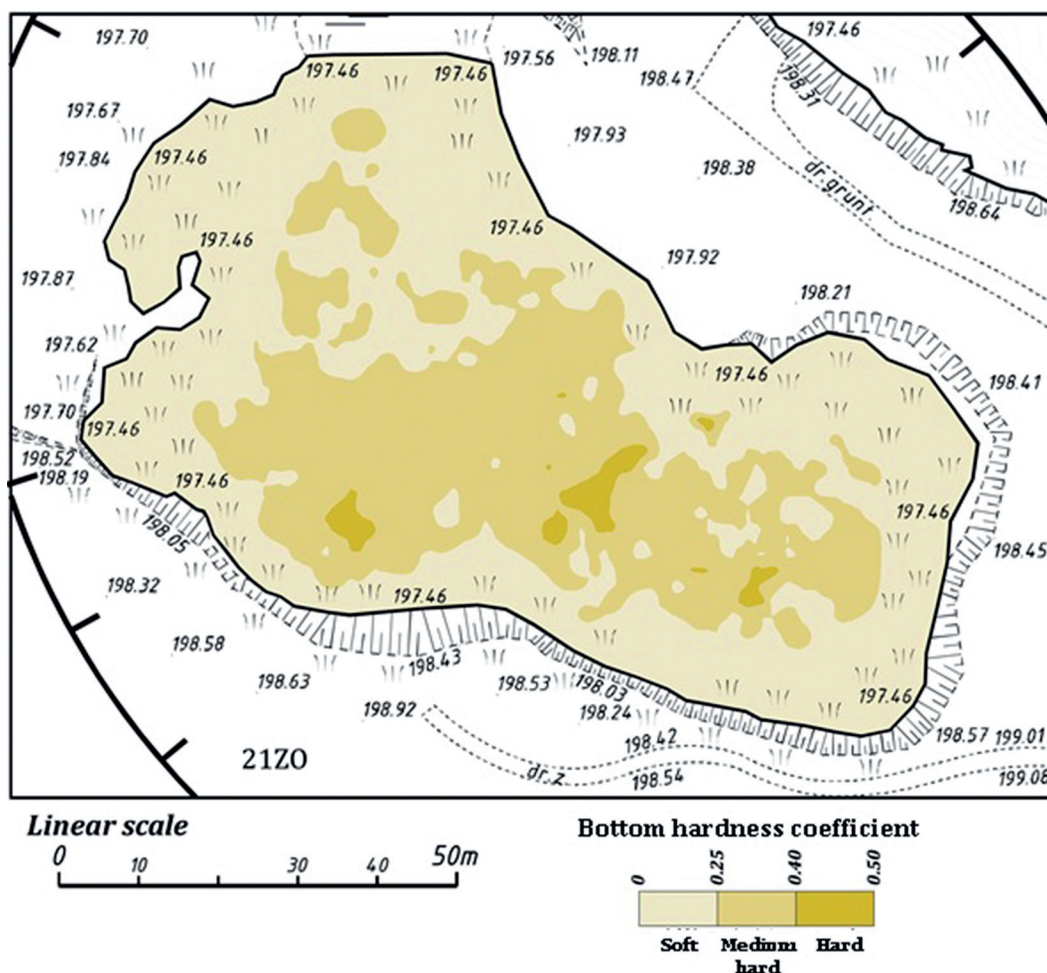


Fig. 4. The composition map of the bottom hardness in the “ecological” part of the water body
Rys. 4. Mapa twardości dna (Composition Map) części ekologicznej zalewu

shallow coastal zones of soft bottom (60.9% of the total area) and the areas of bottom of maximal slope and medium indicator of hardness (37.4% of the water body). The map of the distribution of the bottom hardness indicator was made based on 2929 points (measurement by sonar Lowrance Mark-4) and illustrated in figure 4. Data referring to the hardness of the bottom are not generated only in the situation, when the biovolume coefficient of vegetation is calculated from the formula:

$$\text{Biovolume} = \frac{G_{\text{water}} - G_{\text{plant}}}{G_{\text{water}}} \cdot 100\%$$

exceeds 60%.

where:

G_{water} – depth of the water body in the point;

G_{plant} – depth of the water body measured to the area of the vegetation „cap”.

Graphic image of bottom hardness (figure 4), indicates that endorheic character of the small water body in south-west part of Bagry and the lack of reclamation works (temporary cleaning the water body from silt) for over 50 years of the existence of Bagry led to significant pollution with organic substances, which is reflected by the percentage of the area of soft bottom and medium-hard bottom at the level of 98.3%. Zone of shallow waters of litoral (to 1.5 m of depth, the area of the water body makes 42.9%) is overgrown with associations of reed (*Phragmitetum australis*) and cattail (*Typhetum latifoliae*). The impact of atmospheric conditions (wind), small changes of the water level, human factor (vegetation removals made by anglers to create angling sites), accelerate mudding process (biomass decomposition) in this part of the water body.

The hardness of the bottom is often not uniform, thus the best projection of the hardness map is obtained when the speed of mapping is slowing down. In the zones of high bottom inclination, the best results of hardness classification are obtained when the trajectory of sonar is relatively perpendicular to the direction of the highest slope (contour line in the point) and making many courses in the regions of very differentiated morphology and changeable directions of the course of the measurement set (User Reference Guide 2017).

The examined water area is planned to be an ecological enclave (the border marked in figure 2), which will mean the protection of the resources of existing flora (including underwater vegetation) and fauna (hab-

itats of birds – geese (*Anser anser*), black-headed gulls (*Chroicocephalus ridibundus*) and Caspian gulls (*Larus cachinnans*), loons (*Gavia arctica*), bearded reedlings (*Panurus biarmicus*), little bitterns (*Ixobrychus minutus*), coots (*Fulica atra*), moorhens (*Gallinula chloropus*), tufted ducks (*Aythya fuligula*), terns (*Sterna hirundo*), black-necked grebes (*Podiceps nigricollis*) and great crested grebes (*Podiceps cristatus*), kingfishers (*Alcedo atthis*), pochards (*Aythya ferina*), redshanks (*Tringa totanus*), mallards (*Anas platyrhynchos*) and spawning grounds for fish – Mytych D., 2016; Kudłek J. et al. 2005). An important element in preserving ecological values is keeping high level of the water table (growth in the retention of the water body), so as to guarantee hydraulic connection between the part of sports and recreation and ecological part, today significantly limited. Water balance within Bagry Reservoir can go through slow and long-lasting changes as a result of natural processes (climatic changes) and intensive dynamic changes as a result of economic activities of humans (anthropogenic changes).

In authors' opinion one of the options of the protection of natural resources of the examined water body in the situation of anthropogenic distortion of hydrological balance seems to be liquidation of earth barrier separating both parts water body (deepening), which will facilitate free exchange of retained waters of the reservoir (figure 1) and the increase of the utility value of Bagry (unmanaged area).

For many years, due to the ability of self-purification of the water body, cleanness of the waters of the Bagry Reservoir has been classified as class I or class II of purity (according to the classification of waters, according to the Enactment of the Minister of Environmental Protection, Natural Resources and Forestry of 5th November 1991). Regardless the origin of the water body, its utility value depends not only on morphometric parameters of the lake basin, but also the character of vegetation overgrowing subsequent zones of the bottom, i.e.: litoral, slope and profundal zone. The litoral zone to the depth of about 1.5m (depending on the fluctuations of the water table – to depth: 1÷1.5 m), are overgrown by high rush, represented by the common reed (*Phragmitetum communis*) and broad-leaf cattail (*Typhetum latifoliae*), making a ring of the wideness up to 10m (figure 2).

On the other hand slopes and benthic zones of lake basins in the biggest water bodies of Kraków (ponds,



Fig. 5. Clusters of spiked water-milfoil in the difficult-to-access part of the water body found in June 2016 (photo R. Gawalkiewicz)
Rys. 5. Skupiska wywłócznika kłosowego w części trudnodostępnej akwenu zarejestrowane w czerwcu 2016 roku (fot. R. Gawalkiewicz)

post-exploitation excavations) according to Budnik A., et al. (2013), were dominated by plants of leaves submerged in water, i.e.: the Canadian waterweed (*Elodea canadensis*), rigid hornwort (*Ceratophyllum demersum*), spiked water-milfoil (*Myriophyllum spicatum*), small pondweed (*Potamogeton pusillus*) and sago pondweed (*Potamogeton pectinatus*). These plants are common and dominant in Polish inland standing waters and slowly flowing waters. In case of the analysed water body a dominant water plant is the spiked water-milfoil, which in vegetation period, i.e. from June to August makes underwater meadows, and their stems reaching water table, making dense and compact clusters, making it more difficult or impossible to use water body for recreation and sports, and often economic purposes (angling) – figure 5. Such a case was recorded in an anthropogenic water body - Jezioro Średnie in Turawa, situated in the Opole Province. Lake area is 16.5 ha. This is a water body formed as a borrow pit after the exploitation of gravel, where meadows of the spiked water-milfoil made it more difficult to use the water body for recreation. The application of new reclamation technologies in the framework of the carried out revitalization financed from the Provincial Fund of Environmental Protection and Water Management (WFOŚiGW) led to bringing back its recreational function (source: <https://www.youtube.com/watch?v=SQsb-tuBpHAM> – access February 2018).

In autumn and winter aquatic vegetation falls on the bottom („dormant” state), making a thick layer of ground-

cover on the bottom and making optimal conditions for the hydrographical measurements. There is no danger of possible catching up the stems into the rotors (remote-controlled boat). Thus the measurement was carried out in January 2018.

Due to the applied interpretation algorithm of acoustic signals in the software of sonar Lowrence Mark-4, it became possible not only to measure the depth of the lake in a given point, but also not to determine the thickness of the plant layer. The analysis of the data showed that maximal thickness of the vegetation layer is 1.4 m, but the mean value for 2929 records was 0.5 m. The distribution of water vegetation is graphically illustrated in figure 6. The correlation of bathymetric data, hardness of bottom and the distribution of vegetation allows us to state that in the zone of sudden depth increase (maximal depth and hard bottom) vegetation does not occur. Because of the morphological properties, the spiked water-milfoil perfectly adapts in the zones of sandy bottom with the layers of organic sediments (zones of silted bottom). In favourable environmental conditions stems of milfoil (with whorled pinnatifid-filamentous leaves) reach even do 4÷5 m of leaves. Thus the picture of the localization and thickness of the layer covering the bottom of the examined water body perfectly reflects the morphological characteristic of the analysed plant.

Water bodies, as territorial ecosystems, are subdued to the system of the quality assessment by the Inspection of Environmental Protection (Kudelska D.,

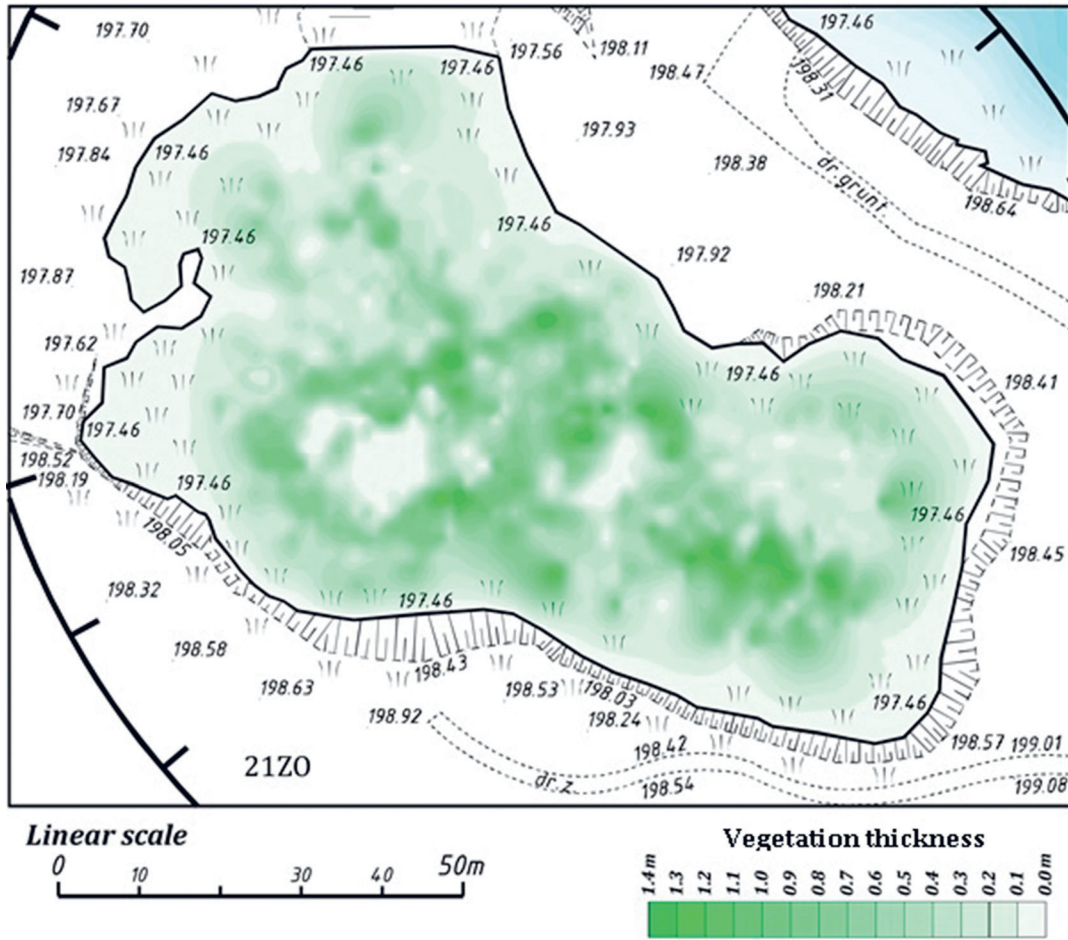


Fig. 6. The map of the bottom vegetation thickness in the “ecological” part of the water body

Rys. 6. Mapa miąższości roślinności dennej części ekologicznej zalewu

Tab. 2. Selected indexes and their normative values for three classes of susceptibility to degradation defined for the examined part of the Bagry Reservoir (classification according to Kudelska D., et al. 1994)

Tab. 2. Wybrane wskaźniki i ich normatywy dla trzech klas podatności na degradację określone dla analizowanej części wodnej Zalewu Bagry (klasyfikacja według Kudelska D., i inni 1994)

Index	Category of the water body’s susceptibility to degradation		
	I	II	III
Mean Depth [m]	≥10	≥5	≥3
$\frac{V[m^3]}{L_{shoreline}[m]}$	≥4.0	≥2.0	≥0.8

et al. 1994). The conclusions on sustainable use, protection and reclamation of lake waters is based on the results of the assessment of the water body quality, according to two criteria, i.e. susceptibility to degradation

and the state of water quality. The bathymetric measurements facilitated morphometric parametrization of the examined small water body. Thus it is possible to make a partial analysis of the susceptibility of this part

of the water body to degradation (table 2) based on the following indexes: mean depth G_{Mean} and the ratio of the volume of retained waters V to the length of the shoreline $L_{\text{shoreline}}$ (data contained in table 1).

5. CONCLUSION

Post-mining water bodies in Cracow, i.e.: Bagry Wielkie and Staw Płaszowski, should be places of particular protection of the biodiversity in natural ecosystems. Within the borders of Cracow there are some (not very numerous) small enclaves having the status of nature reserve, ecological site (utility) or the monument of nature. The effort is made to increase particularly attractive areas of urban greenery, while the issue of investing into already existing and functioning areas, including water bodies – post-mining relics, and first of all their protection is neglected. The presented in this article results of hydrographic measurements, dividing the information into bathymetry, bottom hardness and thickness of water vegetation, can significantly help in the decision-making process at the stage of preparing revitalization projects in south-west part of the Bagry Wielkie Reservoir.

Up till now none of the revitalization projects of a water body could be fully implemented due to the lack of funds (Szymczewska P., 2015), although the majority of the land adjacent to Bagry is the property of the Cracow municipality. As a result of years-lasting negligence from the city authorities, the greenery is not organized and there are large quantities of rubbish floating in litoral zones, especially those covered with rush vegetation.

The application of mobile and automatic or semi-automatic measurement instruments, such as Smart-Boat-Sonar, makes economical alternative to large vessels and allows us to obtain a large set of valuable data about the aquatic environment (for zoological reports), especially in case of small and difficult-to-access water bodies. According to the authors, the presented results make valuable material to carry out details about the revitalization of the water body (in the framework of the project of the Local Site Development Plan (Miejscowy Plan Zagospodarowania) of the area of the water body of Bagry in Cracow – Płaszow) and its adaptation for the purpose of ecological site and economic purposes (angling), in a bigger scale than it is taking place now.

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