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Renaturization Plan for a River Valley Subject to High Human Impact – Hydrological Aspects

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Abstract

This article presents hydrological aspects of a renaturization plan for a river valley that has been significantly transformed as a result of human impact. A section of the Szarlejka River valley located at the border of the cities of Bytom and Radzionków was used for this purpose.

The hydrographic conditions of the area under consideration have been significantly altered due to human action. These transformations are the result of systematic residential and industrial infrastructure development, which has been accompanied by industrial waste disposal. Underground coal mining in the area has caused subsidence and discharge of saline mining waters to rivers. The Szarlejka is considered one of the most polluted rivers in Silesia Province (Polish: województwo śląskie) and all of Poland.

The primary objective of the renaturization plan is to improve abiotic conditions and water status. This plan is based on the analysis of all accessible data, including archival maps and field work. Hydrological and hydrotechnical renaturization actions are proposed for the Szarlejka River valley that cover the elements, structures, and facilities, of which the mere presence brings the waters closer to their natural state (barrages inhibiting erosion, connections allowing for the circulation of aquatic organisms). The proposal also includes building astatic reservoirs, creating oxbow tanks in retained sections of the old river bed, and building a pond with a wetland and an island.

The restored structures will affect abiotic and biotic conditions, consequently influencing the water recovery process with the aim of bringing it closer to its natural state.

For the purposes of the planned renaturization, a geographic information system (GIS) was created, enabling digital map generation, database creation, and calculations.

Keywords: river renaturization, environmental protection, water management, human impact, GIS

Introduction

River renaturization consists of a series of projects with the essential purpose of restoring a river that has been destroyed as a result of diverse anthropogenic influences to its natural state [1-3]. The reclamation of a river and its valley can be achieved by methods developed in several fields of study, including river engineering, water management, landscaping and environment protection [4, 5]. The territorial and material scope of action is wide and varied, as it may include the river channel and its bank zone, floodplains, and even the entire catchment area.

The primary objective of renaturization is to improve abiotic conditions and water status. The restoration of waters to their natural state may not be the sole aim of renaturization; these projects can provide benefits for the economy, community, recreation, and technology, and they can improve landscape features [6].

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The renaturization plan under study was conceived within the framework of the “Clean River – the Szarlejka” (Polish: “Czysta Rzeka – Szarlejka”) - restoration of the Szarlejka River valley project financed by Radzionków municipality, partly with EU funds[1]. This project covers part of the Szarlejka river valley located in the city of Radzionków in Silesia Province (Fig. 1). The length of the section of river covered by the project is 1.94 km, with a catchment area of 8.37 km^2. The total length of the Szarlejka is 11.88 km, and its total catchment area covers 41.56 km^2.

According to the physico-geographical division of Poland [7], the area under consideration is located in the mesoregion of the Katowice Upland (Polish: Wyżyna Katowicka) within the macroregion of the Silesia Upland (Polish: Wyżyna Śląska). The basal complex of the area includes Upper Carboniferous claystones, mudstones, sandstones and hard coal. Surface deposits comprise Neopleistocene fluvioglacial sands and gravels, glacial sands, gravels, and clays, and later deposits, till eluviums. River valleys are filled with silts, sands, and river gravels. In the area under analysis, under the influence of industry and land development, land relief lost its original character. Natural land forms have undergone significant human impact with new forms appearing, including workings, spoil tips, subsidence basins, and artificial embankments. Hydrographically, the area is located in the catchment of the Szarlejka River (4^{th} order), the Szarlejka being a right-bank tributary of the Brynica River. The Brynica is part of the Przemsza River system, and the Przemsza is a left-bank tributary of the Vistula (Polish: Wisła). The border of the catchment area of the Szarlejka River is mainly defined by the border of the entire Vistula River basin, which is a watershed of the 1^{st} order.

The Szarlejka River’s main tributaries are Segiet Stream (Polish: Potok Segiet) and the Radzionków Ditch (Polish: Rów Radzionkowski). The Szarlejka also receives water from several smaller streams and ditches. Anthropogenic reservoirs of different origins and purposes, usually old workings and post-mining subsidence basins permanently or periodically filled with water, complement the hydrographic network [8].

Fig. 1. Location of the study area.

Developed, industrial, and postindustrial lands prevail in the whole Szarlejka catchment land development structure. Forests appear only in the upper part of the catchment. Agricultural land has only a small share in the catchment's development structure.

The Szarlejka Valley is clearly shaped, and the river collects water from all natural and artificial tributaries of the area. Within the part of the valley subject to the plan, the land has been almost completely transformed by man: both slopes are entirely “masked” by barren rock dumps and the post-mining waste from coal mines located nearby. Moreover, old metallurgical waste dumps are located in the lower part of the area [9]. Within the past several hundred years, the relief of the valley has undergone multiple transformations, starting with workings developed in the initial period and concluding with dumping grounds that fill the valley today [10].

The hydrographic conditions of the area under consideration have been significantly altered as a result of human activity. Many of these alterations are characteristic of urban catchments, where the so-called “urban stream syndrome” is observed [11, 12]. These transformations are due to a systematic residential and industrial infrastructure development that includes underground coal mining (causing subsidence and, consequently, the emergence of water basins on the surface); rock mass drying (as a result of drainage); mine water discharge into the surface water system; industrial and municipal waste disposal sites; industrial, municipal, and storm water sewage discharge into the surface water system; hydraulic engineering works carried out on watercourses; and the construction of reservoirs and transfer of water between catchment areas. Transformations of the surface waters in the analyzed section of the Szarlejka include the following:

- changes in the surface water system – the channel has been straightened and strengthened with fascine
- anthropogenic destabilization of the discharge regime which is shaped by external water inflow (wastewater and mining water discharge) and modified by wastewater discharge
- impediments to the surface runoff in the area of mining-induced subsidence – lowered terrain caused by subsidence impedes surface runoff to watercourses
- changes in the hydraulic connection – in sections of the watercourse running through areas subject to drainage connected to underground coal exploiting the character of the watercourse changed from draining to infiltrating
- increased surface retention as a result of flood land formation in the areas of mining-induced subsidence (within Szarlejka's catchment but outside the area directly under investigation)
- construction of water supply systems accompanied by transfer of drinking and industrial water between catch-

[1]The plan was approved and will be implemented. In 2010, a technical project based on the present plan was developed, and the work started in 2011.

ment areas – these transfers increase the quantity of water running in the Szarlejka channel

- surface water quality deterioration caused by the discharge of municipal and industrial sewage and saline mine water into the water system

Research Goals, Methods, and Procedures

The aim of this study is to present hydrological aspects of selected solutions within the Szarlejka River renaturization plan. The article also aims to present the problems occurring during preparation of renaturization plans in areas significantly transformed by human activity and to give some solutions to these problems.

The renaturization plan for the Szarlejka River valley was based on an analysis of accessible data, including archival maps. The plan was elaborated in such a way as to use the natural properties of the channel to the greatest extent possible without risking its security [13]. Therefore, in order to develop the plan, exhaustive fieldwork was performed, including flow rate measurements (with StreamPro ADCP by Teledyne RD Instruments), geodetic measurements to determine terrain elevations at selected points, longitudinal sections and cross sections of the valley, and measurements of channel-bed slope at selected points, hydromorphological mapping of the channel, and identification of pollution sources. Several site inspections to verify the hypotheses were made and photographic documentation was prepared.

For the purposes of the planned renaturization, a geographic information system (GIS) was created that enabled digital map generation, database creation, and calculations. Several available maps were also used in the creation of the system.

Several vector layers were developed and used in the elaboration of the renaturization plan. Each vector layer was fitted with a database, and some of the databases were then used for the calculations. Basic vector layers include:

- hydrographic network (current and from 1883 (1929))
- reservoirs (current and from 1883 (1929))
- land relief (contour-lines, escarpments, erosion scars)
- land use (forests, residential development, industrial development, spoil-heaps, dumping grounds, etc.)
- water supply and sewerage network
- points of wastewater discharge with division into urban (domestic), industrial, rainwater, mining (saline)
- existing hydrotechnical structures
- geodetic control network and measurement points
- proposed renaturization measures (hydrological, hydrotechnical, and other)

Results

In the first part the results of fieldwork and GIS analyses are presented. Measurements of discharge in the Szarlejka were made in June 2009 near the cross-section closing the analyzed part of the river. Comparing results with known and metered profiles of neighboring rivers (e.g. the Namiarki gauging-station on the Brynica) make it possible to state that the measurements were taken in conditions reflecting the range of low water levels. In the analyzed catchment no constant hydrological measurements are made, making it necessary to use empirical formulas for calculating selected characteristic flows necessary for the later design of hydrological structures. The following values were measured: mean annual flow SSQ, mean annual unit runoff SSq, and peak annual flow with a certain probability of exceedance. The calculated mean annual flow in the analyzed Szarlejka's section is SSQ = 0.262 $m^3 \cdot s^{-1}$, mean specific discharge SSq = 7.40 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Flow $Q_{1\%}$ is 29.2 $m^3 \cdot s^{-1}$ and $Q_{50\%}$ is 6.57 $m^3 \cdot s^{-1}$.

Cartographic analyses carried out on the basis of the created geographic information system (GIS) consisted of comparing archival maps with current maps, an important element of the Szarlejka river renaturization plan. An archival topographic map at a scale of 1:25,000 (the so-called Messtischblatt) from 1883 (edited in 1929) – Beuthen sheet has been compared with current topographic maps. This made it possible to asses changes in the course of a river channel and valley shape, and to identify the location of reservoirs existing over 100 years ago. The comparison of the course of the river in 2000 and 1883 (1929) revealed that the Szarlejka's channel has been straightened and relocated, practically at the whole analyzed section. In 1883 (1929) the length of the analyzed section was 1.92 km, with two small functioning reservoirs of 3,500 m^2 and 1,900 m^2. Currently, the length of the analyzed river section is 1.94 km and only on two short sections (144 m and 140 m long) does it have the same course as in 1883 (1929). In some places the contemporary channel runs over 60 m away from the channel of 1883 (1929).

The Szarlejka river channel carried out hydromorphological mapping of the at the analyzed section of the valley made it possible to identify the condition of the river channel and to assess the possibility of implementing the proposed solutions aimed at renaturizataion. A preliminary forecast of changes in the flora caused by the predicted changes in water relations was made on the basis of inventory of plant and animal species prepared by another team [14]. This enabled choosing the most environmentally friendly technical solutions.

Geodetic works consisted in measurements taken in 8 cross-sections of the Szarlejka valley. Channel bed drops as well as terrain elevations in places of proposed technical solutions were also determined. All measurement data were entered in the created GIS system.

In the study area and in the catchment upstream, 9 important wastewater discharge points have been identified that reach the Szarlejka directly and indirectly (by tributaries). Urban wastewater is the main Szarlejka pollution type, with Q_{max} = 30,000 $m^3 \cdot 24\ h^{-1}$. The second biggest type are mining waters from draining coal mines (discharge points are located upstream of the analyzed valley section). Mining waters from natural inflow to mining workings have the following quantitative parameters: Q_{max} = 3.2 $m^3 \cdot min^{-1}$, which corresponds to Q_{max} = 4,608 $m^3 \cdot 24\ h^{-1}$. They cause deterioration of water quality manifesting itself with increase in the concentration of mineral substances, such as chlorides or sulphates. During stock taking and identification of wastewater discharged directly to Szarlejka, one discharge point without water right permit was also identified.

The following causes of the loss of naturalness were identified in the watercourses in the catchment area of the Szarlejka River:

- Hydraulic engineering works and facilities as well as their impact on the watercourses and terrain within their range:
  – Works in the catchment area resulting in increased water flow and sediment transport change: deforestation, embankments, melioration, watercourse regulation, bank protection and sealing, destruction of old channels and hollows and other relief features that increase retention; important negative factors are urbanization and transport infrastructure together with drainage and water discharge systems; and increased sediment transport is due to deforestation, grassland changes and increased river gradient, causing increased sediment transport and channel erosion
  – Straightening channels and increasing the river gradient, uniforming the channels with respect to their shape and size, eliminating bank and bottom irregularities, destroying ecotone and eliminating islands
- Unnecessary or excessive maintenance works, including vegetation removal, reduction of morphological diversity of the channel (deposits, knickpoints and island removal, river bank evening), elimination of holes and breaches, and slope gradient unification by filling up the valley with mining waste products
- Old watercourses (oxbow lakes, cut-off river branches, pools and ponds) that were filled in the floodplains, destruction of wetlands and dry land, deforestation and neglect of trees and scrub in areas without flow and along the banks, improper selection of trees
- The impact of numerous external factors, including the most dangerous: water discharges contaminated with chemical, particulate, or bacterial matter into the river.

Many of these measures are also taken in other catchments subject to human impact, but the Szarlejka catchment is distinguished by a substantial degree of valley narrowing caused by decades – long processes of storing metallurgical and mining waste. Waste material has also been used to level the valley bottom. Besides total transformation of the valley's morphology, waste materials (particularly metallurgical) also carry the risk of polluting water with specific substances such as zinc. Another element distinguishing the Szarlejka is its pollution with saline mining waters – it is an important problem that also concerns other rivers draining the Upper Silesian Coal Basin.

Renaturization is usually a process that includes various types of projects (works) together with the spontaneous natural conversion of the watercourse and neighbouring land. In the Szarlejka River valley, these projects will cover the following:

- Elements, structures and facilities whose mere presence brings the waters closer to their natural state (barrages inhibiting erosion, construction enabling circulation of aquatic organisms). The restored structures will affect abiotic and biotic conditions, influencing, as a consequence, the water recovery process to bring it closer to its natural state.
- Works that will not produce a completely restored component of renaturized water but will initiate a natural process aimed at restoring the watercourses to their natural state, such as planting or seeding different plants (in this case the choice of plants needs to be done very carefully so that they can survive in conditions of significant acidity or acidity and salinity of ground, connected with the specific character of the area).
- Maintenance works consisting of minor adjustments of natural transformations when they do not contribute to restoring the waters to their natural state (e.g. replacing and removing dead trees and scrub).
- Upkeep of the renaturization process (maintenance and conservatory works, water protection and quality improvement).
- Discontinuation of certain maintenance activities with respect to artificial watercourses. Such watercourses may, as a result of solely natural processes (natural succession), undergo transformations that bring them closer to the natural environment (e.g. due to channel processes or animal and vegetation impacts).

Water quality in the river is influenced by the development of the whole catchment. Therefore, watercourses cannot be restored to their natural purity without relevant works and activities taken in the entire catchment system. Renaturization measures taken in the entire catchment cannot be treated as a substitute for the necessity of wastewater treatment and alleviating the effects of its discharge to the recipient.

Szarlejka is one of the most polluted rivers in Silesia Province. It is subject to monitoring and its waters are tested by the Regional Inspectorate for Environmental Protection in Katowice. The control and measurement site is located at the confluence of Szarlejka and Brynica. Szarlejka carries poor quality waters with almost all of the tested indexes exceeded. Poor quality and low potential of water are influenced by e.g. total suspension, dissolved oxygen, BOD_5, TOC, conductivity, dissolved substances, sulphates, chlorides, ammonia nitrogen, Kiejdahl's nitrogen, total nitrogen, and total phosphorus (Table 1).

Water right permits issued for wastewater discharge in identified points contain data about permitted quantities of certain substances. But it can be inferred from the quality of water in the Szarlejka that these parameters are not kept, which contributes to deterioration of water quality in the river. This particularly concerns the rainwater that should be treated, but in periods of intensive or long-term rainfall and during thaw – treatment of these waters is inadequate and substantial amounts of petroleum derivatives get into the river as they are washed off roads, car parks, or squares. Such a situation has been noticed a few times during fieldwork.

Table 1. Classification of ecological potential of homogeneous surface water bodies (Szarlejka) in 2010.

Classification of water quality indexes and elements			Szarlejka	Value	Potential
Biological elements			Phytoplankton – chlorophyll "a"		-
			Phytobenthos (diatom index IO)	0.16	IV
			Macrophytes		-
			Biological elements class	IV	
Physico-chemical elements	Physical status		Temperature (ºC)	18	I
			Total suspension (mg·dm^{-3})	169	BGP
	Oxygen conditions		Dissolved oxygen (mg·dm^{-3})	1	BGP
			BOD_5 (mg·dm^{-3})	47	BGP
			TOC (mg·dm^{-3})	21	BGP
	Salinity		Conductivity in 20ºC	5820	BGP
			Dissolved substances (mg·dm^{-3})	3133	BGP
			Sulphates (mg·dm^{-3})	421	BGP
			Chlorides (mg·dm^{-3})	1322	BGP
	Acidity		pH	7.6-7.9	I
	Biogenic substances		Ammonia nitrogen	6.38	BGP
			Kjeldahl nitrogen	14	BGP
			Nitrate nitrogen	1.2	I
			Total nitrogen	15	BGP
			Total phosphorus	3.7	BGP
			Physico-chemical elements class	BGP	
			Particularly harmful substances, specific artificial and non-artificial pollutants	II	
			Ecological potential	IV	
			Chemical status	-	
			Status	-	

BGP – below good potential, I, II, III , IV, V– quality classes: I – maximum potential, II – good potential, III – moderate potential, IV – weak potential, V – bad potential, - no assessment;
Source: on the basis of data of the Regional Inspectorate for Environmental Protection in Katowice.

Inadequately treated domestic wastewater as well as inflow of pollutants from illegally discharged wastewater not only increase concentrations of harmful substances but also lead to significant biological pollution.

Renaturization is usually only partial. Full restoration is impossible, as river processes are often irreversible. The scope of renaturization projects and actions is also determined by the use of water for economic purposes. The current status of the waters is strongly linked to the present economic and natural conditions. Therefore, even if the restoration of a fully natural environment were possible, it would simultaneously require the transformation of these conditions. In that respect, the following actions within the Szarlejka river valley are proposed:

- construction of barrages inhibiting erosion
- restoration of self-cleaning capacity (by improving water quality, increasing water aeration by building artificial rapids, etc.)
- restoration of sections of the river banks to their natural state (by removing unnecessary hydrotechnical elements and planting species specific for this habitat)
- construction of islands
- renaturization of old watercourses in the floodplains

Before elaboration of technical design the following detailed solutions were proposed (Fig. 2):

- building astatic reservoirs – 12 reservoirs have been planned in the upper part of valley sides, each of about 240 m^2, 127 reservoirs in the middle part of valley sides, each of about 14 m^2; in the valley bottom 64 reservoirs have been planned, each of 7.5 m^2. This solution will make it possible to keep the moisture in drought spells and improve biodiversity as well as stimulate growth of the planned plants
- in the river channel there are plans to increase the radius of the existing 20 bends and to create 12 terraces and undercuts to diversify the current
- making 25 stone rapids that will diversify river structures
- using two old uncovered sections of the Szarlejka's channel as old riverbeds – this will lead to the creation of two islands, making the horizontal structure of the river more diversified
- analyses of 1883 (1929) maps point to the existence of two small reservoirs on the river itself, but their recreation is currently impossible; instead, a small pond of 1,900 m^2 is planned with a wetland of 75 m^2 at its inlet; at present there is a partly concrete hollow with an outlet of collecting pipe for rainwater and thaw water connected to the river with a concrete ditch; water will be supplied to the old riverbeds and the pond by small dams built on the Szarlejka upstream of these structures; these structures will have weirs and drain devices at outlets and inlets;
- necessary strengthening of the channel will be made out of natural materials, making it possible for organisms to occupy the banks.

Several examples of recovery and restoration solutions are presented using images and visualizations generated by the project's GIS system (Figs. 3, 4, and 5). Information contained in the following databases is shown: elevation points, dikes, embankments, terraces, erosion scarps, islands, terrace reinforcements, and astatic reservoirs.

Conclusions and Final Remarks

It cannot be expected that the renaturization will re-create a fully natural river and valley. The conditions restored in the renaturization process will produce a new, different, younger naturalness, with a yet unproven capability to survive disasters and cataclysms and to regenerate. The incompleteness of the renaturization means not only that the waters are brought close to their natural state without actually reaching it but also that only some sections of rivers and other water bodies are restored.

The EU's Water Framework Directive commits European Union member states to achieve at least good surface water status by 2015. Both the above objective and flood risk prevention in the areas of high land use at the bottom of the valleys require major changes to existing water management policies.

The Szarlejka River carries water of poor quality, and almost all identified indicators have been exceeded. The quality of water is affected by the water management of the entire catchment area. Therefore, the water cannot be restored to its natural purity without appropriate works and actions being carried out over the entire catchment area. At the same time, renaturization projects should not be considered a substitute for wastewater treatment and the neutralization of the negative effects of wastewater discharge into the river.

The proposed solution also involves a stricter policy for issuing permits required under the Water Law Act and control over the implementation of recommendations set out therein. Moreover, during project implementation, it is important to carry out constant monitoring to identify all illegal sewage discharge sites. Water quality analysis should be conducted that covers the Szarlejka River, Radzionków Ditch and all collectors supplying water to the Szarlejka within the section designated for renaturization. On account of the risks connected with rainwater being fed into the river [15, 16], such analysis should also cover rainwater collectors. Considering the long-term industrial impacts on the catchment area, the composition of bottom sediments should also be tested in the course of the carried out works [17, 18], which will allow for a more accurate identification of the causes of poor water quality and ways

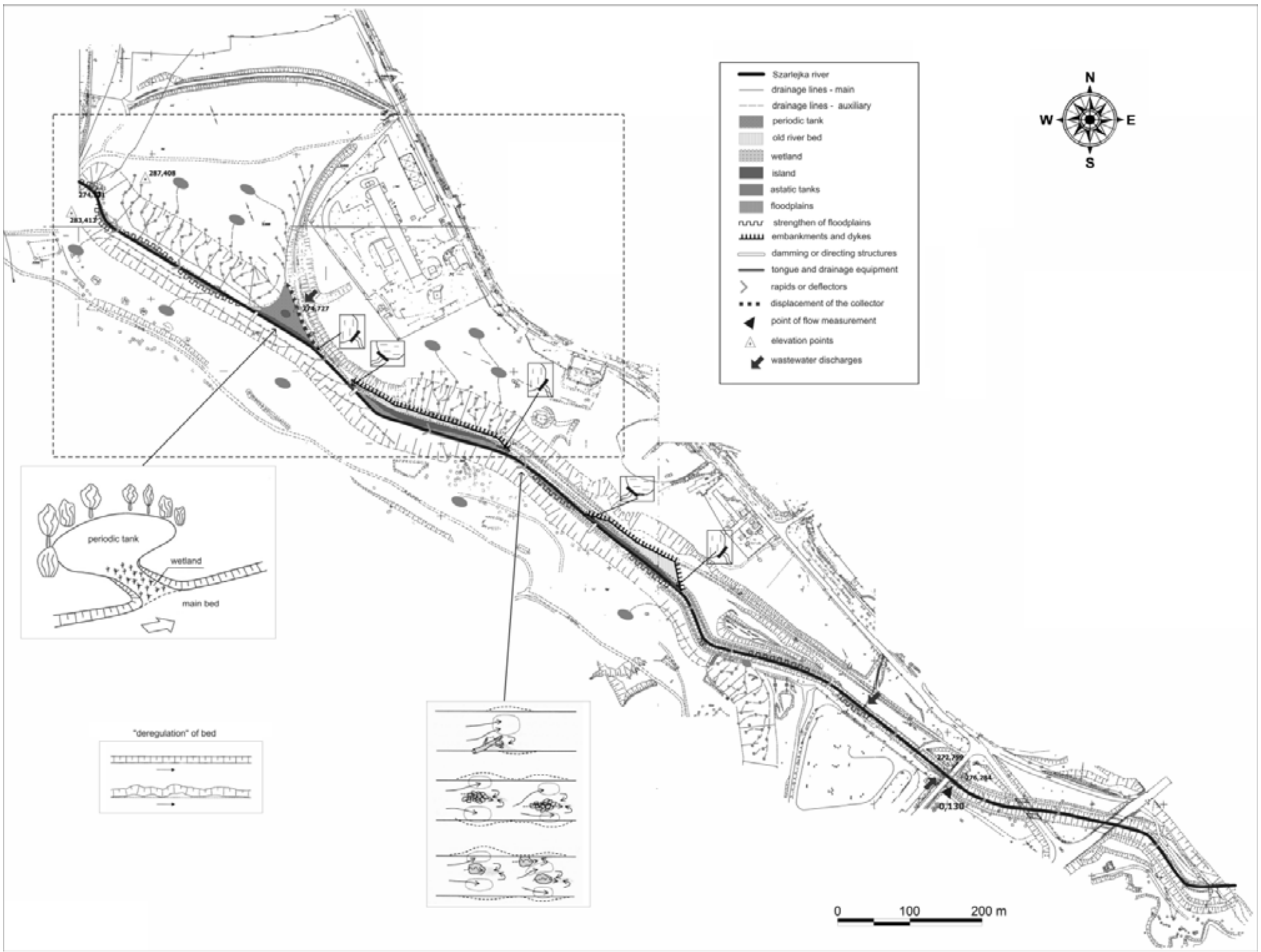

Fig. 2. The scope of hydrotechnical works in the valley of the Szarlejka River (dashed rectangle shows the limited area shown in Figs. 3, 4, and 5).

to improve it, e.g. by removing sediments. Without a major change in water quality, the project will fail to achieve its ecological objectives.

The Szarlejka River renaturization plan assumes that the most important and comprehensive objectives of the recovery and restoration process will be fulfilled, namely the following [19]:

- preservation, support and restoration of biodiversity and geodiversity
- maintenance of the river valley's function as ecological corridors
- maintenance and restoration of natural and landscape values
- protection, support and restoration of natural habitats
- improvement of sustainable water quality
- maintenance and development of the diversity of watercourses and the changing conditions thereof

A measurable benefit of the planned renaturization of the Szarlejka river and its valley will be the improvement of environmental conditions and recreation or creation of new landscape and tourist values. The objectives of the program "Clean River – the Szarlejka" also include the creation of

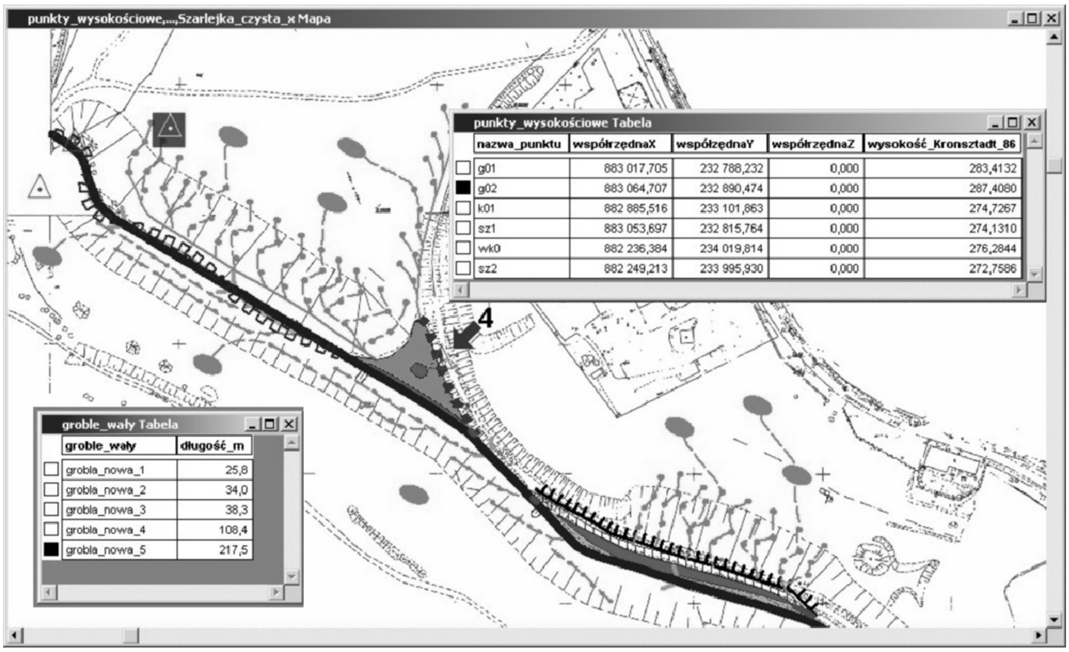

Fig. 3. Structure of the sample databases against the map window – the bases: elevation points, dikes, and embankments.

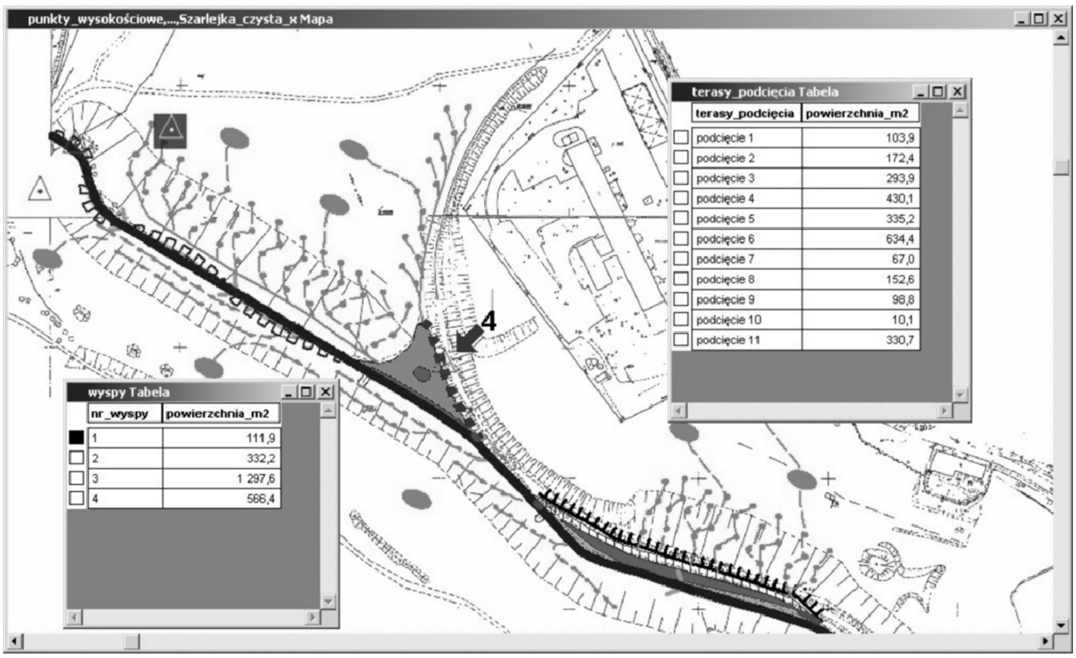

Fig. 4. Structure of the sample databases against the map window – the bases: erosion scarps and islands.

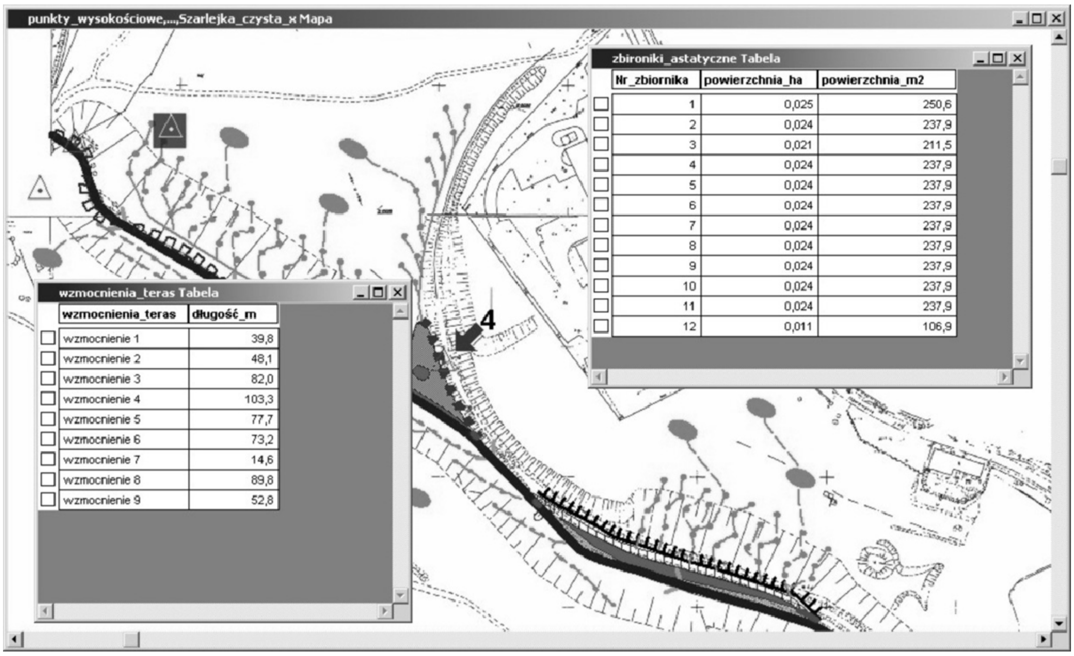

Fig. 5. Structure of the sample databases against the map window – the bases: astatic reservoirs and terrace reinforcements.

footpaths, cycle routes, benches and information boards. All these measures will make it possible for the town and its residents to turn back to the river.

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