Odra River Basin Flood Protection Project: Implementation of a Flood Risk Management Plan

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Abstract. Over the last 30 years large floods have occurred in Central Europe, causing multi-billion euros of losses. There were floods on the rivers Rhine (1991,1993), Odra (1997, 1998), Vistula (2001, 2010), Tisa (2001), and Elbe (2002) to name a few. In response to the floods in the Odra River basin, the states located within the catchment: the Czech Republic, Poland, and Germany agreed upon a common strategy and action plan in order to enhance flood safety, undertaking to implement this plan under their respective national action plans. In 2001, Poland's government and Parliament established a multi-objective strategy for the Odra catchment (Programme for the Odra River – 2006), whose main priority was flood protection. The implementation of the programme was scheduled for years 2002-2016 and the main implementation tool was the project established with support of the World Bank and the Council of Europe Development Bank, called the Odra River Basin Flood Protection Project with financing of 800 million euros. The Project was completed in 2020 because of certain delays in implementation. The paper will describe the content and implementation of the project that included active and passive protection measures. An International Panel of Experts (IPE) provided support for the implementation of the project by issuing reports and recommendations concerning all major technical problems that occurred during the design and construction of the polders. The paper will conclude with lessons learnt and comments on further development concerning the new Odra-Vistula Flood Management Project.

1 Odra River Basin: location, character, flood risk

The Odra (Oder) River is an international river of the Baltic sea catchment that flows through territories of three countries: the Czech Republic, Poland, and Germany. The area of the Odra basin amounts to 118 861 sq. km, of which 106 821 (89%) sq. km is within the territory of Poland, 5% in Germany, and 6% in the Czech Republic. The Odra River is the second largest river in Poland after the Vistula. Its length from the headwaters to the estuary amounts to 854.3 km, of which 741.9 km is within the territory of Poland. The Odra also forms the Polish-German border along 187 km of its length. Only a few western tributaries have their sources higher than 1000 m above sea level (asl). Approximately 21% of the catchment area is above 300 m asl, approximately 55% is between 100 and 300 m asl, and 24% of the area is below 100 m asl. These topographic characteristics have an impact on the hydrology and thus the flood risks in the Odra river valley and the upper part of the catchment.

Figure 1. Location of the Odra River basin in Central Europe

The flood risk in the Odra River basin has specific character, typology, and seasonality resulting from meteorological, hydrological, and climatic conditions. Above all, the anthropogenic conditions within the catchment are a major contributing cause to the flood risks. In particular, the land use in the catchment and regulation

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works implemented in previous centuries have shortened the length of the river from 1020 km to 854 km, a 16% reduction in river length. There are many hydrotechnical structures located on the river (e.g., weirs, locks, dams, etc.), which have served to accelerate water flow downstream. Particularly important elements of these structures impacting the flood risk are retention reservoirs (multi-purpose or flood protection dams), dry polders, levees, and bridges, which frequently reduce the width of the floodplain and thus constrict the natural flow path.

There are three types of floods that can happen in the Odra catchment: spring/summer floods, flash floods, and winter floods.

The most dangerous flood events are those that occur from May to September and are caused by extreme precipitation in the upper parts of the catchment. These events have become more extreme as a result of climate change in the last decades. Spring/summer floods pose the most significant hazards to life and property within the catchment. Spring/summer floods could be of two types: flash floods in mountainous areas, which have a very short time between the precipitation and flood flows (rather in minutes instead of hours), and fluvial floods in the Odra valley characterized by long periods of high water levels, which increase the risk of dike breaks and flooding of quite large areas behind the dikes, or overtopping of dikes in case of catastrophic flows, as it was the case during the 1997 “millennium” flood.

Several important cities and towns of Western Poland are located in the Odra Valley: Wrocław (570,000 inhabitants), Opole (130,000), Racibórz (50,000), Kędzierzyn-Koźle (55,000), Słubice (20,000), Oława (33,000), Brzeg (36,000), and Szczecin (404,000).

The flood events along the Odra have a high probability of concurrent flood flows along the main river and the western tributaries. This occurred during the 1997 flood. In July 1997, two flood events described in detail in [4] occurred within short intervals. In the area between Wrocław, Katowice, and Brno in the Sudety and Beskidy Mountains, precipitation in excess of 200 mm was recorded in a five-day period (July 4 to July 8). And significant portions of the catchment areas recorded rainfall in excess of 300 mm: Praded, Czech Republic recorded 455 mm, Lysa Hora, Czech Republic recorded 586 mm, and Racibórz, Poland recorded 244 mm. Then, a few days later, there was a second period of high precipitation over a period of four days from July 17 to July 21: Praded recorded 139 mm, Lysa Hora recorded 167 mm, Wieluń, Poland recorded 116 mm, and Częstochowa, Poland recorded 115 mm of rainfall. These event totals correspond to the typical monthly precipitation for July for these stations. A second flood wave resulted from this event and an exceptionally long period of high-water levels occurred in downstream areas.

The 2010 flood was also related to extreme precipitation in the Upper Odra river catchment, with recorded rainfall many times above long-term averages for the month of May: with Racibórz recording 304% above normal, Kłodzko, Poland recording 209% above normal, Opole, Poland recording 390% above normal. Water levels in the river were close to levels observed during the 1997 flood, but measurements reveal that discharges were much lower (3000-3600 m^3/s in 1997 compared to 2050-2100 m^3/s in 2010). In contrast to the 1997 event, there was no coincident flood wave on the Odra River and the Nysa Kłodzka River.

Flash floods are typical in the Kłodzka Valley, where flash floods are known to occur as a result of precipitation in excess of 50 mm. Very serious floods have occurred when 100 mm of precipitation is recorded in two days. The topography of the valley and proximity of the towns along the rivers create exceptional conditions for damaging flash floods. The most significant flooding in the Kłodzka Valley occurred in 1997.

When extreme precipitation of 7 to 25 mm per hour took place over a period of 60 hours, flash floods began to be reported in 4 to 7 hours from the start of the precipitation in the following towns: Bystrzyca Kłodzka (613 m^3/s), Kłodzka (1440 m^3/s), and Bardo (1680 m^3/s), causing huge damage. The 1997 flood hit the right-side tributaries of the Nysa Kłodzka River, and a flash flood of similar magnitude hit the left-side tributaries of this river in 1998, causing damages in towns along the Bystrzyca Dusznicka River (Polanica & Duszniki Zdrój). Both the 1997 and 1998 floods caused loss of life. In addition to these more recent events, there are dramatic descriptions of flash floods that occurred in the Kłodzka Valley in 1903 and 1938.

The third type of floods in the Odra river basin is winter flooding that results from rainfall, snowmelt, and ice jams. The most dangerous of these events are floods caused by long periods of very low temperatures, which cover the river with ice and blocking the flow of the water downstream. In this case, joint icebreaking operations managed by German and Polish water management authorities become critical on the river from Szczecin (lower Odra) to Wrocław (middle Odra), that is, along a portion of the river more than 300 km long. When properly performed, icebreaking can substantially reduce the risk of dike breaks and flooding of large flat areas.

Winter flooding in the Odra river valley can be caused by the occurrence of icing on the river that occurs simultaneously with a thaw in the floodplain. However, in the last 20 years, winter flooding was no longer observed on the Odra river due to climate change, but historical floods caused dike failures and flood water staying for a long time in the floodplain. Because of the degradation of the Odra waterway and lack of maintenance, this risk is increasing in case of icing since there is no more possibility for ice-breaking operations on the river.

2 Flooding in the Odra catchment – history, flood losses

Due to hydrological and meteorological conditions described above, large scale flooding in the Odra basin was frequently mentioned in historical annals. Especially after river regulation works in the 18th and 19th centuries, big floods occurred in 1813, 1854 and finally, in 1903. After this last flood, a flood protection system was designed and built along the Odra river, with levees, polders and reservoirs; this system was successful in reducing the flood

risk until the catastrophic flood of 1997, which became a turning point in the modern history of the river.

In 1997, south-western Poland was struck by a flood which, due to its scale and consequences, was called the thousand-year flood. None of the floods on record has caused such huge economic and social losses. This unprecedented flooding in the Odra basin claimed 54 human lives, the areas of 24 out of the 49 voivodships (provinces) then existing in all of Poland were flooded and 680,000 homes were affected by the flood, including 50,000 that were totally inundated. In total, the flood affected as many as 143,000 small enterprises, as well as 4,000 education, culture and health care institutions [16].

Based on studies on flood damages conducted by the Main Statistical Office (Główny Urząd Statystyczny) at the beginning of 1998, flood losses are estimated at PLN 12-12.2 billion (3-3.1 billion euros). If the costs of rescue operations are included, the value of losses will increase up to PLN 14 billion (3.5 billion euros).

The 1997 flood fully exposed the strengths and weaknesses of the existing flood protection system put in place in the upper and middle Odra basin. This system, gradually developed chiefly after the 1903 flood, is composed of river embankments, retention reservoirs, diversion channels, polders (flood storage areas) and dry flood control reservoirs. In July 1997 all flood management structures and facilities proved to be entirely insufficient, in particular, with respect to the flood protection of urban areas located within the valleys of the Odra and Nysa Kłodzka rivers, where the largest losses were incurred not only in municipal infrastructure, power transmission systems, telecommunication systems, but also in embankments, hydrotechnical structures, infrastructure along brooks, etc. Thus, losses resulting from the damage and destruction of hydrotechnical facilities and structures, as well as of the network of flood defences, estimated at PLN 2.5 billion, account for a significant part of these losses.

The flash flood of 1998 in the Kłodzka Valley caused huge damages in towns and villages. The last big flood threat was in 2010 when, despite very high levels of water (almost as much as in the 1997 flood), there were no dike breaks, but only local flooding with limited losses.

3 Strategic documents preparing flood risk management activities

The scale of the 1997 flood and the magnitude of losses clearly demonstrated a need to create a comprehensive and consistent strategy for the modernization of the Odra water system. The Programme for the Odra River – 2006 [15], being a set of integrated measures (regulatory, organizational and structural) relating to the development of the entire Odra basin, with special attention to flood protection issues, encompasses such a strategy. The objective of the Programme for the Odra River - 2006 was to develop an integrated water management system for the Odra basin, which would incorporate flood control needs, preparation of flood prevention land use plans, protection of water quality and natural and cultural environment, as well as transport needs, economic development of regions located on the Odra river and consumer needs. Thus, the Programme for the Odra River - 2006 provided for modernization of the Odra Water System and sustainable social and economic development in the Odra region, including human safety. Principles of ecodevelopment were formulated and respected in all components of the Programme, both at the planning and implementation phases.

The Act on Establishment of the Multi-Annual "Programme for the Odra River - 2006" was adopted by the Sejm (Polish Parliament) on 6 July 2001, following wide social consultations held in the years 1998-2001, during which the Programme was considerably modified. The adoption of the Act was preceded by the preparation of a pre–feasibility study on the Programme for the Odra River - 2006, which is a document necessary to negotiate international co-financing of the Programme. The study was co-financed by the Canadian International Development Agency (CIDA) and was carried out by Roche Ltd (Canada) and WARR (Poland). Under the Act, the scope of the Programme for the Odra River - 2006 encompasses modernization of the Odra Water System, and it is a multi-annual government programme within the meaning of art. 80 of the Act on Public Finances of 26 November 1998. The Act provided that the Programme for the Odra River - 2006 would be implemented in the years 2002-2016. Under the Act, the Programme implemented tasks relating to the following areas:

1) construction of passive and active flood risk management systems,
2) protection of the natural environment and water cleanliness,
3) flood recovery,
4) preventive land use planning and ecosystems re-naturalization,
5) increase of forest areas,
6) maintenance and development of the inland navigation,
7) utilization of rivers for power generation.

The most important component of the programme was flood risk management and due to that fact, strategic development for flood risk reduction in the cities and towns along the Odra river was prepared in cooperation with the World Bank. The implementation was undertaken again in cooperation with the World Bank, and also with a second sponsor, the Council of Europe Development Bank, the most strategic intervention being the Odra River Basin Flood Protection Project [12].

After becoming an EU member in 2004, Poland started to implement EU directives including the one established in 2006 on the assessment and management of floods [5]. In preparation for this implementation, three EU co-financed projects were executed in the basin:

- OderRegio I in years 1999-2001,
- OderRegio II in years 2003-2007,
- OdraRegion in years 2005-2006.

3.1 OderRegio projects

The OderRegio projects [2] were coordinated by the Berlin and Brandenburg Joint Spatial Planning

Department for Associated Countries (Germany). In addition to Germany, Poland and the Czech Republic participated in the project.

Its first phase - OderRegio I - related to the development of the "Concept for flood prevention including spatial management measures in the Odra River basin". This project was supported by EU funding under the INTERREG II C Initiative. One of the essential results of the project, apart from the development of the concept itself, was the initiation of the process of creating a stable interdisciplinary transnational group and the development of mechanisms for its activity. The results of OderRegio I induced the government representatives from the three countries participating in the project to make, on 29 June 2001, a ministerial-level joint declaration relating to preventive flood protection on the Odra River under "The Szczecin Initiative". In this declaration, the results of the OderRegio I project were acknowledged and it was stressed that, thanks to the good and trust-based cooperation of all the three states participating in the project, their joint knowledge relevant for preventive flood protection was successfully combined. At the same time, emphasis was put on the need of spatial and technical concretisation of areas of activity such as: rainwater retention in the place of rainfall, retention through structural flood protection, the maintenance and protection of existing retention areas, the creation, extension and protection of structures through structural flood protection and the minimisation of possible damage. In connection with that, the signatories of the declaration supported the continuation of the already started fruitful cooperation under the European Union aid programme INTERREG III.

As a result, the next project, OderRegio II became the expansion of OderRegio I. In taking the initiative to prepare this project, its partners – including the Government Plenipotentiary for the "Programme for the Odra River -2006" and the Ministry of Infrastructure on the Polish side – were convinced that the international nature of flood problems requires not only a concept, but, in the first place, a plan for transboundary preventive action and the development of integrated strategies. The main aim of this project, this time co-financed under the INTERREG III B Community Initiative, was therefore the expansion of the concept, prepared during the first phase of the project, to arrive at a transnational action programme which will comprise, among other things, appropriate regulatory and planning instruments, as well as an active information policy. It was also assumed that outcomes of the OderRegio II project would be prepared in close cooperation with institutions of regional extent and significance, operating within the whole basin area. As a result of the implementation of the second phase of the project, areas of operation for preventive flood projection were made specific by defining undertakings on the partial areas. On the flood risk maps, essential information for the population and decision-taking institutions was presented. An analysis of effectiveness of flood protection measures was made for selected areas. The significance of the OderRegio II project consists primarily in the fact that it contributes to a better understanding of the importance of preventive flood protection problems based on an approach which surpasses state, administrative and industry-related borders.

3.2 OdraRegion project

In spite of the fact that the Flood Directive has not yet taken its final shape, and its implementation has not yet started in the form of national laws, actions strictly implementing its objectives were taken in the Odra River basin by the OdraRegion project [17]. This project was commissioned by the Polish Government Plenipotentiary for the "Programme for the Odra River - 2006" and it was financed from the government budget allocation and EU pre-accession aid funding under the programme PHARE CBC POLAND – GERMANY 2003. Its aim was to create a basis for the development of flood risk management operational programmes prepared by regional or local governments to improve the safety of human settlements in flood risk areas, as well as for spatial planning, water management and regional development measures based on, inter alia, transboundary cooperation within the Odra basin area.

As part of the work on the OdraRegion project, a study entitled: "Programme for preventive flood protection in the Odra river basin with special attention to the Warta river basin and the Szczecin Lagoon" was prepared. Thematic maps were drawn showing land use, flood hazard and potential damage. Under the project, data were also integrated into the existing Spatial Information System for the Odra River Basin (SIPDO). A very essential element of the project was information activities relating to its outcomes, targeted at institutions involved in water management and spatial planning, as well as local and regional governments. As a result of the project implementation, recommendations for the implementation of proposals supporting the development of broad-based preventive measures were successfully agreed, defined, and incorporated in the package of necessary structural protection measures scheduled for implementation.

It is important to indicate that after the 1997 flood, The International Commission for the Protection of the Odra against Pollution (ICPO) extended the mandate to flood protection topics and has produced strategic documents which were agreed by all countries in the basin related for preparation of documents:

- Joint strategy and rules for flood prevention in the Odra River basin -1999
- Flood prevention programme in the Odra River basin - 2004

The step from programming to implementation must be based on detailed technical documents. The important technical documents for flood risk management in the Odra basin were:

- concept study of flood protection of the Wrocław Metropolitan Area prepared by a coalition of local consulting companies (WARR & Hydroprojekt Wrocław) and Universities (Wrocław University of Technology & Wrocław Agriculture University) in years 1999-2000,
- feasibility study prepared by JacobsGIBB during the implementation of World Bank initiated Flood

Recovery Project (1998-2005) as a base for negotiating and establishing by the Polish Government of a strategic flood protection project.

These documents and the Project Appraisal Document (PAD) [12] led to the Odra River Basin Flood Protection Project.

4 Odra River Basin Flood Protection Project (ORFPP)– descriptions, goals, actions, implementation, sponsors

4.1 Description of the project

The main objective of the project is to protect life and property of over 2.5 million residents of the Odra basin threatened by disastrous floods [12]. It will be possible to achieve this objective by reducing the flood wave peak by storage of flood water in the planned Racibórz dry retention flood reservoir and by integrated management with the other reservoirs located within the Odra basin upstream of Wrocław, as well as through the modernization of the Wrocław Floodway System. In the Feasibility Study, analysis of many alternative solutions was carried out, which would lead to the achievement of the above-defined objective. Ultimately, a project composed of four components was selected:

Component A: Construction of the Racibórz dry retention flood reservoir described below as the most important component in the project.

Component B: Modernization of the Wrocław Floodway System (WFS). The existing flood control system in Wrocław protects the city against a flood not larger than 2200 m^3/s, whereas during the July 1997 flood, the peak flood waters were 3640 m^3/s. The Racibórz dry reservoir will reduce the peak flood wave, but it is necessary to increase the carrying capacity of the Odra channels passing through Wrocław and to increase the possibilities of using the Widawa river valley for transfer of a part of flood waters and to take some burden off the city centre's flood protection system. Necessary modernization works can be divided into three groups:

- B.1 Modernization of dikes and boulevards. These works involve the strengthening of the structure of existing embankments and boulevards, reducing the risk of their failure, as well as the raising of their structure, where necessary.
- B.2 Modernization of the Odra channels. The increase of the carrying capacity of the Odra channels involves the widening and deepening of the channels and modernization of selected hydraulic structures affecting the flood waters carrying capacity.
- B.3 Modernization of the transfer of flood waters in the Widawa valley. The modernization of the existing Widawa spillway channel enables the transfer of about 185 m^3/s, and under extreme conditions, 320 m^3/s. The increase of the carrying capacity will involve the construction of a new structure diverting flood waters from the Odra to the spillway channel feeding the Widawa, the widening and deepening of the spillway channel and modernization of embankments and many bridge structures.

Component C: Improvement of flood management, monitoring, evaluation and supervision of the implementation of the Environmental Management Plan (EMP) and the Resettlement Action Plan (RAP). This component includes actions aimed to strengthen hydro-meteorological forecasting, as well as forecasting of threats related to extreme flood events in the Odra valley and planning of mitigation measures. This component envisages monitoring and evaluation of the implementation of EMP and RAP, as well as support for the implementation of the idea of building an ecological corridor within the project area.

Component D: Project management, technical support and training of Implementing Agencies. This component involves the Government of Poland's support in the project implementation by establishing a Project Coordination Unit and supporting Implementing Agencies, as well as financing all actions related to the supervision and coordination of design and construction works, considering social and environmental considerations.

4.2 Costs of the project

Total project costs estimated in PAD [12] were ca. €500 million euros. Table 1 shows the expected and realised investment costs based on Project Coordination Unit (PCU) estimation in March 2020 and ICR [7].

Project components	Costs (PAD 2007) in million €	Estimated Final Costs (ICR 2020) in million €
A. Racibórz dry retention flood reservoir		
A.1 construction costs	137.4	404.63
A.2 RAP implementation costs	64.9	54.16
A.3 Design and technical supervision	16	28.09
Total A	218.3	486.88
B. Wrocław Floodway System		
B.1 Modernization of dikes and boulevards	55.9	35.55
B.2 Modernization of Odra channels	121.5	213.46
B.3 Modernization of Widawa flood waters transfer	43.2	79.36
B.4 Design and technical supervision	20.0	38.08
B.5 Resettlement cost	13.3	17.23
Total B	253.9	383.68
C. Improvement of flood management, monitoring, evaluation and supervision of the implementation of Environmental Management Plan (EMP) and Resettlement Action Plan (RAP)	27.0	13.74
D. Project management, technical support and training of Implementing Agencies	5.8	6.7
Total project cost	505.0	891.0

Table 1. Project costs assumed in 2007 and spent until 2020.

4.3 Economic analysis of the project

The fundamental aim of the economic evaluation was to establish whether the proposed project's contribution to future improvements in social and economic welfare of the communities in the project area protected from flooding is of greater value than the resource costs incurred by the national economy. The economic analyses have been carried out based on a comparison between the incremental capital and operating costs of the project scenarios with the incremental economic benefits resulting from their implementation. The parameters for the economic evaluation include a 30-year period of operation and a 90% economic conversion factor.

The economic viability of the project has been tested through estimation of an economic rate of return (ERR) based on the above-described assumptions [9]. The estimated ERR for the project is 17.4%, meaning that the Polish economy would realize a 17.4% rate of return from implementing the project, which is well in excess of the opportunity cost of capital (OCC), taken at the rate of 10%. The project ERR was robust and not very sensitive to variations in project costs or benefits. A 10% increase in project cost or 10% decrease in benefits would reduce the ERR by about one percentage point. Sensitivity based on various risks that the project may face indicates that it is very unlikely that unfavourable developments would reduce the ERR below the OCC. The total cost of the project would have to increase by 200% and benefits decrease by 50% to reduce ERR to the OCC. The ERR was also tested against changes in major assumptions such as no economic growth, reduction in benefits appropriate to conventional flood probabilities, 10% increase in construction costs, primary benefit only i.e., excluding secondary and intangible benefits, and reduced Racibórz resettlement costs.

As a result of implementation, the total cost of the project has increased by 80% in current prices, but benefits did not reduce, so the project is economically successful.

4.4 Environmental assessment of the project

Potential environmental impacts of the project were screened [11] by taking into account the effects caused by the projects' location, design, construction and project operation. In describing the detailed impacts a differentiation should be made between: (i) the combined impacts of the ORFPP on the area of influence, which is the entire 240 km of flood plain between Racibórz and Brzeg Dolny; (ii) the impacts of the construction of the Racibórz reservoir (Component A) on the reservoir area and the area downstream; (iii) the impacts of Modernization of Wrocław Floodway System (Component B), which includes (re)construction of dikes and structures in the Odra and Widawa flood plain up to 30 km upstream and 15 km downstream of the historical city of Wrocław.

Negative impacts of the construction of the dry reservoir on the natural environmental could be largely avoided by proper mitigation measures during the preparation of detail design and during construction, such as reallocation of borrow areas and respecting buffer zones around nature reserves. Natural areas like Sudol oxbow, the Psina outlet, the Odra banks and Tworkowski forest should be spared and gravel excavation banned on the entire left bank of the reservoir in order to maintain the north-south ecological corridor, which is already interrupted by the dam and river regulations north and south of Racibórz.

It was critical to consider the function of the Upper and Middle Odra valley, as an important international ecological corridor between the Baltic Sea and lowlands with the Central European Highlands and enhance its function as much as possible. As a compensation for the losses, measures have been proposed and implemented to preserve and enhance this corridor function, which could include the preparation of management plan for Natura 2000 sites and further hydro-ecological research on mitigation measures. These measures were focused on the part of the Upper Odra valley between Chalupki and Opole, where this corridor was particularly threatened.

Among the most important problems in the Wrocław Floodway System area were the conflicts between land use regulations allowing development in the floodplain and flood protection requirements. This problem was solved by design of proper legal designation of the active flood plain areas with flood control as the main function. Other conflicting land uses were banned or restricted and made subordinated to flood control. Negative impacts of the (re)construction of the embankments in the areas upstream and downstream of Wrocław were largely avoided by including proper mitigation measures in the detailed design and during construction. By opening up a number of embankments in forested areas near the confluence of the Odra and Widawa rivers, parts of flood plain is now accessible to flood waters, which is beneficial to sustaining and revitalizing these forests.

5 Risk reduction by retention – Racibórz reservoir design, construction & resettlement activities

5.1 Racibórz reservoir

The construction of the Racibórz dry flood retention reservoir was the crucial element of the whole flood risk management system in the Odra river basin in Poland and Germany. The importance of the reservoir's retention capacity was analyzed in feasibility studies developed before starting construction [9] and when applying for EU financing. Later, it was also verified by the JASPERS completion note [3], which was the mandatory procedure in applying to finance large infrastructure projects from EU Cohesion Funds. The basic findings summarized in the JASPERS Completion Note [3] indicate that for the design flood of 0.1% probability, which was similar to the 1997 flood "… the proposed measures of the Racibórz retention reservoir will result in a reduction in the peak wave during a 1 in 1000-year event in Wrocław falling from 3900 m^3/s to 3100 m^3/s, this being equivalent to lowering river water levels by:

- 0.35 to 1.10 m in the City section of the Odra;

- 0.4 to 1.10 m in the Flood Channel section of the Old Odra;
- 0.58 to 0.7 m in the section between Szczytniki and Psie Pole weirs on the Old Odra;
- 0.7 m in the section of the Odra to the Redzin weir.

This reduction of the flow and high levels of water would indicate that Wrocław will not be flooded during the 1000-year flood (under the condition that there are no levee failures).

When preparing the operation manual for the reservoir, additional research was done in relation to the impact of the Racibórz reservoir on the risk reduction further downstream in the catchment. This research [1] developed transformation of flood waves for probabilities of 0.1%, 0.3%, 0.5% and 1%. It also analysed, using 2D modelling, the largest historical flood wave of 1997. The example of the 0.2% flood wave transformation, which is very close to the historical flood of 1997, is presented in figure 2. Hydrograms show a 1200 m^3/s reduction in the outflow from reservoir by the assumption that maximum outflow could be 2460 m^3/s

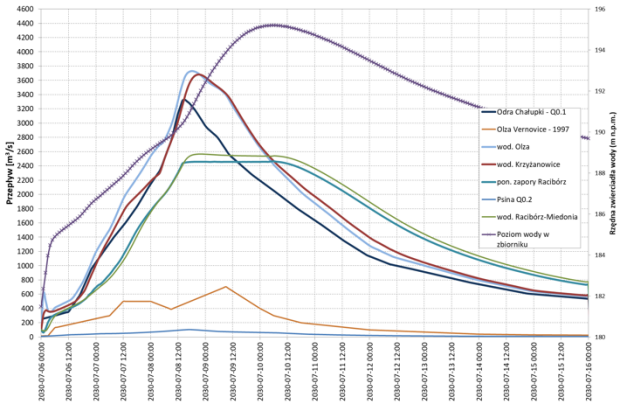

Figure 2. 2-D modelling results (flows/przepływ and water levels/rzędne zwierciadła wody) [1]

The Racibórz reservoir, with a storage capacity of 185 million m^3, is located in the upper part of the Odra, close to the border with the Czech Republic, just upstream of the city of Racibórz. This reservoir (Fig. 3) is created by constructing a dam across the Odra channel, 4.0 km long and with the maximum height of 11.1 m (Fig. 4).

Left- and right-bank embankments upstream of the dam with the total length of 18.65 km are the footprint of the reservoir area. The total area of the reservoir is 26.3 km2. The level of crest of embankments and dikes was designed at 197.50 m asl and the maximum level of water in the reservoir during floods was assumed at 195.20 m asl. The width of the crest for the front embankment and dikes is 6 m and the volume of the compacted embankments is 7.4 million m^3.

Figure 3. Map of the Racibórz reservoir.

Figure 4. Front dam in Racibórz reservoir (source: AECOM technical assistance team)

The location of the dry polder in the catchment is presented in Figure 5.

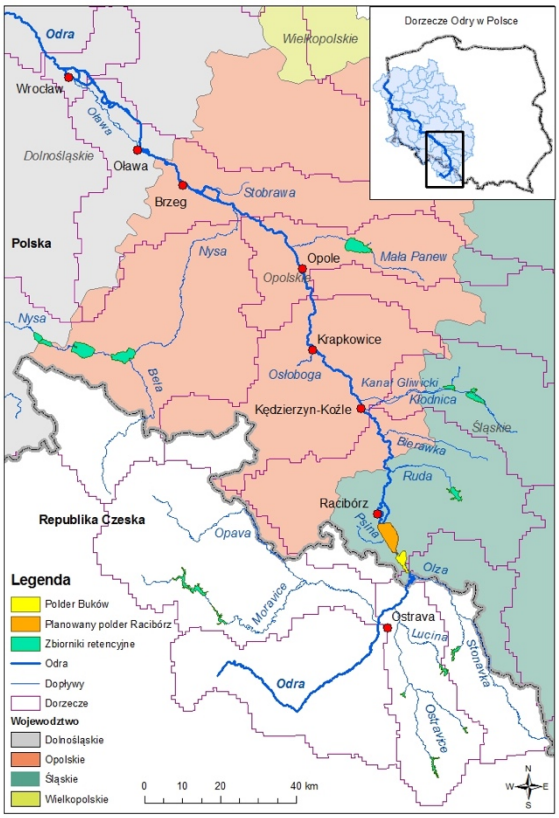

Figure 5. Location of the Racibórz reservoir in the Upper Odra River catchment [6]

The structure of the dam includes facilities that convey normal water flows and enable free migration of fish and inland navigation, as well as emergency outlets that guarantee dam safety. The construction of the dam required land located within the reservoir footprint to be used and farmers living there to be resettled. Social aspects of the reservoir implementation are described further below.

The construction of the polder including all associated actions took place from July 2013 to June 2020, that is 7 years. This was not an easy investment to realize and during the period of construction, there were two changes of the implementation engineering company and one change of the contractor. All these changes caused delays. In the case of the change of contractor there was a one-year stop in the construction process – from November 2016 to January 2018, when only limited activities were possible on the construction site. This means that the real duration of the construction was 6 years. The estimated final cost of construction can be found in Table 1.

5.2 Land Acquisition and Resettlement Activities

A very important and socially sensitive part of the investment were resettlement activities and access to land necessary for the construction of the reservoir and its operation in the future [6,10]. All resettlement activities were planned according to World Bank policies and described in the Resettlement Action Plan (RAP). The RAP [10] covered the area of the Racibórz dry polder, approximately 2630 ha in total, 37 percent of which was covered by the footprint of the embankment. The current land use when starting the investment was as described in table 2.

Land Use	Area (ha)
Agricultural (crop, pasture) lands	1854
Forests	148
Coppices	14
Waters	185
Ditches	25
Mineral/aggregate excavations	17
Transport areas	53
Residential areas	40
Waste lands	292
Total	2628

Table 2. Land use in resettlement area in 2004[10]

Twenty businesses were located within the polder area, most of which were relocated or closed. Twenty-two community assets were also closed or relocated elsewhere including church, chapel, cemetery and school. 689 people were living in the polder area located in two villages: Nieboczowy, 564 and Ligota Tworkowska, 125. In all, 260 families lived in 197 residential houses.

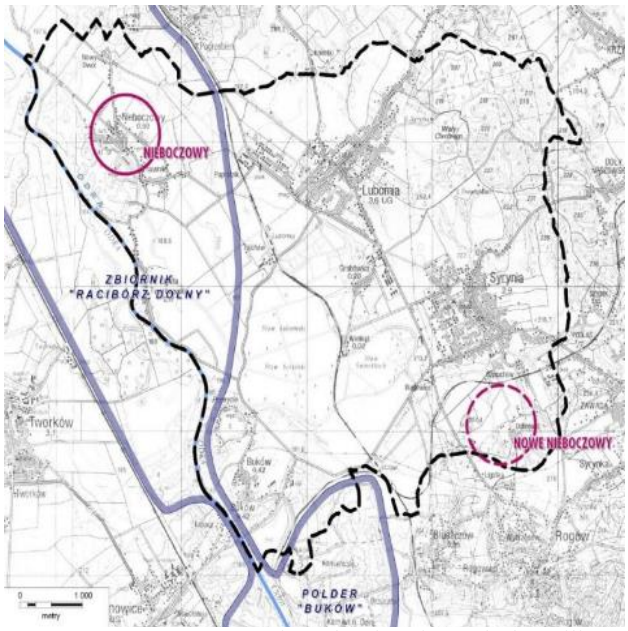

Figure 4 Map presenting the location of the village Nieboczowy before construction of the reservoir (inside the polder) and the new location of the village Nowe Nieboczowy nowadays: blue line – delimitation of the polder area, dotted line – borders of the Lubomia municipality [6].

Based on the results of a household survey undertaken in 2002, it appeared that as much as 20 percent of the population derive their principal income from agriculture. The remainder worked in the gravel pits, coal mines, industry, commerce and services, most of which were located outside of the polder area. In addition to current residents and businesses in Ligota Tworkowska and Nieboczowy, and also absentee residential owners, as many as 1300 landowners of plots in the polder were affected by the project.

The Polish law enables administrative units to purchase land and property for public use through negotiation. If that fails and the site in question has been identified in the local land use master plan and designated as needed for public purposes, the land and assets can be expropriated. The Act of Management of Real Properties governs the land acquisition and expropriation processes. RZGW Gliwice, which is the regional water management administration, has been granted a location permit for the Racibórz polder, thus it has the authority to purchase by negotiation or through expropriation. In practice, expropriation is only exercised as a last resort. Compensation can take three forms: monetary compensation, property swapping and both monetary compensation and swapping. Landowners and entities holding perpetual usufruct or limited proprietary rights are entitled to compensation for property that can be expropriated. Tenants are compensated by landowners according to their lease arrangements, but illegal occupiers are not entitled to compensation. There were no indications that any property is illegally or informally occupied in the project area. Residents and other property owners were entitled to compensation as follows:

- Non-resident owners were compensated at market rates;
- Residents had three options:
  1) Cash compensation for land and property
  2) Cash compensation for land and provision of alternative housing
  3) Provision of alternative agricultural land, cash compensation for property or provision of alternative housing in lieu of cash compensation.

The overall impact of resettlement for residents of Nieboczowy and Ligota Tworkowska was mitigated by a number of factors, which affected households to varying degrees:

- Non-agricultural income sources were primarily outside of the polder area, in nearby towns and Germany, and some people expected to move closer to employment sites;
- Few households depended primarily on agricultural income; the land-for-land option has enabled farmers to continue farming and cash compensation enabled others to capitalize their assets for other uses;
- Some families have built or purchased homes outside of the polder area in anticipation of resettlement;
- RZGW was flexible in the timing of relocation, giving residents as long as two years to purchase or build new housing and prepare for a smooth transition;
- Residents who wanted to maintain community ties had the option of moving to one of the resettlement sites;
- Vulnerable people were given special assistance in finding alternative residential sites and moving.

The process of resettlement of households took place in years 2003-2012, and the process of acquiring the land necessary for construction and operation of the polder in years 2003-2017. Between 2003 and 2007, only Polish regulations were used and this created huge social conflicts with the local community who had even declared a "state of war against the government". After establishing the Odra River Basin Flood Protection Project in 2007, World Bank procedures were used for land acquisition and resettlement (OP 4.12) and important changes in Polish law were also introduced. This created more equitable rules for the process and made a good cooperation with the local community possible. Transferring the task of creation of the new village to local government and leaving the financing of this development and supervision of the implementation to the government were the most crucial solutions. The local government and the charismatic mayor were able to convince the inhabitants to move from polder areas to the new village or to leave the area in an amicable way.

The total cost of implementing the RAP was assumed to be 46 million euros (in 2004 prices). Some contingencies and VAT totalling 63.3 million euros were allocated under the project for financing of the RAP related cost. The final cost of this component that is already completed was 57.5 million euros (Table 1), which is less than assumed.

6 International Panel of Experts on Dam Safety, role and activities

The International Panel of Experts (IPE) was created as a requirement of the World Bank loan to the Polish Government according to the "Operational Manual OP 4.37-Safety of Dams", and was initially composed of two international experts, three Polish experts from the Institute of Meteorology and Water Management, and one expert from the Project Coordination Unit.

The task of the IPE was to advise on technical matters relative to the safety of the polder and the large hydraulic infrastructure works. It was to meet periodically during project implementation, from the start of the design process and until the start-up of the polder, after which periodic safety inspections would be performed by independent qualified professionals; the frequency of these inspections was to be decided based on the recommendations of the Panel.

The Panel was initially formed during the fall of 2011 with the following members: Chair: Prof. S. Kostecki, Wrocław University of Technology. Members: Prof. S. Pietruszczak, Department of Civil Engineering, McMaster University, Hamilton, Canada; D. Hamilton, P.E., Irvine, U.S.A.; Prof. J. Winter, Institute of Meteorology and Water Management, National Research Institute, Warsaw; R. Kosierb, PhD, Eng. Institute of Meteorology and Water Management, National Research Institute, Wrocław; E. Sieinski MSc, Eng., Institute of Meteorology and Water Management, National Research Institute, Warsaw. A "second IPE" was formed in November 2015 by D. Hamilton, B. Trak, R. Kosierb and E. Sieinski. R. Tourment joined the IPE in 2018.

The IPE provided technical and scientific recommendations generally in the form of memoranda for the Project, and its focus was the safety and integrity of the resulting works. Two major technical issues were discussed in IPE meetings during the construction of the Racibórz polder in 2016: 1) "Black shale" and 2) soil strengthening.

The "black shale" (mine waste) was proposed by the Contractor as a suitable material to be used in embankment construction because alternative aggregates were approved for use in the Building Design. The Contractor had obtained a Technical Approval for the material, which was subsequently approved also by the project Engineer. During construction, it was found that certain parts of the embankment was constructed with black shale particles that were too large and did not meet the grain size requirements. Ultimately, all of the black shale was removed from the dam embankments. This was both to repair the gradation issue and also meet a new technical requirement imposed by the Ministry of Environment prohibiting the use of black shale in the construction of major flood control projects. Currently, the dam embankment contains no black shale material.

The second major technical issue concerning the Racibórz polder was related to the strengthening of the foundation soil. The Contractor had submitted "Executive Designs of subsoil reinforcement using CSC piles", justifying this solution by the need to reinforce and increase the stiffness of the subsoil in order to reduce settlement under the reservoir embankments. The Controlled Stiffness Columns (CSC) or "rigid inclusions" are generally used to increase the bearing capacity of weak or cohesive subsoil and reduce its compressibility. The use of CSC piles was evaluated, and ultimately it was decided that these were not suitable for the construction of the reservoir embankments at Racibórz. Instead, gravel columns were constructed in areas with low bearing capacity soils based on *in situ* test results. The selective use of gravel columns has proven to be a successful methodology at Racibórz.

In 2019, the IPE team composed of B. Trak and R. Tourment conducted surveys of the construction of four new polders in the Kłodzka Valley. They made specific recommendations concerning the anti-seepage barrier design and sealing of the embankments in Roztoki, outlined the importance of taking particular care of the contact between different parts of the embankment that are being raised separately, and recommended that tests of efficiency of the anti-seepage barrier be conducted. In Boboszow, the design and construction of the anti-seepage barrier were to be reviewed in the light of observations made in Roztoki, and an analysis of the order of construction for the two parts of the barrier be undertaken. The IPE recommended in Krosnowice to avoid the concrete slab between the core and the injection and replace it with a trench filled with core material and compacted as the rest of the core. In Szalejow Gorny, careful monitoring of the groundwater during construction and operation of the dam was recommended.

7 Conclusions

It took 23 years from the catastrophic flood 1997 to create a new flood protection system in the Odra river basin, which is a huge modernization of the existing system originally built by the Germans after 1903 flood. The Racibórz dry polder was the last and the costliest element to complete the system. In earlier years all the other elements of the system were designed and built, including the Buków polder upstream of the Racibórz reservoir and flood protection systems of dikes and polders for all cities and towns located downstream within the Odra River floodplain. It is important to stress that all investments and non-structural measures were planned assuming that the Racibórz reservoir will be built and will be responsible for substantial reduction of the flood wave on the river's inflow to the Polish part of the catchment. Such a long time was used for a very advanced process of planning and building social consensus with all stakeholders, including people to be resettled and environmental activists. International acceptance was built between Czech, Polish, and German public institutions responsible for water management and crisis management. A key role was played by the International Odra River Commission accepting the flood protection masterplan for the whole international catchment [8] which was later confirmed in the basin flood risk management plan prepared as implementation of the European Flood Directive.

It could be noticed that the final cost of the reservoir construction was 80% higher than the basic estimates from year 2004 [9]. In reality, taking into account the difference in unit costs for construction works between year 2004 and construction years 2014-2020, the real difference in constant prices is much lower. It is important to indicate that in Poland, after the country became a member of EU and following a huge cohesion policy investment financing, a substantial increase of the unit costs was visible, mostly due to increases in labour costs.

It was critical for the construction of the reservoir to get support from the World Bank and the Council of Europe Development Bank, delivering substantial financing and very professional technical assistance for preparation and implementation of the project.

From the technical point of view:

- This is a project which includes a comprehensive and consistent set of measures in:
  - spatial planning,
  - upstream flood retention,
  - local protection by levees and improvement of the river channels,
  - flood forecasting, and
  - integrated flood management.
- Dams and levees (dikes) are useful in flood risk reduction and are complementary: they do not have the same hydraulic function and impact, and also not the same limits [14].
- This type of ambitious project requires long period for planning and implementation.
- The IPE role is important. It could be applied not only to dams, but also to levees (dikes) as a levee failure in a populated area can have consequences as important as a dam failure.

Finally, some important recommendations for the future:

- At the local scale: for such an investment to be useful and efficient in the long term, there is a need for efficient and sustainable management and maintenance of the whole system. This includes the

production of a detailed operations and maintenance manual for the works, in dry periods and also during floods, as well as a organisation to oversee the management of the system, with an adequate staff and sustainable funding sources.

- At the national scale: experience gained during the whole process of preparation and construction of the reservoir should be used for future development of strategic flood risk management plans and its implementation in the Vistula basin (the largest river in Poland, where a catastrophic flood happened in 2010). This is the aim of the new (ongoing) Odra-Vistula Flood Management Project.
- At an international scale: the resettlement activities in the project could be treated as an example of best practices when conducting very difficult and sensitive operations of moving people from their homeland in order to reduce flood risk in downstream cities and towns as well as managing sensitive environmental conditions.

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