Raciborz Flood Reservoir

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SYNOPSIS. The river Odra, which rises in the Czech Republic and disgorges into the Baltic, suffered an extreme flood in July 1997 which was responsible for the loss of 50 lives and over a billion dollars worth of damage in southern Poland. The return period of the flood is variously estimated between 250 and 1000 years.

The paper describes the studies for a flood reservoir to be constructed on the Odra just upstream of the ancient town of Raciborz. These studies include the hydrological studies, the hydrodynamic modelling of a 220km stretch of the river where most of the damage occurred, flood damage studies both with and without the proposed reservoir, environmental impact assessments and resettlement plans, in addition to the engineering studies of the dam itself.

INTRODUCTION

This paper describes the feasibility studies for a flood protection reservoir carried out by Jacobs GIBB in association with Hydroprojekt Warsaw for the Regional Water Management Board in 2002 and 2003. The study area is shown in Figure 1.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

LONG-TERM BENEFITS AND PERFORMANCE OF DAMS

Figure 1: The study area

<u>Background</u>

The Odra river rises in the Czech Republic and flows north through Poland to the Baltic Sea. The river has been liable to flooding, 14 floods having been recorded in the last two centuries which have caused considerable damage to the cities, towns and villages of the upper Odra valley – Raciborz, Opole and Wroclaw. These floods have lead to a the construction of a complex system of flood defences including embankments, by pass channels and flood storage areas which are designed to be capable passing floods of up to a 1 in 100 year return period without serious damage.

Figure 2: The river Odra during the 1997 flood event

These flood defences were overwhelmed by the flood of 1997, known in Poland as the Great Flood, which exceeded all previous floods in flow rate and volume.

The possibility of the construction of a flood reservoir at Raciborz was first proposed after the 1880 flood and by 1906 a scheme with a storage capacity of 640Mm³ had been designed. Over the course of the century the scheme characteristics evolved with a gradual reduction in the storage capacity due to the expansion of towns and villages. The present project, the conceptual design of which was prepared by Hydroprojekt, comprises three stages:

1. the Bukow Polder close the Czech border (constructed 2001)
2. the construction of a flood storage reservoir at Raciborz
3. channel improvements, and the construction of a new polder and bypass for the city of Wroclaw

RACIBORZ FLOOD RESERVOIR

Purpose

The primary role of Raciborz Reservoir is to reduce the frequency and severity of flooding in the Upper Odra River. This will be achieved in two ways:

1. Firstly, the reservoir will provide flood storage so that the flow rate downstream of the reservoir will be greatly reduced and the effectiveness of the existing flood defence system in containing the flows will be improved.
2. Secondly the reservoir will delay the timing of the flood peak at the confluence of the important left-bank tributary Nysa Klodzka with the Odra so that the adverse combination of the two floods that was so damaging in 1997 is very much less likely.

Two stages of development are envisaged: the first being the 'dry reservoir' the sole purpose of which is flood mitigation: in the second the reservoir will be partially impounded when important secondary benefits will be navigation, water supply and recreation. The reduction in flood storage resulting from partial impounding will be offset by gravel extraction from the reservoir in the 'dry reservoir' stage.

Layout

The location of the reservoir was selected to be upstream of the town of Raciborz and within Polish territory: the maximum flood level is constrained by a Czech/Polish protocol. The storage volume of the reservoir will be 185 Mm³. In normal operation the reservoir will be dry with the river flowing through a main gated outlet structure into the bypass channel.

Releases will also be made through a subsidiary outlet into the old river that flows through the town. In times of flood the outflow through the outlet structure will be controlled by operating the gates so that excess water is stored within the reservoir. The outflow is varied according to the magnitude of the expected flood and therefore a flood warning system is essential. The strategy of the operation rules is that for any flood, irrespective of return period, the flood storage is used to its maximum extent and the reservoir outflow is selected to achieve this.
The layout of the reservoir is shown in Figure 3.

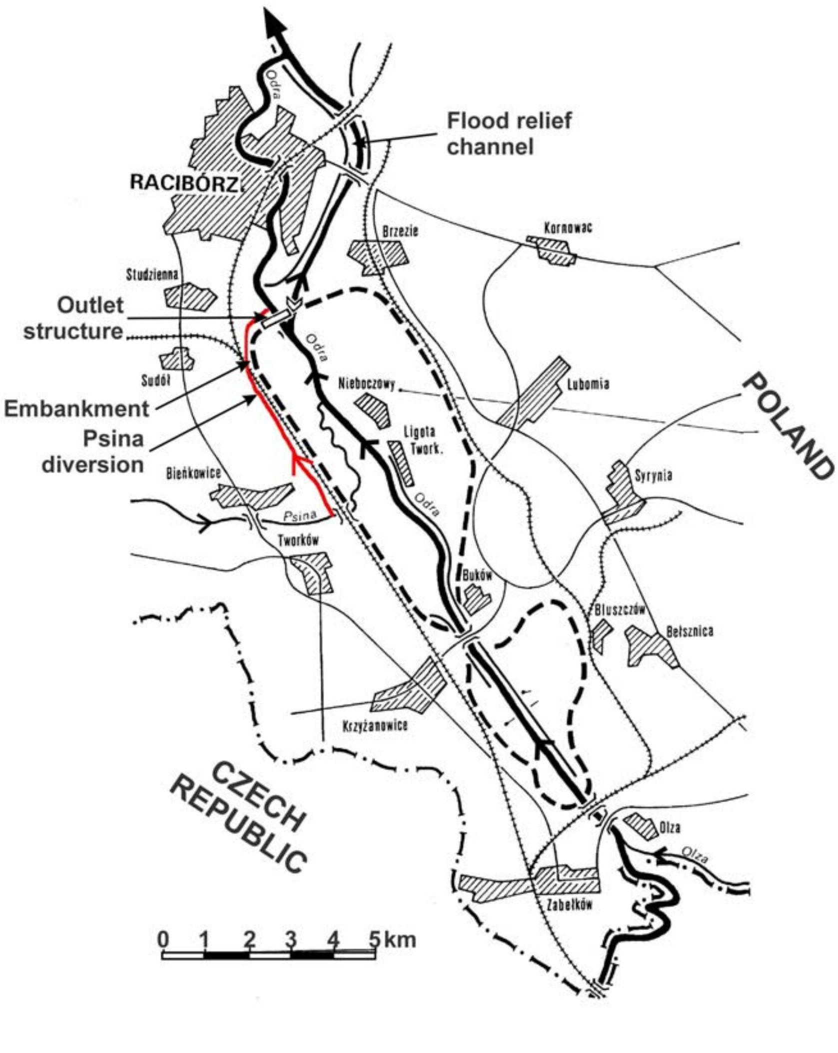

Figure 3: Layout of Raciborz reservoir

Design

Foundations

The reservoir is formed by an earth embankment dam, 22.5km long and with a maximum height of 10m. The dam foundations consist of alluvial deposits comprising alternate layers of silty clay and granular material, with interspersed peat lenses. The top layer will be stripped and the dam founded on the upper cohesive layer. Although foundation seepage is not an issue in the dry reservoir stage - the reservoir will not be full long enough for steady state seepage conditions to become established – it will become a consideration when the reservoir is permanently impounded and therefore a 5 km length of cut off wall through the main granular layer is proposed. In addition the excavation of embankment fill or gravel extraction will be prohibited within a 100 m strip of the upstream toe, the upper cohesive layer forming a natural blanket.

Embankment

The embankment will be constructed over a four year period, from April to October of each year. The embankment which utilizes both the cohesive overburden and the underlying sandy/gravel with the minimum of selection, is essentially a homogenous clay cross section with a substantial drainage bund at its downstream toe. Drainage of the underlying water bearing layer will be provided either by a trench drain or by wells, depending on the depth. A typical cross section of the embankment is shown in Figure 4.

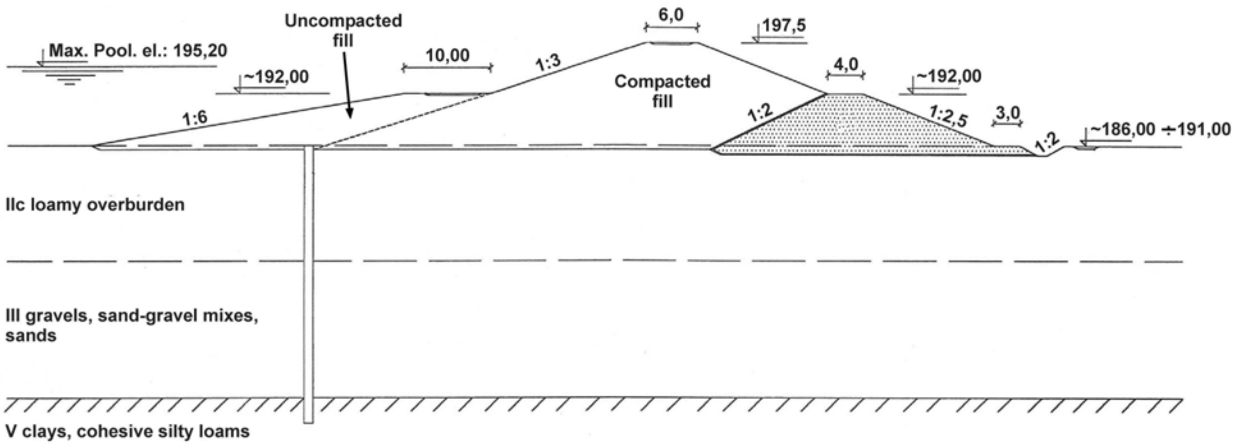

Figure 4: Typical cross section of the embankment

Outlet works and spillway

The outlet works comprise a gated structure consisting of

- a reinforced concrete forebay with a 115m wide apron
- 5 bays each 12m wide with one navigable flat sill at a slightly lower level. The bays are separated by 7.4 m wide piers which house the gate operating mechanism
- vertical lift gates, 1 per bay 12m wide x 8.5m high
- a reinforced concrete bridge over the bays
- a reinforced concrete stilling basin, 109m wide x 55 m long,
- an outlet channel, protected with gabions and riprap, discharging into the river downstream.

Operation

In normal operation the reservoir will be dry with the river flowing through a main gated outlet structure into the bypass channel. Releases will also be made through a subsidiary outlet into the old river that flows through the town. In times of flood the outflow through the outlet structure will be controlled by operating the gates so that excess water is stored within the reservoir. The outflow is varied according to the magnitude of the expected flood and therefore a flood warning system is essential. The strategy of the operation rules is that for any flood, irrespective of return period, the flood storage is used to its maximum extent and the reservoir outflow is selected to achieve this.

SOCIOLOGICAL AND ENVIRONMENTAL ASPECTS

Sociological and environmental issues are dominated by the need for 240 families living in the two villages of Nieboczowy and Ligota Tworkowska to be resettled. The study, which included the formation of an outline resettlement plan, was carried out shortly after the publishing of the World Commission on Dams reports and great effort was made to follow their precepts in this area. An alternative dam alignment excluding the village of Nieboczowy, proposed by the villagers was examined in detail but the reduction in storage volume made this option uneconomic. Despite two public meetings and door to door interviews public opinion remained adamantly hostile, largely due to fears of inadequate levels of compensation.

Compared with this the adverse environmental impacts are relatively minor and in any case are heavily outweighed by the environmental benefits of the scheme to the river valley downstream of the dam.

HYDROLOGY

Data

Flow data from the 20 gauging stations shown in Figure 5 were used in the hydrological analyses. The data record at most stations is at least 50 years.

1997 flood

The 1997 flood was caused by exceptionally intense and prolonged rainfall in the upper catchment: 200mm was recorded in the 5 days from 4th to 8th July 1997 over a wide area with a peak intensity of 585mm over the same period at one station, Lysa Hora in the upper catchment. Peak flow rates are approximate because the river levels so far exceed the calibrated rating curves but were in the region of 3,120 m^3/s at Raciborz , and 3,640 m^3/s at Wroclaw, the upstream and downstream limits of our study area.

Probabilities

Synthetic input hydrographs for the model for a range of return periods were derived from an analysis of the historic flow data and a prediction of the peak flows for as range of return periods computed according to Polish standards by the Institute of Meteorological and Water Management. These predictions were based on the statistical analysis of historic data at single stations which led to the 1997 flood being assigned a return period of 1000 years.

Regional Analysis

The estimation of the frequency or the return period of rare floods is not easy, as extrapolation from the record at a single station involves uncertainty about the choice of statistical distribution to represent the extreme floods, and also the choice of method of fitting the curve to the records. It was therefore decided to test the sensitivity of the estimation of return period by considering the regional flood frequency approach to flood frequency analysis which has been found to give consistent estimates of the relation between flood magnitude and return period or frequency of occurrence when applied to areas of reasonable hydrological homogeneity.

The method depends on the collection of annual maximum flood series from the gauging stations within a region. The method derives from the approach developed during investigation of floods in the British Isles (Natural Environment Research Council, 1975) and its application to many different regions of the world has been described in a number of papers (Farquharson et al., 1987, 1992, 1993: Meigh et al.,1997; Sutcliffe & Farquharson, 1995).

After inspection of the results, the stations were grouped as follows:

- the 6 stations on the upper Odra in the Czech Republic

- the 6 stations on the main Odra below Raciborz
- the 4 stations on the Nysa Kłodzka
- the remaining 6 stations on the Odra.

The curves for these four regions are illustrated in Figure 5

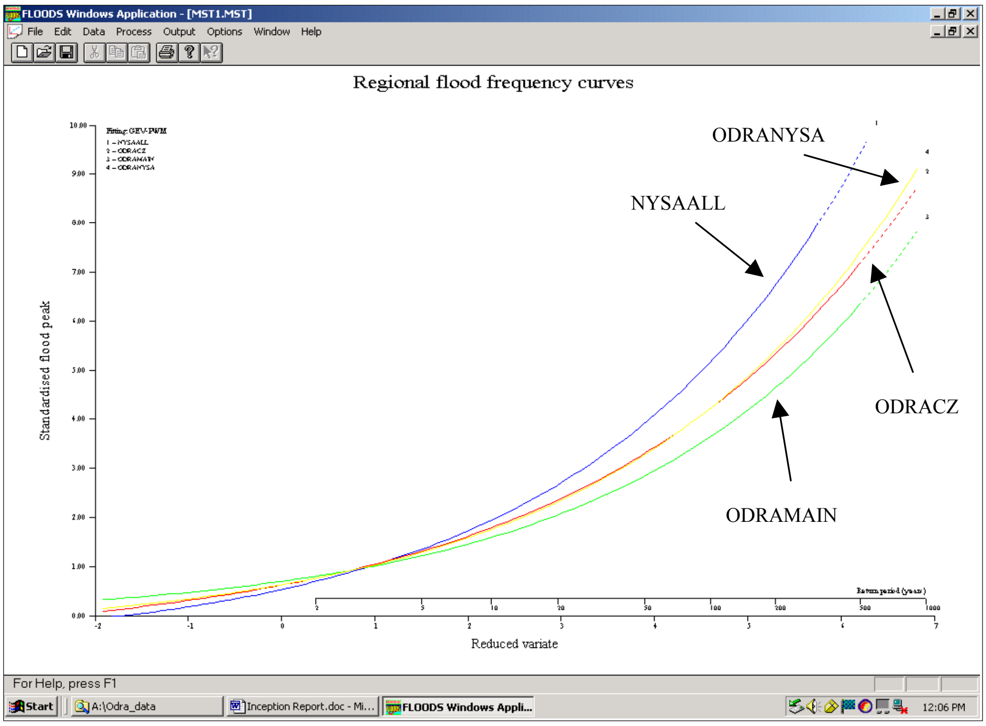

Figure 5: Regional Flood curves

It will be seen that the curves for the upper Odra groupings are very similar up to 50-100 years, but the Nysa curve is higher at longer return periods. The curve for the lower basins is different and is treated separately. The curve for the whole upper Odra is considered as reasonably representative of the whole area.

Comparison of the 1997 flood at individual stations, expressed as Q/MAF, with the regional curve derived from the 16 stations in the upper Odra basin, indicates a lower limit of the range of return periods which could be allocated to this event. This implies that the whole set of records is typical of the region, but it has been shown that the group curves are similar to each other and that the regional curve is similar to that of the upper Vistula. The lower limit for the return period of the 1997 event, on this basis, is about

200 years for the Odra stations from Bohumin down, but rather higher at about 300 years for the Nysa stations.

HYDRODYNAMIC MODELLING

Model description

The Upper Odra hydrodynamic model has been built using MIKE 11, a software package developed by the Danish Hydraulic Institute (DHI).

The model covers approximately 204 km of the main river channel (between the village of Olza, situated near the Czech border and the village of Trestno, immediately upstream of Wroclaw) and includes the floodplain on the right and left bank as well as the two main tributaries: the Nysa Klodzka and the Mala Panew (63.5 km and 18 km respectively). A total of 342 cross sections were included in the model. The cross sections used in the hydrodynamic model are the result of a recent survey carried out after the 1997 flood event.

The MIKE 11 model does not cover the six relevant reservoirs situated on these two tributaries. The effect of these reservoirs operating under the current rules has however been considered in separate flood routing calculations and the resulting outflows included in the model as input hydrographs.

The methodology adopted for modelling the floodplain of the Odra has involved three different techniques:

- extension of the in-bank river cross sections into the floodplain;
- introduction of flood cells so that when the bankful capacity of the main channel is exceeded water spills into them (this technique has been used in particular to model some of the polders);
- simulation of the adjacent floodplain as a ‘separate river’ using parallel river branches attached to the main channel by lateral spill units (link channels).

A global value of 0.05 of Manning’s roughness has been considered in the computations although different values in the range of 0.03-0.100 have been used for many of the modelled reaches in order to reflect the land use and improve model calibration.

The Odra River is maintained as a navigable river. A large number of sluices and lock structures have been constructed along its watercourse as well as bypass and diversion channels in order to improve and increase the capacity of the system during a flood event. There are two main types of hydraulic structure which have been incorporated in the hydraulic model by using the recently surveyed river cross-sections (1997-2000) and the inventory of the existing hydraulic structures between the Polish-Czech boundary and Trestno compiled during the study:

1. weir complexes, which may consist of a variety of broad and sharp crested weirs, barrages, sluice and radial gates associated with culverts and/or bridges
2. polders

Only permanent structures have been taken into account and modelled as fixed (without operation rules). Removable gates have not been included in the model because they are usually removed from the watercourse during flood events. Navigation locks have been simulated with the gates open.

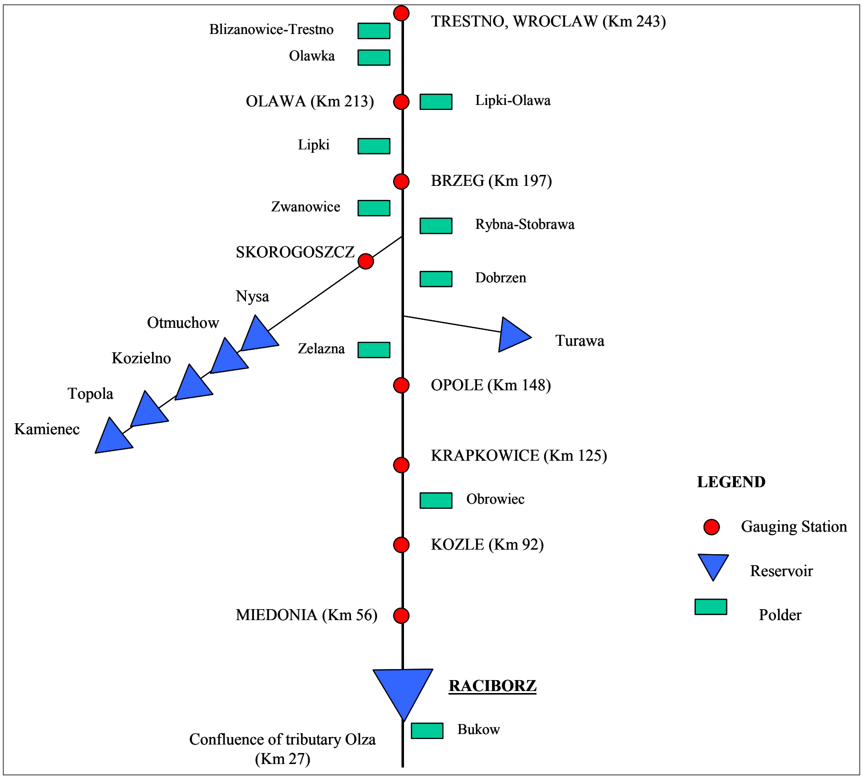

Figure 6: Model schematic

Model calibration

Once the hydrodynamic model was completed, it was calibrated progressively from upstream to downstream using the 1997 flood event by adjusting the roughness, the hydraulic structures and spill (out-of-bank) discharge coefficients so that modeled river levels match those measured as closely as possible. The results of the calibration are presented in Table 1

Table 1 Calibration results

Gauging Stations	Recorded peak level (m OD)	Modelled peak level (m OD)
Miedonia	186.73	186.67
Kozle	171.98	172.02
Krapkowice	165.83	165.88
Opole	154.89	154.70
Skorogoszcz	145.12	145.37
Brzeg	136.50	136.55
Olawa	129.64	129.66
Trestno	121.76	121.71

Model results

The model results, in terms of the reduction of the peak water level attributable to the Raciborz reservoir are shown in Figure 7.

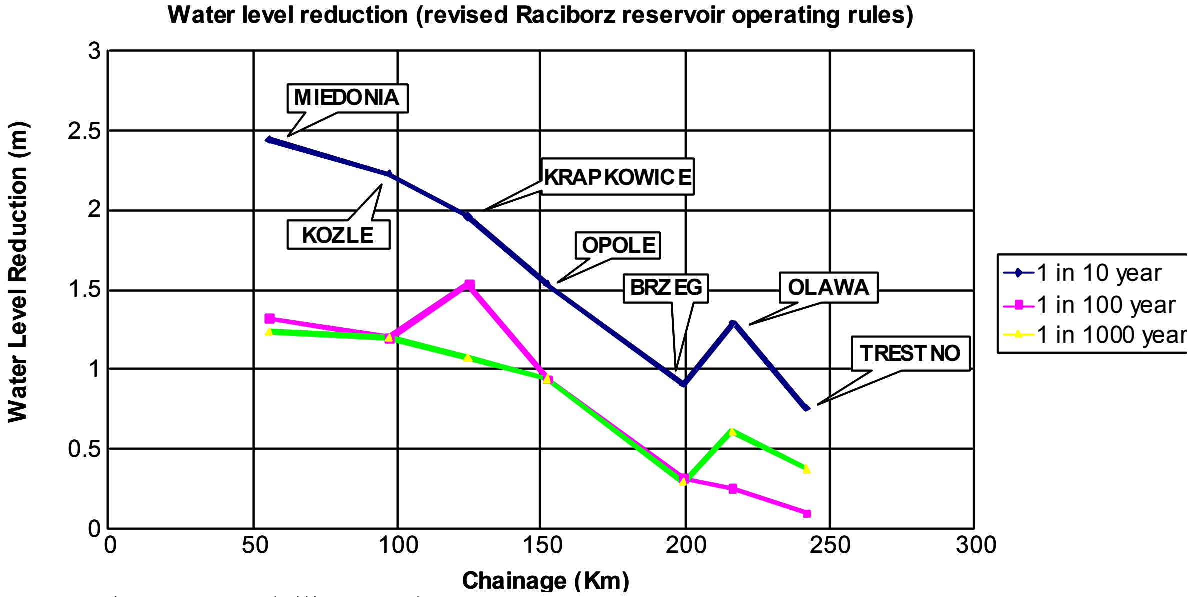

Figure 7: Modelling results.

Sensitivity

The sensitivity of the model results has been examined for the following changes:

- Reservoir volume
- Storm timing
- Operation rules for the reservoirs on the Nysa river

The model was run with a reservoir volume of 154Mm³ (16% reduction on the base case), representing an option which minimised resettlement, and with a reservoir volume of 290Mm³ (50% increase on base case) representing a possible future condition in which gravel deposits within the reservoir are extracted. The modelling showed that on average the effectiveness of the reservoir would decrease and increase by approximately 5% and 15% for the reduction and the increase in volume respectively.

The modelling shows that the river levels are not very sensitive to the relative timing of the main river and tributary flood peaks: a delay of 12 hours in the time to peak of the Nysa result in an increase in water level of 4cm below the confluence.

The sensitivity analysis shows that the flood levels on the Nysa river are sensitive to changes in the operating rules of these reservoirs and to the proposed construction of a new reservoir at Kamieniec Zabkowicki. However these changes will have little impact on flood levels in the main Odra river downstream of the confluence.

BENEFITS

Inundation mapping

The effect of the Raciborz reservoir on the area inundated by floods of the range of return periods considered is illustrated in Figure 8

Flood damages

Flood damages were estimated for the with and without reservoir cases by estimating the areas of each of 20 land use categories flooded in each case and applying damage init rates that were derived from 1997 flood damage data. The results are illustrated, for the range of flood probabilities, in Figure 9.

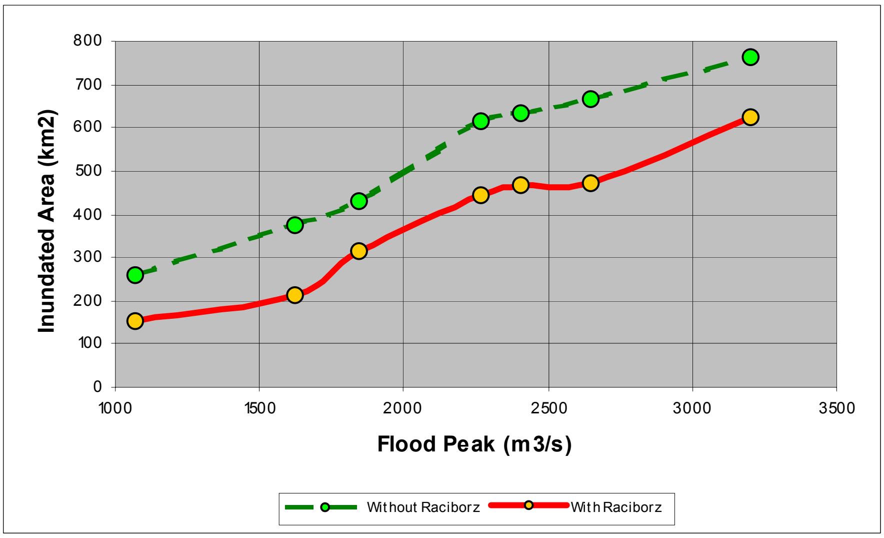

Figure 8: Inundation areas with and without Raciborz reservoir

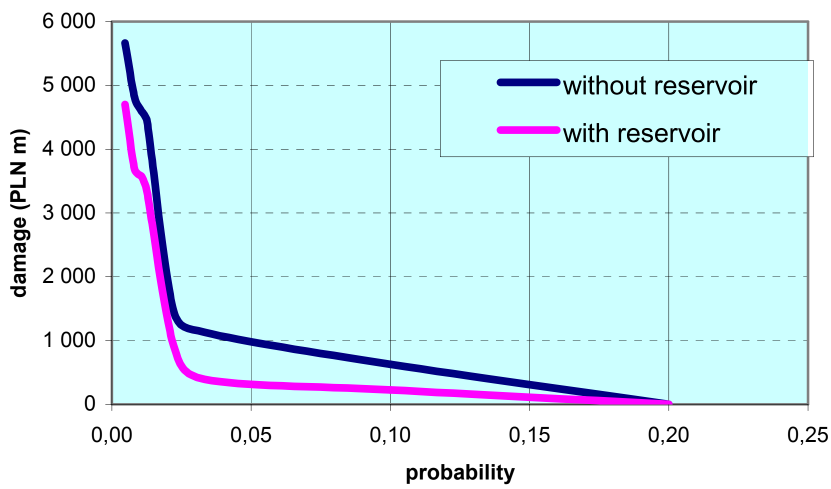

Figure 9: Reduction in flood damage

CONCLUSIONS

The conclusions of the study are that the Raciborz reservoir offers substantial but not complete protection against inundation of the Upper Odra against severe floods. The effectiveness of the reservoir is sensitive to reservoir volume and must be accepted that the proposed reservoir is at the small end of the range of useful volumes: a larger reservoir would be considerably more effective. The level of protection provided by the reservoir is naturally greatest immediately downstream and decreases, especially downstream of the Nysa confluence. However it is likely that Raciborz reservoir together with the implementation of the various channel improvements mitigation measures proposed for Wroclaw will provide adequate protection to that city. The effectiveness of the reservoir will depend on careful operation in which a reliable flood warning and conjunctive use with the Nysa reservoirs are vital.

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