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Deliverable 4.5
Estimation of environmental flows using building block methods for all major sections of the Narew River

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Deliverable 4.5

Estimation of environmental flows, using an adapted building block methodology, on all the major reaches of the Narew River.

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1. Introduction

This report is a deliverable of the Work Package 4 (WP4): Impact Indicators, of the Project 'SCENES'. SCENES is a 4-year European research Project developing and analysing a set of comprehensive scenarios of Europe's freshwater futures up to 2025 and 2050, covering all of "Greater" Europe from the Caucasus to the White Sea, and including the Mediterranean rim countries of North Africa and the Middle East (referred to as pan-European area). These scenarios will provide a reference point for long-term strategic planning of European water resource development, alert policymakers and stakeholders about emerging problems, and allow river basin managers to test regional and local water plans against uncertainties and surprises which are inherently imbedded in a longer term strategic planning process. Full description of the background and main elements of the SCENES project, including WP4 objectives, was provided by Kämäri *et al*. (2008).

In WP4, impact indicators are identified at the pan-European scale for the four water system services: Water for Food, Water for Nature, Water for People, Water for Industry & Energy. In the Water for Nature two out of six indicators correspond to the quantity of water in rivers and floodplains: NATURE1 (Environmental flows impact indicator) and NATURE2 (Floodplain wetlands impact indicator) (Meijer, 2009). Since the Narew basin, situated in North-Eastern Poland, is one of the Pilot Areas in SCENES and environmental issues were clearly raised by the stakeholders during SCENES Pilot Area Workshops, it was decided that it is worth developing some type of Water for Nature indicators at the Narew basin scale as well. This report, Deliverable 4.5, can be seen as an initial step in this process. It discusses the environmental flow method which emphasizes the links between the river flow and two ecosystems: fish and floodplain wetlands vegetation and is based on the building block approach developed by Acreman *et al*. (2009). Due to the basin's size and limited resources, the application of this method in the Narew basin required readily available (i.e. no field measurements) ecological and hydrological data. For the same reasons, this study is confined to sixteen reaches of the Narew River and its main tributaries.

Apart from the direct motivation which comes from the SCENES project, a few other reasons for undertaking this study were:

(1) term „environmental flows" is hardly known in Poland; the existing methods for estimation of "environmental flows" focus on minimum in-stream flow requirements which tend to be very low (an example method which is now in force in Polish water law is described in Section 2.1);

(2) most of environmental flows studies found in literature were carried out for heavily impacted rivers; the Narew River system can be seen as a very moderately impacted river system for the European conditions, as described in more detail in the next section;

(3) it has recently become more and more widely accepted that environmental flows will be a key measure for restoring and managing river ecosystems in the context of implementation of the Water Framework Directive (WFD) of the European Union (Acreman and Ferguson, 2010).

In the following sections, first, the study area description is given in 1.1, then various existing methods for assessment of environmental flows are discussed in 2.1 and the method applied in the Narew basin in 2.2. Next, the impact indicators concerning environmental flows are presented in 2.3, followed by the Chapter 3, in which the results divided into their functional interpretation are discussed. In the final Chapter 4 some concluding remarks, including the opportunities of future developments of this study are presented. Additional information about the fish species abundance and division into reproductive groups as well as the photographs of selected reaches can be found in annexes.

1.1 Study area

The Narew River basin is situated in the North-Eastern part of Poland (Figure 1.1). The Narew River is a tributary of the Vistula and its drainage area is ca. 75 000 km^2. However, in the SCENES project, as well as in this study, the focus is on the part of the basin situated upstream from Zegrzyńskie Lake, which is a reservoir formed by a dam constructed in the 1960s. The first gauging station upstream from the lake, Zambski Kościelne, closes the area of ca. 28 000 km^2, 5% of which lies in western Belarus. Use of the name "the Narew basin" in this report equates to the area described above and shown in Figure 1, unless stated differently.

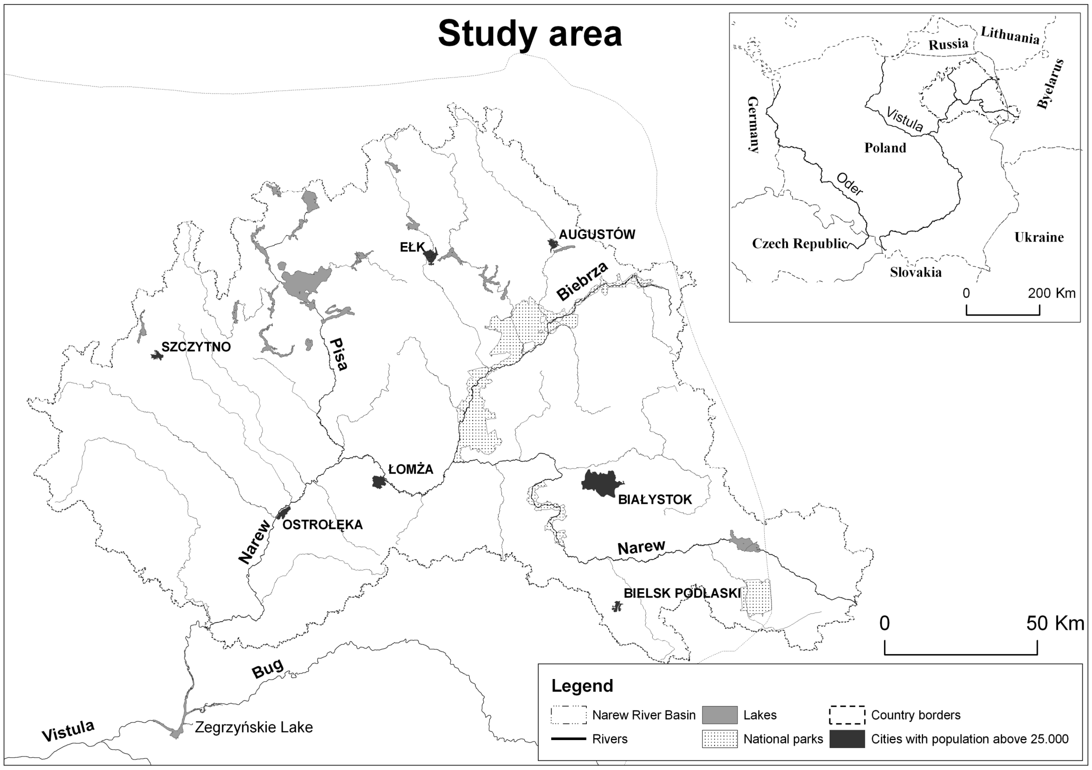

Figure 1.1 Map of the Narew River basin

The flow regime of the Narew is typical for the large lowland floodplain rivers in Central Europe. The peak flows occur during spring snowmelt periods while the low flows take place usually in late summer. The average flow recorded at Zambski Kościelne gauge between 1965 and 2008 was 138 m^3s^{-1}, 1150 m^3s^{-1} being the peak flow in this period. The Narew basin is the core part of the region known as "the Green Lungs of Poland". There are three national parks (ca. 750 km^2) protecting wetland and forest ecosystems and a number of other protected areas.

The river network of the Narew basin is in natural or semi-natural state. There is only one large man-made structure, Siemianówka dam situated in the Upper Narew built in the late 80s, whose operation affects the flow a few dozens kilometres downstream. The second important human impact is the Pisa River draining the majority of the Great Mazurian Lakes. The outflow from the lakes is controlled by a system of weirs and locks built in the middle of 19th century, which make the flow more stable. The third important example of human impact is regulation of the 50 km long reach of the Narew in its middle course downstream from the Narew National Park. The channel was straightened and deepened and a system of six weirs was constructed in order to drain swamps and meadows in the valley for agricultural purposes. Similar works were carried out on a few tributaries (including Supraśl and Orzyc). Many of the locks are no longer operational and those that work are used mainly in summer. Despite these 3 examples of human impact and perhaps a few others of smaller importance, it has to be stressed that compared to other river systems in Poland and especially to ones in Western Europe, the Narew is a fairly natural river.

2. Methodology

2.1 Overview of methods for assessment of environmental flows

Various factors determine the health of a river ecosystem (Norris and Thoms, 1999) and its ability to deliver ecosystem services. These include discharge (flow), the physical structure of the channel and riparian zone, water quality, channel management such as macrophyte cutting and dredging, level of exploitation (e.g. fishing) and the presence of physical barriers to connectivity. The Millennium Ecosystem Assessment (2005) showed that many ecosystems were being degraded or lost, with aquatic systems suffering particularly from the withdrawal of water for direct human needs for drinking, growing crops and supporting industry. The quantity of water required to maintain a river ecosystem in its desired state is referred to the environmental flow (*http://www.eflownet.org/*). The first environmental flows were focused on the concept of a minimum flow level; based on the idea that all river health problems are associated with low flows and that, as long as the flow is kept at or above a critical level, the river ecosystem will be conserved. However, it is increasingly recognised that all elements of a flow regime, including floods, medium and low flows are important (Poff *et al.*, 1997; Hill and Beschta, 1991; Junk *et al.*, 1989).

The complexity of natural ecosystems makes it difficult to define thresholds at which the flow regime will maintain a desired river condition (Acreman, 2005). Nevertheless, since the mid-1970s, methods have been developed to define just what the environmental flow for a given river should be. Over 200 different methods have been identified (Tharme, 2003), but many are similar and a few broad groups of methods can be defined (Acreman and Dunbar, 2003). Each method has advantages and disadvantages which make it suitable for a particular set of circumstances. Criteria for method selection include the type of issue (abstraction, dam, run-of-river scheme), the management objective (e.g. pristine or working river), expertise, time and money available and the legislative framework within which the flows must be set.

The approaches developed in various countries around the world to define environmental flow allocations can be divided into four categories.

(1) Look-up tables.

The most commonly applied method has been the use of rules of thumb based on simple indices given in look-up tables. A hydrological index is used in France (Freshwater Fishing Law, June 1984) required that residual flows in bypassed sections of river must be a minimum of 1/40 of the mean flow for existing schemes and 1/10 of the mean flow for new schemes (Souchon and Keith, 2001). This was largely based on engineering judgement rather than ecological knowledge. In Australia, Jones (2002) suggested that the probability of having a healthy river falls from high to moderate when the hydrological regime is less than two-thirds of the natural. Look-up tables are also well established in Poland (Witkowski *et al.*, 2008). The method now in force in Polish water law, known as Kostrzewa method (Kostrzewa, 1977), enables calculation of in-stream flow values for two criteria: hydrobiological and fishing. In case of the hydrobiological criterion, in-stream flow is estimated as the mean annual minimum flow times a parameter k, whose values can be found from a look-up table and ranges from 0.5 and 1.52 depending on the basic catchment features.

(2) Desktop analysis

These methods generally focus on analysis of existing, mainly hydrological data. Within the SCENES project generic environmental flow indicators have been developed for Water for Nature (using the Indicators of Hydrological Alteration (IHA: Richter *et al.* 1996) and the Range of Variability Approach (RVA; Richter *et al.,* 1997)). The IHA/RVA method assesses the degree of departure from the natural flow regime that is acceptable whilst still conserving the river ecosystem. The departure is indexed by up to 32 parameters including magnitude (of both high and low flows), timing (indexed by monthly statistics), frequency (number of events), duration (indexed by moving average minima and maxima) and rate of change. Rather than focusing on specific species or biological communities it assumes that some part of the ecosystem is adapted to each flow element; thus all elements are needed to maintain a healthy system.

(3) Functional analysis

This type of method relies on explicit understanding of the functional links between aspects of hydrology and ecology of the river system. Perhaps the best known is the Building Block Methodology (BBM) developed in South Africa (Tharme and King, 1998; King *et al.* 2000); its basic premise is that riverine species are reliant on specific elements (building blocks) of the flow regime. For example low flows provide nursery areas for small fish with limited swimming capacity, medium flows sort river sediments and stimulate fish migration and spawning), whereas floods maintain channel structure and allow movement of species on to the floodplain habitats.

(4) Habitat modelling

This method recognises that it is not flow itself that creates the appropriate habitat conditions for different species, but rather the interaction of flow and channel geometry (and in many cases aquatic plants) that creates the required depth and velocity of water needed at different life stages. Research in this field started with introduction of the concept of weighted usable area by Waters (1976) which quickly led to development of a computer model, the Physical Habitat Simulation (PHABSIM) system (Bovee, 1982), that uses various hydraulic models to model cross-sectional velocities. The physical habitat modelling approach has now been adapted in many countries (Parasiewicz and Dunbar, 2001), including France (Ginot, 1995), Norway (Killingtviet and Harby, 1994), and New Zealand (Jowett, 1989), while other countries, independently, have developed similar approaches (e.g. Germany (Jorde, 1996)). However, it requires field data collection of cross-section geometry and depths and velocity measurements at three flows and is thus expensive and labour-intensive.

2.2 Development of a method for the Narew basin

BBM has a detailed manual for implementation (King *et al.* 2000) that includes a series of structured stages to assess available data and model outputs and to involve a team of professional experts to a consensus on the building blocks of the flow regime. Acreman *et al* (2009) took the basic BBM concept of linking species and biotic communities to specific elements of the flow regime and adapted it for application of the WFD in the UK (Figure 2.1).

The use of the building block approach of Acreman *et al*. (2009) was further developed in order to estimate the environmental flows for the major reaches of the Narew River. In this approach the emphasis was put on two ecosystems which are considered the most important and relevant for the study area: fish and floodplain wetland vegetation. Therefore the underlying assumption was that healthy fish populations and wetland vegetation reflect wider ecological health. Instead of organizing a series of structured discussion panels (as in the original BBM), a team of specialists including a hydrologist, an ecohydrologist, a fish biologist and a wetland ecologist assessed the environmental flow regime of the Narew River. In the following sections the methodology adopted for setting flow requirements in these two different ecosystems is presented.

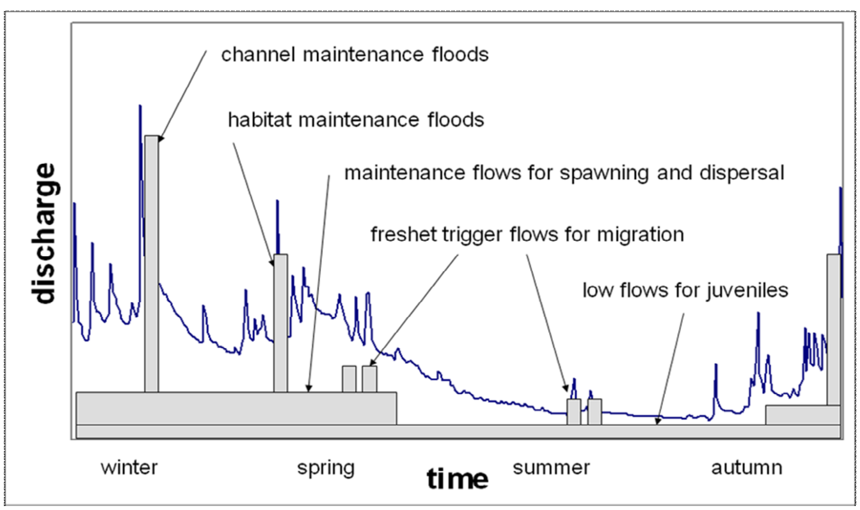

Figure 2.1 Building blocks of the flow regime and dependent elements of the river ecosystem (after Acreman et al. 2009)

2.2.1 Flow requirements of fishes

This section summarizes the internal report which was prepared for the purposes of this deliverable (Teodorowicz, 2009). Due to the large size of the catchment it was necessary at the very beginning to define for which river reaches the study is being undertaken. The final selection was based upon three criteria:

1. spatial coverage of the whole length of the Narew River and its six longest tributaries (the rivers of Narewka, Supraśl, Biebrza, Pisa, Omulew and Orzyc);
2. availability of sufficiently long (>15 years) daily river flow data from the flow gauging station representative for the particular reach;
3. natural or semi-natural condition of the reach.

The second criterion was verified during the reconnaissance field visit which took place from 29 June to 1 July 2009 (summarized in the form of an internal report (Stratford and Piniewski, 2009)). The map of selected reaches and corresponding gauges is presented in Figure 2.2. It is assumed that information about fish fauna and its habitat requirements acquired by the fish ecologist for a river reach close to a corresponding gauge apply for a distance of several kilometres from the gauge, but exact limits for each gauge cannot readily be defined.

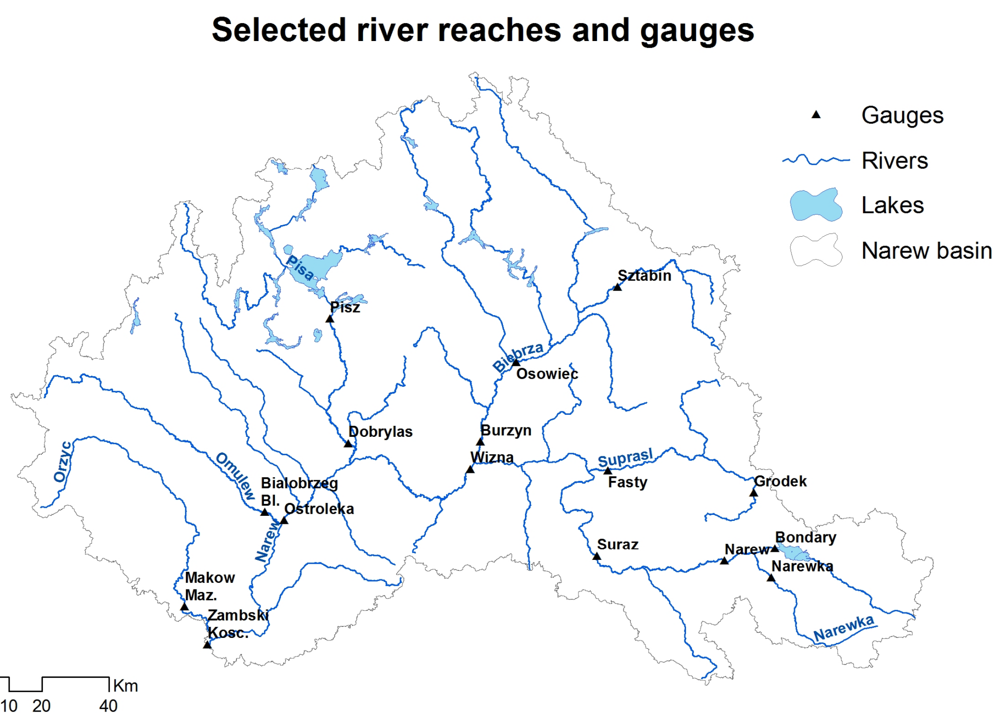

Figure 2.2 Map of selected reaches and corresponding gauges

Fish fauna composition

The second step was the identification of fish fauna composition in the selected river reaches. It has to be stressed that the area covered by this study is characterized by dynamic changes in observed fish fauna composition: species observed at a specific point in time may disappear, while some other species emerge only to "fade" several years later. The fading is related to sampling variability of a small population which may be absent from catches for some time – the basis for the knowledge on the fish population structure. The catches can be divided into the following three basic categories:

(1) Commercial catches with professional fishing equipment, nets in particular. Due to their commercial nature, such catches provide knowledge on commercially exploited species. Some species escape identification; nevertheless the catches reveal changes in the commercially exploited fish populations. With respect to segments where commercial fishing is carried out, information on species found in the catches and the dynamics of changes in the populations of fishes should be contained in fishery plans.

(2) Amateur catches, especially angling, provide information about species of interest to anglers.

Information from this source are valuable to the extent that anglers exploit a much bigger area compared to fishermen; additionally, a variety of methods are applied, making it possible to identify a greater range of species. Information contributed by anglers is more valuable if the catches are recorded on a regular basis. As in the case of commercial fishing, such information makes it possible to trace the dynamics of population changes.
The drawbacks of information from the two aforementioned sources include its selectiveness and insufficient biological knowledge of the anglers and fishermen. This leads to cases of misidentification of species.
(3) Fishing with electric equipment, often utilized for research purposes, makes it possible to identify species that are of interest to neither professional fishermen nor anglers. The disadvantages include sporadic nature and different effectiveness in different areas of the river. Electrofishing provides a relatively extensive knowledge on the fish fauna inhabiting the coastal areas, but its effectiveness within fast flowing and deep water is significantly lower.

Detailed identification of the fish fauna at the sites under analysis would require several years of research involving at least a combination of electrofishing and angling information. At most of the sites under analysis, there is no commercial fishing. However, due to limited time and resources, such research could not be carried out. Instead information from literature (Penczak *et al.* 1993, 1992, 1991a, 1991b, 1990a, 1990b) that was based on complex monitoring of the Narew River fish fauna made between 1986 and 1991 at the request of the Polish Anglers Association was the main data source in this study. As reported in the later study of Kruk *et al.* (2007) electrofishing was conducted at 331 sites across the river system excluding the Biebrza River, which was investigated previously by Witkowski (1984). A total of 49,675 individual fish were caught and 36 species were identified. The second number implies a relatively high species diversity and good ecological status of the river.

One of the few recent studies on fish fauna population in the Narew River basin was carried out within the EFI+ FP6 European Project (Improvement and Spatial extension of the European Fish Index, contract no. 044096; Deliverable 3.4 (Anon., 2008)). Electrofishing was carried-out in 50 sampling sites in the Narew and Biebrza rivers (sites corresponding to the following gauges used in this study: Sztabin, Osowiec, Burzyn, Suraż and Wizna). In total, 28 different species were found, three of which were alien species and 30453 specimen were caught. The lower species diversity than in the 1980s could be either due to the fact that the electrofishing was carried out in a smaller number of sites or because there was an overall decrease of fish population in the Narew River system during last 20 years. According to this study, the most common fish species were: roach, pike, perch and white bream (>80%), followed by ide, burbot, rudd, tench, bleak, bitterling, gudgeon, crucian carp, spined loach, loach, and bream. In terms of abundance, fish communities were highly dominated by roach (>45%), followed by pike, white bream, perch, loach and rudd. Such fish community structure clearly corresponds to environmental conditions in rivers sampled in this region (mainly large, slowly flowing rivers and their oxbows). Values of river slope in this part of Poland range between 0.7 and 1.8‰ and half of the sites were located in oxbows. This explains the high share of roach, white bream, rudd, pike and perch in the fish communities.

The composition of the today's fish fauna is the result of its natural development and the many decades of fishing/angling management. In addition to its indigenous fish fauna, intensive fishing in the Narew basin has led to invasion of foreign species such as racer goby, Chinese sleeper and grass carp. The fish species occurring at the sites analyzed in the Narew River basin (all indigenous species and selected species that are foreign to the native fish fauna), identified on the basis of available materials, are summarized as a table in Annex 1. Data on approximate frequency of occurrence of individual species is also given in the table.

Ecological breeding groups
Fish species were divided into ecological breeding groups (Balon, 1975) according to their preferred spawning area and time of spawning. On that basis, a specification of the spawning times,

temperatures and areas of the individual fish species occurring in the analyzed river basin was drawn up. The first species to breed – in March, in the shallow spring flood waters – is pike. At that same time, over a gravelly bottom within high velocity areas of the river bed, also asp starts its spawning season. It is only later on, as the temperature goes up, that ide, dace, perch, roach, zander, bream, and chub spawn; early summer is the spawning season of white bream, crucian carp, rudd, tench and wels catfish, which prefer flood waters and old river beds. During the autumn, brown trout spawns in the Supraśl River and the Pisa River basin. The species that ends the breeding season in winter is burbot.

A table in Annex 2 lists species by their classification in specific ecological breeding groups. The fish fauna set of the Narew River basin includes representatives of all groups, which demonstrates the high differentiation of this basin's ecosystem. The basin offers the appropriate conditions for the breeding, growth and wintering of species with much diversified requirements. The litho- and psammophilous species select their main habitats according to water velocity in the Narew River, while phyto- and litho-phytophilous species inhabit oxbow lakes. Stressed here should be the particularly favourable conditions for breeding offered to pike by marshy meadows flooded during the spring and by the oxbow lakes scattered in the neighbourhood. These areas are also perfect spawning grounds for wels catfish. Both these species are highly valued due to their usability and important for the ecosystem's equilibrium, as they control the structure of the fish communities. Therefore in further analysis of flow requirements of fish, if only two species were to be recorded in the fish community in a particular reach, these two would be selected as the key species. In 13 out of 16 sites it was the case, in two other sites only pike was present and in one site neither pike nor wels catfish were selected because brown trout was found to be more important (Figure 2.3).

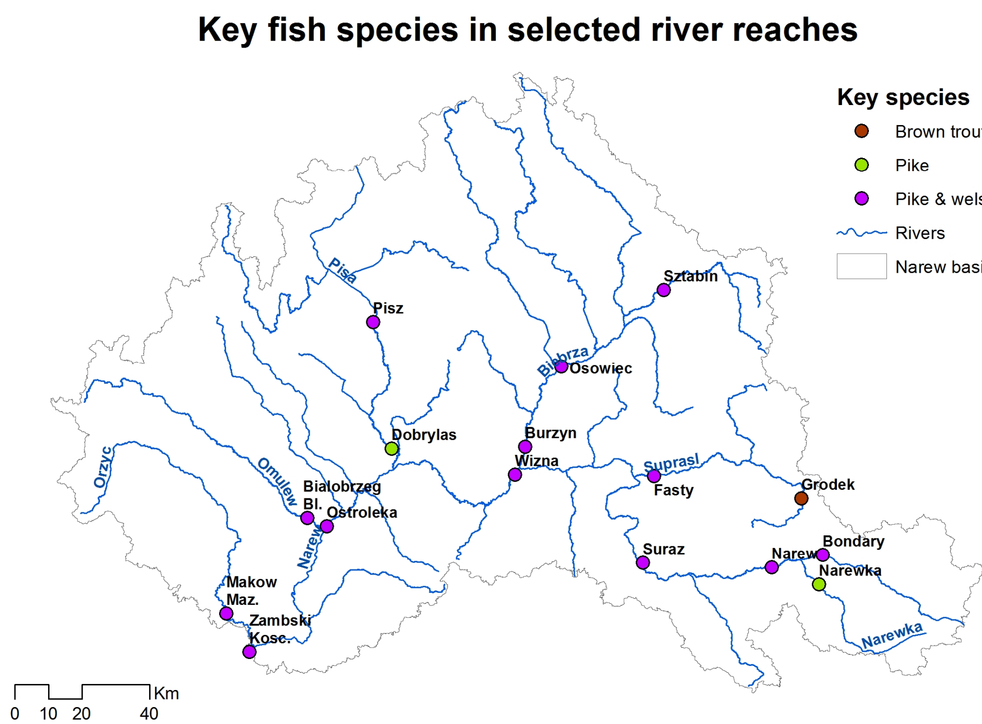

Figure 2.3 Key fish species in selected river reaches

As mentioned above, spawning (and first days of growing) is the most critical life history stage for fish in the Narew River. This is consistent with findings of King *et al.* (2010) in Australia, Webb *et al.* (2001) in Scotland and Kondolf *et al.* (1987) in California, who were also looking at flow requirements of fish during the spawning period. For phytophilous species the conditions in the Narew River system are optimum if the water level covers the marginal plants, but depth is not too critical. It is more important for the level to remain steady i.e. if the level is high and then drops before the eggs have hatched, leaving the eggs exposed, they are unlikely to survive; it can also leave fish stranded. The most important hydrological characteristics are the timing and duration of flooding, and the minimum water level. The requirement for pike is flow above bankfull for 20 days between March and May, whereas for wels catfish a flow above bankfull for 10 days between June and July is needed. The method of estimation of bankfull flows is described in the next section.

Brown trout spawn in October-November on the gravelly bed. It is critical that there are no extreme low flows during both spawning and egg incubation, i.e. from October to March, as frost can then penetrate the spawning grounds. Flooding in this period can also have negative consequences since it may lead to erosion and silting up of the spawning grounds. Therefore the flow in brown trout-inhabited reaches should remain steady from October to March, which we, based on expert knowledge, translate into interval ($0.75 \cdot Q_{50}$, $3 \cdot Q_{50}$), Q_{50} being median flow.

Apart from spawning, two other important periods during life of fish are feeding and wintering. Feeding is crucial for pike and wels catfish between March and September whereas wintering in the coldest months, i.e. from December to February. For both feeding and wintering, water level (and thus flow as well) should exceed a certain threshold whose definition is somewhat arbitrary. Most of studies concerning flow requirements of fish focus on spawning (King *et al.*, 2010, Webb *et al.*, 2001, Kondolf *et al.,* 1987), whereas little is known about requirements for wintering (Young, 2007) or feeding (Weisberg and Burton, 1993). Therefore the building blocks for fish wintering and feeding were set according to expert knowledge. Different approaches to set the proper thresholds were tested: a fraction of bankfull flow, a flow percentile, flow value determined from the flow-discharge curve after setting a threshold level in the channel cross-section. Finally the fractions of bankfull flow were used as thresholds but conditioned on the ratio of bankfull flow to median flow in particular gauged sites:

$$Q_{wint} = \frac{1}{2^{i+1}} \cdot Q_{bank} \quad \text{if} \quad 2^i \leq \frac{Q_{bank}}{Q_{50}} < 2^{i+1} \tag{2.1}$$

where Q_{wint} denotes an optimum flow for wintering of fish, i is an integer, Q_{bank} is a bankfull flow and Q_{50} is a median flow (we took daily time series from 1976-83 and 2001-08, see more in 2.2.3). In practice, the ratio of bankfull flow to the median flow ranged from 1.29 to 8 which implied that Q_{wint} could be 12.5%, 25% or 50% of the bankfull flow. Using such a formula implies that the value of Q_{wint} can vary from $0.5 \cdot Q_{50}$ to Q_{50} and therefore is of a similar order of magnitude (usually a little higher) as observed baseflows. It means that it is realistic, i.e. neither too high (i.e. does not exceed bankfull flow) nor too low.

The requirements for feeding were set (also by expert judgement) to be always 50% higher than for wintering:

$$Q_{feed} = 1.5 \cdot Q_{wint} \tag{2.2}$$

where Q_{feed} denotes an optimum flow for feeding of fish. The schematic graph presenting flow requirements of fish in the form of building blocks compared to the actual hydrograph is shown in the Figure 2.4, which also illustrates how low the value of in-stream flow defined by Kostrzewa method (see Section 2.1) can be, compared to the hydrograph and the building blocks.

The requirements of brown trout during wintering and feeding are much less crucial (its environmental tolerance is higher than that of pike and wels catfish), therefore we did not take them into account.

2.2.2 Flow requirements of floodplain wetlands' vegetation

The second ecological aspect considered in the selected approach is vegetation on the floodplain wetlands. This section summarizes another internal report which was prepared for this deliverable (Rycharski, Oświecimska-Piasko, 2010). Due to the different nature of data available for vegetation compared to those for fish, it was easier to perform a fully spatial, GIS-based analysis. Because the focus was rather on high water demands than on minimum requirements, we decided not to analyze all the habitats and vegetation present in the valleys of the Narew River network but to focus on fluviogenic (requiring frequent inundation of river waters) habitats and their vegetation of high natural value. For simplicity we will further refer to ”the floodplain wetlands” rather than ”fluviogenic habitats and vegetation”.

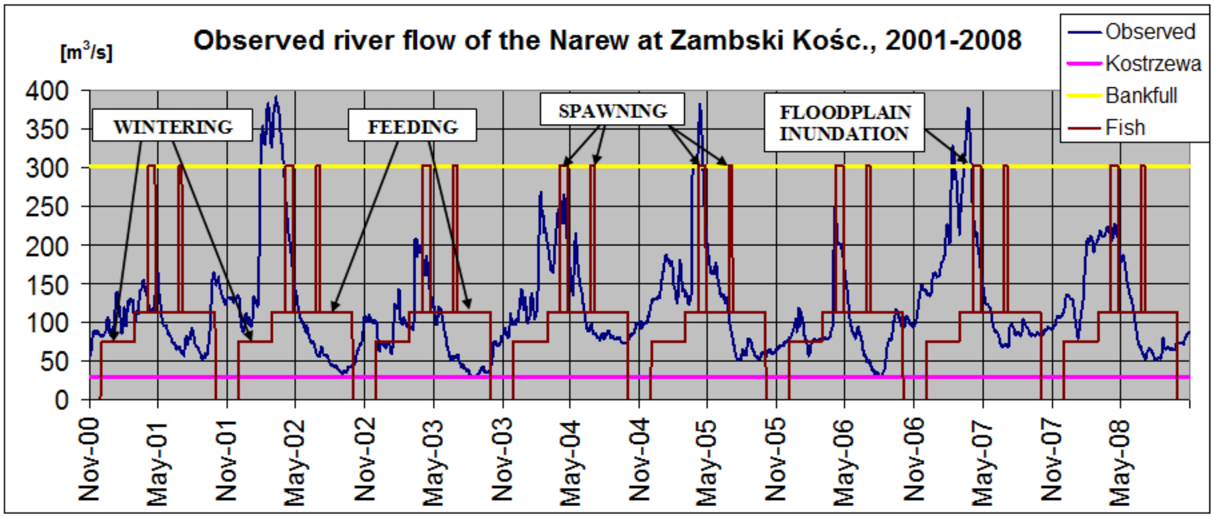

Figure 2.4 Building blocks for fish compared to the hydrograph of the Narew at Ostroleka (brown line defines the building blocks, pink line is instream flow defined by Kostrzewa method).

The first step in defining adequate building blocks for floodplain wetlands was the identification of their spatial occurrence. This was achieved using various available GIS and non-GIS data, one of them being especially important: GIS-Mokradła (GIS-Wetlands – a spatial information system about the Polish wetlands based on maps in the scale 1: 100 000; http*://www.gis-mokradla.info*). The following additional data were used:

- Komputerowa Baza Danych o Torfowiskach Polski “TORF” (Computer Database of the Polish Peatlands);
- topographic maps 1: 50 000;
- geomorphologic map1 : 500 000;
- Habitats Directive inventory.

Some data were also acquired from the other project reports, in which the Institute of Technology and Natural Sciences was one of the partners (Dembek *et al*., 2008, Anon., 2009).

In this step one of the problematic issues was generalization. Because it is planned to use the SWAT model (Soil & Water Assessment Tool; Neitsch *et al.,* 2005) which has already been calibrated and validated for the Narew basin (Piniewski and Okruszko, 2010) as a tool for testing SCENES scenarios, it was decided to adapt 151 river reaches used in SWAT as the basic spatial units for floodplain wetlands’ aggregation. This decision led to certain problems caused by the fact that the average SWAT river reach length is 24 km and thus many reaches were heterogeneous in terms of their floodplain vegetation.

Each river (or valley) reach was given the following attributes: geomorphological and hydrological description, longitudinal diversity, channel modifications, drainage ditches, occurrence of lakes, occurrence of wetlands, dominating/sub-dominating types of wetlands, number of peat deposits in the valley stretch, dominating peat type in top layer and most importantly: dominating/sub-dominating wetland vegetation community.

The final selection of floodplains requiring inundation was made for each reach separately but followed the general procedure based principally on dominating wetland vegetation type:

(1) Rushes => long-term inundation (up to 1 year);
(2) Sedges => medium-term inundation (2-4 months);
(3) Molinia meadows, shrubs, alder forests => short-term inundation (0-2 months);
(4) Mesic meadows => no inundation.
Some additional criteria included:

- share of wetlands < 40% => no inundation;
- share of lakes > 60% => no inundation;
- microrelief, meandering, oxbow lakes => premises for inundation.

In cases when a particular reach was highly heterogeneous, usually the highest requirements were set.

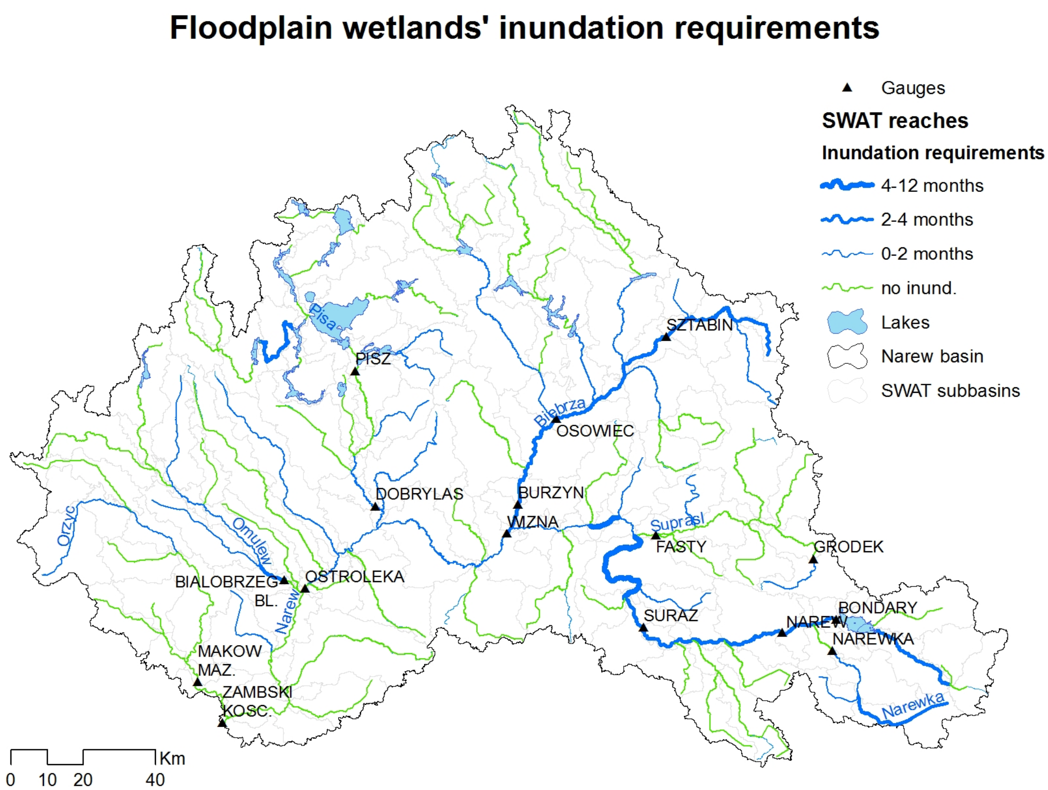

Figure 2.5 Map of floodplain wetlands' inundation requirements

The map of floodplain wetlands' inundation requirements is shown in Figure 2.5. Approximately 40% of total river network length and 44% of the total number of SWAT reaches have floodplains which require more or less frequent inundation. These numbers confirm a high natural value of the Narew River system.

Regarding environmental flows, the building blocks for the floodplain wetlands are thus defined only by the magnitude and duration of the overbank flow for a particular reach. Timings were not taken into account in this approach. It should be stressed that four identified vegetation classes are very broad and often composed of various vegetation communities having individually quite different requirements. Bankfull flow values were estimated in most cases from the longitudinal profile of the bankfull flow which is in operational use of the Institute of Meteorology and Water Management (and in such case these were average values for particular reaches). In some cases, usually for smaller streams, bankfull flows were estimated for the particular cross-sections (based on cross-section geometry and stage-discharge relationship).

In the next stage a method of verification whether, and to what extent, the established flow requirements were met in the actual hydrographs was elaborated. The method requires daily flow time series (the longer, the better) for each analyzed river reach, either observed or modelled. In the next two sections it is described which flow data were used in the analysis (Section 2.2.3) and how the idea of indicators was used as a measure of satisfaction of environmental flow requirements.

2.2.3 Preparation of input data

To make cross-comparisons we have used periods for which river flow data from the gauging stations were available for each site: hydrological years 1976-83 and 2001-2008 (hydrological year in Poland begins on November 1st). The use of longer and compact period of records was impossible due to problems with data availability. The summary of how the gaps in the time series were filled is shown in Table 2.1.

Table 2.1 Filling the gaps in flow time series

Gauge	River	Period	Method
Bondary	Narew	02/2006 – 10/2006	SWAT model
Narew	Narew	07/2005 – 10/2006	SWAT model
Narewka	Narewka	11/2002 – 10/2006	SWAT model
Gródek	Supraśl	11/2000 – 10/2001	SWAT model
Pisz	Pisa	11/1975 – 10/1978 11/1979 – 10/1980 11/1982 – 10/1983	Regression analysis using data from Jeże gauge downstream on the Pisa
Białobrzeg Bliższy	Omulew	11/1982 – 10/1983	Regression analysis using data from Krukowo gauge upstream on the Omulew

Because of different spatial scales for which the studies for fish and wetlands were performed, analysis was constrained for this report to SWAT reaches corresponding to gauging stations (Figure 2.6). These were reaches situated either downstream from the gauge (Bondary, Suraż and Pisz) or upstream (remaining 13 gauges). If the bankfull flow estimate was the average for a reach, flows were rescaled using areas ratio. If it was a gauge cross-section value, then flows remained unchanged.

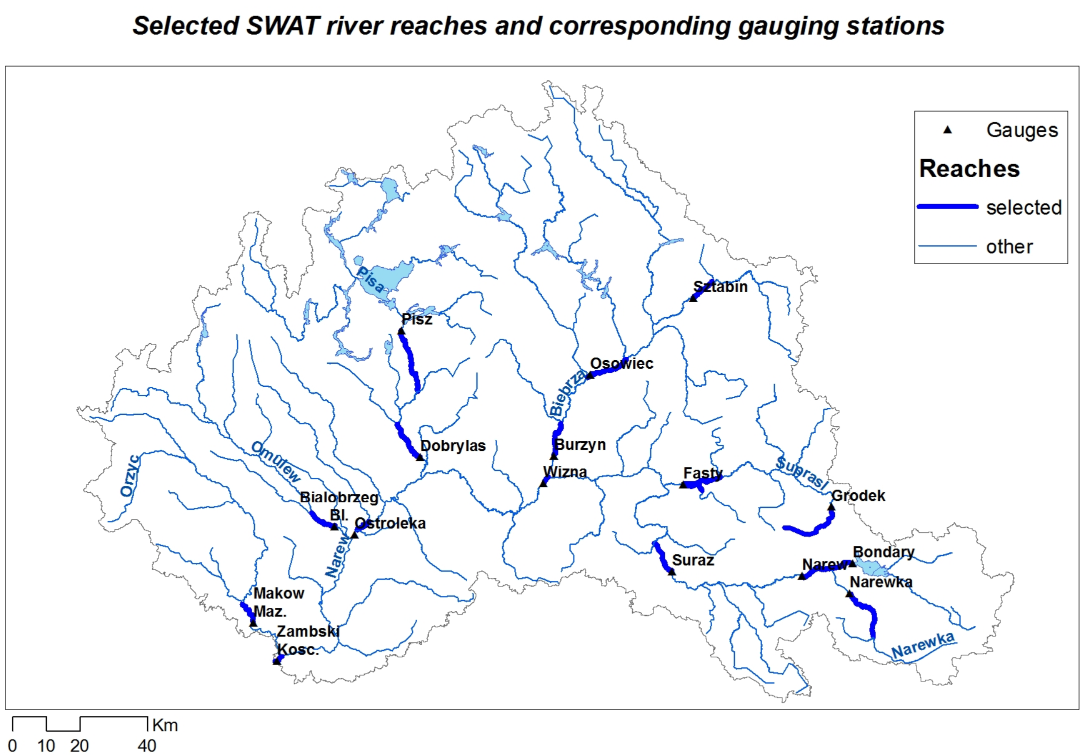

Figure 2.6. Map of selected river reaches and corresponding gauging stations

For wetlands, making the analysis for the whole river network (instead of constraining it to selected reaches) would require either using data from more gauging stations to better interpolate flows in all reaches or using modelled data, which is much more feasible but may yield bigger uncertainty. For fish, it would require making additional, more detailed spatial analysis of fish fauna composition, especially in smaller streams, to define key species and their flow requirements.

2.3 Environmental flow indicators

According to the SCENES glossary of terms (www.ymparisto.fi/default.asp?node=24687&lan=en), an indicator is an observed value representative of a phenomenon to study. In general, indicators quantify information by aggregating different and multiple data. The resulting information is therefore synthesised. In short, indicators simplify information that can help to reveal complex phenomena.

Impact indicators developed in SCENES (see other WP4 deliverables, e.g. D4.3 (Meijer, 2009) can be either interpreted as values representative of a period of study (i.e. baseline period, when talking about observed/modelled flow series) or as relative changes between scenarios and baseline. Indicators presented in this report belong to the first group because no scenarios have been quantified for modelling in the Narew basin yet. However once scenarios will have been modelled, it will be straightforward to transform the resulting indicators into those showing relative changes.

Keeping in mind that indicators should be easy to calculate and interpret a common feature of all the indicators presented below is that they can reach values between 0 and 1, zero having a negative sense and one a positive.

Fish indicators

We have developed three indicators for fish, each of them connected to a particular life history stage: spawning, feeding and wintering. Indicators for feeding (*FISH2*) and wintering (*FISH3*) are the same for both pike and wels catfish, whereas for brown trout, they were not defined because these two life history stages are less important for this species. Indicators for spawning depend on fish species – for pike it is a "Spring spawning indicator" (*FISH1a*), for wels catfish a "Summer spawning indicator" (*FISH1b*), whereas for brown trout an "Autumn&Winter spawning indicator" (*FISH1c*). If there was only one key species in a particular reach, then the "Fish spawning indicator" (*FISH1)* equalled to *FISH1a, b* or *c*. If there were more than one key species in a particular reach, like pike and wels catfish in 13 sites, *FISH1* was calculated as an average of two respective "seasonal" indicators.

Each indicator was calculated as an average of individual scores attributed to each year. Scores measure degree of compliance of observed flows with particular requirements which were defined in the previous chapter. In case of wintering and feeding scores were calculated in the following way:

$$Score = \frac{Days_{exc}}{Days_{tot}} \tag{2.3}$$

where $Days_{exc}$ denotes the number of days between the beginning and end of the analyzed period during which flow exceeded the particular threshold and $Days_{tot}$ is the total number of days in the analyzed period. Therefore *Score* can reach the values from 0 to 1 inclusive.

In case of spring and summer spawning indicators there was another variable that played a role – duration of inundation (minimum 20 days for pike in March-May and 10 days for wels catfish in June-July). Therefore *Score* was calculated as

$$Score = \min\left\{\frac{Days_{exc}}{Days_{spawn}}, 1\right\} \tag{2.4}$$

where $Days_{spawn}$ equals 20 for pike and 10 for wels catfish and $Days_{exc}$ is as in (Eq. 2.3). The other way to understand the idea of scores for these two indicators is shown in Figure 2.7. For instance, in the case of wels catfish, if in a particular year there is no overbank flow between June and July, *Score* equals to zero, if there is at least 10 days of inundation, then *Score* equals to 1 and if it's between 0 and 10 Score is linearly interpolated from 0 to 1.

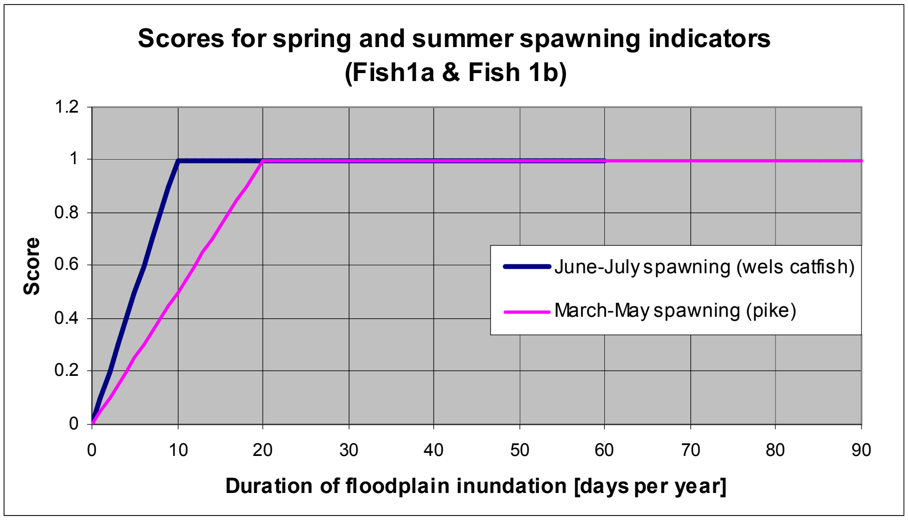

Figure 2.7 Graph of scores for spring and summer spawning indicators.

In the case of brown trout (described in Section 2.2.1) flow should remain stable from October to March for effective spawning. Therefore a lower threshold of $0.75 \cdot Q_{50}$, and an upper threshold of $3 \cdot Q_{50}$ were set. The *Score* variable equalled to the sum of days during which flow remained in the desired range divided by the total number of days from October to March.

It should be stressed that interpretation of all these indicators is relatively simple. They correspond to frequencies of exceeding the threshold flows set as optimum requirements for fish. Values close to 1 mean thus that requirements are almost always fulfilled, values close to 0 on the contrary, whereas values in between have intermediate interpretation. On the other hand, these are only average values and can often be misleading, thus it would also be interesting to include other statistics such as range, standard deviation, etc. or even look at the entire distribution of yearly scores. However this would be contrary to the concept of simplicity of indicators, hence we retained the basic idea of averaging yearly scores in this report.

Floodplain wetlands indicators

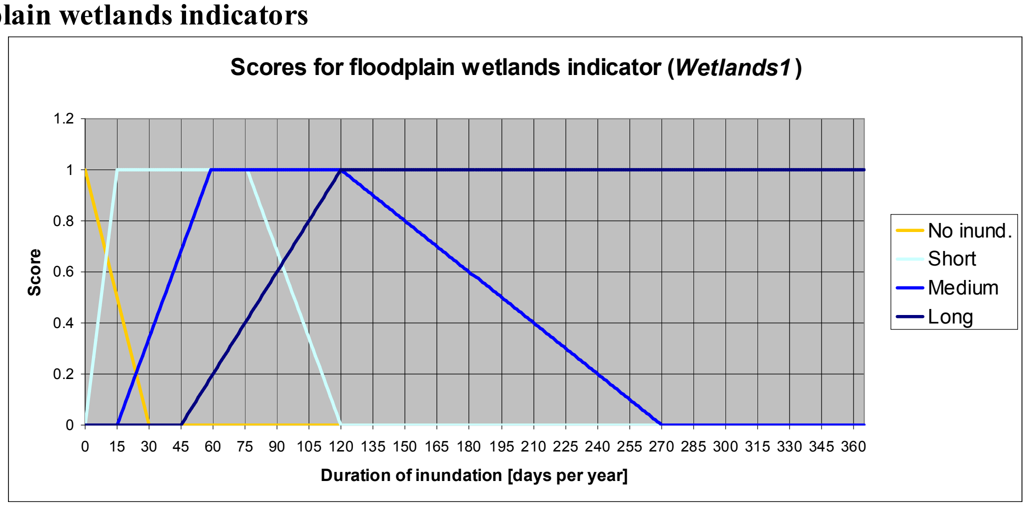

Figure 2.8 Graph of scores for floodplain wetlands indicator (in colours different vegetation classes' requirements).

For floodplain wetlands' vegetation, we developed an indicator that we called *WETLANDS1*, which is similar in notion to the fish indicators presented above. Yearly scores depend on inundation requirements of a vegetation class attributed to a particular river reach and on two hydrological variables: magnitude and duration of bankfull flow in a reach. Due to the fact that four vegetation groups are very broad as described in Section 2.2.2, duration of inundation was calculated in the simplest way, as the total days per year, time independent. The method of calculation of scores can be expressed numerically, but it is perhaps more intelligible to express it graphically (Figure 2.8). For instance, in the case of floodplain wetlands requiring short-term inundation, if the duration of inundation (total days per year, time independent) is between 15 and 75 days, then *Score* equals to 1. If it's between 0 and 15 days, *Score* is linearly interpolated from 0 to 1, whereas if duration is between 75 and 120 days, then *Score* is interpolated from 1 to 0. If duration is more than 120 days, *Score* equals to 0.

As with the previous examples, values of *WETLANDS1* are in the range 0 to 1 inclusive. Interpretation is also the same as previously. By virtue of the fact that both *WETLANDS1* and *FISH1* are additive and have the same ranges, it is possible to calculate their average. We thus call *NATURE1* an indicator which is an average of *FISH1* and *WETLANDS1*. It yields information about the measure of satisfaction of fish requirements for spawning and of vegetation requirements to be or not to be inundated. It does not take into account fish requirements for feeding and wintering which were said to be less crucial.

3. Results

In this chapter the results of application of the environmental flow method are presented. First of all some background information on the hydroclimatological differences between the time periods used in the further analysis is shown, as these differences impact further results.

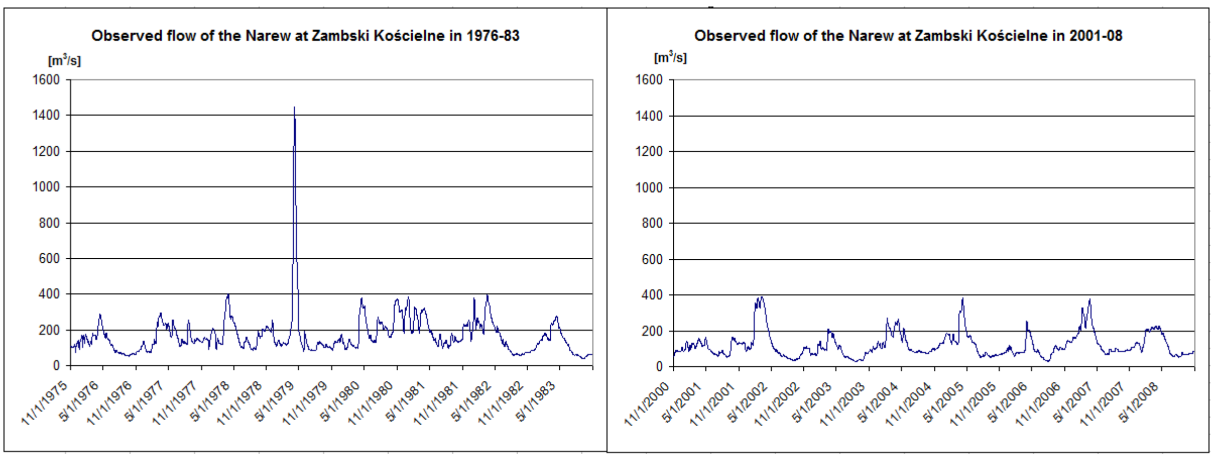

Figure 3.1 Comparison of hydrographs of the Narew at Zambski Kościelne in two time periods.

Figure 3.1 illustrates that the time period 1976-83 was substantially wetter than the time period 2001-08. Both the magnitude and frequency of flooding and low flows are indicative of this. Mean flow during 1976-83 was approximately 40% higher than during 2001-08. It further suggests considerably longer duration of inundation, as illustrated in Figure 3.2. The difference yielded values ranging from 5 days in two reaches of the Supraśl River to 67 days in the Narew at Wizna.

3.1 Spawning

Figures 3.3 and 3.4 illustrate spatial distribution of *FISH1a* and *FISH1b* indicators. It is clearly evident that pike have considerably better hydrological conditions for spawning than wels catfish. The Rivers Biebrza and Narew are able to offer the most frequent 20-day long spring floodplain inundation (even during drier years), whereas the Rivers Pisa (upstream reach), Narewka and Supraśl the least frequent. In the downstream part of the Biebrza (Burzyn gauge), requirements for pike were satisfied in each of 16 years of analysis. There is a drastic difference of FISH1a values for the upstream Narew (Bondary) between the two time periods. This is certainly an effect of Siemianówka dam operation, which substantially altered the natural flow regime in this reach (Figure 3.5).

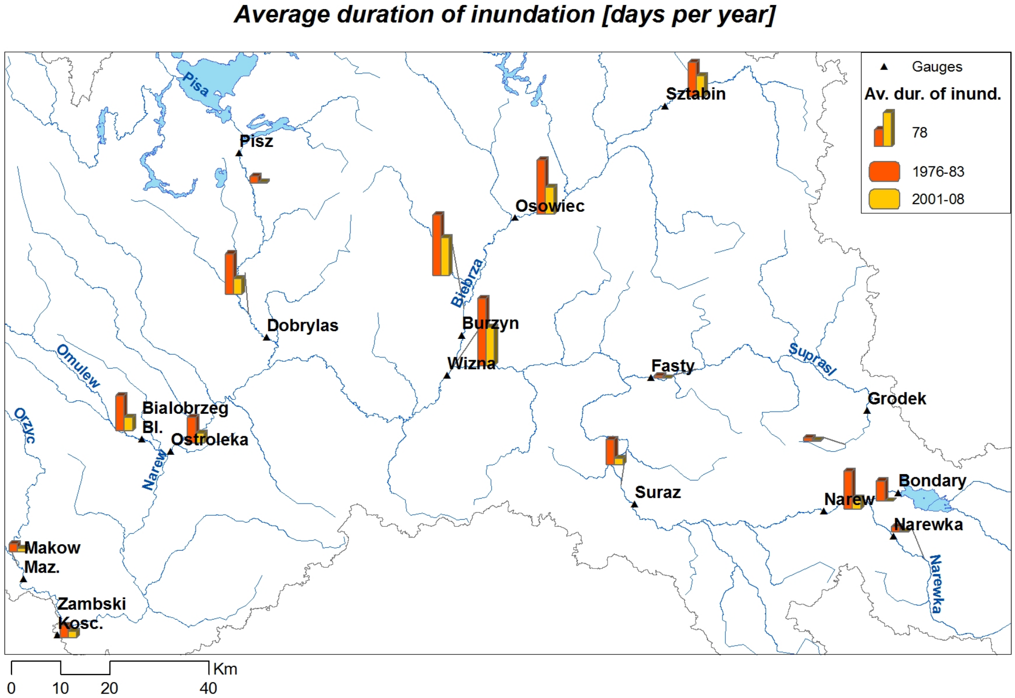

Figure 3.2 Average duration of inundation

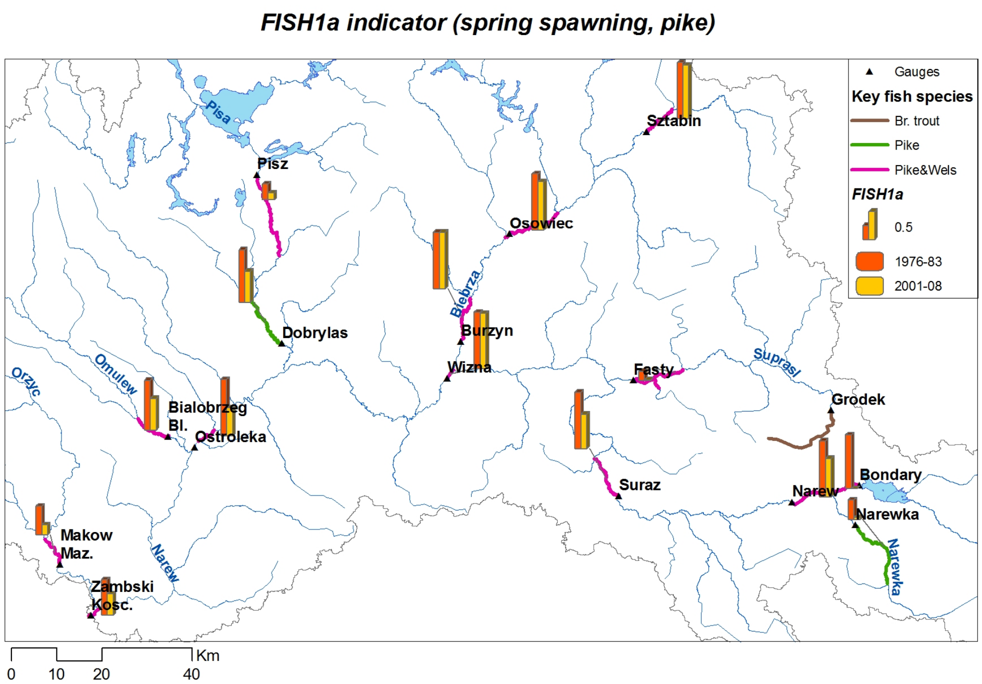

Figure 3.3 FISH1a indicator in reaches with pike as one of the key species.

In the case of wels catfish, it can be seen that hydrological conditions in the Narew at Zambski Kościelne and the Pisa at Pisz do not favour spawning of this species (*FISH1b* equal to zero in both time periods). The requirement for 10-day long floodplain inundation between June and July, which enhances effective spawning of wels catfish, was rarely satisfied in most of the reaches in the Narew basin, mostly due to the fact that summer flooding seldom occurs. The best conditions were offered by the Biebrza at Burzyn and by the Narew at Wizna, where bankfull flows were the most frequently exceeded.

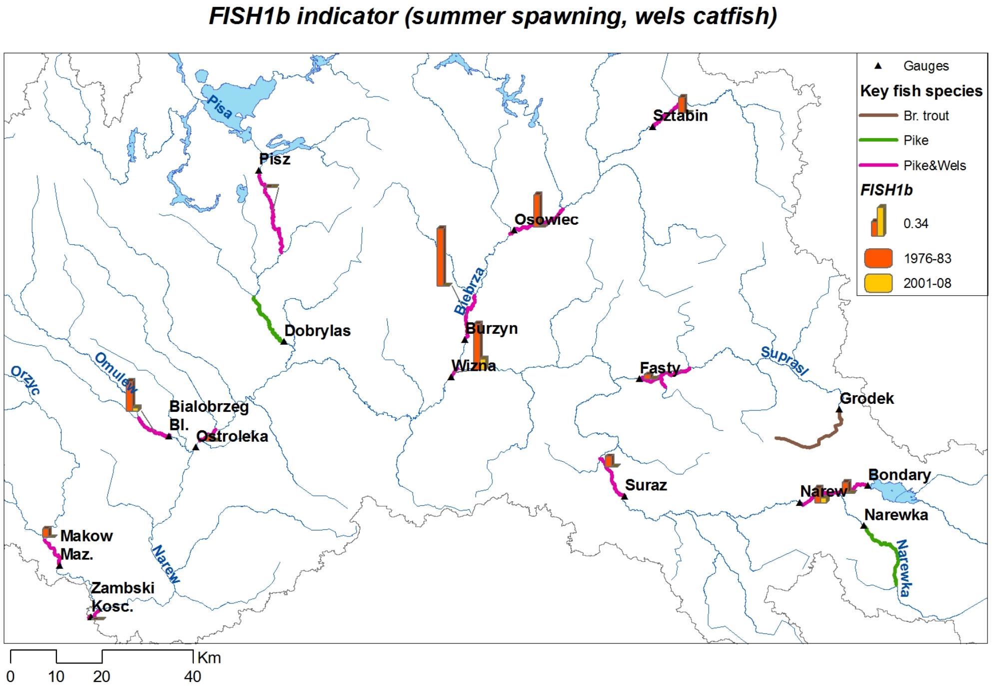

Figure 3.4 FISH1b indicator in reaches with wels catfish as one of the key species.

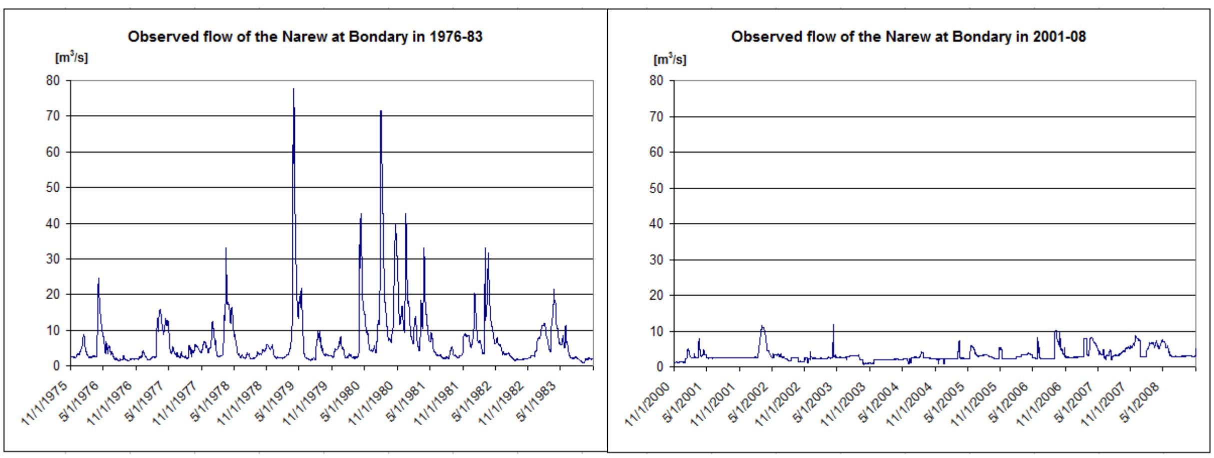

Figure 3.5 Observed flow of the Narew at Bondary before (1976-83) and after (2001-08) Siemianówka dam operation.

In the case of brown trout, there is only one reach (the Supraśl River at Gródek) for which it has been selected as the key species, therefore we have not illustrated this on a map. *FISH1c* (autumn & winter spawning indicator) yielded 0.64 for the time period 1976-83 and 0.59 for 2001-08. Since there is only one site for analysis and the thresholds were set by expert knowledge, it is difficult to interpret these values. Figure 3.6 illustrates the hydrograph at Gródek for the earlier time period vs. lower and upper thresholds between which flow should remain to provide effective spawning habitat. It can be observed that in autumn 1980 – winter 1981 there was a lack of spawning habitat due to very frequent flooding, whereas during the previous year conditions were much more stable and thus probably good for brown trout.

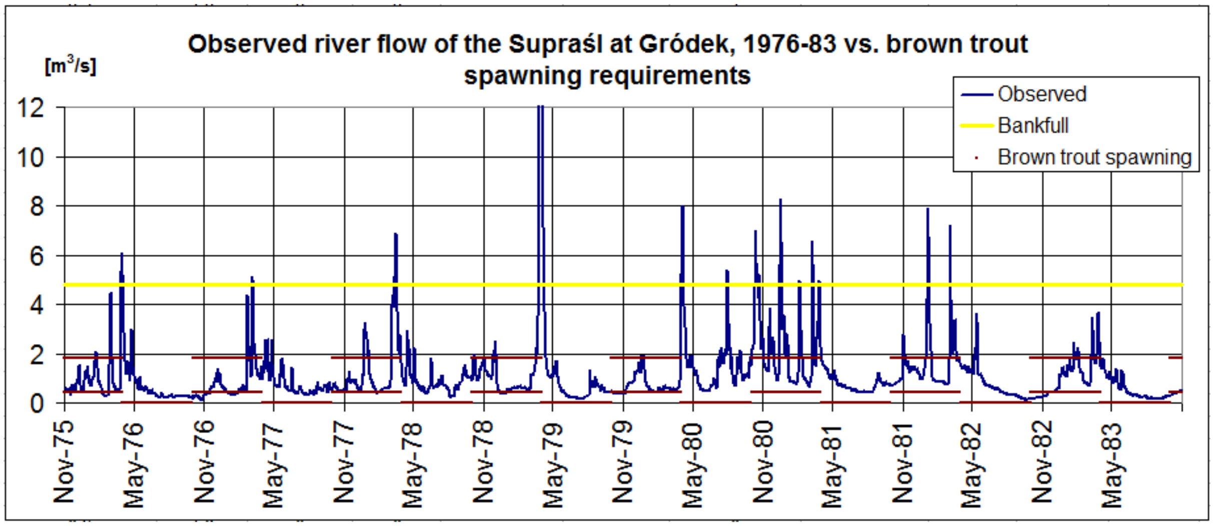

Figure 3.6 Observed river flow of the Supraśl at Gródek in 1976-83 vs. brown trout spawning requirements (brown lines between October and March are lower and upper flow thresholds between which flow should remain in optimum conditions).

3.2 Feeding & Wintering

The results of both feeding and wintering indicators have higher uncertainty than the results for spawning because estimation of bankfull flows is more reliable than the method for estimation of flow thresholds for fish feeding and wintering (described in Section 2.2.1). Figures 3.7 and 3.8 illustrate the spatial distribution of *FISH2* and *FISH3* indicators. FISH2 ranged from 0.16 on the Supraśl at Fasty for 2001-08 to 0.71 on the Narew at Bondary for 1976-83. However it is probably too risky to draw further conclusions from the spatial variation of this indicator. It is clear however, that the wetter time period 1976-83 offered better hydrological conditions for feeding of pike and wels catfish than 2001-08.

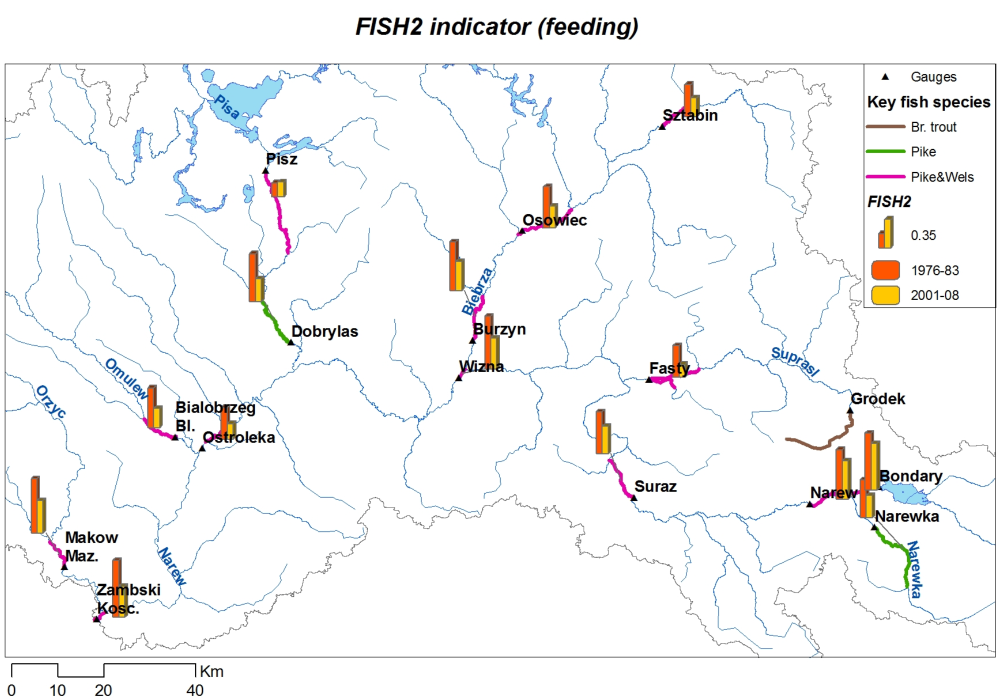

Figure 3.7 FISH2 indicator in reaches with pike and wels catfish as the key species.

In general, *FISH3* yielded significantly higher values than *FISH2* at all sites (on average 0.35 in 1976-83 and 0.42 in 2001-08). This was because the requirements of fish during wintering were considered to be lower than during feeding and also because during low flow periods which happen usually in August-September in the Narew basin it was very rare to observe exceedance of feeding flow threshold. *FISH3* was also less sensitive to climate – conditions during the time period 2001-08 were only slightly worse than during the earlier period.

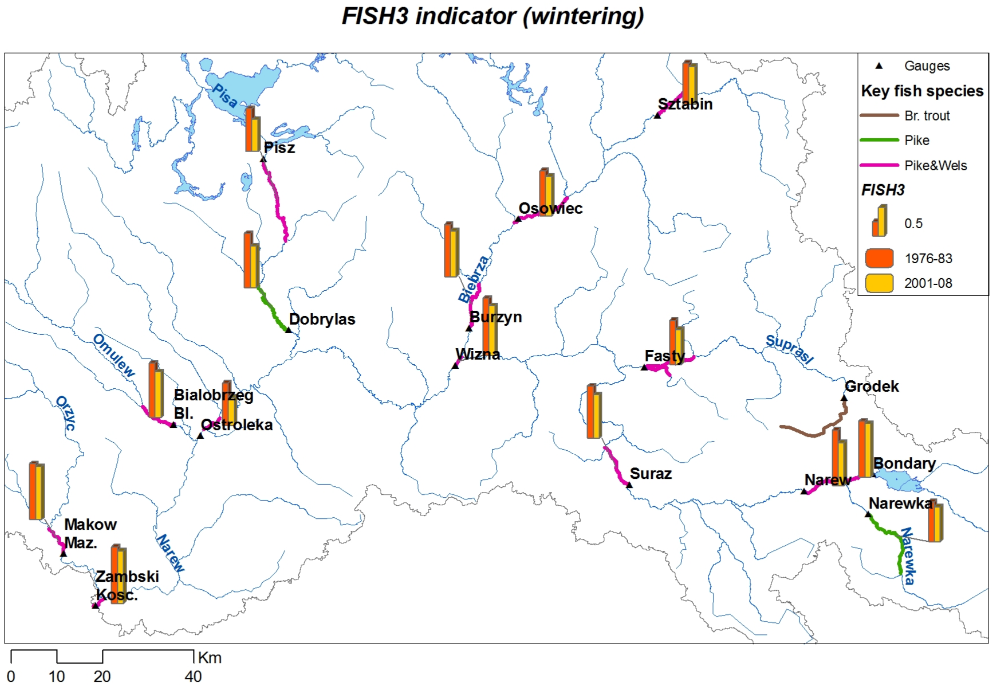

Figure 3.8 FISH3 indicator in reaches with pike and wels catfish as the key species.

3.3 Floodplain wetlands

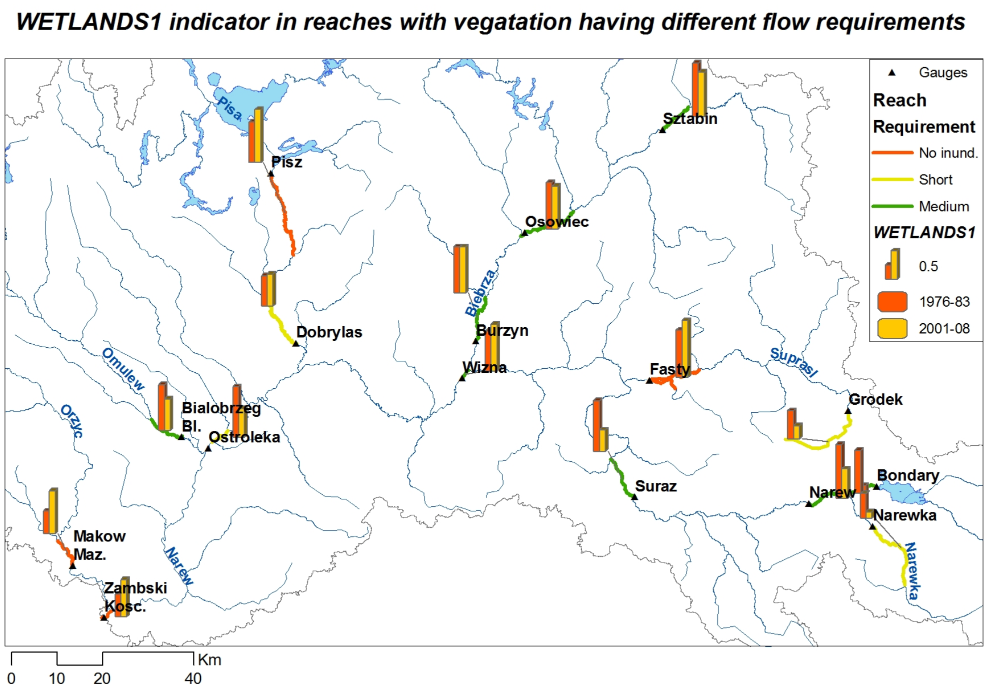

Figure 3.9 WETLANDS1 indicator in reaches with vegetation having different flow requirements

Figure 3.9 illustrates that *WETLANDS1* yielded the highest values at Fasty gauge on the Supraśl (0.9 in average), where floodplain vegetation does not require inundation at all. These high values mean that inundation was very rare in this reach. In most of sites with short (15-75 days optimum) and medium (45-120 days optimum) requirements *WETLANDS1* yielded quite high values (above 0.5). There was only one river reach with *WETLANDS1* equal to zero. This happened to the most upstream reach on the Narew (Bondary gauge) with medium inundation requirements during 2001-08. As for spring and summer spawning, the effect of Siemianówka dam operations is clear (Figure 3.5) since in 1976-83 when there was no reservoir, the flow regime was fairly more natural and the floodplain was being inundated very frequently (*WETLANDS1* equal to 0.76).

Figure 3.10 gives more insight into the interpretation of the *WETLANDS1* indicator i.e. it explains whether low values of *WETLANDS1* resulted from too frequent or too rare inundation. For the most interesting (valuable) floodplains, with medium requirements, it can be seen that during drier years not only Bondary, but also Narew and Suraż on the Narew and Białobrzeg on the Omulew experienced inundation that was too brief. In the case of floodplains with optimum requirements of 15-75 days long inundation, two sites: Dobrylas on the Pisa and Ostrołęka on the Narew experience inundation that was too long during wet years, whereas Narewka on the Narewka and Gródek on the Supraśl, on the contrary, experience no inundation during dry years. Finally, floodplains with vegetation that does not require inundation are occasionally inundated during wet years (Zambski Kościelne on the Narew). Despite these individual deviations, it can be concluded that the overall picture (i.e. looking at average values and three classes as a whole) is quite consistent, especially given the environmental tolerance of vegetation communities.

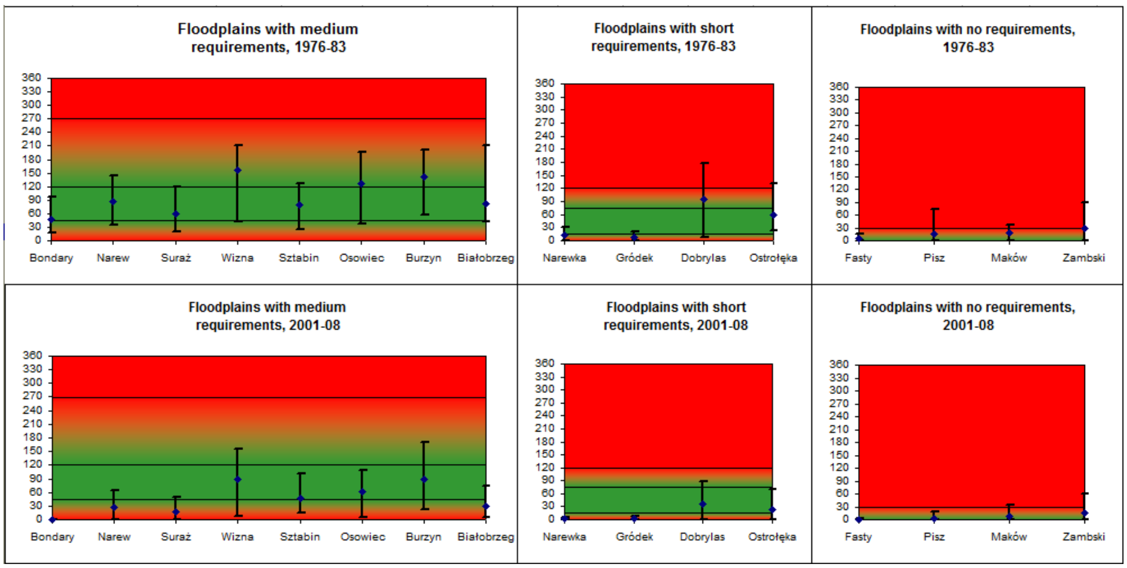

Figure 3.10 Average, minimum and maximum duration of inundation in days per year for floodplains with different requirements. Green colour corresponds to optimum conditions, red to bad conditions and green-red to a transient zone. The horizontal lines correspond to the thresholds defined in Figure 2.8.

3.4 Overall indicator

Figure 3.11 illustrates the spatial distribution of the *NATURE1* indicator. The mean value of *NATURE1* during the time period 1976-83 equalled 0.62. The lowest values of 0.35 and 0.36 were reached by the Narew at Zambski and the Orzyc at Maków respectively whereas the highest value of 0.82 by the Biebrza at Burzyn. During the time period 2001-08, the mean was 0.44 and the extremes were: 0 for Bondary on the Narew and 0.68 for Wizna on the Narew. Overall, there is a clear spatial pattern visible: three reaches of the Biebrza (upstream at Sztabin, middle course at Osowiec and downstream at Burzyn) together with one reach at the Narew at Wizna, which originates where the rivers of Biebrza and Narew join together yield similar and highest values. In contrast, the south-western part of the catchment tended to yield rather low indicator values regardless the time period. On the contrary, the time period has a large impact in case of all three upstream Narew basin reaches (the Narew at Bondary and Narew and the Narewka at Narewka). In case of Bondary which is the only site with zero value for 2001-08, as explained earlier this is an obvious example of big impact of dam operation. This impact becomes much smaller downstream at Narew (but is still visible) mainly because the bankfull flow is quite low in the corresponding reach. The difference in *NATURE1* between the two time periods at Narewka is also much smaller than at Bondary but this certainly cannot be explained by the dam operation but only by different hydroclimatological conditions.

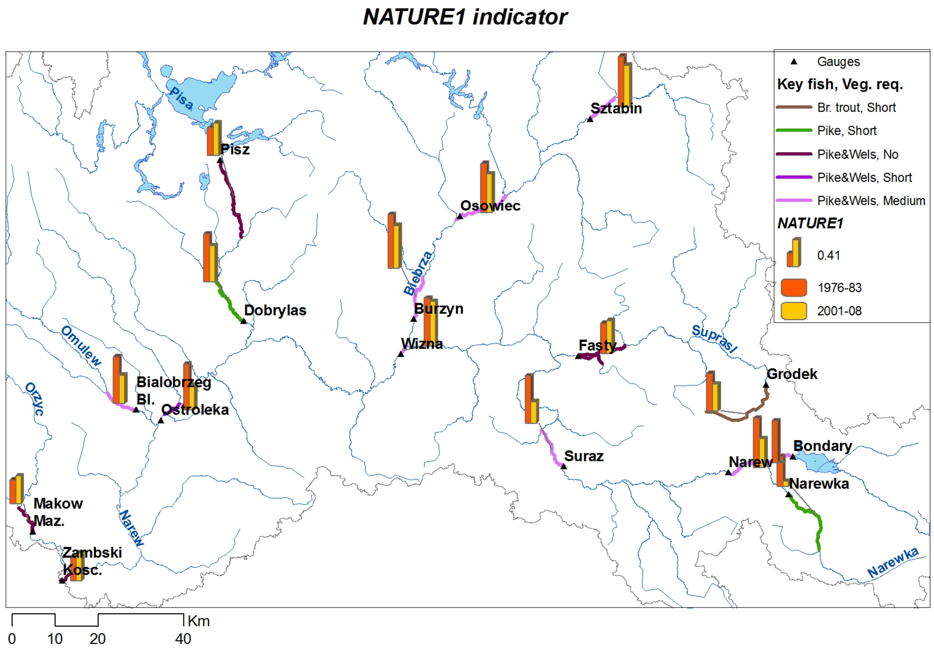

Figure 3.11 NATURE1 indicator.

4. Conclusions

As regards the method presented in this report, it must be stressed that the most critical issue and probably the largest source of uncertainty in this approach was defining the ecosystems' flow requirements. The requirements that were used in this study should be seen as optimum rather than minimum, which means that both selected key fish species and floodplain wetlands' vegetation can survive long and frequent periods with flow below the thresholds. In other words, if any of the indicators is close to zero, it does not necessarily imply (although it may imply) that the ecosystem is in danger; however if the indicator values are close to one, it is very likely that the hydrological conditions are close to optimum. For instance, in the case of wels catfish spawning, in the majority of sites *FISH1b* yielded zero values for the time period 2001-2008. This does not mean that breeding of this species was ineffective, but it means only that it was less effective that it could have been if the floodplains were inundated for a few days in June-July in any year between 2001 and 2008. For the time period 1976-83 *FISH1b* yielded over 0.3 in four reaches and this is consistent with the anglers' observations that the abundance of wels catfish was in those days significantly higher than at present.

It should also be stressed that there are other environmental factors than just river flow, which are of big importance to ecosystems such as fish and floodplain vegetation. In the case of fish, water temperature and quality can control fish population dynamics. In the case of floodplain wetland vegetation, it is not only the river which can provide water to them; it might be as well interflow or shallow groundwater recharge. Water quality is also important. All these types of things have not been taken into account in presented approach.

The results presented in the previous sections should be seen as an introductory testing of developed environmental flows indicators which were built with a basic knowledge about the Narew basin's fish and floodplain vegetation ecosystems. Similar abundance of information can be found elsewhere, therefore the approach can be tested in other regions as well. However, at least some of the relationships between ecosystems and river flow presented in this report cannot easily be extrapolated outside the Narew basin. They should be correct mostly in the neighbouring lowland river systems. The results indicate that this relatively simple environmental flow method was able to capture both anthropogenic and hydroclimatological impact on river and floodplain ecosystems very well. It therefore can be assumed that it will be appropriate also for the purpose for which it was designed: impact assessment of SCENES scenarios on environmental flows. This challenging objective will require a few more steps:

- making the baseline SWAT model run and comparing the indicators calculated with SWAT output to those presented in this report;
- quantification of climate change, land use change and water management practices change scenarios and making scenario runs with SWAT;
- transforming indicators presented in this report so that they could show deviations from the baseline rather than current state.

The first task is currently almost finished, the second task is the most demanding and will be ongoing for the next few months and the third task should be quite straightforward. It would be desirable for the future applications to incorporate also a measure of variation, e.g. standard deviation, into the indicators, instead of using only the mean value of individual scores. Standard deviation has not been used in this study because the time series were too short.

Once all the above steps are done, it will be possible to make a true cross-scale analysis by comparing the impact indicators quantified at the pan-European scale (NATURE1, NATURE2) using WaterGAP output with those quantified at the local scale using SWAT output.

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Annex 1. Fish species found at all sites of the Narew River system covered by the analysis.

No	Species	Occurrence			Trophic group	Reproductive group	Environmental tolerance
		S.	Fr.	C.			
1.	Grass carp *Ctenopharyngodon idella*	(+)			H	Pelagophilous	
2.	Asp *Aspius aspius*	+			P	Lithophilous	IS
3.	Barbel *Barbus barbus*	+				Psammophilous	IS
4.	Vimba *Vimba vimba*	+?			I	Lithophilous	IS
5.	**Three-spined stickleback *Gasterosteus aculeatus***			+	**I**	**Phytophilous**	
6.	Nine-spined stickleback *Pungitius pungitius*				I	Phytophilous	
7.	Stone moroko *Pseudorasbora parva*		(+)				
8.	Huchen *Hucho hucho*		(+)			Lithophilous	IS
9.	Common bullhead *Cottus gobio*					Lithophilous	IS
10.	Ruff *Gymnocephalus cernuus*		+		I	Phytophilous	
11.	**Ide *Leuciscus idus***			+	**O**	**Phytophilous**	
12.	Dace *Leuciscus leuciscus*				I	Phytophilous	IS
13.	Goldfish C*arassius auratus gibelio*		(+)			Phytophilous	
14.	Common crucian carp *Carassius carassius*				O	Phytophilous	IS
15.	Common carp *Cyprinus carpio*		(+)		O	Phytophilous	
16.	Gudgeon *Gobio gobio*				O	Psammophilous	
17.	White-finned gudgeon, *Gobio albipinnatus*				O	Phytophilous	IS
18.	Chub *Leuciscus cephalus*	+			O/P	Lithophilous	IS
19.	Spined loach *Cobitis taenia*				I	Phytophilous	
20.	**White bream *Blicca bioerkna***			+	**I**	**Phytophilous**	
21.	Bream *Abramis abramis*		+		O	Phytophilous	
22.	**Tench *Tinca tinca***			+	**O**	**Phytophilous**	
23.	Grayling *Thymallus thymallus*				I	Lithophilous	IS
24.	Burbot *Lota lota*		+		I/P	Litho-pelagophilous	IS
25.	**Perch *Perca fluviatilis***			+	**I/P**	**Phytophilous**	
26.	Spirlin *Alburnoides bipunctatus*				I	Phytophilous	IS
27.	Weatherfish *Misgurnus fosilis*		+		I	Phytophilous	
28.	**Roach *Rutilus rutilus***			+	**O**	**Phytophilous**	
29.	Brown trout *Salmo trutta m. fario*				O/P	Lithophilous	
30.	Bitterling *Rhodeus sericeus amarus*	+			O	Ostracophilous	IS
31.	Zander *Stizostedion lucioperca*				P	Lithophilous	

32.	Belica *Leucaspius delineatus*		+		I	Phytophilous	
33.	Wels catfish *Silurus glanis*		+		P	Phytophilous	IS
34.	**Pike *Esox lucius***			+	**P**	**Phytophilous**	**IS**
35.	Eurasian minnow *Phoxinus phoxinus*				O	Lithophilous	IS
36.	Stone loach *Noemachilus barbatulus*				I	Psammophilous	
37.	Sneep *Chondrostoma nasus*	+			O	Lithophilous	IS
38.	**Bleak *Alburnus alburnus***			+	**I**	**Phytophilous**	
39.	Eel *Anguilla anguilla*				I/P	Special	
40.	**Rudd *Scardinius erytmophtalmus***			+	**O/P**	**Phytophilous**	

Note: S – sporadic occurrence, Fr – frequent occurrence, C – common species (in **bold**); ? – no data on present occurrence, () – species resulting from stocking or brought to the area, I – invertivore -feeding on invertebrate fauna, O – omnivore - omnivorous, P – piscivore - predatory, H – herbivore - herbivorous, IS – species with low environmental tolerance.

Annex 2. Ecological reproductive groups after Balon (1975) for species found in the Narew River basin.

Species	Spawning season	Temperature	Spawning ground
Lithophilous			
Asp	April - May	6-8 ^{o}C	Gravelly bottom, marked water current
Barbel	May - July	14-18 ^{o}C	Gravelly bottom, marked water current
Huchen	March - April	5-8 ^{o}C	Gravelly and pebbly bottom, no deposits
Bullhead	March - May		Gravelly and sandy bottom
Chub	May – June	18-19 ^{o}C	Gravelly and sandy substrate
Grayling	March - April	5-8 ^{o}C	Gravelly bottom, no deposits
Spirlin	April - June	19^{o}C	Gravelly and sandy bottom near immersed trees
Brown trout	Sep - Nov	5-11 ^{o}C	Nest dug in a gravelly substrate
Sneep	April	13-17 ^{o}C	Gravelly and sandy bottom, maximum depth 1 m.
Litho-phytophilous			
Ruff	April - May	6-14 ^{o}C	Underwater plants or gravelly bottom
Ide	April - May	7-8 ^{o}C	Pebbly and sandy areas, bottom plants at times
Dace	April - May	10-12 ^{o}C	Gravelly and pebbly substrate, on plants at times
Perch	April - May	6-12 ^{o}C	Immersed plants and branches
Zander	May		Nest on the roots of plants growing on hard bottom
Phytophilous			
Stickleback	May - July	16-18 ^{o}C	Nest of plant debris at the bottom
Nine-spined stickleback	April - July		Nest of plant debris at the bottom
Crucian carp	May - July	18-20 ^{o}C	On water plants
Goldfish	May – June	16-22 ^{o}C	On water plants
Carp	May – June	18-22 ^{o}C	On gramineous plants during river floods
Spined loach	May	>16 ^{o}C	On immersed plants
White bream	June	20-24 ^{o}C	On immersed plants in shallow areas
Bream	May – June	17-20 ^{o}C	On immersed plants at 0.4-0.7 m depth
Tench	June - July	19-24 ^{o}C	On immersed plants in shallow areas
Weatherfish	April - June	about 15 ^{o}C	On immersed plants, far up from the bottom
Roach	April - May	10-11 ^{o}C	On immersed plants in shallow areas
Belica	May - July	15-25 ^{o}C	On immersed plants and the bottom
Wels catfish	June - July	19-24 ^{o}C	On immersed plants, usually within flood waters
Pike	March - April	5-9 ^{o}C	Spring flood waters, waterside plants
Bleak	June	16-21 ^{o}C	On immersed plants in coastal area
Rudd	May – June	>14 ^{o}C	On immersed plants

Psammophilous			
Vimba	May – June	14-16	Sandy and – less frequently – gravelly bottom
Gudgeon	April - June		Sand and gravel in overgrown areas
White-finned gudgeon	May – June		Sandy areas
Eurasian minnow	April - June		Sandy and – less frequently – gravelly bottom
Stone loach	April	9 ^{o}C	Sandy bottom between pebbles
Litho-pelagophilous			
Burbot	Dec - Feb	0-4 ^{o}C	Sandy and pebbly bottom, relatively big depth
Ostracophilous			
Bitterling	May – June	12-24 ^{o}C	Into a mollusk's branchial cavity
Pelagophilous			
White grass carp	June - July	22-24 ^{o}C	Pelagic spawn, no breeding in Poland

Annex 3. Photos from selected reaches of the Narew River system


The Narew at Bondary


The Narew at Zambski Kośc.


The Biebrza at Burzyn


The Narew at Narew


The Supraśl at Gródek


The Pisa at Pisz


The Narew at Suraż


The Supraśl at Fasty


The Pisa at Dobrylas


The Narew at Wizna


The Biebrza at Sztabin


The Omulew at Białobrzeg Bl.


The Narew at Ostrołęka


The Biebrza at Osowiec


The Orzyc at Maków Maz.