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Title

En studie av retentionen i floden Oder och dess avrinningsområden, Polen.
Investigation on the riverine retention in the Odra River, Poland

Author

Dorota Dorozynska

Abstract

Nutrient enrichment is the main cause of the increasing eutrophication process in the Baltic Sea during last century. A prerequisite counteract this process the load of nutrients to the Sea must be investigated. The large contribution of nutrients to the Sea is caused by emission from the rivers within the drainage basin. For the total emission of nutrient into the Sea the retention process in the rivers has big influence. This process in the river system has been assumed as a not important part of the nutrient cycle. However some investigators have pointed out that the retention process occurs in the river and be an important part of the nutrient dynamics in the river.

For the object of investigation the Odra River Basin was chosen, as an example of a large river basin in the Baltic Sea Drainage Basin. The Odra River is mainly localized in Poland and contributes substantially to the eutrophication of the Baltic Proper. The Odra River is one of the least dammed major rivers of the Baltic Proper and as such of especial interest in retention studies. The phosphorus was chosen as an example of nutrient in the eutrophication process. The purpose of the investigation is to determine the phosphorus retention within the river.

Two different models were used to calculate the retention process in the river. The "Multiple Regression Model" turned out to be insignificant, therefore the results were computed by using a "similarity model", based on similarities between load from monitored tributary basins and the rest of the sub-basin.

The retention in the Odra River in the amounted to -4608 t yr^{-1}, which is 43% of the total phosphorus emission to the Odra River. There is also stated that in the Notec and the Warta rivers the retention process occur in the amount of -1940 t yr^{-1} and -3007 t yr^{-1} respectively.

Keywords

phosphorus retention, riverine retention, the Odra River Basin, the Warta River Basin, the Notec River Basin

Abstract

Nutrient enrichment is the main cause of the increasing eutrophication process in the Baltic Sea during last century. A prerequisite counteract this process the load of nutrients to the Sea must be investigated. The large contribution of nutrients to the Sea is caused by emission from the rivers within the drainage basin. For the total emission of nutrient into the Sea the retention process in the rivers has big influence. This process in the river system has been assumed as a not important part of the nutrient cycle. However some investigators have pointed out that the retention process occurs in the river and be an important part of the nutrient dynamics in the river.

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Glossary and abbreviations

- **River basin** is treated as total river basin (e.g. for the Warta River Basin it means the total area including the Notec River Basin, for the Odra River Basin it also means the Warta River Basin) (appendix 1 - 3);

- **“Notec above 4”**, **“Warta above 31”** and **“Odra above 17”** means the sub-basin upstream from measurement point 4 in Notec River case (appendix 1 – 3);

- **“Warta 13 and 14”** denotes “the Warta river sub-basin between station 13 and 14;

- Negative sign on the emission indicates a **riverine retention**. Positive sign indicate **leakage from the river bed**.

Abbreviations:

P – phosphorus;
TP – total phosphorus;
PCA – Principal Components Analysis;
PC1 – result from Principal Components Analysis; further computations were based on the extracted components one (appendix 6);
MRM – “Multiple Regression Model”;
SM – “Similarity Model”;

1. Introduction

The Baltic Sea is a shallow inland sea, surrounded by the countries of North-eastern Europe and Scandinavia. Nine countries boarder to the sea and five more are found in its drainage basin area (Fig. 1.). The total area of the Baltic Sea drainage basin is about 1 745 000 km^2, and the sea represents about 370 000 km^2. The mean annual inflow of freshwater to the Baltic Sea from rivers is 475 km^3 yr^{-1}, which is equal to 15 000 m^{3}s^{-1} (Bergström & Carlsson, 1994; Hannerz, 2002). Almost 85 million people live within the drainage basin (Sweitzer & Langaas, 1995; Pastuszak et al. 2003).

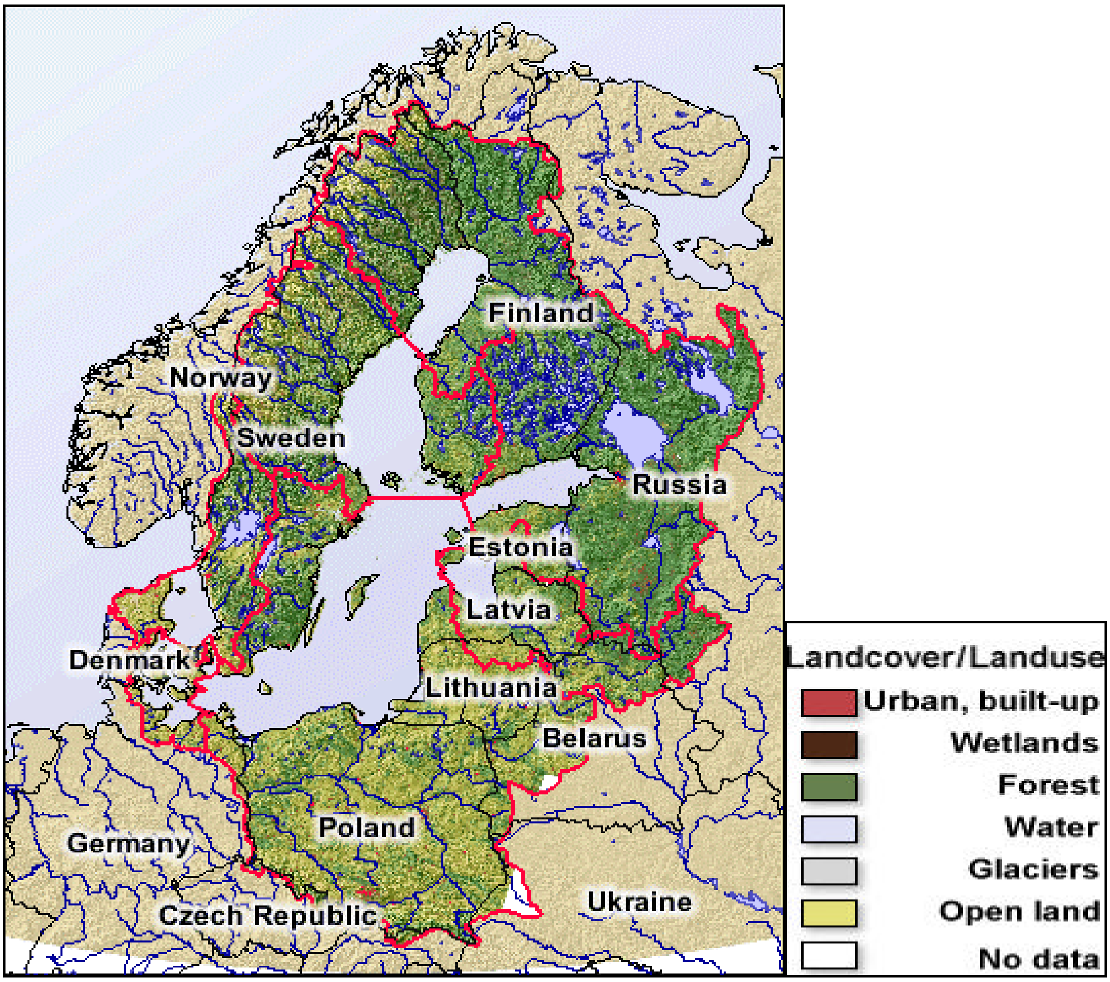


Fig. 1. The Baltic Sea drainage basin (http://maps.grida.no/baltic/)

The eutrophication process of coastal waters is a global phenomenon (Rönnberg & Bonsdorff, 2004), and the Baltic Sea is one of the more well-studied areas with respect to marine eutrophication. According to Larsson (1985) the Baltic Sea has changed from an oligotrophic sea into a eutrophic one and "the amount of nutrients and the deposition of organic matter into the Baltic Sea have increased considerably since the beginning of the 20th century" (Larsson et al., 1985). Sub-regions of the Baltic Sea have become overloaded by nutrients (HELCOM, 1998).

The main impacts of this overloading are changes in the structure and functioning of the marine ecosystem, reduction of biodiversity, and less income from fishery and tourism (Künitzer et al., 2001).

As Künitzer et al. (2001) pointed out eutrophication of marine coastal areas generally results from input of nutrient with the runoff of freshwater. Rönnberg and Bonsdorff (2004) describe that during last century the concentration of nutrients in the brackish water of the Baltic Sea has increased several times. The reason for this is higher load of nutrients to the river and in consequence to the sea. The point sources can be easily identified, while the non-point sources are harder to localise and eliminate (Sivertun & Prange, 2003). Major point sources have been defined by HELCOM, for each of the Baltic Sea states. For Poland one has defined 57 hot spots, but 27 of them are removed from this list until 1.02.04 (http://www.helcom.fi/pitf/LIST_per_010204.pdf). According to Stålnacke (1996), 1360000 tons of nitrogen (N) and 60 000 tons of phosphorus (P) are annually discharged into the Baltic Sea through riverine load. With the increasing environmental problems caused by nutrient over-enrichment, public awareness to the problem has also risen (Rönnberg & Bonsdorff, 2004). In fact, the conditions were so bad in the 1960's that the HELCOM was founded as a result of the UN-meeting on environment in Stockholm 1972 to combat these negative effects on the Sea.

When the point sources are known it is easier to cooperate and decrease the load of nutrients to the river. In 1988 the Ministers of Environment of the Baltic Sea States decided "that anthropogenic loading to the Baltic Sea should be reduced by 50% from 1987 levels by the year 1995" (Lääne & Pitkänen, 2001). Nearly every one of the riparian countries reduced their point-sources even more than 50% (Table 1) Poland, which is one of the main polluters of the Baltic Sea, only reduced the nitrogen load to about 27% and the phosphorus one to 20 % (Table 1) (Lääne & Pitkänen, 2001).

Table. 1. Overall nitrogen and phosphorus load reductions achieved by countries between the late 1980s and 1995 (Lääne & Pitkänen, 2001)

Country	**N [t/yr]**		**Reduction**		**P [t/yr]**			**Reduction**
	Late 1980s	1995	[t]	[%]	Late 1980s	1995	[t]	[%]
Denmark	101 400	64 300	37 100	37	5 890	1 870	4 020	68
Estonia	49 360	17 440	31 920	65	1 080	545	535	50
Finland	67400	57 400	10 000	15	4 150	3 380	770	19
Germany	53 260	36 000	17 260	32	3 820	1 300	2 520	67
Latvia	46 310	21 510	24 800	54	2 473	1 371	1 102	45
Lithuania	72 500	43 400	29 100	40	4 530	2 040	2 490	55
Poland	298 900	219 700	79 200	27	36 050	28 680	7 370	20
Russia	129 100	54 300	74 800	58	9 700	5 190	4 510	47
Sweden	98 400	78 700	19 700	20	2 240	1 310	930	42
Grand Total	916 780	592 800	323 980	35	69 935	45 688	24 247	35

As stated by HELCOM (1996), the Baltic Sea is strongly influenced by riverine input, particularly along the southern and eastern coastlines where all the large rivers: Neva, Vistula, Daugava and Odra, dscharge 150 km^3 of freshwater per year (or a third of the total discharge to the Baltic Sea). Human activity is to a high degree responsible for the increase of phosphorus and nitrogen compounds in the Baltic Sea (HELCOM, 1996) as a majority of the Baltic Sea population lives here.

Behrendt & Optiz (2000) state that it has often been assumed, that the processes operating within the waters of small basins can be ignored when river basins are used to estimate the non-point source loading. They argue that this is a wrong point of view. Their work presents a detailed analysis of the retention processes in the various Baltic river basins. The temporary or permanent nutrient storage in the watercourses is often called retention. Kronvang et al. (1999) states that “nutrient removal and storage take place in different components of the river basin (watercourses, riparian areas and lakes) and is controlled by physical, chemical and biological processes”. The retention process may increase rapidly when consumption of nutrients by benthic organisms such as macrophytes and mussels occurs in the river system (Macrae et al., 2003) but human influence on the nutrient hydrological cycle through drainage of riparian areas and channelization of watercourses has decreased the nutrient retention capacity of the river basins (Kronvang et al., 1999).

The number of studies on P-retention is, compared to nitrogen, limited up to now, but it is known that P-retention occurs at low flow conditions as well as during floods, when the river flows partly outside of its bed (Behrendt & Optiz, 2000). The increasing knowledge of the pathways of nutrient emissions from point and diffuse sources makes it possible to estimate the total input into a river system. According to Behrendt & Optiz (2000) "if the emissions are known, the riverine retention can be estimated from the difference between the emissions and the measured load". This is to be done in the present study.

The first detailed investigation of the nutrient loads to the Baltic Sea was carried out by Stålnacke (1996). This study takes into consideration loads from main rivers contributing to the nutrient load to the Baltic Sea. He estimated the total phosphorus load to the Baltic to be about 59 500 t yr^{-1}. In the Baltic Proper, the major sub-basin of the Baltic Sea the Vistula, the Odra and the Neman rivers were considered in his work. A detailed investigation of the Odra River Basin was carried out by Tonderski (1997). He focused on control of nutrient fluxes in large river basins as the Odra and the Vistula rivers. Behrendt et al. (1999) studied point and diffuse nutrient emissions and transport in the Odra River and its main tributary. Further Behrendt & Optiz (2000) made investigations on retention of nutrients in these rivers systems; one of them was the Odra River basin. Similar research was also carried out by Polish and German scientists (Behrendt et al., 2002). The nutrient emissions were estimated for 45 sub basins of the Odra river basin (Behrendt et al., 2002). Investigation on the retention of nutrients in streams has also been carried out by Macrae et al, (2003) in the Strawberry Creek catchment (Canada). Garnier et al. (2002) have, in order to develop a drainage model, established how land use and management of whole watersheds are linked to nutrient (N, P, Si) export and retention in the Danube River. Vassiljev and Stålnacke (2003) presented a statistical model on the "Diffuse Pollution Conference" in Dublin which among other things computes the retention in drainage basins.

2. The goals and motivation of the thesis

2.1. Goals

Main goal:

- To analyze the phosphorus retention in the whole Odra River;

Secondary goals:

- To study the retention in the three major sub-basins as well as in smaller sub-basins between monitoring stations;
- To build a phosphorus budget for the Odra River Basin;

2.2. Thesis motivation

The Odra River Basin was chosen, as an example of a large river basin in the Baltic Sea Drainage Basin. The Odra River is mainly localized in Poland and contributes to the eutrophication of the Baltic Proper due to heavy load of nutrients. The purpose of the present investigation is to determine the phosphorus retention in the river and give an overview of how much of P that stays in the basin. The Odra River is one of the least dammed major river of the Baltic Proper and thus of special interest in this context. Various factors potentially important for this process are investigated below.

The phosphorus was chosen because it is crucial in the eutrophication process. On land the phosphors is usually a limiting factor for the primary production. Increased load of P may cause rapid growth of algae and other kinds of plants. In the Baltic Proper nitrogen is generally assumed to be the limiting factor but the occurrence of nitrogen fixating blue-green algae may weaken this assumption (Sauchuk & Wulff, 1999; Graneli et al., 1990). For the load of phosphorus to the river man has made a significant impact e.g. farmers place too much fertilizer on their fields which leak phosphorus to the ground or surface water to finally end up in major rivers discharging into the sea, other sources are sewage treatment plants, detergents in washing powder ect.

There is numerous works studying nitrogen influence on the eutrophication (Mcisaac et al., 2001; Mitsch et al., 2001; Gren, 2001). In this thesis the focus will be in stead on P as it is necessary also to expand our knowledge about phosphorus loads. This partly because P often is linked to particles and thereby has a transportation characteristic different from N.

A statistical model was chosen to carry out the retention studies. When the Multiple Regression Model was used it did not give significant results, it was then decided to use a simpler model that is based on the similarity between neighbouring areas. This model gives the opportunity to compute total phosphorus load from land and in the end the riverine retention.

Monitoring data for river Odra were obtained for the period 11.1992 – 12.1995 from the Polish statistics office (http://www.stat.gov.pl/english/index.htm). The availability of data for the river during year 1995 was the reason for choosing this period.

3. Study area: The Odra River Basin

This part of the thesis presents basic information about the Odra River and its tributaries. The chapter consist of following parts:

- The Odra River Basin characteristics
- General outline of the hydrological situation in Odra River Basin
- General outline of the influence of industrial and municipal loads to the Odra River Basin

3.1. The Odra River Basin characteristics

The Odra River is one of the biggest rivers in the Baltic Sea catchment (Behrendt et al., 1999; Migon, 2000; Dembicki, 1999). The basin of the Odra covers almost one third of the Polish territory and drains into the southern part of the Baltic Proper (Fig. 1 and Fig. 2) (Dembicki 1999; Humborg et al., 2000).

Fig. 2. The Odra River Basin (http://teams.dhi.dk/freshco/Oder/)

The Odra River has its source in the Odrzanskie Mountains (the Sudety Mountains) (632 m a.s.l.). From the Bogumin to the mouth of the Olza River, the Odra is a transboundary river between Poland and Czech Republic. Further, over a distance of 176 km the Odra forms the state border between Poland and Germany (Migon, 2000; Dembicki, 1999, http://socrates.gyrec.cz/project/).

The Odra is the second longest river in Poland with 741,9 km within Polish boundaries of total length 845,3 km (fig. 2.). The basin of the Odra River covers an area of about 118 861 km^2, inside Polish territory is found 106 821 km^2, within Czech Republic area 6453 km^2 and 5587 km^2 within German territory (fig. 2.) (Migon, 2000; Dembicki 1999; Tonderski, 1997; http://www.mos.gov.pl/1materialy_informacyjne/archiwum/program_dla_odry/pdo_30.html#1.1.1).

Table. 2. The Odra River Basin parameters

	Total	Poland	Germany	Czech Republic
length	845,3 km	741,9 km		
basin area	118 861 km^2	106 821 km^2	5587 km^2	6453 km^2

The main left-bank tributaries of the Odra are: Opava, Nysa Klodzka, Bystrzyca, Kaczawa, Bobr, Nysa Luzycka and right-bank tributaries are as follows: Olza, Mala Panew, Barycz, Warta with Notec, Plonia, Ina (Migon, 2000; http://www.rzgw.szczecin.pl/v2.php?site=2.1). 55 km before the Odra enters the Szczecinski Lagoon the river splits up into two branches, the Eastern and Western Odra, which are interconnected by numerous canals. After 854,3 km the river flows into the Szczecinski Lagoon and through the Pomeranian Bay into the Baltic Sea. The Szczecinski Lagoon catchment covers of 129 591 km^2 from which the Odra basin represents 91.5% of the whole (Humborg, et al., 2000; HELCOM 2002, http://www.rzgw.szczecin.pl/v2.php?site=2.1).

The Odra River is connected to the Vistula River through the Warta River - Notec River – Bydgoczsz Canal. It is also a European waterway through canals Odra – Szprewa and Odra – Hawela (http://www.mos.gov.pl/1materialy_informacyjne/archiwum/program_dla_odry/pdo_30.html#1.1.1).

The Warta and Notec River Basins

- **The Warta River**

The Warta is the longest tributary of the Odra River (Fig. 2) with a length of approximately 808 km. It is the third longest river in western-central Poland. The Warta has a basin area of 54 529 km^2. One of its major tributaries is the Notec River. The Warta basin covers lowland forested area with large numbers of lakes (Migon, 2000; Dembicki, 1999).

- **The Notec River**

The Notec River is a tributary of the Warta and flows through central Poland (Fig. 2). This river is the 7^{th} longest river in Poland with a length of 388 kilometres and a basin area around 17 330 km^2 (all in Poland). The Notec is connected to the Vistula River by the Bydgoszcz Canal (Migon, 2000).

3.2. General outline of water resources and hydrological situation in Odra River Basin

- **Water resources of the Odra River Basin**

The annual volume of water resources (total amount of water in river system) for the Odra River basin is $23{,}5 \cdot 10^9$ m^3 of which 84,6% is surface water ($19{,}9 \cdot 10^9$ m^3). Annual outflow from the Odra to Baltic sea is on average $18{,}5 \cdot 10^9$ m^3, which make up only to 29,5% of the precipitation within this basin (http://www.mos.gov.pl/1materialy_informacyjne/archiwum/program_dla_odry/pdo_29.html#2.1.1).

- **Hydro technical objects in the Odra basin**

In the upper and middle Odra and its 15 main tributaries, 450 hydro-technical objects (weirs, flood-gates, water-power plants, polders, storage reservoirs, water swings) have been created. In the upper part, dams have also been frequently constructed (http://www.otkz.pol.pl/zapory/en/index.htm).

3.3. General outline of influence of industrial and municipal loads for the Odra River Basin

The basin is situated in an industrialised and highly populated part of Central Europe, shared by Poland (89 %), the Czech Republic (6 %) and Germany (5 %) (Dembicki, 1999). 15.4 million people live in the Odra River Basin: 13 million in Poland, 1.4 million in the Czech Republic and 1 million in Germany.

In the southern part of the Odra basin there is localized an urban-industrial region – the Silesia region (Tonderski, 1997). There are a lot of factories in this area. From 375 cities, 278 of them have different types of sewage treatment plants – 43 cities have mechanical treatment plants, 200 mechanical and biological treatment plants and only 30 of them have mechanical and biological treatment plants with higher stages of biogens particles removal (Debicki, 1999; http://socrates.gyrec.cz/project/polish/locpol.html; http://www.mos.gov.pl/1materialy_informacyjne/archiwum/program_dla_odry/pdo_30.html#1.1.1).

4. Theory of phosphorus load to the river

The phosphorus circulation in the ecosystems is presented in the figure below (Fig. 3). From the bedrock and soil phosphorus may be weathered and taken up by plants. Animals graze plants, and release phosphorus (P) into the environment as excrements. One more way for releasing P into the environment from animals and plants is as dead organic matter (Pierrou, 1979). Then phosphorus elements soak through soil to groundwater and leak to the river.

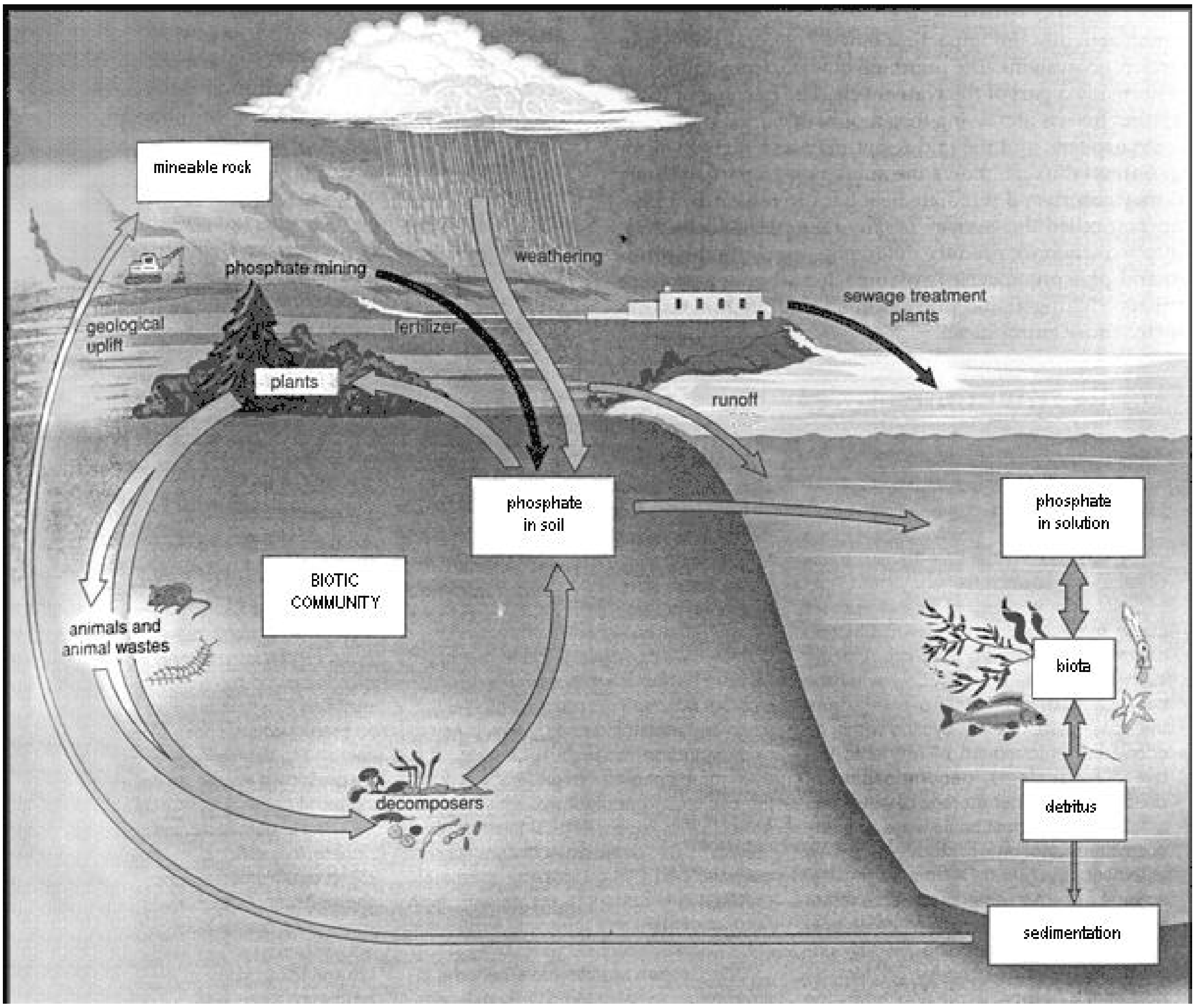


Fig. 3. An example of phosphorus cycle within the environment (http://www.npc.edu/Bio105/media_htm/M2_L8-01.htm).

Phosphorus in the soil may be immobilized in the form of complex with e.g. iron, aluminium and calcium. In this way it becomes inaccessible to plants. Another source of phosphorus to the river is bank erosion. In rivers phosphorus is deposited in sediments, especially in reservoirs and lakes with long residence time.

Human activities lead to increased inputs of P into streams and groundwater. The most obvious sources are from municipal wastewater (sewage) treatment plants and from industry. These are called point sources (Pierrou, 1979). Diffuse or non point sources are much more difficult to measure and to control.

According to Richey (http://www.icsu-scope.org/downloadpubs/scope21/chapter13.html) and McConnel (1979) a significant contribution of P to surface waters is caused by use of phosphate fertilizers in highly cultivated areas. From rural and urban areas the input of P to the river includes detergents, excrements etc. These enter the environment via waste water treatment plants or it can enter directly to the river (Pierrou, 1979).

One of the sources is the atmospheric deposition. P does not exist as a gaseous component, but it is easily absorbed on particulate matter as dust, fumes or dissolved in sea spray. In fact, while N is often transported in dissolved form, P behave quit different due to its high affinity to particulate matter with implications on its transport process. The phosphorus particles fall out either as dry deposition or by precipitation (Pierrou, 1979). The load of phosphorus from air within the Baltic Sea drainage area is estimated to be very small. Phosphorus is analyzed by some countries in rain water samples, but only in very few cases do the concentrations exceed the detection limit (http://www.baltic.vtt.fi/balticinfo/).

5. Research material and methods

5.1. The geographical information system data and computation:

5.1.1. The geographical information system data:

- The administrative units for Baltic Sea drainage basin region. They are in form of an Arc View shape file. The data map was downloaded from Baltic Sea Region GIS, Maps and Statistical Database (http://www.grida.no/baltic/htmls/idrisi.htm).
- The river segments and catchments for these segments were ordered from River and Catchment Database for Europe Catchment Characterisation and Modelling (CCM); European Commission, Joint Research Centre (JRC) - Institute for Environment and sustainability (IES) - Land Management Unit (LMU) (http://data-dist.jrc.it/portal/subscription.php).
- The administrative units for Poland – are given by an Arc View voivodship shape file for period 1975 – 1998 (personal communication with Hanna Eriksson from Stockholm University)
- The administrative units for Poland – consist of an Arc View voivodship shape file for the period after 1998 (personal communication with Hanna Eriksson from Stockholm University)

5.1.2. The geographical information system computation:

Calculations were made for river data and statistical data for year 1995. Computations were made on 18 sub-basins and 15 tributaries. In some cases within a sub-basin more than one tributary was localized, and then the computations were made for the sum of these tributaries.

The Projection

To have possibility to work on the maps in Arc View it was necessary to convert the projection of existing shape files. Some of the shape file maps have undefined projection, others have already defined ones. To define a projection ArcGis Toolbox was used. This was done according to the following parameters:

Projection: Lambert_",GEOGCS
GCS_WGS_1984,
DATUM["D_WGS_1984",
SPHEROID["WGS_1984",6378137.0,298.257223563]],
PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],
PROJECTION ["Lambert_Azimuthal_Equal_Area"],
PARAMETER["False_Easting",0.0],
PARAMETER["False_Northing",0.0],
PARAMETER["Central_Meridian",10.0],
PARAMETER["Latitude_Of_Origin",52.0],
UNIT["Meter",1.0]]

The map computations (Arc View 3.3)

- The river segments and their catchments were exported from their Arc/Info equivalent files compressed and packed to ZIP. By using an Import 71 program, files were converted to shape file.
- The investigated river basin of 118,861 km^2 was divided into three main sub-basins (Odra, Warta and Notec river basins) Each of these sub-basins were divided into 18 smaller ones according to the location of the monitoring stations, as it is presented in Appendix 1 for the Notec River, Appendix 2 for the Warta River and Appendix 3 for the Odra River. Sub-basins and tributaries were characterised by localisation of a monitoring station. Sub-basin area was defined as the whole area of the basin between two monitoring stations. Tributary area was defined as the area upstream of the monitoring station.
- From voivodship shape files for years 1995 and 2002 the specific sub-basin areas were identified.

5.2. The data from Polish Official Statistics Bureau and their computations

5.2.1. Data gathered from Polish Official Statistics Bureau (http://www.stat.gov.pl/english/index.htm):

- Land use for years 1995 – 2002; table 1 – 8;
- Animal populations for years 1995 – 2002; table 33 – 40;
- Population by age group and sex for years1995 – 2002; table: 47- 55;
- Population served by waste water treatment plants for years 1995 – 2002; table: 293 – 300.

5.2.2. The fertilisers data

Fertilizer consumption data for Poland during the period 1955 – 2002 were obtained from SIBER program coordinator (Stochkolm University)

5.2.3. The computations for sub-basins and tributaries

From voivodship maps in Arc View shape files for the specific sub-basin areas were identified. To get information about how large part of each voivodship is localised in the actual sub-basin the computations must be based on proportion. This is presented below.

It was assumed that all data from the statistical bureau (http://www.stat.gov.pl/english/index.htm) were evenly distributed in each voivodship. Then with the information of total area of each voivodship and area within sub-basin (tributary) all statistics for sub-basins (tributaries) were computed. Next the voivodships within each sub-basin were summarised. All computations were made according to the following procedure:

- The computation for the sub-basin (S_x) and tributary basin (S_t) was based on the same equation:

$$S_x = \sum_i (V_b * x_i)/V \qquad (1)$$

or

$$S_t = \sum_i (V_t * x_i)/V \qquad (2)$$

If a tributary was located within a sub-basin then the calculations were based on the following general equation:

$$S_x = \sum_i (V_b * x_i)/V - \sum_j (V_t * x_j)/V \qquad (3)$$

where:

$\sum_i$ – sum over all voivodships within a sub-basin area

$\sum_j$ - sum from each voivodship within tributary area;

V_t - voivodship area within tributary [ha];

V_b – voivodship area within sub-basin [ha];

V – total area of voivodship [ha];

x_i x_j - is a general parameter over voivodships for which computations are conducted. Depending what one wants to analyse it is one of the following variables were used:

- population [person],
- arable land [ha],
- orchards [ha],
- meadows and pastures [ha],
- wooded area [ha],
- fallow land [ha],
- cows [heads],
- pigs [head],
- sheep [head],
- poultry (6-months and above) [head],
- fertilizer P [g/ha];

All computed statistics were further used in the principal components analysis. The tributaries statistics data are presented in Appendix 5 and the sub-basin statistics data in Appendix 7.

5.3. The river data and computations

5.3.1. The river data

The river data contain monthly measurements of the river flow along its length and total phosphorus concentrations at monitoring stations for the period 1992. 11. – 1995. 12. Data were obtained from Institute of Meteorology and Water Management in Poland.

5.3.2. The computations for river data

Concentration and flow data were multiplied for each monitoring station and aggregated into annual ones. Then the average was computed in order to get annual average P-flux at each monitoring station and net change in P-flux.

Net change in P-flux within each reach of the river (N_{TP}) was defined as:

$$N_{TP} = P_{out} - P_{in} \qquad (4)$$

If within this sub-basin a tributary was located (Fig. 4) then the calculations were modified as follows:

$$N_{TP} = P_{out} - (P_{in} + P_{trib}) \qquad (5)$$

where:

P_{in} – total phosphorus in initial measurement station within sub-basin [t yr $^{-1}$];

P_{out} – total phosphorus in final measurement station within sub-basin [t yr $^{-1}$];

P_{trib} – total phosphorus load from tributary [t yr $^{-1}$];

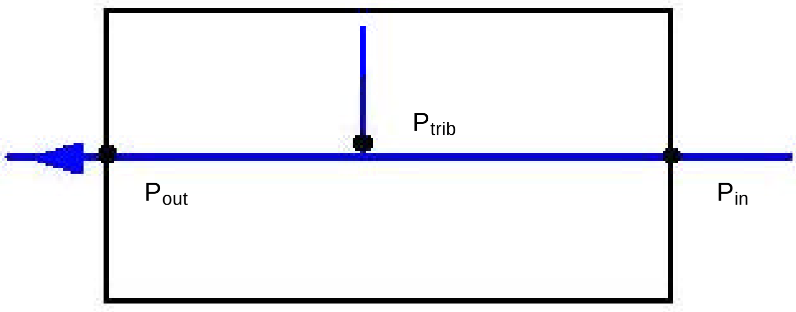


Fig. 4. The diagram of the localisation of measurement stations

5.4. The structure of the sub-basin and computations of phosphorus load

The sub-basin (S_w) consists of a basin area between two monitoring stations: upstream station (P_{in}) and downstream station (P_{out}). The P flux in these stations is known. The sub-basin (S_w) consists of tributary basin (S_t) and the rest of the basin (S_x). The load of e.g. total phosphorus (P_{trib}) from tributary basin (S_t) is known. To calculate phosphorus retention (R) in the river, the phosphorus load (P_x) from the rest of the sub-basin (S_x) also must be computed (fig. 5.).

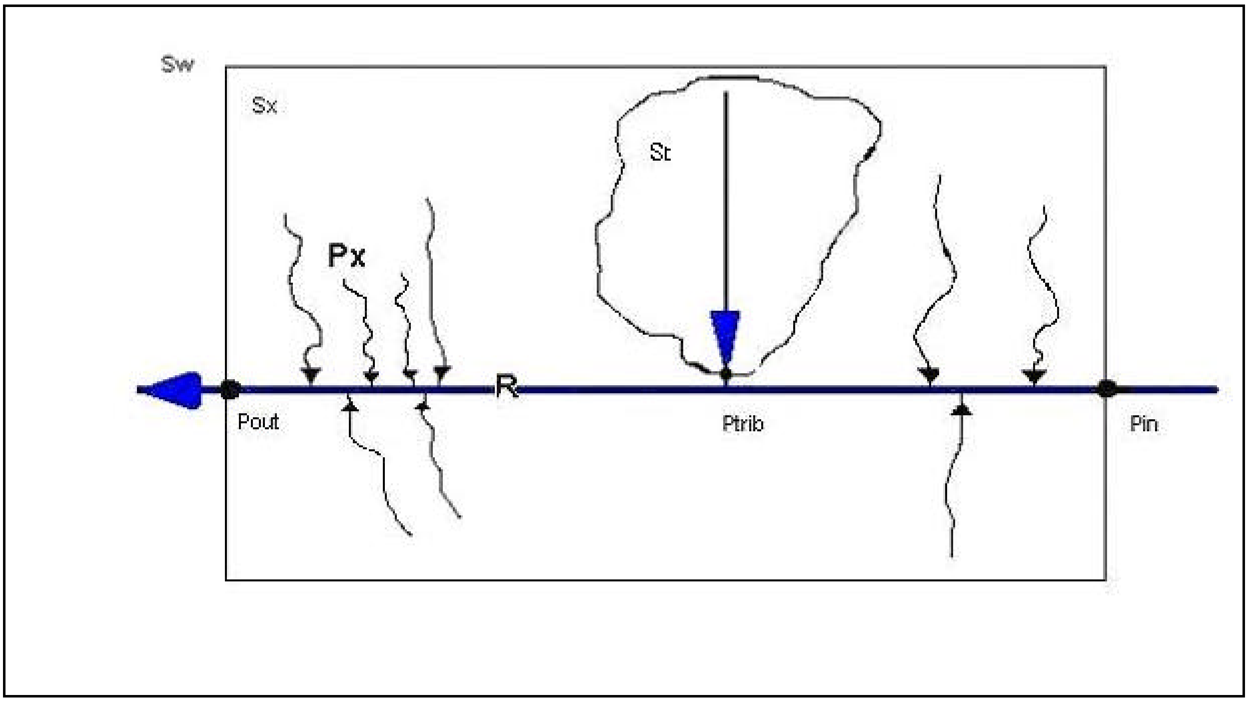


Fig. 5. The diagram of sub-basin structure

5.5. The principal components analysis and multiple regression analysis

5.5.1. An overview of the Principal Components Analysis

Principal Components Analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called *principal components* (PCs)

The object of the analysis is to take *n* variables X_1, X_2,…, X_n and find combinations of these to produce indices PC1, PC2,…, PCn that are uncorrelated. The PC1 are called the principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

The best results are obtained when the original variables are highly correlated, positively or negatively. PCA is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifested variables.

5.5.2. An overview of the Multiple Regression modelling

Multiple regression may be used when you want to predict the dependent variable (y) by several independent variables (x) (Sendecor & Cochran, 1980). The relationship between dependent variable (y_i) and independent variables (x_i) is formulated as a linear model:

Suppose there is *i* independent variables $x_1,\dots,x_i$; then the regression model is:

$$y_i = b_0 + b_1 * x_{1i} + b_2 * \mathrm{x}_{2i} + \dots + b_p * x_{pi} + e_i$$

…

$$y_n = b_0 + b_1 * x_{1n} + b_2 * \mathrm{x}_{2n} + \dots + b_p * x_{pn} + e_n$$

where: $b_0, b_1, b_2, \dots, b_p$ are constants referred to as the regression coefficients and the residual e_i is a random disturbance – error term for the *n* number of dependent variables (Chatterjee & Price, 1991).

The multiple regression model assumptions are:

1. Normality assumption

In regression analysis the dependent variable should have a Normal distribution. It is also assumed in multiple regression that the residuals (predicted minus observed values) are normally distributed. Non-normally distributed residuals can distort relationships and significance tests. In the case of non-normality transformations should be used to improve normal distribution. The transformations as e.g., square root, ln, log, or inverse can improve normality but this complicate the interpretation of the results.

2. Linearity assumption

It is assumed that the relationship between dependent and independent variables is linear. If the relationship between independent variables (x_i) and the dependent variable (y) is not linear, the results of the regression analysis will underestimate the relationship.

3. Homoscedasticity assumption

Homoscedasticity means that the variance of errors is the same across all levels of the independent variables. On a scatter plot residuals are randomly scattered around 0. When the variance of errors differs at different values of the independent variables, heteroscedasticity is indicated.

4. Multicollinearity assumption

The assumption is that there should be no multicollinearity. It occurs when some of the *x* variables are highly correlated. Multicollinearity leads to many problems that confound the interpretation of regression analysis models. The primary problem related to regression coefficients are (1) being far from the true parameter value of which they are estimates; and (2) not being significantly different from zero when theory or common sense dictates otherwise. Multicollinearity does not affect the ability of a regression equation to predict the response but it poses a real problem if the purpose of the study is to estimate the contributions of individual predictors (Osborne & Waters, 2002; Grapentine T. 1997; Zar J. H., 1984).

5.6. Approach of the “Multiple Regression Model” and “Similarity Model”

5.6.1. The “Multiple Regression Model” approach

The data for tributaries and sub-basins were standardized (appendix 6 and appendix 8).

The problem of multicollinearity frequently occurred when the model was run. The variables were so highly correlated that it is impossible to come up with reliable estimates of their individual regression coefficients.

To create a set of factors to be treated as uncorrelated variables as one approach to handling multicollinearity the Principal Component Analysis was used. The relationships of the individual one most influential variable PC1 (explaining about 80 % of the variance) were then used as independent variables in a multiple regression analysis.

The model was run for each tributary basin (S_t). The idea was that the dependent variable will be the measured discharge of total phosphorus for the tributary (P_{trib}) and the independent variables were taken from the PCA. Here the PC1 and PC2 were estimated for each tributary basin (S_t). Then the errors (e) of the regression model were estimated. To fulfil the assumption of normality and linearity of the dependent variables the discharge of total phosphorus was transformed by using the logarithm (ln)

Next the model for the net change of phosphorus (N_{TP}) for sub-basin (S_x) was to be estimated. As the dependent variable now fulfilled the assumption of normality there was no need to transform it. The PC1 and PC2 were obtained, as mentioned above, from sub-basins (S_x) which contained information for the sub-basin minus tributary area.

For both models the following multiple regression equation was used (SPSS):

$$\ln y_1 = b_0 + b_1 * PC1_1 + e$$

$$y_2 = b_0 + b_1 * PC1_2 + e \qquad (6)$$

where:

$\ln y_1$ – logarithm of dependent variable from discharge of total phosphorus for tributary (P_{trib}) – 1st model;

y_2 – dependent variable for the net change of phosphorus (N_{TP}) – 2nd model;

b_0, b_1 - are constants referred to as the regression coefficients;

$PC1_1$, – the Principal Components Analyses factor one computed from tributary independent data;

$PC1_2$, – the Principal Components Analyses factor one computed from sub-basin data;

e_i - random disturbance, the error term.

5.6.2. The "Similarity Model"

The "Similarity Model" is based on the assumed similarities between tributary basin area (S_t) and sub-basin area (S_w). Computations were made for the whole area of the Odra River Basin, which mean the Polish part together with the German and the Czech Republic parts of the river basin.

Model assumptions:

- the tributary basin (S_t) is similar to the rest of the sub-basin area (S_x) with respect to land use leakage and nutrient loads, and will be used to estimate the unmeasured loads (P_x);
- in a sub-basin without a tributary the neighbouring sub-basins or tributaries are assumed to have similar load to the investigated sub-basin.

The "Similarity Model" is as follows:

- for the total load of phosphorus (P_{tot}) from the rest of the sub-basin area (P_x) with tributary:

$$P_x = (S_x * P_{trib}) / S_t \qquad (7)$$

- for the total load of phosphorus (P_x) from sub-basin without tributary:

$$P_{tot} = (S_w * P_m) / S_m \qquad (8)$$

where:

S_x – the rest of the sub-basin area [ha];

S_t – tributary basin [ha];

S_m – mean from neighbouring sub-basins or tributaries [ha]

S_w – sub-basin area [ha];

P_x - total phosphorus load from the rest of the sub-basin area [t yr^{-1}];

P_{tot} – total phosphorus load from the sub-basin [t yr^{-1}];

P_m – mean total phosphorus load from neighbouring sub-basins or tributaries [t yr^{-1}];

5.7. Retention computations

The retention was computed separately from two models.

5.7.1. The retention computations based on the multiple regression model

$$R = P_{out} - (P_{in} + P_{trib} + P_x) \qquad (9)$$

where:

R – retention [t yr $^{-1}$];

P_{in} – total phosphorus flux in upstream monitoring station within the sub-basin;

P_{out} – total phosphorus flux in downstream monitoring station within the sub-basin [t yr $^{-1}$];

P_{trib} – phosphorus load from tributary [t yr $^{-1}$];

P_x –the phosphorus load from the unmeasured part of the sub-basin to the river [t yr $^{-1}$], calculated by using the multiple regression model from the equation (6).

5.7.2. The retention computations based on the "Similarity Model"

$$R = N_{TP} - (P_x + P_{trib})$$

or

$$R = N_{TP} - P_{tot} \qquad (10)$$

where:

R – retention [t yr $^{-1}$];

P_x –the total phosphorus load from the unmeasured part of the sub-basin area to the river [t yr $^{-1}$], from the equation (7)

P_{tot} –the total phosphorus load from the sub-basin to the river [t yr $^{-1}$], from the equation (8);

P_{trib} – phosphorus load from tributary [t yr $^{-1}$];

N_{TP} –the net changing of total phosphorus [t yr $^{-1}$] from the equation (4).

5.8. The budget computations

The budget computations for the river basins were calculated according to the "similarity model".

For budget computations the following parameters were taken into account:

- The sub-basin sum of loads from the tributaries (P_{trib}) of TP into the main river [t yr^{-1}];
- The sub-basin sum of loads from the land (P_x) of TP from land [t yr^{-1}];
- The sub-basin sum of retention (R) of TP in river sub-basin [t yr^{-1}];
- Discharge from river mouth (P_{out}) [t yr^{-1}].

$$\sum P_{trib} + \sum P_x + \sum R = P_{out}$$

The budget computations were made for the Notec river Basin, the Warta River Basin, the Odra River Basin.

6. Results

The figures presented in Appendix 1 – 3 show the Notec River Basin, the Warta River Basin, and the Odra River Basin. These maps present divisions for sub-basins, tributary basins and measurement stations. In the appendix 4 the data for tributary and sub-basin are presented.

The River basin is treated as total river basin i.e. the Warta River Basin includes the Notec River; the Odra River Basin includes the Warta River. Both, the Notec and the Warta rivers were treated as tributaries and integral part of river basin.

6.1. The retention results from multiple regression model

Appendix 9 was created as a detailed description of the results from principal component analysis and regression model.

- **Results from the building of the model**

The original observations for the tributaries are represented in appendix 5 for the year 1995, while appendix 7 does it for sub-basins in the same year.

The MRM was created for tributaries in order to check how big the uncertainty can be found in the results, which are presented in appendix 10. The dependent variables were measured at monitoring stations and values predicted by the model (P_x) should be very similar to these. The whole model was significant. The required level of significance is 0,05. The variations in the dependent variables were explained to 66% of variations in the independent variables with significance level equal to 0,007 (appendix 10). The coefficient significance PC1 was under 0,05 The error term in this model was significantly high, the mean error term was around 20% (appendix 11).

Further the model was applied for sub-basins. The variations in the dependent variables were explained in 32% of variations with significance equal 0,013 (appendix 12). The summary of results from the PCA and MRM are presented in the appendix 13.

The retention was computed from this model in order to compare both used models. Further computation for phosphorus budget was made from computations after similarity model, because of insignificant results from MRM.

Retention results

The results from computation of the retention based on the MRM are presented in appendix 14.

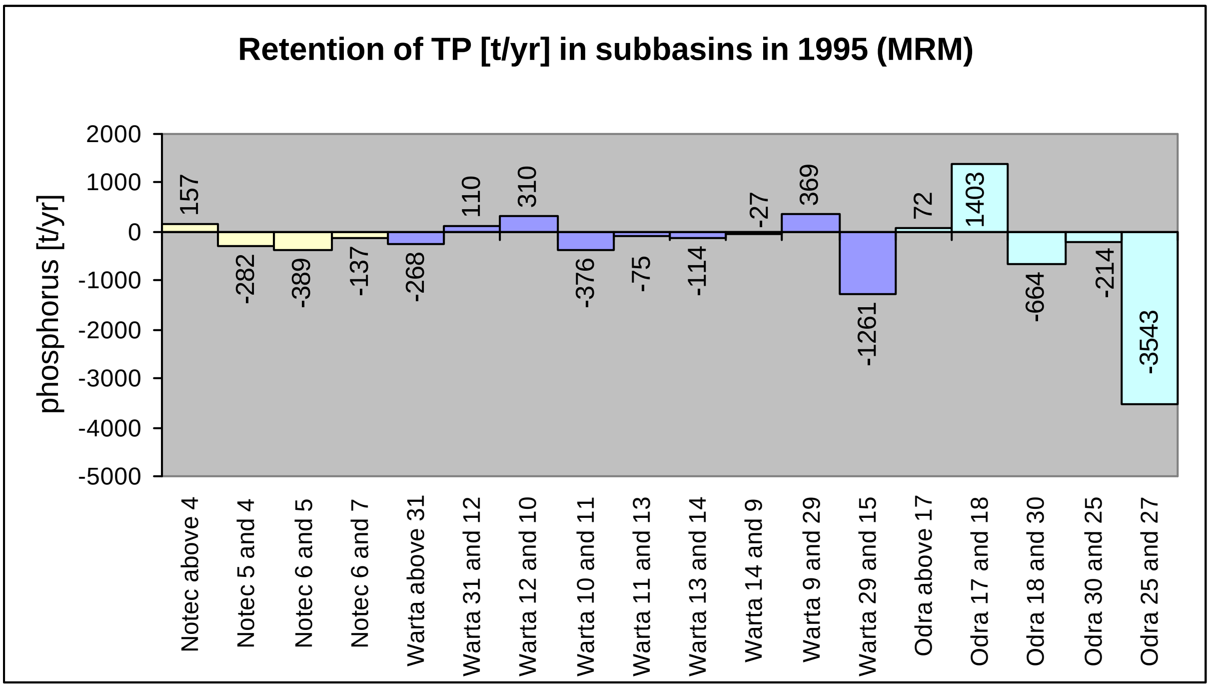


Fig. 6. The retention process or leakage from the river bed in sub-basins in 1995 based on the MRM.

In the Notec River Basin the retention process is observed in three sub-basins (Fig. 6). The highest retention is observed in sub-basin "Notec 6 and 5" (-389 t yr^{-1}), also similar high is in "Warta 10 and 11". In the first sub-basin of the Notec Basin the removal process from the bed occur and is equal to 157 t yr^{-1}(Fig. 6 and appendix 1).

In six sub-basins out of nine in the Warta River Basin the retention process occurs. The highest is in sub-basin "Warta 29 and 15" where the discharge from Notec River takes place (Fig. 6 and appendix 2). The leakage from the river bed occurs in three sub-basins and in two of them is around 300 t yr^{-1} (Fig. 6).

In the Odra River Basin the highest retention takes place in sub-basin "Odra 25 and 27" and is equal to –3543 t yr^{-1}. In this sub-basin Warta River has its mouth discharge (Fig. 6 and appendix 3). The highest leakage from the river bed is observed in "Odra 17 and 18" sub-basin, with the amount of 1403 t yr^{-1}.

6.2. The retention results from similarity model (SM)

The results from computation of the retention based on the similarity model (SM) are presented in the appendix 15 and appendix 16.

In the Notec River (appendix 1 and Fig. 7) the retention process is studied in three sub-basins. The amount of retained phosphorus is -336 t yr^{-1} in “Notec above 4” and -200 t yr^{-1} in “Notec 6 and 5”. In “Notec 5 and 4” sub-basin the amount of retained TP is -1351 t yr^{-1}. There is also an observed leakage of TP from the river bed in sub-basin “Notec 6 and 7”.

For the Warta River retention is observed for five sub-basins out of total nine sub-basins (appendix 2). The largest amount of retained total phosphorus in the Warta Basin is found in “Warta 29 and 15”sub-basin (-2191 t yr^{-1}) but also “Warta 11 and 13” and “Warta 13 and 14” show a large amount of retained TP. In e.g. “Warta 31 and 12” and “Warta 14 and 9”, sub-basins there is a slight tendency to export little more than is imported for the study period (Fig. 7).

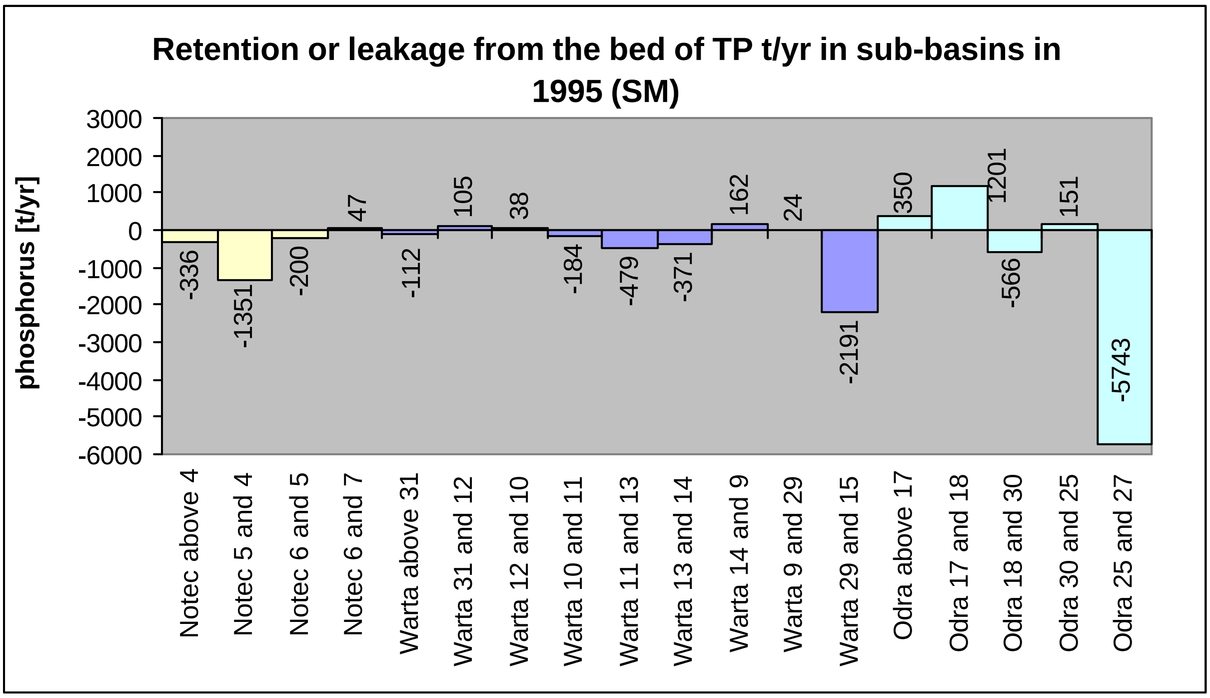


Fig.7. The retention of total phosphorus in sub-basins in 1995 computed from SM

The highest retention amount (-5743 t yr^{-1}) is observed in the last sub-basin (Fig. 7). “Odra 25 and 27” is the biggest investigated sub-basin (appendix 3). In the Odra River Basin the retention is observed in one more sub-basin such as “Odra 18 and 30” in the amount -566 t yr^{-1}.

The net specific retention for the Notec, the Warta and the Odra rivers were 21,96 t/yr/m^2; 8,43 t/yr/m^2 and 4,37 t/yr/m^2 respectively.

In six sub-basins out of ten in which the retention process have taken place the percentage value of retention is higher than 40% e.g. “Notec 5 and 4”, “Warta 29 and 15” (Fig. 8). The highest retention process, equal to 65%, is observed in “Warta 13 and 14” sub-basin. In the rest of them the retention is around or less than 30%. The percentage calculations were based on total phosphorus input to the river.

In the seven sub-basins the leakage from the river bed is observed and the percentage value is between 2% and 48%. The highest percentage value (48%) is observed in “Odra 17 and 18” (Fig. 8). The structure of sub-basin localisation is presented in the appendix 1- 3.

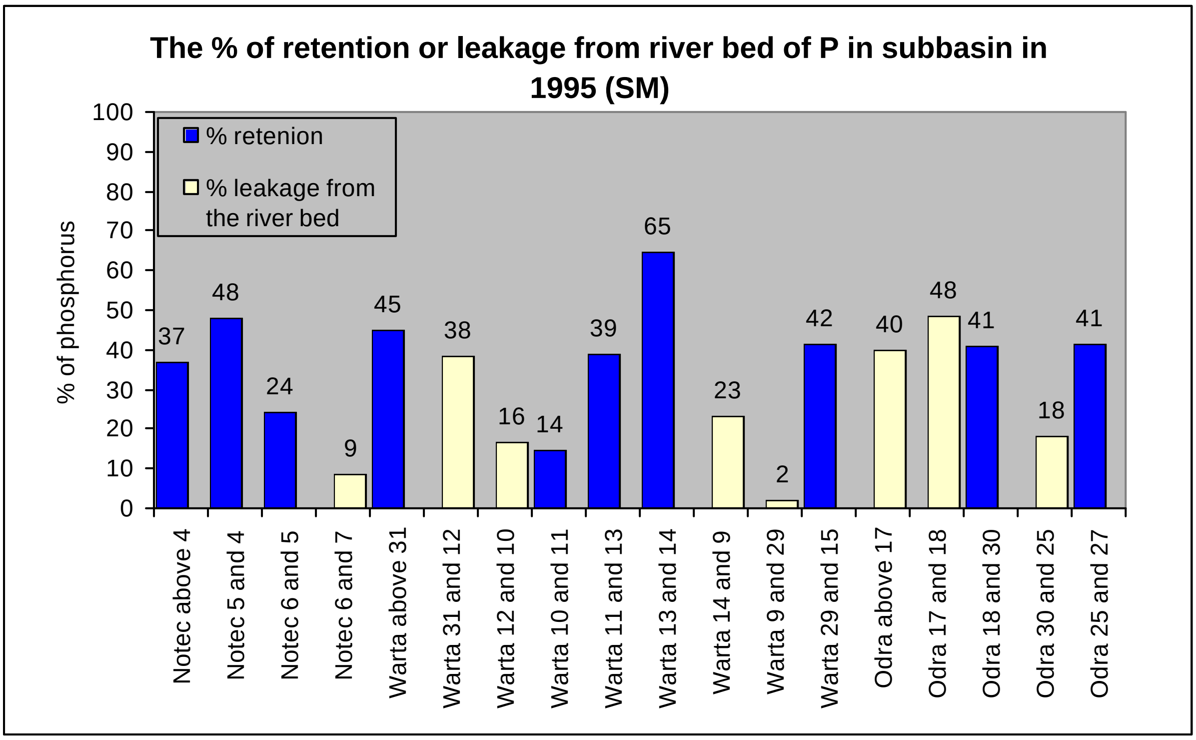


Fig 8. The percentage of the retention or leakage from the river bed of TP in sub-basin in 1995

6.3. Comparison of retention results from “Similarity Model” and “Multiple Regression Model”

In Fig. 9 is presented a difference between the results in both models (appendix 17 and Fig. 9.). In four out of 18 cases the results are opposite to one another, as e.g. in sub-basin “Notec above 4” and “Warta 14 and 9”. The highest retention process still occurs in “Odra 25 and 27” sub-basin but the value from SM is much higher than from MRM (Fig. 9.). Also the volume of retention in “Notec 5 and 4” and “Odra above 17” is much higher in SM than in MRM.

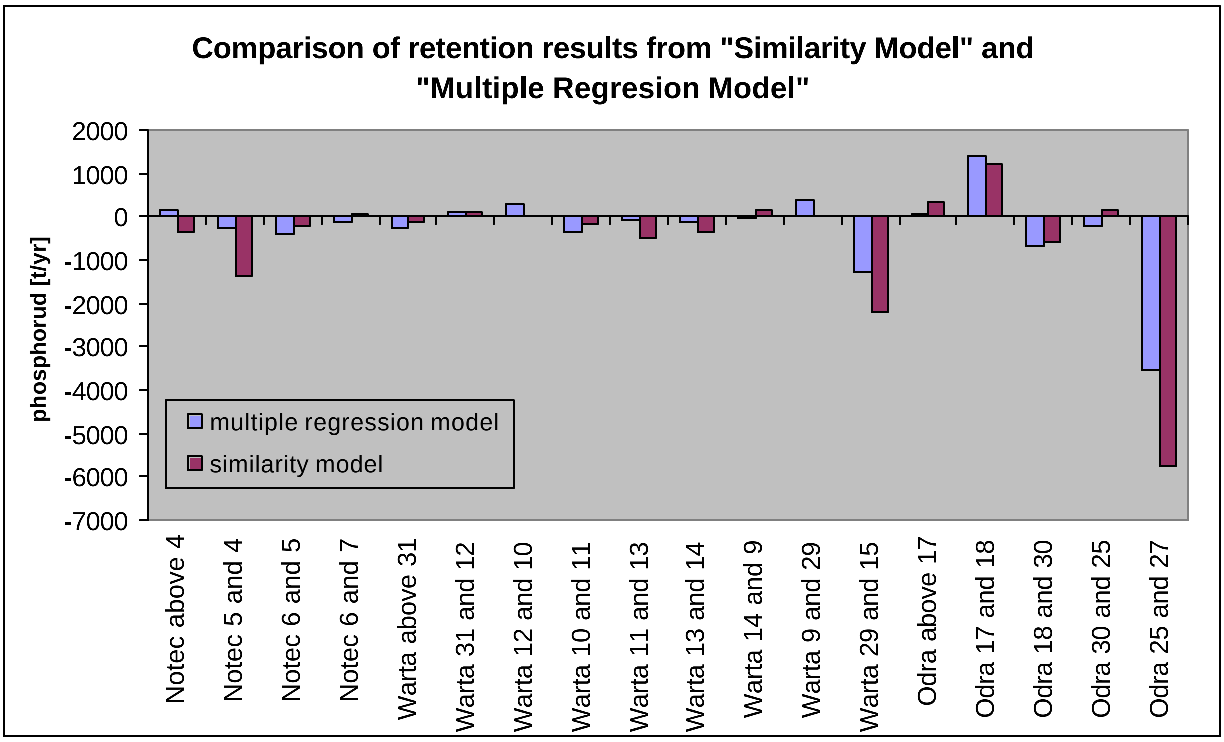


Fig. 9. Comparison of retention results from “Similarity Model” and “Multiple Regression Model”

The highest difference (2200 t yr^{-1}) between results from MRM and SM is observed in “Odra 25 and 27”. Also in “Notec 5 and 4” and “Warta 29 and 15” the difference is around 1000 t yr^{-1} (Fig. 10). In one sub-basin “Warta 31 and 12” the difference is 5 t yr^{-1}. In the rest of sub-basins the difference between results is between 150 t yr^{-1} and 400 t yr^{-1} (Fig. 10).

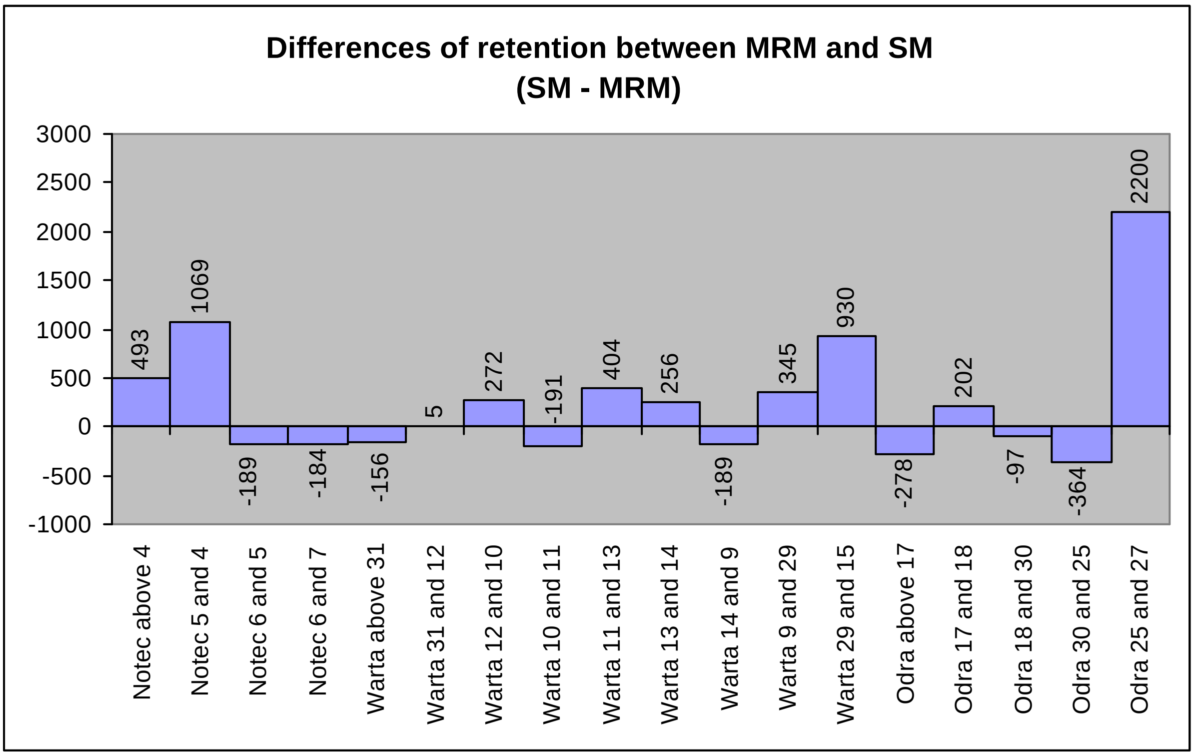
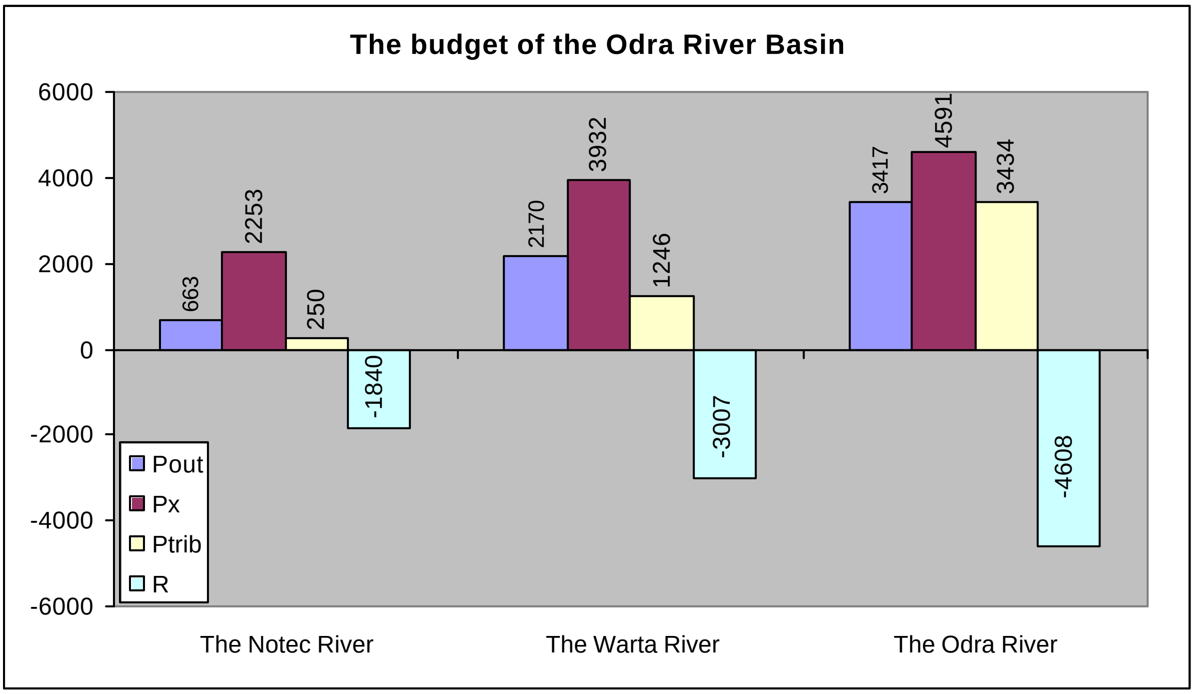


Fig.10. The difference between retention results from “MRM” and “SM”

6.4. The budget of total phosphorus in the Odra River Basin

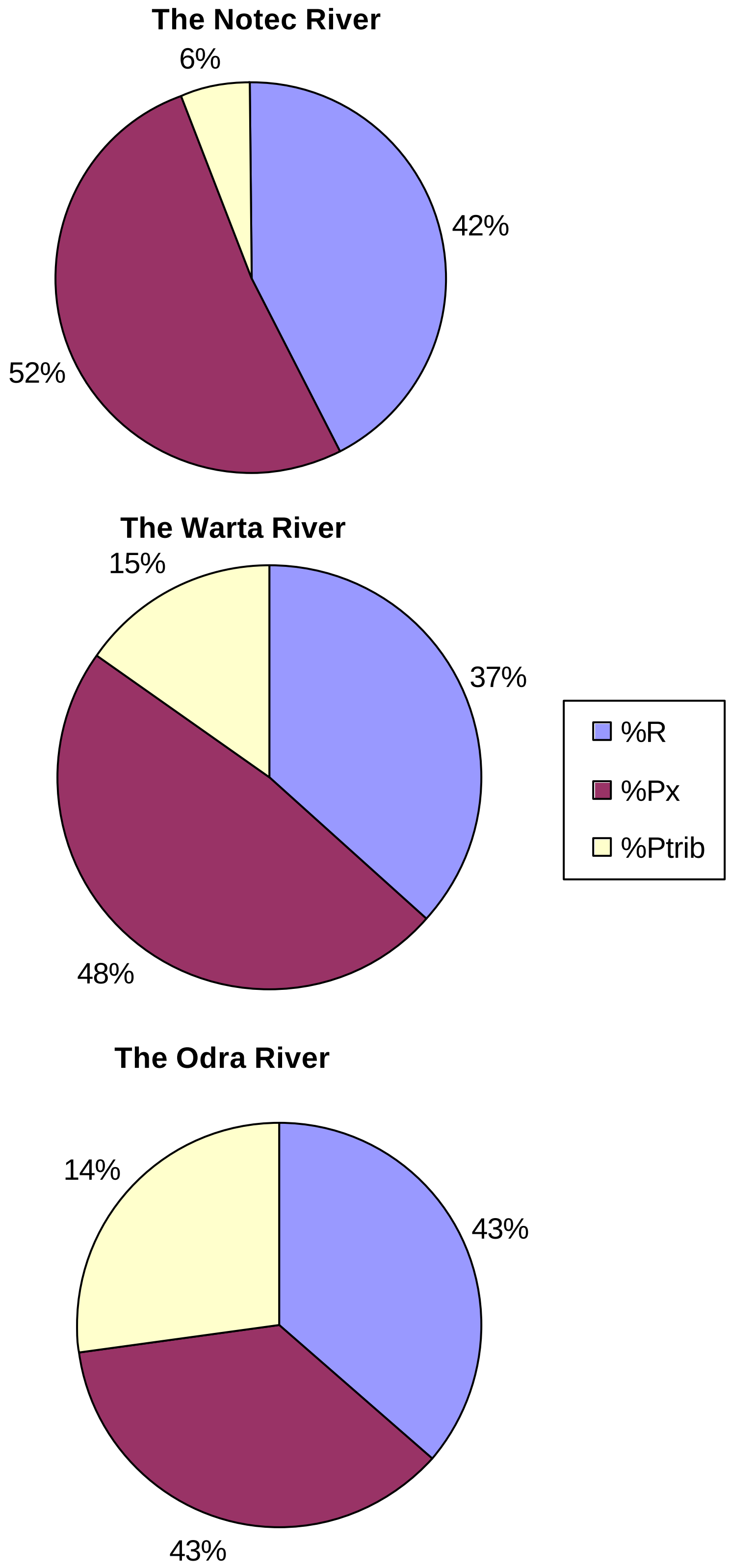
The structure of the individual components of the TP budget is similar in all river basins (Fig.11). The highest discharge, in all river basins, is from land. In each river basin the retention process occurs. It balances the load of total phosphorus from the land and tributaries (Fig. 11). Each value increases from the Notec River to the Odra River. E.g. the TP load from the land is 2253 t yr^{-1} in the Notec River and 4591 t yr^{-1} in the Odra River.



where: P_{out} – total phosphorus mouth discharge from river [t yr^{-1}]; P_x –the TP load from the land to the river [t yr^{-1}], P_{trib} – the TP from tributary [t yr^{-1}];
R- retention [t yr^{-1}];

Fig. 11. The total phosphorus river budget

The percentage load from tributaries is around 15% in both the Warta River Basin and the Odra River Basin. In Notec River Basin the percentage load from tributaries is 6% and the load from the land is 52% (Fig. 12). In the Warta River the load from the land is 37%, while in the Notec River and the Odra River it is 42% and 43% respectively (Fig. 12). The percentage of retention and load form the land in the Odra River is similar and equal 43%. In every river basin the percentage of retention is similar and is around 40% (Fig. 12.).



where:

$\%P_x$ –the percentage of TP load from the unmeasured part of the sub-basin to the river;
$\%P_{trib}$ – percentage of phosphorus load from tributary in total budget;
%R- percentage of retention in total budget;

Fig. 12. The percentage of total phosphorus budget in the river basins

7. Discussion

7.1. The "Multiple Regression Model" validation

The tributary model was significant (Appendix 10 and 11.). However in this model the average error term was around 20%. The predicted value should be similar to the dependent variable. As it is presented in the appendix 11 there are quite big differences between these two values. The model was however accepted since the obtained result was the best that was achieved during building the models.

The model applied for the sub-basin gave higher uncertain results than the tributary model (Appendix 12 and 13). There might be a need to apply the model for the whole Odra River Basin, not only for the basin within Polish boundary area. The measurements made in measurement stations give information about discharge from whole river basin. So in computations total area of basin should be considered. However lack of data from Germany and Czech Republic was a reason for considering only the Polish part of the basin.

The other problem, that may lead to uncertain model results may be caused by using not enough amount of data such as point sources (waste water treatment plant, factories), soil type and slope. These data are important for the phosphorus cycle.

Garnier et al. (2002) pointed out that a higher population density will increase inputs from both point sources (increased wastewater input) and non-point sources (increased fertilizer inputs). Behrendt et al. (1999) state that for phosphorus, the point emissions, and especially the input from municipal sewage treatment plants, are the dominant sources in the region. Behrendt et al. (2002) also showed that in the Odra River Basin the contribution from diffuse sources is 38% of the total.

7.2. Weakness of the “Similarity Model”

The “Similarity Model” represents the simplest way to achieve the total load of phosphorus from a sub-basin to the river. When in the sub-basin, the load from tributary is measured, it is easy by extrapolation to compute load from the whole area of the sub-basin. The “Similarity Model” is based on the assumed similarities between tributary basin area and the sub-basin area it belongs to. To fulfil this assumption in each sub-basin there should be an identified tributary load. However in several sub-basins there was not a tributary with data. This of course causes problem with calculation the phosphorus load from the whole sub-basin. The simple proportion assumption could not be used. The mentioned situation is presented for sub-basins i.e. the Notec River between no. 5, the Warta River between no. 31 and 12 and 4 the Odra River between no. 17 and 18 in the appendix 1, appendix 2 and appendix 3 respectively. For such sub-basins another assumption has to be taken into consideration, that the neighbouring sub-basins or tributaries have similar load as in sub-basins without tributary. This assumption leads to increasing error in calculations and is the biggest weakness of this method. From 18 sub-basins half of them were calculated based on the similarities in the neighbouring sub-basins or tributaries.

The next weakness of this model may be too high inaccuracy in computations when tributary covers small area of the whole sub-basin. In this case the differences between tributary basin and sub-basin may be too high and extrapolation for the rest of the area may lead to higher uncertainty.

In contrast to the “Multiple Regression Model”, in the “Similarity Model” the whole Odra River Basin was investigated.

7.3. Results discussion

7.3.1. Retention in the sub-basins and river basins

Retention in sub-basins

The retention process in sub-basins may be higher because of water reservoirs (lakes, dams) through which the river flows. As it was found by Vassiljev and Stålnacke (2003) the retention process in lakes may reach 30%- 35%. The Notec Rive flows through Goplo Lake in the "Notec above 4" sub-basin and the retention in this sub-basin become about 37% (fig. 8, Gorski & Jedrzejewska, 1987). The Warta River flows through Jeziorsko Lake in sub-basin "Warta 10 and 11" (Gorski & Jedrzejewska, 1987).

In the first two sub-basins of the Odra River the leakage from the river bed is caused by morphometry of this river - in this part, the Odra River has a mountainous character (Migon, 2000; Dembicki, 1999). The Odra River flows much faster there than in its lower part where it becomes a lowland river.

It is also observed that the retention process occurs nearly up to 40% of the sub-basins when the tributary mouth in the sub-basin is localised there. As an example:

- "Warta 29 and 15" where the Notec River has its mouth;
- "Odra 18 and 30" where four tributaries have their mouth;
- "Odra 25 and 27" where mouths of the Warta River and the Bobr river are localised (fig. 8. and appendix 1 – 4);

The TP retention is also affected by several factors such as macrophyte biomass, flow velocity, extent of riparian zone and concentration of nutrients (Kronvang et al., 1999) in sub-basins.

Retention in river basin

In all investigated river basins the retention process was observed (Fig. 11 and Fig.12.). The biggest retention rates were found in the Odra River Basin. This is shown in Fig. 11.

Kronvang et al. (1999) presented for the Gjern River in Denmark is that phosphorus retention in this river basin was -0,90 t yr^{-1}, which amounted to 23.4% of the total P from the river basin. A Value of 14% also has been reported by Vassiljev and Stålnacke (2003) in the rivers of Peipsi Lake drainage basin. 70% phosphorus retention was stated by Garnier et al. (2002) in the Danube drainage network calculated. In the present thesis the retention 43% of the TP siacharge from the Odra River(Fig. 12).

7.3.2. Budget of phosphorus in the Odra River Basin

The total emission to the Odra River was calculated by Behrendt et al., (2002) in amount of 12840 t yr^{-1} in period 1993 – 1997. In their stud the load from point sources has an important influence (62%) on phosphorus emission into the river system. Tonderski (1997a) found that annual non-point source emission of TP in 1992 – 1994 were about 2500 t in the same river basin.

In the Odra River (Fig. 11.) the sum of load in this thesis from land and tributaries amounts to 8025 t yr^{-1}, which is balanced by retention process in the amount of -4608 t yr^{-1}. The discharge from the Odra River to Dabie Lake amounts to 3417 tyr^{-1} in 1995 year.

Before the Odra enters the Baltic Sea it flows through Dabie Lake and Szczecinski Lagoon (Gorski & Jedrzejewska, 1987; Grelowski et al., 1999). The discharge from the Odra River into the Szczecinski Lagoon was measured to be 3416 t yr^{-1} in 1995. Stålnacke (1996) and Stålnacke et al., (1999) estimated average annual riverine load to be 6630 t in years 1980 - 1993. After Sczszecinski Lagoon the Swina River flows to the Pomeranian Bay, part of the Baltic Proper (Gorski & Jedrzejewska, 1987; Grelowski et al., 1999). Grelowski et al. (1999) shows that the nutrient concentrations in the Swina River were much lower than in the Odra. He also pointed out that 73 – 80% of total phosphorus introduced by the Odra River was exported from the lagoon to the Pomeranian Bay.

There is a need to remember that for the total emission from the Odra River to the Baltic Sea also the Szczecinski Lagoon should be taken into account, because the retention process occur in this reservoir. But the investigation of TP retention in the Szczecinski Lagoon was not the scope in this thesis. However the thesis results indicate that temporary nutrient storage in the river system represents an important component of the river basin nutrient budget.

8. Conclusions

- The retention occurs in the Odra River Basin as well as in the Warta River and the Notec River.
- In the Odra River Basin the retention was about -4608 t yr^{-1}, which is 43% in the budget;
- In all investigated river basins the percentage value of retention was similar;
- The retention process as well as leakage from the river bed was stated in all investigated sub-basins
- Temporary storage of TP in the river is important component of riverine phosphorus budget;

9. Summary

For the object of investigation the Odra River Basin was chosen, as an example of a large "weakly" regulated river basin in the Baltic Sea Drainage Basin. The main purpose of the investigation was to determine the phosphorus riverine retention in this river basin. In the present thesis were also investigated the retention for the Notec River Basin and the Warta River Basin. Investigations were also made for smaller sub-basins divided from studied area.

Two different models were used to calculate retention process in the river. The "Multiple Regression Model" turned out to be insignificant, therefore the results were computed by using a "Similarity Model" based on similarities between load from monitored tributary basins and the rest of the sub-basin.

The retention occurred in the Odra River in the amount of -4608 t yr^{-1}, which is 43% of the TP load to the Odra River. There is also stated that in the Notec and the Warta rivers the retention process occur in the amount of -1940 t yr^{-1} and -3007 t yr^{-1} respectively. For all mentioned river basins the budget was build.

In the present thesis the retention process in the river is an integral part of the budget and balances the phosphorus load from tributaries and land.

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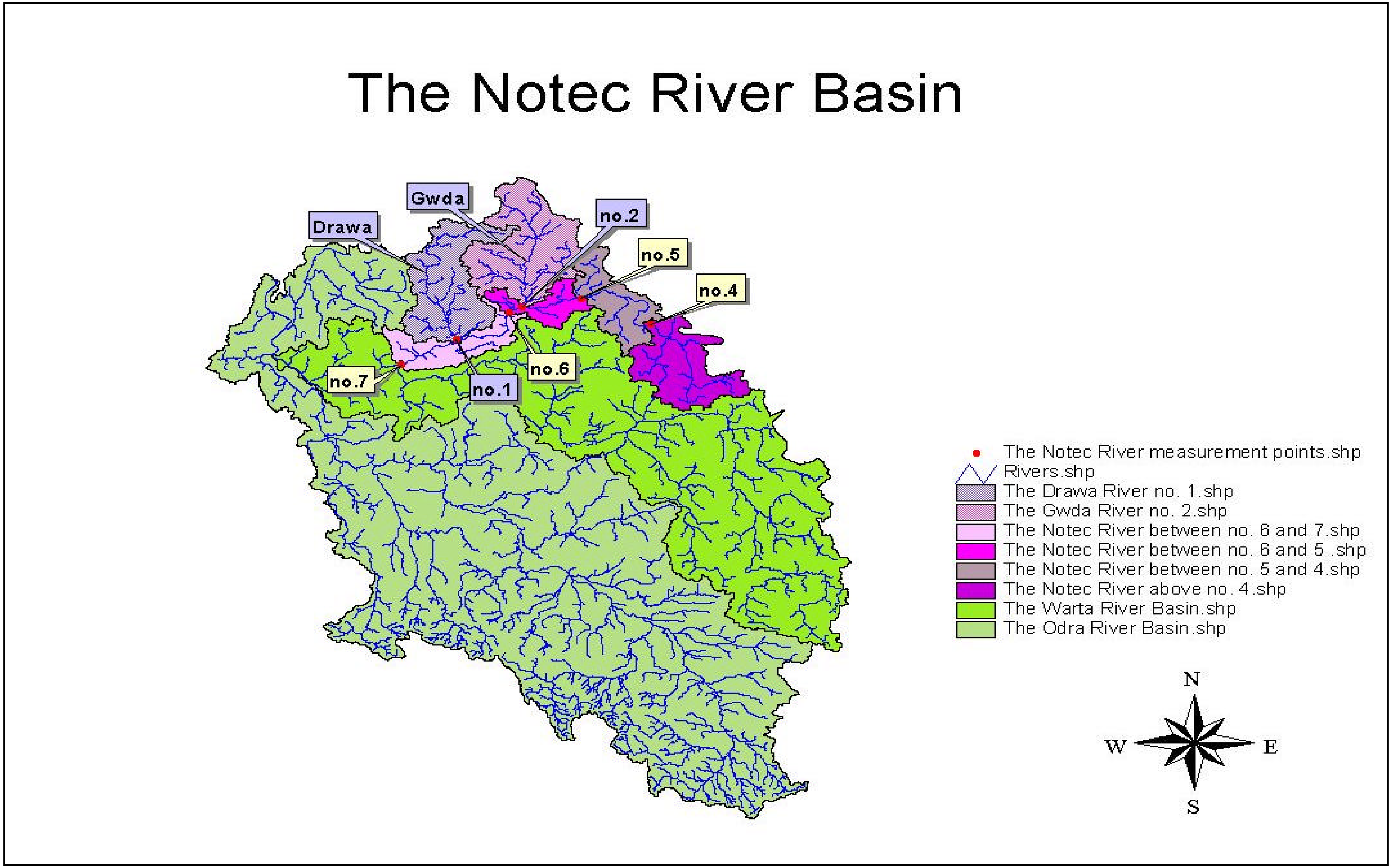
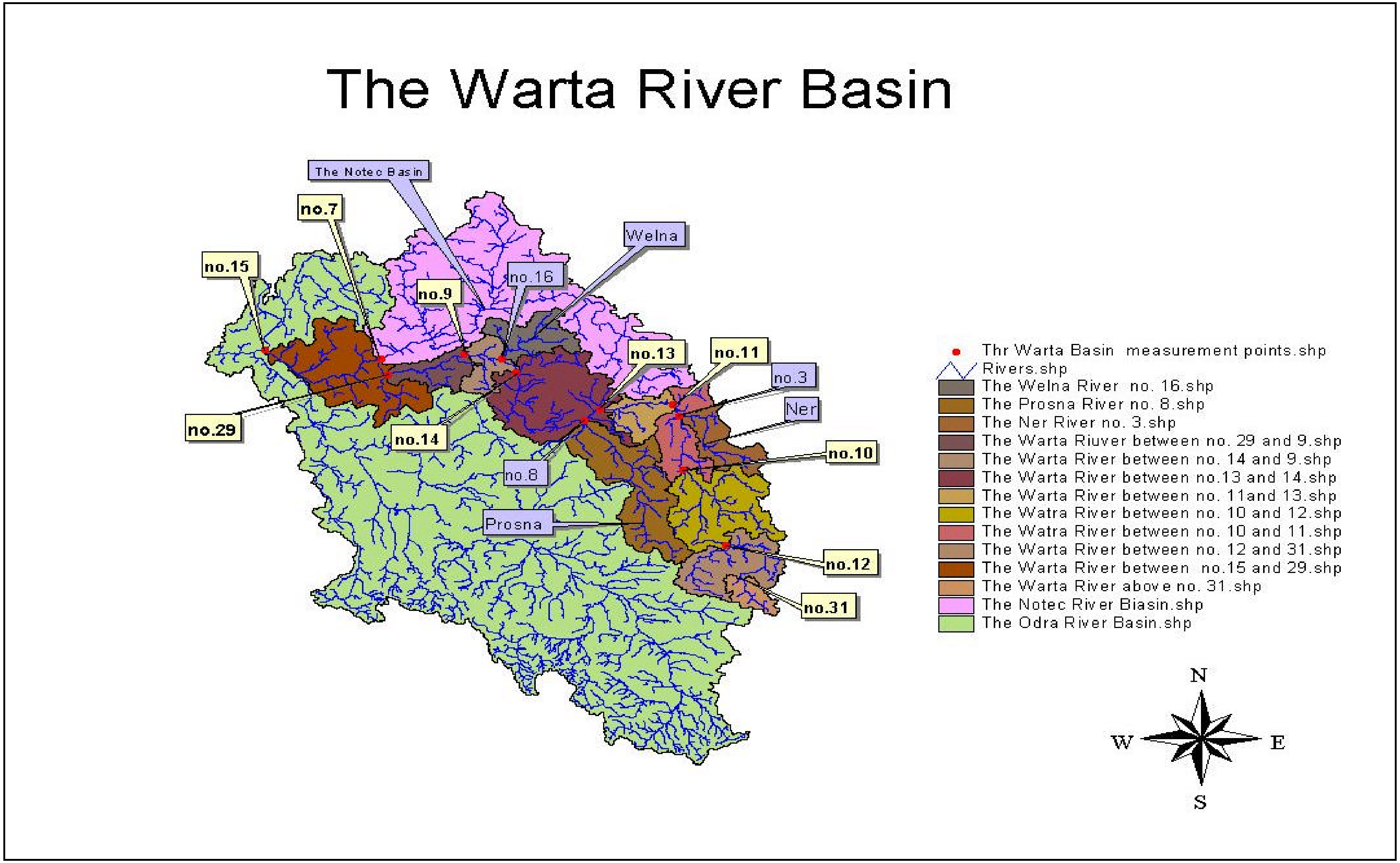
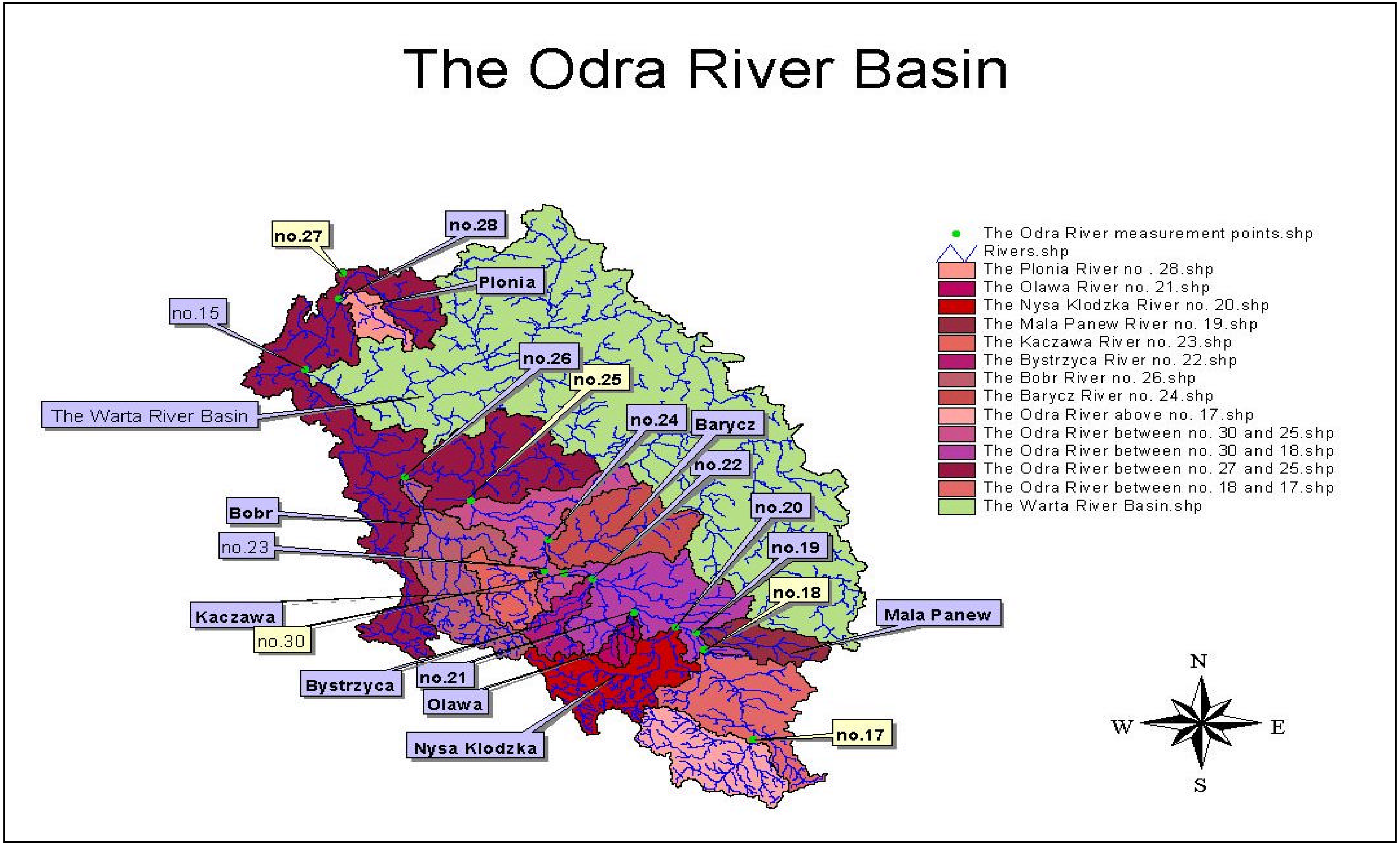
APPENDIXES



Appendix 1. The division of the Notec River Basin into sub-basins



Appendix 2. The division of the Warta River Basin into sub-basins



Appendix 3. The division of the Odra River Basin into sub-basins

Appendix 4. The tributary and sub-basin data

The tributary data table

Tributary	Sub-basin	P_{trib} [t yr^{-1}]
Gwda	Notec 6 and 5	174,06
Drawa	Notec 6 and 7	76,03
Ner	Warta 10 and 11	356,65
Notec	Warta 29 and 15	662,68
Welna	Warta 14 and 9	73,77
Prosna	Warta 13 and 14	152,43
Olawa	Odra 18 and 30	23,70
Bystrzyca	Odra 18 and 30	124,53
Mala Panew	Odra 18 and 30	47,74
Nysa Klodzka	Odra 18 and 30	257,99
Kaczawa	Odra 30 and 25	31,15
Barycz	Odra 30 and 25	145,43
Warta	Odra 25 and 27	2170,03
Bobr	Odra 25 and 27	620,59
Plonia	Odra 25 and 27	12,49

The sub-basin data table

	mean flow [m^3 s^{-1}]	Pin [t yr^{-1}]	Pout [t yr^{-1}]	P trib [t yr^{-1}]	Net TP [t yr^{-1}]
Notec above 4	0,00	0,00	120,43	0,00	120,43
Notec 5 and 4	28,21	120,43	180,32	0,00	59,89
Notec 6 and 5	133,47	180,32	389,40	174,06	35,02
Notec 6 and 7	446,30	389,40	662,68	76,03	197,25
Warta above 31	0,00	0,00	11,88	0,00	11,88
Warta 31 and 12	25,63	11,88	149,20	0,00	137,32
Warta 12 and 10	211,30	149,20	265,42	0,00	116,21
Warta 10 and 11	395,45	265,42	716,96	356,65	94,90
Warta 11 and 13	541,55	716,96	851,61	0,00	134,65
Warta 13 and 14	616,30	851,61	767,92	152,43	-236,11
Warta 14 and 9	1005,95	767,92	1112,90	73,77	271,21
Warta 9 and 29	1166,85	1112,90	1725,85	0,00	612,95
Warta 29 and 15	1235,23	1725,85	2170,03	662,68	-218,51
Odra above 17	0,00	0,00	436,38	0,00	436,38
Odra 17 and 18	395,71	436,38	1680,56	0,00	1244,18
Odra 18 and 30	1000,80	1680,56	1803,46	453,96	-331,06
Odra 30 and 25	1478,50	1803,46	2218,17	176,57	238,14
Odra 25 and 27	2013,00	2218,17	3416,66	2803,10	-1604,62

Appendix 5. The tributaries statistics data table

tributary	River mouth to the sub-basin	discharge of TP [t yr $^{-1}$]	area [ha]	population [person]	arable land [ha]	orchard [ha]	meadow and pasture land [ha]	wooded area [ha]	fallow land [ha]
Gwda	Notec no.5 - 6	174,06	349577,86	386705,57	170856,75	1990,74	36239,32	96360,17	10243,36
Drawa	Notec no. 6 - 7	76,03	413161,54	324194,51	160446,99	1453,34	43103,16	144765,49	34974,94
Ner	Warta no. 10 - 11	356,65	179011,10	261172,31	102210,83	2499,27	20002,27	36065,66	5045,64
Notec	Warta no. 29 - 15	662,68	1600792,10	1552988,97	901711,54	731830,53	8967,81	160913,21	481639,33
Welna	Warta no. 14 - 9	73,77	189351,46	211303,26	100257,57	1368,69	19033,97	46404,31	2864,06
Prosna	Warta no. 14 - 13	152,43	499272,17	590360,57	265909,31	3940,97	52847,52	119974,53	9188,16
Olawa	Odra no. 18 - 30	23,70	78305,32	114234,92	35075,06	352,06	10974,94	21893,07	3480,24
Bystrzyca	Odra no. 18 - 30	124,53	160548,64	241968,62	70381,38	720,66	23328,20	45409,43	7627,62
Mala Panew	Odra no. 18 - 30	47,74	207186,41	549153,74	91092,71	1480,56	23099,66	59841,12	9833,58
Nysa Klodzka	Odra no. 18 - 30	257,99	396828,15	530596,86	187299,57	1791,42	50468,84	107693,37	14570,57
Kaczawa	Odra no. 30 - 25	31,15	221604,92	333988,74	97147,26	994,72	32199,87	62678,53	10528,38
Barycz	Odra no. 30 - 25	145,43	488607,08	639016,12	235405,72	2721,93	60889,89	129835,38	15200,90
Warta	Odra no. 25 - 27	2170,03	3442143,15	4739080,76	2076101,96	1684168,18	27107,00	364826,77	941832,70
Bobr	Odra no.25 -27	620,59	605279,84	778614,97	240214,56	2458,64	80162,20	203251,37	38595,24
Plonia	Odra no. 25 - 27	12,49	121864,96	91857,06	47151,43	389,68	12827,45	41824,01	11007,16

Appendix 5. The tributaries statistics data table (continuation)

tributary	River mouth to the sub-basin	cow [head]	pig [head]	sheep [head]	poultry [head]	fertilizer (P) [kg ha $^{-1}$]
Gwda	Notec no.5 - 6	32384,03	449897,59	10226,85	425862,18	2,78
Drawa	Notec no. 6 - 7	16988,24	202444,61	4095,86	299681,97	1,88
Ner	Warta no. 10 - 11	28746,30	143840,28	2778,40	425496,28	0,84
Notec	Warta no. 29 - 15	300699,55	119809,96	1583946,58	35167,58	12,09
Welna	Warta no. 14 - 9	20524,34	292144,95	6613,53	269428,01	2,02
Prosna	Warta no. 14 - 13	58546,39	673874,28	15017,23	835395,83	4,86
Olawa	Odra no. 18 - 30	4297,52	36521,36	1015,14	131511,75	1,33
Bystrzyca	Odra no. 18 - 30	7813,86	67336,81	1927,15	249824,74	2,82
Mala Panew	Odra no. 18 - 30	20291,89	109921,41	5699,42	514649,39	1,83
Nysa Klodzka	Odra no. 18 - 30	27992,43	232074,78	6105,08	789908,20	6,12
Kaczawa	Odra no. 30 - 25	10785,45	92944,85	2660,04	344832,53	3,89
Barycz	Odra no. 30 - 25	38349,05	489823,68	11659,80	713705,79	6,90
Warta	Odra no. 25 - 27	843024,76	364492,40	3719446,57	89436,58	28,85
Bobr	Odra no.25 -27	25681,46	232334,22	5966,42	755342,36	9,21
Plonia	Odra no. 25 - 27	4233,11	46126,52	907,48	83749,45	0,36

Appendix 6. The tributaries standardised data table

tributary	mouth to the river	Zscore: population	Zscore: arable land	Zscore: orchards	Zscore: meadows and pastures	Zscore: wooded area	Zscore: fallow land	Zscore: cow	Zscore: pigs	Zscore: Sheep	Zscore: Poultry	Zscore: fertilizer
Gwda	Notec	-0,31	-0,28	-0,33	0,11	-0,19	-0,34	-0,29	1,05	-0,32	0,10	-0,37
Drawa	Notec	-0,35	-0,29	-0,33	0,45	0,20	-0,28	-0,34	-0,22	-0,33	-0,37	-0,46
Ner	Warta	-0,39	-0,37	-0,33	-0,69	-0,68	-0,36	-0,30	-0,52	-0,33	0,09	-0,56
Notec	Warta	0,45	0,70	0,82	-1,23	0,33	0,91	0,63	-0,64	0,80	-1,36	0,55
Welna	Warta	-0,42	-0,37	-0,33	-0,73	-0,59	-0,36	-0,33	0,24	-0,33	-0,48	-0,45
Prosna	Warta	-0,17	-0,15	-0,32	0,92	0,00	-0,34	-0,20	2,21	-0,32	1,62	-0,17
Olawa	Odra	-0,48	-0,46	-0,33	-1,13	-0,79	-0,36	-0,38	-1,07	-0,33	-1,00	-0,52
Bystrzyca	Odra	-0,40	-0,41	-0,33	-0,52	-0,60	-0,35	-0,37	-0,91	-0,33	-0,56	-0,37
Mala Panew	Odra	-0,20	-0,38	-0,33	-0,53	-0,49	-0,34	-0,33	-0,69	-0,33	0,43	-0,47
Nysa Klodzka	Odra	-0,21	-0,26	-0,33	0,81	-0,10	-0,33	-0,30	-0,07	-0,33	1,45	-0,04
Kaczawa	Odra	-0,34	-0,38	-0,33	-0,09	-0,46	-0,34	-0,36	-0,78	-0,33	-0,20	-0,26
Barycz	Odra	-0,14	-0,19	-0,33	1,32	0,08	-0,33	-0,26	1,26	-0,32	1,17	0,04
Warta	Odra	3,52	3,47	3,45	0,10	3,27	3,42	3,50	1,23	3,46	-1,02	3,42
Bobr	Odra	-0,05	-0,19	-0,33	2,26	0,67	-0,27	-0,31	-0,06	-0,33	1,32	0,27
Plonia	Odra	-0,50	-0,44	-0,33	-1,04	-0,63	-0,34	-0,38	-1,02	-0,33	-1,17	-0,61

Appendix 7. The sub-basin statistics data table

sub-basin	net change TP [t yr $^{-1}$]	sub-basin area without tributary [ha]	total sub-basin area with tributary [ha]	population [person]	arable land [ha]	orchard [ha]	meadow and pasture land [ha]	wooded area [ha]	fallow land [ha]
Notec above 4	120,43	346996,33	346996,33	394865,64	188069,82	3094,27	31410,65	81435,46	5678,38
Notec 5 and 4	59,89	23663,88	23663,88	27370,48	13076,91	244,92	1941,33	5345,17	412,11
Notec 6 and 5	35,02	258871,41	608449,27	228879,72	113370,68	1174,56	27001,27	79787,6	16257,8
Notec 6 and 7	197,25	208521,07	621682,61	190973,05	86009,36	1009,97	21217,48	73945,44	12307,1
Warta above 31	11,88	80199,2	80199,20	315778,21	30542,39	752,78	9200,68	25215,01	5346,69
Warta 31 and 12	137,32	304402,21	304402,21	978381,6	130307,84	2972,33	34560,08	87746,73	16943,9
Warta 12 and 10	116,21	452964,1	452964,10	686184,32	257793,66	6397,48	50764,54	91447,51	13301,4
Warta 10 and 11	94,90	228655,61	407666,70	238040,87	118082,84	1200,08	23419,87	58916,56	2769,49
Warta 11 and 13	134,65	140769,82	140769,82	156034,25	73934,94	936,6	14629,64	34995,94	2069,88
Warta 13 and 14	-236,11	565559,19	1064831,37	623265,71	296657,03	3698,52	58595,1	141019,52	8182,65
Warta 14 and 9	271,21	127450,58	316802,04	141267,46	66937,57	847,73	13246,91	31686,27	1873,85
Warta 9 and 29	612,95	147174,95	147174,95	149977,39	69427,8	855,88	15133,76	44076,26	5206,08
Warta 29 and 15	-218,51	527332,75	2128124,85	387314,82	172106,4	1636,68	53392,43	224284,42	52215,4
Odra above 17	436,38	6809,53	6809,53	7862,67	3459,61	30,93	733,64	1764,33	171,18
Odra 17 and 18	1244,18	521686,41	521686,41	1354570,03	230655,61	3678,94	58093,22	150117,36	24340,1
Odra 18 and 30	-331,06	686895,42	1529763,93	911031,26	325634,8	3150,7	86758,99	185806,87	24642,1
Odra 30 and 25	238,14	1438499,75	2148711,75	1095563,73	493902,83	4818,69	146303,1	587734,15	133470
Odra 25 and 27	-1604,62	1706755,24	5846461,15	1858218,19	800338,3	9807,69	183683,16	486807,16	73552,6

Appendix 7. The sub-basin statistics data table (continuation)

sub-basin	cow [head]	pig [head]	sheep [head]	poultry [head]	fertilizer (P) [kg ha $^{-1}$]
Notec above 4	37688,98	491572,82	11302,62	552481,58	36,64
Notec 5 and 4	2574,71	30989,61	723,53	41075,58	2,48
Notec 6 and 5	15941,70	210434,93	4569,22	243976,07	14,96
Notec 6 and 7	14232,30	198607,01	4249,49	192418,44	20,26
Warta above 31	8126,19	26559,72	2792,37	201095,94	4,11
Warta 31 and 12	33955,94	138198,45	9016,89	756733,66	17,71
Warta 12 and 10	73052,91	346688,39	6843,22	1095215,02	20,34
Warta 10 and 11	22469,77	396999,36	9057,88	267707,35	27,03
Warta 11 and 13	15247,79	223237,82	5029,52	192189,64	15,02
Warta 13 and 14	60685,28	904042,73	20401,48	762951,98	61,00
Warta 14 and 9	13805,06	202134,48	4554,00	173980,01	13,60
Warta 9 and 29	13204,28	190228,36	4209,86	170372,17	15,20
Warta 29 and 15	16128,13	181497,74	3122,21	287766,11	37,44
Odra above 17	640,13	5190,85	129,47	16729,10	0,89
Odra 17 and 18	51019,99	281142,41	14190,87	1295351,16	46,85
Odra 18 and 30	49408,46	426756,61	11062,94	1352561,00	104,75
Odra 30 and 25	51901,53	618441,02	11541,94	877605,14	102,38
Odra 25 and 27	130673,93	1685244,00	38486,27	2114085,60	162,09

Appendix 8. The sub-basin standardised data table

sub-basin	Zscore: population]	Zscore: arable land	Zscore: orchards	Zscore: meadows and pastures	Zscore: wooded area	Zscore: fallow land	Zscore: cow]	Zscore: pigs	Zscore: Sheep	Zscore: Poultry	Zscore: fertilizer
Notec above 4	-0,29	-0,02	0,21	-0,30	-0,32	-0,49	0,12	0,32	0,26	-0,06	-0,06
Notec 5 and 4	-1,00	-0,91	-0,93	-0,90	-0,80	-0,64	-0,98	-0,84	-0,92	-0,96	-0,85
Notec 6 and 5	-0,61	-0,40	-0,56	-0,39	-0,33	-0,17	-0,56	-0,39	-0,49	-0,60	-0,56
Notec 6 and 7	-0,68	-0,54	-0,63	-0,51	-0,37	-0,29	-0,61	-0,42	-0,53	-0,69	-0,43
Warta above 31	-0,44	-0,82	-0,73	-0,75	-0,67	-0,50	-0,80	-0,85	-0,69	-0,68	-0,81
Warta 31 and 12	0,85	-0,32	0,16	-0,23	-0,28	-0,15	0,00	-0,57	0,01	0,29	-0,49
Warta 12 and 10	0,28	0,33	1,53	0,09	-0,26	-0,26	1,22	-0,04	-0,24	0,89	-0,43
Warta 10 and 11	-0,59	-0,38	-0,55	-0,46	-0,46	-0,57	-0,36	0,08	0,01	-0,56	-0,28
Warta 11 and 13	-0,75	-0,60	-0,65	-0,64	-0,61	-0,59	-0,58	-0,35	-0,44	-0,69	-0,56
Warta 13 and 14	0,16	0,53	0,45	0,25	0,05	-0,41	0,83	1,36	1,28	0,30	0,51
Warta 14 and 9	-0,78	-0,64	-0,69	-0,67	-0,63	-0,60	-0,63	-0,41	-0,49	-0,72	-0,59
Warta 9 and 29	-0,76	-0,63	-0,69	-0,63	-0,56	-0,50	-0,64	-0,44	-0,53	-0,73	-0,55
Warta 29 and 15	-0,30	-0,10	-0,37	0,15	0,57	0,89	-0,55	-0,46	-0,65	-0,53	-0,04
Odra above 17	-1,04	-0,96	-1,02	-0,92	-0,82	-0,65	-1,04	-0,90	-0,98	-1,00	-0,88
Odra 17 and 18	1,58	0,19	0,44	0,24	0,11	0,06	0,53	-0,21	0,58	1,24	0,18
Odra 18 and 30	0,72	0,67	0,23	0,83	0,33	0,07	0,48	0,16	0,23	1,34	1,52
Odra 30 and 25	1,08	1,53	0,90	2,03	2,84	3,30	0,56	0,64	0,29	0,51	1,47
Odra 25 and 27	2,57	3,08	2,89	2,79	2,21	1,52	3,01	3,32	3,29	2,67	2,85

Appendix 9. The overview about interpretation of Principal Components Analysis and Multiple Regression results

- **Principal Component Analisys**

Total Variance Explained

The variance explained by the initial solution, extracted components, and rotated components is displayed. This first section of the table shows the Initial Eigenvalues**.** The Total column gives the eigenvalue or amount of variance in the original variables accounted for by each component.

The % of Variance column gives the ratio of the variance accounted for by each component to the total variance in all of the variables.

The Cumulative % column gives the percentage of variance accounted for by the first *n* components. For example, the cumulative percentage for the second component is the sum of the percentage of variance for the first and second components.

The second section of the table shows the extracted components (components higher than 1 in total column of Initial Eigenvalues).

The rotation maintains the cumulative percentage of variation explained by the extracted components, but that variation is now spread more evenly over the components. The large changes in the individual totals suggest that the rotated component matrix might be easier to interpret than the unrotated matrix (Gupta V., 2000; http://dss.princeton.edu/online_help/analysis/interpreting_regression.htm;

- **Regression results**

Model Summary table

"Adjusted R-square" - measures the proportion of the variance in the dependent variable that was explained by variations in the independent variables. The "Adjusted R-square" tells that x% of the variance was explained.

"R-square" - measures the proportion of the variation in the dependent variable that was explained by variations in the independent variables. "R-square" tells that x% of the variation was explained.

"Std Error of Estimate"- measures the dispersion of the dependent variables estimate around its mean. If the Std. Error is more than 10% of the mean, it is high.

ANOVA table

Significance of the model *("Did the model explain the deviations in the dependent variable").* The last column shows the goodness of fitting of the model. The lower significance, the better the fit. Typically, if "Sig" is higher than 0.05, it is concluded that model could not fit the data (Gupta V., 2000; http://dss.princeton.edu/online_help/analysis/interpreting_regression.htm;

Coefficients table

"Constant" – this is the predicted value of dependent variable when the other independents are 0.

"B" – these are the values for the regression equation for predicting the dependent variable. These are called unstandardized coefficients because they are measured in their natural units. The coefficient cannot be compared with one another to determine in the model which one is more influential in the model, because they can be measured on the different scales.

"Sig." - If the value in "Sig." is less than 0.05, then it can be assumed that the estimate in column "B" (beta in the equation) can be asserted as true with a 95% level of confidence. This table gives information about the effect of individual variables on the dependent variable. If "Sig." is greater than 0.05 but less than 0.1, we can only assert the veracity of the value in "B" with a 90% level of confidence.

"Collinearity Statistics"

- The tolerance statistic ranges from 0 – 1, with 0 indication the perfect multicollinearity occur. The tolerance below 0,2 may indicate multicollinearity;
- Variance Inflation Factor (VIF) - if larger the value the greater problem with multicollinearity. If an individual VIF is greater than 10 this may indicate multicollinearity.

(Gupta V., 2000;
http://dss.princeton.edu/online_help/analysis/interpreting_regression.htm;

Appendix 10. The results from the Principal Components Analysis and Multiple Regression for the tributary

- **Principal Components Analysis for the tributary**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8,041	73,104	73,104	8,041	73,104	73,104	8,036	73,059	73,059
2	2,369	21,534	94,638	2,369	21,534	94,638	2,374	21,580	94,638
3	,429	3,897	98,536						
4	,140	1,274	99,809						
5	,014	,124	99,933						
6	,006	,053	99,985						
7	,001	,011	99,997						
8	,000	,003	100,000						
9	8,304E-06	7,549E-05	100,000						
10	5,115E-07	4,650E-06	100,000						
11	1,357E-08	1,234E-07	100,000						

Extraction Method: Principal Component Analysis.

Rotated Component Matrix(a)

	Component	
	PC1	PC2
Zscore: population [person]	,995	,058
Zscore: arable land [ha]	,999	,013
Zscore: orchards [ha]	,996	-,085
Zscore: meadows and pastures [ha]	,015	,932
Zscore: wooded area [ha]	,943	,273
Zscore: fallow land [ha]	,996	-,083
Zscore: cow [head]	,998	-,030
Zscore: pigs [head]	,346	,760
Zscore: Sheep [head]	,996	-,082
Zscore: Poultry [head]	-,320	,900
Zscore: fertilizer (P) g/ha	,983	,132

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a Rotation converged in 3 iterations.

- **Multiple Regression for the tributary**

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,666(a)	,443	,400	1,06840	,443	10,342	1	13	,007

a Predictors: (Constant), REGR factor score 1 for analysis 1
b Dependent Variable: ln discharge of TP

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11,805	1	11,805	10,342	,007(a)
	Residual	14,839	13	1,141		
	Total	26,644	14			

a Predictors: (Constant), REGR factor score 1 for analysis 1
b Dependent Variable: ln discharge of TP

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	4,910	,276		17,801	,000	4,314	5,506		
	REGR factor score 1 for analysis 1	,918	,286	,666	3,216	,007	,301	1,535	1,000	1,000

a Dependent Variable: ln discharge of TP

Appendix 11. Summary table after Principal Components Analysis and Multiple Regression for tributary

tributary	mouth to the river	ln from river mouth discharge of TP [t/yr]	PC1	Unstandardized Predicted Value (Px)	Unstandardized Residual (error)	% of mistake
Gwda	Notec	5,16	-0,27	4,67	0,49	9,56
Drawa	Notec	4,33	-0,26	4,67	-0,34	7,78
Ner	Warta	5,88	-0,42	4,52	1,35	23,04
Notec	Warta	6,50	0,69	5,54	0,95	14,64
Welna	Warta	4,30	-0,35	4,59	-0,29	6,67
Prosna	Warta	5,03	-0,21	4,72	0,31	6,17
Olawa	Odra	3,17	-0,43	4,52	-1,35	42,60
Bystrzyca	Odra	4,82	-0,39	4,55	0,27	5,64
Mala Panew	Odra	3,87	-0,39	4,55	-0,68	17,67
Nysa Klodzka	Odra	5,55	-0,31	4,62	0,93	16,74
Kaczawa	Odra	3,44	-0,36	4,58	-1,14	33,13
Barycz	Odra	4,98	-0,20	4,73	0,25	5,11
Warta	Odra	7,68	3,48	8,10	-0,42	5,47
Bobr	Odra	6,43	-0,15	4,77	1,66	25,83
Plonia	Odra	2,52	-0,41	4,53	-2,01	79,71

Appendix 12. The results from the Principal Component Analysis and Multiple Regression for the sub-basins

- **Principal Components Analysis for the sub-basins**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9,229	83,897	83,897	9,229	83,897	83,897	6,528	59,343	59,343
2	1,074	9,765	93,662	1,074	9,765	93,662	3,775	34,319	93,662
3	,406	3,692	97,354						
4	,183	1,666	99,020						
5	,101	,920	99,941						
6	,003	,027	99,967						
7	,003	,023	99,990						
8	,001	,010	100,000						
9	6,418E-06	5,834E-05	100,000						
10	7,961E-17	7,237E-16	100,000						
11	-4,030E-16	-3,664E-15	100,000						

Extraction Method: Principal Components Analysis.

Rotated Component Matrix(a)

	Component	
	PC1	PC2
Zscore: population [person]	,793	,467
Zscore: arable land [ha]	,795	,598
Zscore: orchards [ha]	,875	,382
Zscore: meadows and pastures [ha]	,678	,732
Zscore: wooded area [ha]	,440	,896
Zscore: fallow land [ha]	,203	,973
Zscore: cow [head]	,937	,307
Zscore: pigs [head]	,862	,344
Zscore: Sheep [head]	,926	,263
Zscore: Poultry [head]	,893	,329
Zscore: fertilizer (P) g/ha	,729	,614

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 3 iterations.

- **Multiple Regression for the sub-basins**

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,571(a)	,326	,284	461,24334	,326	7,753	1	16	,013

a Predictors: (Constant), REGR factor score 1 for analysis 1
b Dependent Variable: net change TP t/yr

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1649405,864	1	1649405,864	7,753	,013(a)
	Residual	3403926,698	16	212745,419		
	Total	5053332,562	17			

a Predictors: (Constant), REGR factor score 1 for analysis 1
b Dependent Variable: net change TP t/yr

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	73,339	108,716		,675	,510	-157,128	303,807		
	REGR factor score 1 for analysis 1	-311,487	111,868	-,571	-2,784	,013	-548,636	-74,337	1,000	1,000

a Dependent Variable: net change TP t/yr

Appendix 13. The summary table after Principal Components Analysis and Multiple Regression for sub-basins

sub-basin	net change of TP [t yr^{-1}]	PC1	Unstandardized Predicted Value (P_x)	Unstandardized Residual (error term)	% of mistake
Notec above 4	120,43	0,35	-36,82	157,25	130,57
Notec 5 and 4	59,89	-0,86	342,11	-282,22	471,24
Notec 6 and 5	35,02	-0,57	249,63	-214,61	612,81
Notec 6 and 7	197,25	-0,59	258,39	-61,14	31,00
Warta above 31	11,88	-0,66	279,83	-267,95	2255,48
Warta 31 and 12	137,32	0,15	27,58	109,74	79,92
Warta 12 and 10	116,21	0,86	-193,60	309,81	266,60
Warta 10 and 11	94,90	-0,13	113,95	-19,05	20,07
Warta 11 and 13	134,65	-0,44	209,71	-75,06	55,74
Warta 13 and 14	-236,11	1,12	-274,12	38,01	16,10
Warta 14 and 9	271,21	-0,49	224,91	46,30	17,07
Warta 9 and 29	612,95	-0,55	243,80	369,15	60,23
Warta 29 and 15	-218,51	-0,98	379,81	-598,32	273,82
Odra above 17	436,38	-0,93	364,30	72,08	16,52
Odra 17 and 18	1244,18	0,74	-158,63	1402,81	112,75
Odra 18 and 30	-331,06	0,62	-121,21	-209,85	63,39
Odra 30 and 25	238,14	-0,65	275,10	-36,96	15,52
Odra 25 and 27	-1604,62	3,01	-864,62	-740,00	46,12

Appendix 14. The retention results computed after "Multiple Regression Model"

sub-basin	length [km]	net change of TP [t yr^{-1}] (N_{TP})	discharge of P from tributary [t yr^{-1}] (P_{trib})	P load from the rest of sub-basin (P_x)	P retention (R) [t yr^{-1}]	% of TP removal and retention
Notec above 4	107,40	120,43		-36,82	157,25	50,00
Notec 5 and 4	117,40	59,89		342,11	-282,22	41,25
Notec 6 and 5	64,00	35,02	174,06	249,63	-388,67	45,87
Notec 6 and 7	99,50	197,25	76,03	258,39	-137,17	20,51
Warta above 31	56,70	11,88		279,83	-267,95	47,88
Warta 31 and 12	118,30	137,32		27,58	109,74	39,96
Warta 12 and 10	121,40	116,21		-193,60	309,81	50,00
Warta 10 and 11	87,70	94,90	356,65	113,95	-375,70	39,92
Warta 11 and 13	53,30	134,65		209,71	-75,06	17,90
Warta 13 and 14	119,70	-236,11	152,43	-274,12	-114,42	14,72
Warta 14 and 9	87,90	271,21	73,77	224,91	-27,47	4,60
Warta 9 and 29	71,00	612,95		243,80	369,15	30,11
Warta 29 and 15	89,80	-218,51	662,68	379,81	-1261,00	50,00
Odra above 17	20,00	436,38		364,30	72,08	8,26
Odra 17 and 18	123,00	1244,18		-158,63	1402,81	50,00
Odra 18 and 30	135,00	-331,06	453,96	-121,21	-663,81	42,28
Odra 30 and 25	150,80	238,14	176,57	275,10	-213,53	23,64
Odra 25 and 27	332,80	-1604,62	2803,11	-864,62	-3543,11	40,19

- the TP retention; - TP removal from river bed within sub-basin

Appendix 15. The computations in “Similarity Model” for sub-basins

sub-basin	length [km]	net change TP [t yr $^{-1}$]	area of sub-basin [ha]	mean area of tributary or sub-basin [ha]	total area of tributaries within sub-basin [ha]	total area of sub-basin [ha]	phosphorus load from tributary [tyr $^{-1}$]; (P_{trib})	total extrapolation from land without tributary [t/yr] (Px)	TP removal or retention [t yr $^{-1}$] (R)	% of TP removal and retention
Notec above 4	107,40	120,43	346996,33	518152,73		346996,33	0,00	456,32	-335,90	36,80
Notec 5 and 4	117,40	59,89	23663,88	269464,66		23663,88	0,00	1411,02	-1351,13	47,88
Notec 6 and 5	64,00	35,02	258871,41		349577,86	608449,27	174,06	235,05	-200,03	24,45
Notec 6 and 7	99,50	197,25	208521,07		413161,54	621682,61	76,03	150,65	46,60	8,53
Warta above 31	56,70	11,88	80071,14	207186,41		80071,14	0,00	123,54	-111,66	45,19
Warta 31 and 12	118,30	137,32	304402,21	207186,41		304402,21	0,00	32,50	104,83	38,17
Warta 12 and 10	121,40	116,21	452964,10	452964,10		452964,10	0,00	78,05	38,16	16,42
Warta 10 and 11	87,70	94,90	228655,61		179011,10	407666,70	356,65	279,21	-184,31	14,49
Warta 11 and 13	53,30	134,65	140769,82	140769,82		140769,82	0,00	613,23	-478,58	39,02
Warta 13 and 14	119,70	-236,11	565559,19		499272,17	1064831,37	152,43	134,56	-370,68	64,58
Warta 14 and 9	87,90	271,21	127450,58		189351,46	316802,04	73,77	109,60	161,61	23,42
Warta 9 and 29	71,00	612,95	291296,63	287768,14		291296,63	0,00	589,14	23,81	1,94
Warta 29 and 15	89,80	-218,51	537918,24		1600792,10	2138710,35	662,68	1972,07	-2190,58	41,57
Odra above 17	20,00	436,38	458405,24	396828,15		458405,24	0,00	86,45	349,92	40,09
Odra 17 and 18	123,00	1244,18	630373,07	521686,41		630373,07	0,00	43,66	1200,52	48,25
Odra 18 and 30	135,00	-331,06	1625267,01		842868,52	2468135,53	453,96	235,43	-566,49	41,09
Odra 30 and 25	150,80	238,14	1438499,75		710212,00	2148711,75	176,57	87,18	150,96	18,20
Odra 25 and 27	332,80	-1604,62	2823851,68		4169287,95	6993139,63	2803,10	4138,66	-5743,27	41,37

- the sub-basins without tributary ; - the TP retention; - TP removal from river bed within sub-basin

Appendix 16. The retention results computed after "Similarity Model"

River	P_{in}	P_{out}	P_{trib}	P_x	R
Notec above 4	0,00	120,43	0,00	456,32	-335,90
Notec 5 and 4	120,43	180,32	0,00	1411,02	-1351,13
Notec 6 and 5	180,32	389,40	174,06	235,05	-200,03
Notec 6 and 7	389,40	662,68	76,03	150,65	46,60
Warta above 31	0,00	11,88	0,00	123,54	-111,66
Warta 31 and 12	11,88	149,20	0,00	32,50	104,83
Warta 12 and 10	149,20	265,42	0,00	78,05	38,16
Warta 10 and 11	265,42	716,96	356,65	279,21	-184,31
Warta 11 and 13	716,96	851,61	0,00	613,23	-478,58
Warta 13 and 14	851,61	767,92	152,43	134,56	-370,68
Warta 14 and 9	767,92	1112,90	73,77	109,60	161,61
Warta 9 and 29	1112,90	1725,85	0,00	589,14	23,81
Warta 29 and 15	1725,85	2170,03	662,68	1972,07	-2190,58
Odra above 17	0,00	436,38	0,00	86,45	349,92
Odra 17 and 18	436,38	1680,56	0,00	43,66	1200,52
Odra 18 and 30	1680,56	1803,46	453,96	235,43	-566,49
Odra 30 and 25	1803,46	2218,17	176,57	87,18	150,96
Odra 25 and 27	2218,17	3416,66	2803,10	4138,66	-5743,27

P_{in} – total phosphorus flux in upstream monitoring station within the sub-basin;
P_{out} – total phosphorus flux in downstream monitoring station within the sub-basin [t yr^{-1}];
P_{trib} – phosphorus load from tributary [t yr^{-1}];
P_x –the phosphorus load from the unmeasured part of the sub-basin to the river [t yr^{-1}];
R- retention [tyr^{-1}];

Appendix 17. The comparison of retention and removal from the river bed results from MRM and SM

sub-basin	length [km]	"multiple regression model" [t yr^{-1}]	"similarity model" [t yr^{-1}]
Notec above 4	107,40	157,25	-335,90
Notec 5 and 4	117,40	-282,22	-1351,13
Notec 6 and 5	64,00	-388,67	-200,03
Notec 6 and 7	99,50	-137,17	46,60
Warta above 31	56,70	-267,95	-111,66
Warta 31 and 12	118,30	109,74	104,83
Warta 12 and 10	121,40	309,81	38,16
Warta 10 and 11	87,70	-375,70	-184,31
Warta 11 and 13	53,30	-75,06	-478,58
Warta 13 and 14	119,70	-114,42	-370,68
Warta 14 and 9	87,90	-27,47	161,61
Warta 9 and 29	71,00	369,15	23,81
Warta 29 and 15	89,80	-1261,00	-2190,58
Odra above 17	20,00	72,08	349,92
Odra 17 and 18	123,00	1402,81	1200,52
Odra 18 and 30	135,00	-663,81	-566,49
Odra 30 and 25	150,80	-213,53	150,96
Odra 25 and 27	332,80	-3543,11	-5743,27