Original Research

Principles of Developing Limnological Restrictions in the Planning Process

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Abstract

Our study was carried out in the rural areas of the Olsztyn Lakeland in Poland. The obtained results provided a basis for determining principles accounting for hydrological requirements in the planning process, and for introducing to the Polish planning procedure a new document detailing the terms of managing lake buffer zones (a new opinion on limnological restrictions to a planning permit). Three zones where different planning constraints apply were identified in the study. The width of protective lake zones was then determined by applying an adjusting factor that accounts for the zone's slope gradient. The proposed method for developing limnological restrictions to a planning permit supports the identification of stagnant surface waters in the planning process. The results of the procedure should be taken into account at the stage of determining the functional characteristics of the surveyed terrain and proposing land management solutions for shoreline zones in rural areas.

Keywords: lakes, buffer zones, rural area, environmental management, spatial planning

Introduction

In addition to matter, energy, and time, space is one of the scant assets remaining at our disposal. The limits on space resulting from the growth of the human population has resulted in the increased use of areas that are ecologically valuable or sensitive to human pressure. Effective solutions supporting rational management of those areas, including water resources, have not been proposed to date.

The scope of planning in water management arises directly from the Act on Water Law [1], especially from Art. 113. It transposes to the necessary extent the requirements that stem from EU directives related to water management – Directive 2000/60/EC, also known as the Framework Water Directive [2].

The aim of the directive is to be achieved by various actions, including planning in water management with a view to programming and coordination of moves aimed at [1, Art. 112]:

1) achieving or maintaining at least good conditions of waters and water-dependent ecosystems
2) improvement of the condition of water resources
3) improvement of water resource availability
4) reducing the amount of substances and energy released to the soil or water, which may have a negative impact on waters
5) improving flood control

Implementation of the Framework Water Directive in Poland requires actions both on the national level (in the

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catchments), on the regional level (in the eight water regions) and – if needed – on the catchment scale.

According to the provisions of the Act on Water Law [1; Art. 113 section 1], planning in water management includes developing the following planning documents:

1) a water-environmental programme for the country, taking into account the division into catchments, further in the document referred to as "water-environmental program for the country"
   1. a) water management plan for the catchments
2) flood control plans and prevention of the effect of drought in the country, taking into account division into catchments
3) flood control plans of a water region
4) conditions of using waters in a water region
5) conditions of using water resources in catchments, prepared when the need arises.

Land use has always had an effect on water resources. Eutrophication, namely the excessive fertilization of water, is a natural process that takes place in water bodies, yet intensive economic development, waste dumping, agricultural fertilization and forest degradation have intensified this process so that today eutrophication poses one of the greatest threats to lakes. The rate of lake "aging" is determined by the characteristic features of the water body as well as the surrounding areas.

The "catchment – lake" system relies on a set of mutual interconnections. Catchment vegetation affects the hydrobiology and the chemical composition of water. Forests regulate water outflow from the catchment area and reduce erosion. Agricultural catchments supply more biogenic substances than afforested areas or permanent grasslands. Buildings and roads deteriorate retention and contribute to the transfer of pollutants to water. The inflow of substances responsible for the eutrophication of water bodies in the catchment area is determined by various factors, mostly by the physiography and the type of catchment land use. Pollution preventive measures should propose environmentally-friendly solutions in the catchment that rely on the natural ability of vegetation cover comprising various ecological communities to limit adverse effects of pollution.

This study involves developing a method of preparing a planning document to help implement the principles of the Framework Water Directive, such as protection from further degradation of aquatic ecosystems as well as actions aimed at protection and improvement of the environment by restriction and elimination of the discharge of substances that may have a negative impact on waters. A new opinion on limnological restrictions to a planning permit is to be an ancillary instrument for regional planners, as it focuses on the issue of area impurities at the level of water body catchments.

Objective and Subject Matter of the Study

Our study focuses on water resources, one of the environmental components taken into account in the planning procedure. As it is a broad topic, the object of this study was narrowed down to water in water bodies, and the study investigated water as an element of the planning process ("spatial phenomenon"). The aim of planning activities concerning water is to supply water of adequate quality; therefore, the detailed objective of this study was the planning procedure in the part concerning water resources in water bodies.

Spatial planning and spatial development are instruments that support the rational use of space. Land improve-

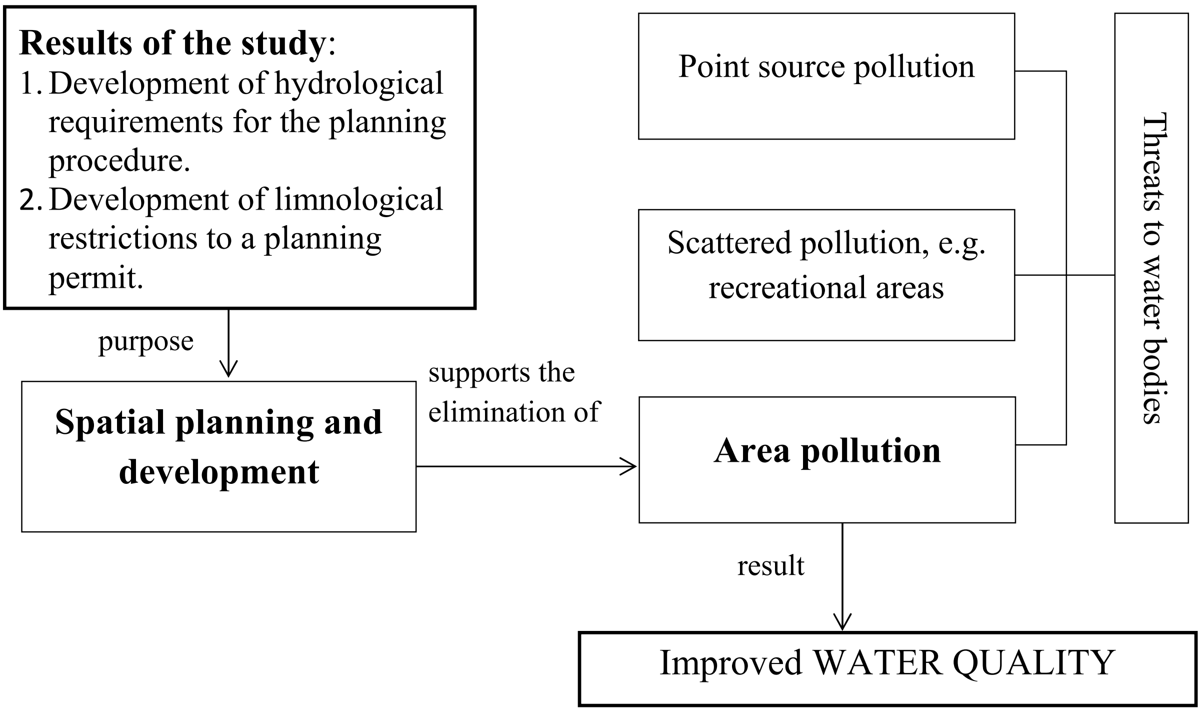

Fig. 1. Schematic presentation of the study's contribution to water protection.

ment solutions introduced in a given area affect the surrounding space and are also influenced by the surrounding space. If spatial planning affects spatial design, then it also influences water and shoreline zones. Hydrological requirements have to be taken into account in spatial planning to ensure the satisfactory condition and quality of water.

The aim of this study was to improve the planning procedure in the part concerning the hydrological condition of lakes. The authors developed a set of principles for managing shoreline zones, subject to the morphometric characteristics and hydrological conditions of water bodies. The priority goal of the above planning principles (procedures) was to achieve and maintain the highest possible level of water purity (Fig. 1). Despite many similarities, lakes may differ substantially. In spatial planning, the diversity resulting from the lakes' individual attributes poses both a difficulty and an opportunity. It is a difficulty because every lakes requires an individualized approach, and an opportunity because it supports the development of a variety of spatial planning measures for shoreline zones.

The main objective was met by achieving partial goals that comprised the following tasks:

1. Determining the effect of land use type, i.e. a potential source of pollution, on water quality and determining the catchment's impact on the lake.
2. Determining water susceptibility to pollution, subject to the morphometric properties of a water reservoir, and evaluating the lake's resistance to the inflow of pollutants.
3. Determining the reach of planning restriction zones and the width of lake buffer zones as barriers for area pollution.
4. Developing hydrological requirements for the planning procedure.

The above experimental goals were pursued at each stage of the study, as presented in the diagram (Fig. 2).

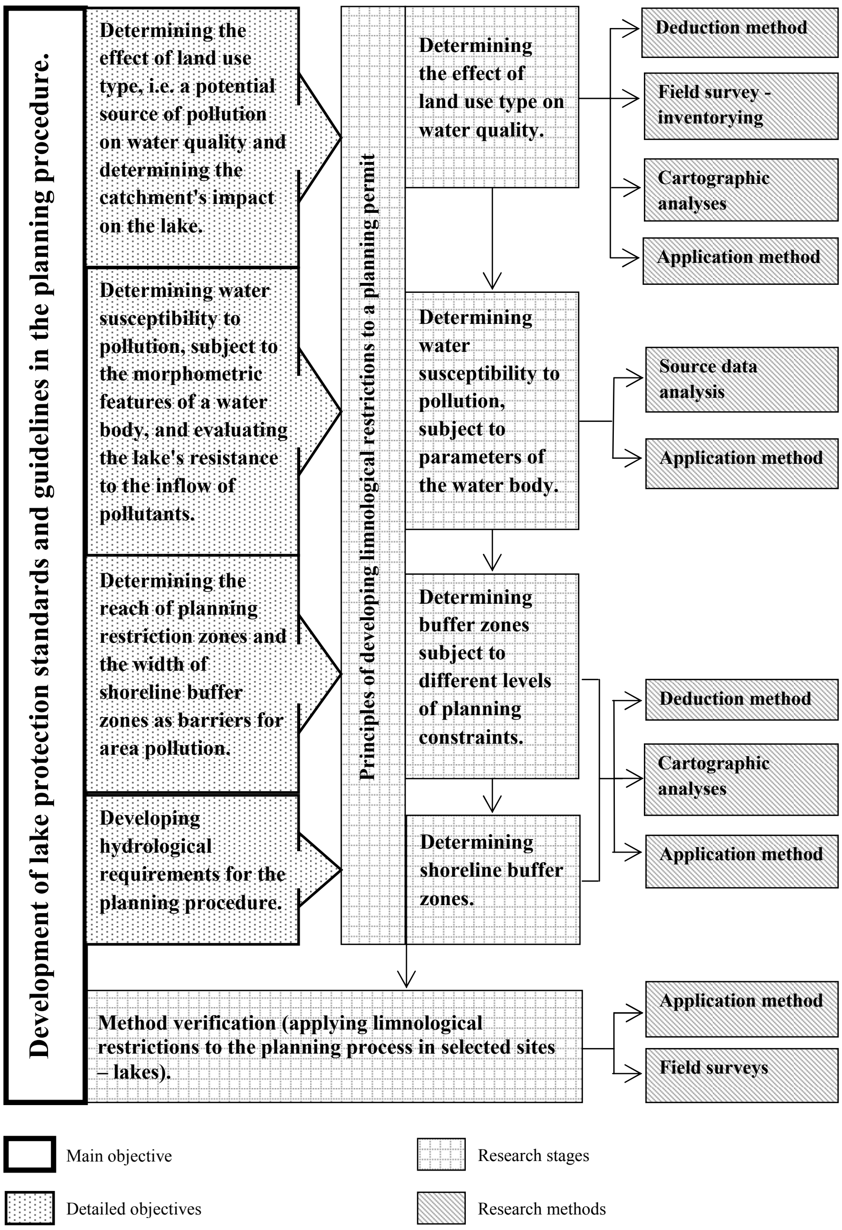

Fig. 2. Diagram of research stages and methods.

The obtained results provided a basis for determining principles accounting for hydrological requirements in the planning process, and for introducing to the Polish planning procedure a new document detailing the terms of managing lake buffer zones (a new opinion on limnological restrictions to a planning permit).

Natural lakes interconnected by streams and rivers, swamps, and peat-bogs are among the most valuable natural assets of a lake district. Nearly half of all Polish lakes are found in the rural areas of the Masurian and Suwalki Lakelands, which are characterized by a hilly landscape. For this reason, the study was carried out in the commune of Olsztynek in the Olsztyn Lakeland, a macroregion of the Masurian Lakeland. The proposed limnological restrictions to a planning permit have been verified, taking as an example eight lakes in the Olsztyn Lakeland [3].

Determining the Effect of Rural Land Use Type, i.e. a Potential Source of Pollution, on Water Quality, and Determining the Catchment's Impact on the Lake

The authors attempted to determine the effect that various types of rural land use have on lakes by examining the pollution load, mainly phosphorus, supplied to the water body. This stage involved the following tasks:

- developing a method for evaluating the suitability of littoral zone use
- developing a simplified method for determining the catchment's effect on the lake for the needs of limnological restrictions to a planning permit.

Developing a Method for Evaluating the Suitability of Littoral Zone Use

Biogenic elements are not uniformly supplied to the lake from the entire catchment area. Protective zones around lakes restrict excessive nutrient inflow [4-14]. The method for evaluating the pressure exerted by the littoral zone on the lake was developed for the purpose of determining buffer zones. The coefficient of suitability of littoral zone use is a helpful factor in developing limnological restrictions for planning during the assessment of the catchment's effect on the lake. The base field method was deployed. The process of determining the coefficient of suitability of littoral zone use involved the following steps:

- a graticule of 2x2 cm squares was plotted on a cadastral map at a scale of 1:5,000, corresponding to a field area of 1 ha
- fields covered by squares in the direct vicinity of the lakeshore were evaluated. The analysis covered squares in which the water body occupied less than 50% of the area. If 50% of the base field was occupied by the lake, the adjacent square was examined. The percentage cover of different area types was estimated in each square, and each area was calculated
- the coefficient was calculated as follows:

Table 1. Evaluation of littoral zone use in view of coefficient Wc.

Wc	Points	Suitability of use
1-1.5	0	satisfactory
1.6-2.5	1	neutral
2.6-3.5	2	adverse
>3.6	3	highly adverse

Source: own study

$$Wc = (W_1 + W_2 + ... + W_n)/n$$

...where:
Wc– coefficient of suitability of littoral zone use
n – number of study fields
$W_1 – W_n$ – unitary coefficients from study fields:

$$W = (ax_1 + bx_2 + cx_3 + dx_4)/100$$

...where:
x_1 – forests, ecological land = 1
x_2 – meadows, pastures = 2
x_3 – arable land = 5
x_4 – developed land = 10
a – percentage forest cover
b – percentage grassland (meadow and pasture) cover
c – percentage arable land cover
d – percentage developed land cover

The coefficients were selected based on an analysis of reference sources to account for the differences in the pressure exerted by various types of land use on the aquatic environment [15-22].

The suitability of littoral zone use was evaluated with the use of a grade point scale presented in Table 1. The values of coefficient Wc were analyzed in view of use suitability, and each value was assigned a given number of reference points.

In subsequent parts of the study, the coefficient of suitability of littoral zone use was applied as one of the parameters of the simplified method for evaluating the catchment's effect on the lake based on the method proposed by Bajkiewicz-Grabowska [23]. For this reason, the grade point scale adopted in the above method was applied to evaluate the suitability of littoral zone use.

The coefficient of suitability of littoral zone use can be computed:

- with the use of a digital cadastral map at a scale of 1:5000 – the base fields method where the cadastral plot is the base field,
- with the use of an analogue or a digital cadastral map at a scale of 1:5,000 for lakes with a plain shoreline – by determining different types of land use inside a 100 m-wide strip extending from the shoreline.

For the evaluation method to be fully effective, the application of the cartographic method should be preceded

Table 2. Indicators of the catchment's impact on the lake.

Indicator	Points			
	0	1	2	3
Type of water balance	with outflow, high through-flow (several turnovers per year)	without outflow	low outflow (one turnover every few years)	inflow
Wc coefficient of littoral zone use suitability	1-1.5	1.6-2.5	2.6-3.5	>3.5
Catchment's geological structure	clay, peat	sandy clay	clay sandy	sandy

Source: own study based on reference data [23-26, 64].

by field surveys (inventory of the existing types of land use in the littoral zone). The resulting coefficient supports an evaluation of the pressure exerted by the littoral zone on the lake without the need to calculate the phosphorus load supplied to the lake, and without the use of complex formulas or hydrological data. The Wc coefficient facilitates the evaluation of the catchment's effect on the lake prior to the development of planning documents.

Development of a Simplified Method for Determining the Catchment's Effect on the Lake for the Needs of Limnological Restrictions to a Planning Permit

Bajkiewicz-Grabowska [24-26] developed a system for grading a catchment's ability to supply biophilous elements to the lake. This system has been simplified for the needs of this study. Two out of the seven parameters proposed by Bajkiewicz-Grabowska were selected, and the method was further expanded to include the coefficient of suitability of littoral zone use. The selected parameters were the type of the lake's water balance, which provides information on the intensity of water turnover in a water body, and the geological structure of the catchment accounting for soil permeability. The selected indicators, as presented in Table 2, are sufficient to determine the catchment's effect on the lake for the needs of establishing limnological restrictions to a planning permit.

The catchment's effect on the rate of organic matter supply to the lake is evaluated based on the grading of each of the above indicators on a scale of 0 to 3 points, where 0 is indicative of very weak contribution to organic matter supply and the absence of biogenic substance flow to the lake, and 3 implies high contribution and quick supply of organic matter to the water body (Table 2). The end result is an arithmetic mean of the points scored in the evaluation of each indicator. Based on that result, the catchment is classified into one of the four susceptibility groups:

group 1 – mean value of ≤1; the catchment strongly inhibits runoff and is practically incapable of supplying biogenic matter to the lake; minimum width of the buffer zone is recommended

group 2 – mean value of 1.1 to 1.4; the catchment is relatively unable to activate the deposited substance load and supply biogenic matter to the lake

group 3 – mean value of 1.5 to 1.9; the catchment has an average capacity of supplying biogenic material to the water body

group 4 – mean value of ≥2.0; the catchment has a high capacity of supplying biogenic matter to the lake. Maximum width of the buffer zone is recommended

Determining Water Susceptibility to Pollution, Subject to the Morphometric Characteristics of a Water Body, and Evaluating the Lake's Resistance to the Inflow of Pollutants

Morphometric indicators are a highly useful tool in solving various limnological problems. The area and the shape of a water body are of key significance (under identical climatic and meteorological conditions) for its ecosystem.

At this stage of the study, the existing methods for evaluating the lake's susceptibility to degradation [23, 27] were deployed and modified for the needs of determining limnological restrictions to the planning process. The three most universally recognized attributes determining a lake's resistance to the influence of its catchment area were selected, namely the average depth of the lake, the modified Schindler coefficient, and index of basin permanence (IBP).

The average depth of the lake, i.e. the quotient of the lake's volume to the surface area of its water table, is a morphometric parameter most closely related to water quality – high depth is a favorable natural attribute. Average depth is the most important morphometric characteristic that is closely related to trophy [23, 27-30].

The Schindler coefficient is the quotient of the sum of catchment area and lake area to the lake's volume (Pz + Pj)/Vj [31]. The entire catchment area affects the lake via the main transit inflow. If river water is polluted, the river's predominant effect will be felt even if the water body and its catchment have highly favorable natural characteristics. For this reason, a modified coefficient, expressed as the ratio of the total area of the lake and its direct catchment to the lake's volume, has been adopted for the needs of the study.

IBP [32] is provided by the ratio of the lake volume divided by shoreline length Vj/l, and indicates the littoral

Table 3. Simplified evaluation of lake susceptibility to pollution.

Indicator	Point total			
	0	1	2	3
Average depth [m]	>10	5-10	3-5	<3
Coefficient (Pj+Pzb)/Vj [m^2/m^3]	<1	1-3	3-10	>10
Quotient of lake volume to shoreline length [$m^3 \cdot 1000/m$]	>5	3-5	1-3	<1

Source: own study based on reference data [27, 28, 65].

effect on basin volume. The ratio of the lake volume to the length of its shoreline accounts for two important parameters, namely the length of the lake's contact line with the surrounding area and the mass of water that receives external pollution. The higher the result, the greater the lake's resistance to the influence exerted by the adjacent areas.

The required characteristics can be calculated based on data in the morphometric plans and charts developed by the Institute of Inland Fisheries. Each parameter that affects the intensity of the analyzed process is graded on a scale of 0 (high resistance) to 3 points (no resistance to the catchment's influence). The end result is an arithmetic mean of all points awarded to the lake's resistance attributes (Table 3).

An average less than or equal to 0.8 is indicative of a category 1 lake (high resistance to external influence), from 0.9 to 1.6 – category 2 lake (average resistance), from 1.7 to 2.4 – category 3 lake (low resistance), above 2.4 – category 4 lake (no resistance, high susceptibility to external influence). Buffer zone strips of a given width are recommended for each category. The most resistant lakes require buffer zones of the smallest width, while the least resistant need maximum protection.

The simplified method of evaluating a lake's resistance to external pollution is applied at one of the stages of developing limnological restrictions for planning purposes.

Determining the Reach of Planning Restriction Zones and the Width of Lake Buffer Zones as Barriers for Area Pollution

Eutrophication can be limited by locating buffer zones between agricultural ecosystems that supply nutrients and surface water bodies that receive them [4-14, 33-38]. The effectiveness of the protective role played by littoral zones is determined by the width of the protective belt, the pollution source, the ratio of the polluting source's area to the protective zone's area, type of vegetation, soil type and the slope gradient of the buffer zone [5, 22, 36, 39-48]. Subject to width, sodded protective areas can capture and eliminate up to 95% of deposits and phosphorus compounds [9, 41, 42, 49, 50].

The exact width of the protective zone is determined by numerous factors, including the catchment's influence and the lake's morphometric attributes. For littoral zones to best serve their protective function, they should be covered with mixed vegetation [12, 34, 37, 43, 44, 49, 51, 52]. To illustrate, the outer strip of the protective zone should be overgrown by grass, which has a high ability to eliminate deposits, while the inner strip should be afforested [53]. Buffer zones overgrown by grass and forests should be excluded from all types of use. Yet in practice this is not possible owing to the recreational value of water bodies. For this reason, adequate management of the littoral zone is an important consideration.

Based on an analysis of published sources and global guidelines, the average protective zone of a water body adopted for the needs of this study ranged from 9 to 61 m, which ensures optimal protection against the inflow of deposits and phosphorus into lakes [54, 55]. Following an analysis of literature data, protective zones were divided into 4 recommended widths, depending on the lake's resistance and susceptibility to the effect of the catchment. The widths of the protective zones, depending on the possibility of removing deposits and phosphorus in surface inflow, examined and recommended by different authors, have been taken into account [5, 9, 33, 39, 44, 48, 49, 52, 56]. The following protective zones were mapped for groups with different levels of susceptibility to the catchment's impact: group 1-9 m, group 2-23 m, group 3-37 m, and group 4-61 m. Similar zone widths were set for different lake resistance categories. Intermediate widths of a protective zone (16 m, 30 m, and 44 m) were determined by taking into account the possibility of limiting nitrogen inflow with surface run-off [54, 55].

By combining the above groups with different levels of susceptibility to the catchment's influence and lake resistance categories (Table 4), the authors were able to determine three zones where different levels of planning constraints apply (Fig. 3).

Table 4. Required minimum width of a protective zone [m].

Susceptibility to the catchment's influence	Lake resistance			
	1	2	3	4
1	≥9	≥16	≥23	≥30
2	≥16	≥23	≥30	≥37
3	≥23	≥30	≥37	≥44
4	≥30	≥37	≥44	≥61

Source: own study

The first zone is delimited by the distance set in view of the lake's corresponding group and category. The reach of the second zone is not lower distance, indicated in the given column or row.

The limit of the first zone is established at a distance that is not lower than that which results from classifying a lake into a specific group or category. The reach of the second zone is established as a distance which is not lower than that given in the column or row where the lake is mentioned. Waterlogged areas are not included in the zone (the zone covered by planning restrictions is mapped from the shoreline of the marshy area).

The first zone should be subject to protective standards applicable to lakes, i.e. a full planning restriction. Light types of development should be allowed in the second zone where limited planning constraints apply (Table 5). There are no planning restrictions in the third zone.

Limnological restrictions to the planning process can be deployed at the initial stage of preparing a local development and management plan at the commune level. The concept of limnological restrictions refers to all constraints imposed upon the planning process due to the presence of lakes. In the process of drafting a local development plan, limnological restrictions should be introduced at the stage of developing ecophysiographic studies. Protective zones would be mapped based on planning restriction zones and the relief of lakeshore areas.

The inflow of biogenic elements into lakes is directly determined by the slope gradient of the littoral zone [33, 38, 44-46, 57, 58]. Analysis of published data points to a simple dependence: the greater the slope gradient of the littoral zone, the wider the required buffer zone [59-61]. For the purpose of developing limnological restrictions to planning permits, the width of the lake buffer strip is determined by adjusting the previously defined planning zones (Table 6).

Table 5. Planning restrictions in protective zones.

Zone	Degree of planning restriction	Land use
I	full	forests
		meadows
		ecological land
II	moderate	forests
		meadows and pastures
		recreational functions, undeveloped
		water sports facilities, e.g. boathouses
III	none	all types of land use authorized by planning permits

Source: own study

Table 6. Relationship between buffer width and slope gradient of a littoral zone.

Slope gradient	Protective buffer
>5-<18%	planning restriction zone I and II + 0.6 m per every 1% of gradient
18-36%	planning restriction zone I and II + 1.5 m per every 1% of gradient
>36%	planning restriction zone I and II + 1.5 m per every 1% of gradient forests

Source: own study

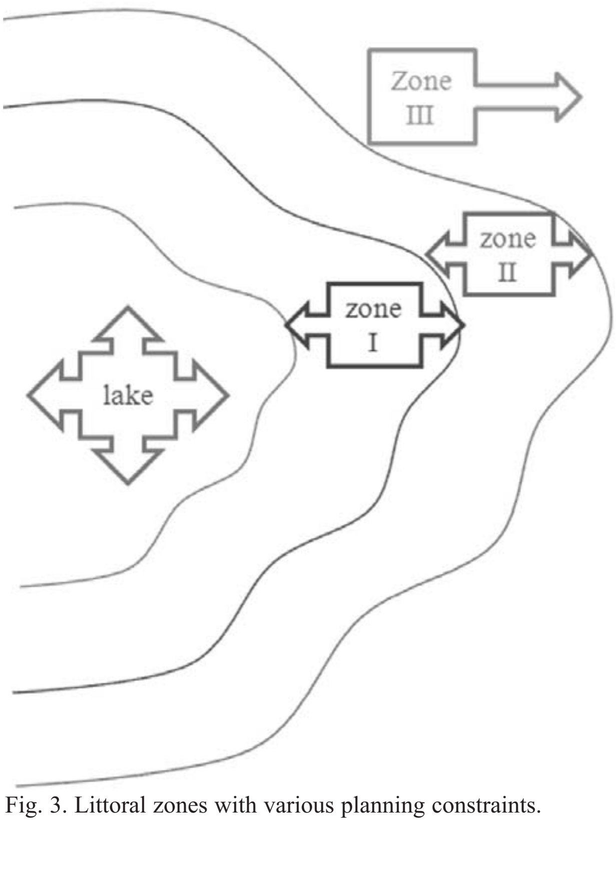

Fig. 3. Littoral zones with various planning constraints.

Slope gradient thresholds have been determined based on published data and the results of research conducted by Kostuch [62] into different types of land use subject to slope gradient. A gradient of 18% corresponds to 10º, 36% – to 20º. An adjustment of 0.6 m per every 1% of gradient was adopted based on the findings of Trimble and Sartz [55], while the adjustment of 1.5 m per every 1% of gradient – based on the work of Palone and Todd [63].

Developing Hydrological Requirements for the Planning Procedure

The majority of planning documents in Poland, mainly local zoning plans, state that the reach of the buffer zone should be indicated in the plan. If the buffer zone is not explicitly marked, a 100-m-wide strip from the shoreline is the observed standard. A protective strip with a width of 100 m is probably an adequate solution from the point of view of lake protection, yet due to growing spatial constraints, detailed planning constraints should be established to protect the highly valuable littoral zone. The proposed method for developing limnological restrictions is a useful tool supporting the detailed determination of buffer zones. The stages of developing limnological restrictions to the planning process are shown in Fig. 4.

The presented method of developing limnological restrictions facilitates the mapping of stagnant surface water in the planning procedure. Its results should be taken into account at the stage of determining the function and the type of land use in littoral zones in planning documents. The proposed method should be applied at the initial stage of preparing a local development plan at the commune level. Limnological restrictions apply up to stage V of the

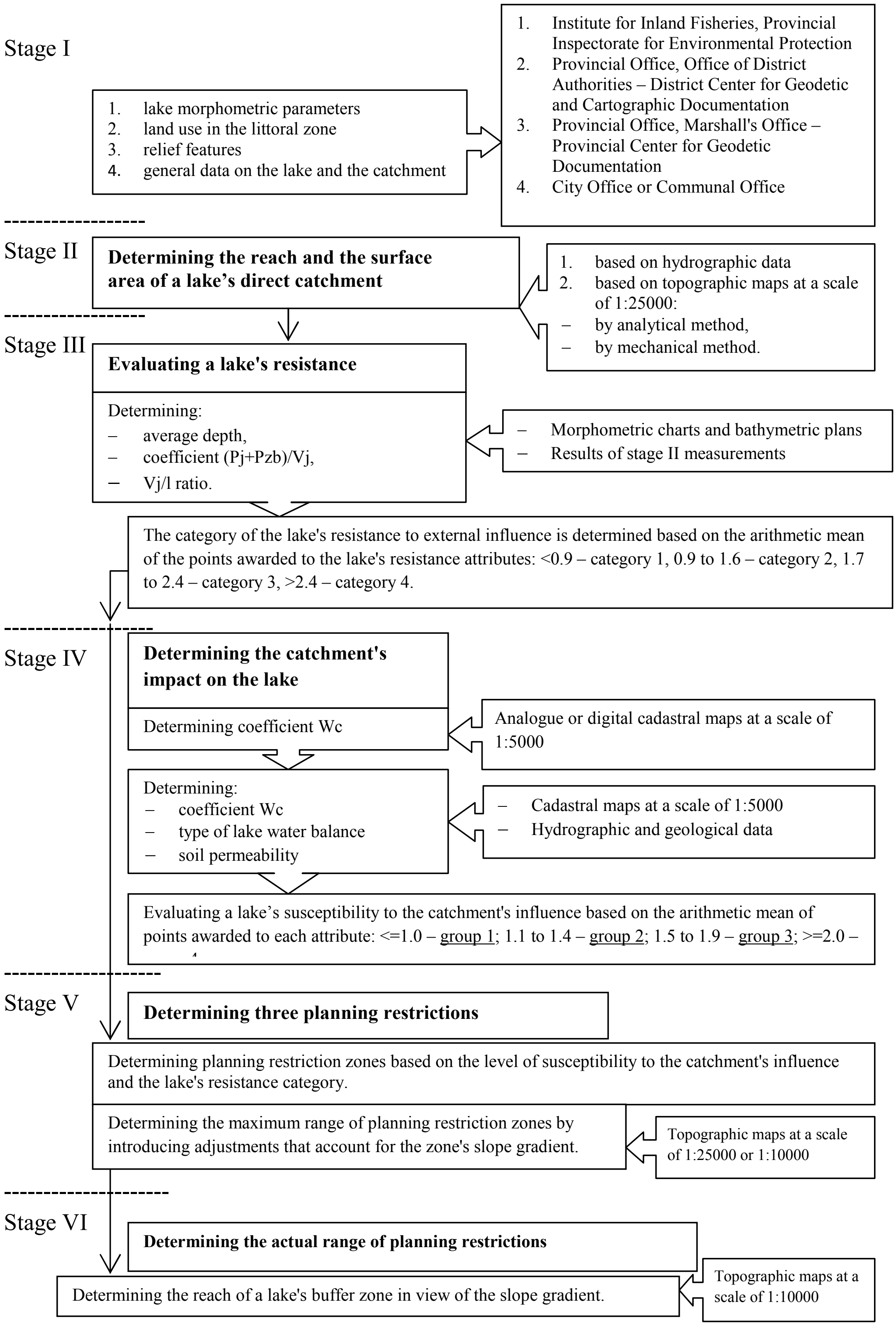

Fig. 4. Schematic presentation of the process of developing limnological restrictions.

planning process. In the process of drafting a local development plan, limnological restrictions should be introduced at the stage of developing ecophysiographic studies. In this document, the introduction of limnological restrictions would imply the mapping of protective zones based on planning restriction zones and the relief of shoreline areas, up to stage VI of the planning process.

The proposed method of developing limnological restrictions to the planning process was verified in selected experimental sites. The reported results [3] validate its usefulness in the planning procedure.

Conclusions

The functions of water determine the sustainable development of rural areas. A water surplus or deficiency affects the biodiversity of water-dependent ecosystems. The above is clearly demonstrated in the landscape of lake districts whose ecological balance is heavily reliant on water. The main problem affecting those areas is the low level of water purity resulting from the inflow of pollutants from catchment areas. The degree of eutrophication is determined by the physical and geographic structure of the catchment and the morphometric attributes of the lake. Surface runoff may be supported or limited by the catchment's physical and geographic structure, as well as the lake's natural attributes.

The introduction of limnological restrictions to the planning procedure is a valuable tool that can contribute to an improvement in water quality. As regards surface water, in particular stagnant water bodies, pollution runoff from catchment areas may be limited by establishing protective zones that are subject to planning constraints. The proposed method of developing limnological restrictions to the planning process introduces guidelines for determining the width of buffer zones in the shoreline area. The term "limnological restrictions" is a new concept that has been introduced for research purposes, and it implies that special planning constraints should apply to lake districts. Limnological restrictions should be deployed in the planning process at the stage of determining the function and the type of land use in littoral zones. They should be an instrument supporting the development of planning policies and a permanent feature of the local law. Spatial planning offers various options for lake protection while delivering rational development options that account for social and economic needs.

The following conclusions have been formulated based on the above observations, the findings of the study and an analysis of reference sources:

1. The growing scarcity of space increases human pressure on ecologically valuable areas, including shoreline zones, prompting the need for rational planning solutions. Limnological restrictions support the optimal use of those areas and protect the quality of lake water.
2. In view of Polish regulations, hydrological conditions have to be taken into account in the planning procedure. It should be noted, however, that hydrological issues related to lakes are not regulated in sufficient detail in Polish legislation. The proposed concept of limnological restrictions is a universal tool that can be used in the process of developing spatial policies as well as the local law.
3. The proposed concept of limnological restrictions is a universal tool that can be used in the process of developing spatial policies as well as the local law.
4. The method for developing limnological restrictions, as proposed in this study, supports the planning procedure in shoreline zones of rural areas. In the course of follow-up research, the suggested method should be modified to suit the needs of other areas.

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