Chapter 6
Natural and Anthropogenic Lakes of River Valleys

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Abstract This chapter discusses the forms and ways of functioning of the lakes in river valleys in Poland. Due to the specific nature of these objects, which are characterized by a distinct separation from natural and artificial lakes, the knowledge gathered so far concerning the appropriate nomenclature and classification has been systematized. The paper presents bathymetric plans of selected objects which origin is related to both natural and anthropogenic lakes. These objects are an important and underestimated element of small retention.

Keywords Floodplain lakes · Lakes typology · Potamophase · Limnophase · Poland

6.1 Introduction

The issue of the forms of occurrence and functioning of lakes located in river valleys is relatively rarely addressed in the literature, despite the high hydrological and ecological significance, as well as their unique function in river valleys landscape. The chapter will present the classification and types of floodplain lakes observed in Polish river valleys, as well as the nomenclature used. Moreover, selected examples of lakes occurring in river valleys – natural, quasi-natural and transformed by

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human activity – will be discussed. The environment of river valleys is characterized by a wide variety of processes and forms resulting from them. Limnic forms, although are frequently observed in some valleys, are generally poorly recognized, and their retention and ecological potential are underestimated in the context of river bed regulation and hydrotechnical interventions in valleys. The floodplain lakes, however, are an essential element of small retention of valley waters. Due to the diversity of types: genetic, balance, hydrochemical, hydrobiological and other, they are also a very attractive subject of research. The specificity of lakes located in river valleys is often characterized by a distinct separation from the environment of river waters, which encourages research and practical solutions aimed at the protection or renaturalization of the limnic environment.

6.2 Definition of Floodplain Lakes

In world literature, the floodplain lakes are called differently. Examples of terms are: "neck cutoff" [1–3], oxbow lake [4–6], fluvial lake [7, 8], or more rarely "river lake" [9], hydro-biological "limnocren" [10, 11], hydrological "floodplain lake" [12–16]. In the Polish literature, especially in reference to lakes, the creation of which is the result of regulatory and hydrotechnical works in river valleys, apart from the general and imprecise name "old riverbed," there are also names: quasi-ox-bows [17], anthropogenic reservoirs, post-training reservoirs [18]. Sometimes local names are used, which are derived from river names (e.g., in the Vistula valley – "wiśliska", in the Odra valley – "odrzyska", Warta – "warciska", Bug – "bużyska"). A separate problem is the definition of a floodplain lake, which is not precise. A general definition of a lake assumes the natural origin of a basin in which water accumulates (from surface and groundwater supply) and the advantage of recharge over losses. However, an important criterion assuming the existence of turbulent flow of river waters through a basin during potamophase, as well as autonomous areas with a laminar character of water movement and stagnation zones, should be added. The number of floodplain lakes within particular genetic groups, presented in Fig. 6.1, depends on macroscale features of the natural environment (e.g., geological structure, relief, climate and others) and human pressure, while the way of functioning is favored by the local conditions of their catchment areas. The ecological separateness of reservoirs is commonly observed, which often determines the uniqueness of floodplain lakes.

6.3 Materials and Methods

The analyses of natural floodplain lakes was based mostly on published papers concerning various river systems. Fluvial, morphological, hydrochemical and hydrobiological aspects were analyzed in order to quantify the main factors determining floodplain lakes heterogeneity. A representative group of temperate zone floodplain

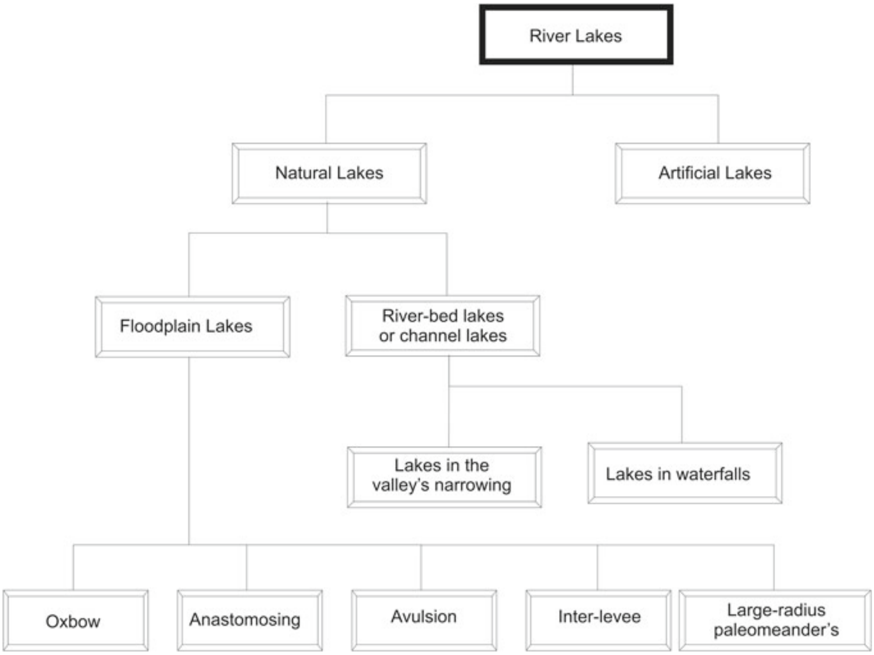

Fig. 6.1 Lakes in the River valeys

lakes located in the Bug river valley, one of very few large, quasi-natural European rivers in Eastern Poland was selected. A functional analysis of lake basins allowed the construction of uniform floodplain lakes classifications.

Bathymetric research was conducted in all seasons, at different water levels of the floodplain lakes. Measurements were made using echo sounder or probe weights (in lakes where intense bottom vegetation was observed) and a GPS receiver. In addition crevasses that connect floodplain lakes with the parent river were identified, and water distribution was determined during the spring potamophase periods.

6.4 Typology of Floodplain Lakes

6.4.1 Natural Lakes

The floodplain lakes are characterized by cyclical changes in the basin's supply forms. In general, there are four phases of the cycle: filling, flooding, drainage and isolation [19, 20]. There is also a division into two basic functional periods called limnophase and potamophase or inundation and isolation phase [21–23]. In the limnophase, the lake has its catchment that can be determined. It is also possible to determine the range of supply and the type and intensity of hydrochemical and hydrobiological processes for this phase of the cycle. In the potamophase, there is a clear convergence of physicochemical parameters of lake and river waters [24, 25], and the area of basin supply is the catchment of the parent river (up to the profile at the place of water supply to the lake). During high recharge of the valley with river waters, lakes may disappear for some time. The lakes are then a hollow in the flooded floodplain terrace. The floodplain lakes are most often found in the lower and middle sections of the river, and the criterion determining the potential for their formation is the predominance of lateral erosion processes over depth one in the river bed. Floodplain lakes do not occur in the crenal and rhithral (spring and stream zones) but appear only in the potamal (river zone). Detailed studies of erosion and cutting of meanders have been carried out since the end of the nineteenth century [26], but initially, they were an addition to comprehensive studies of valleys and rivers [26, 27]. Already then, the need to divide lakes created by the activity of rivers was noticed. Due to a large number of lakes and a large area of meandering lakes, the first typologies of river valley lakes concerned these lakes.

According to [28], for a lake to be classified as a floodplain lake, it must:

(a) be located on a floodplain and shows some apparent relationship to the major stream,
(b) be located within a distance of fifteen stream widths of the major stream,
(c) contain water,
(d) include at least one segment with a crescent-shaped channel (called the "fundamental component"),
(e) have a size of the same general magnitude as the major stream, and
(f) be independent of other topographic influences, which means that each oxbow lake must be free-standing.

Division of lakes by morphometry

The simplest floodplain lakes typologies were based on shoreline shape and development. Three types of lakes were distinguished in terms of oxbow lakes morphometry [29].

- simple oxbow lakes are reservoirs with a compact, curved and not dismembered basin with at least one arm through which river water is supplied (Fig. 6.2a),
- compound oxbow lakes with a dismembered basin, many channels and a developed shoreline (Fig. 6.2b),
- complex oxbow lakes with a complex basin shape, which was created by connecting several floodplain lakes into one body of water (Fig. 6.2c).

Another concept of typological division of meandering lakes by [28] also includes three lake categories:

- open oxbow lakes (Fig. 6.3a)
- normal oxbow lakes (Fig. 6.3b)
- closed oxbow lakes (Fig. 6.3c).

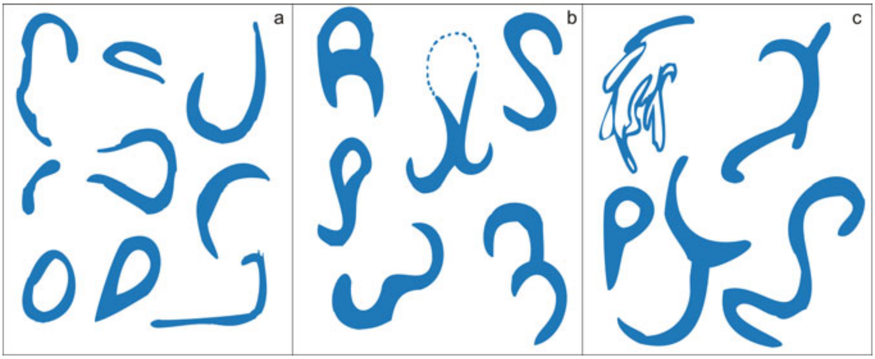

Fig. 6.2 Oxbow lakes typology according to [28]: **a** simple, **b** compound, and **c** complex

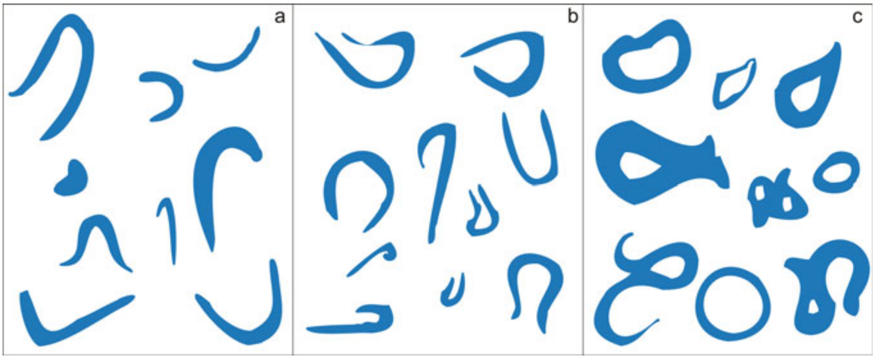

Fig. 6.3 Oxbow lakes typology according to [28]: **a** open, **b** normal, and **c** closed

The criterion determining the lake's belonging to the group was the index of shoreline development, allowing to determine the degree of closure (or opening) of the lake basin. The open lakes had arms exposed in the direction of river waters supplying them and resembled the elongated letter 'c' in shape. Normal lakes were typical moon-shaped meandering lakes. Closed lakes, on the other hand, were water reservoirs with connected arms (Fig. 6.3c).

Division by ratio of bathymetric parameters

Floodplain lakes are generally characterized by their considerable length and narrow width. The basis for the next classification of floodplain lakes in the period of limnophase according to [19] was the index being the quotient of the length and width of the reservoir. They separated two groups of lakes:

– channel lakes, in case of which the size of the index was higher than five. Lakes of this type were characterized by rapid water exchange, mainly based on fluvial supply and short retention time.

– dish lakes with the index size below five. They were characterized by slow water movement in the basin and longer water exchange time (mainly based on atmospheric supply).

Division by location in the valley

The location of the lake in the valley, in relation to the river bed or the edge of the lagoon terrace, may also be a criterion for lakes classification. Four different types of floodplain lakes can be separated:

– the lakes of modern meander belt. These are mainly oxbows and inter-levee lakes, generally referred to as near-bed lakes.
– under-edge lakes. They are located on the opposite side of the floodplain terrace in relation to the above mentioned lakes. They are located in sub-edge depressions. They generally have a small surface area and the depth of the basin.
– lakes of the higher floodplain terrace
– large-radius oxbow lakes. They rarely occur, far from the river bed and are the oldest lakes. They are characterized by very advanced processes of atrophy due to silting and overgrowing of the basin.

Division by manner of lake connection with the river

The criterion of the lake belonging to a specific group is the way of its basin connecting with the river. Three groups of lakes can be distinguished:

– lotic lakes, open lakes, well oxygenated reservoirs, rich in nutrients with a relatively fast metabolism. They are characterized by an apparent slowdown in the rate of succession [30].
– lentic lakes, closed [31] with a very short duration of potamophase, which favors the formation and maintenance of oxygen deficits. Denitrification and sulfate reduction processes often dominate in bottom zones. The circulation of matter in such lakes takes place mainly on the basis of indigenous substances.
– semiopen, semi-lotic lakes, characterized by a wide range of hydrological changes, which results in differentiation of aerobic conditions and water trophy [32], as well as a large mosaic of habitats.

In each of the above mentioned groups, there are also three forms that take into account the shape of the lake. Straight, complex and irregular lakes differ in the degree of complexity of the shoreline of the basins. In the case of straight reservoirs, there is usually one formed basin, typically curved (croissant), being a part of a cutoff river meander. The basins of complex lakes are usually connected through channels. Sometimes it is one basin with a developed system of arms. Irregular lakes have the most complex shape. These are usually several basins connected or a system of irrigated inter-splitter depressions.

The method of connecting the lake with the river determines the dynamics of the ecosystem and the physicochemical composition of the water. This issue is widely discussed in the literature [16, 23, 33–36].

Division by the origin

The oxbow lakes are the most numerous group of floodplain lakes and generally have a relatively large surface area and basin capacity. They are formed in the valleys of meandering rivers. They are always located in the meandering belt of the channel zone of the river valley bottom. They are a fragment of an old river bed, cut off from the present one with a near-bed embankment. The flow of flooding waters through lower and higher flood terraces is the basic factor shaping the surface of inter-levee lakes. Erosion, transport and deposition of sediments directly determine the possibility of such reservoirs creation and functioning. Lithologically diversified forms of dumping, of different durability and size, are most often created under the conditions of free-flowing or standing water. Meander drops are accumulation forms of the largest size and high stability. Lakes can be formed in places where embankments separate depressions, with favorable arrangement of supplying them valley waters. Flows of water in the out-of-bed zone determine the recharge of the basins of inter-splitter lakes during potamophase. The recharge of the lake basin results from the occurrence of erosive forms created during flooding flows. The shape of the lakes refers to the form of an inter-levee depression, which was filled with water. Inter-levee lakes are characterized by a clear loss of water in the limnophase period, a small maximum depth and a relatively small area.

Avulsion occurs in fragments of the valley where a typical free migration of meanders is replaced by the process of abandoning of longer sections of the river bed. Sections of valleys, which are characterized by an increase in the longitudinal slope of the river bed, are predisposed to the occurrence of avulsion. Especially in the gorges zones, before the topographical obstacle of water outflow, the longitudinal slope of the river decreases, but after its crossing, it increases significantly. It is the increase in the gradient of the longitudinal slope during flooding that favors the abandonment of the old bed. Increased slope of the water table also favors an increase in the role of deep erosion at the expense of side erosion, which results in a weakening of the river's tendency to meandering. The modeling processes then took place within abandoned, straightened, narrower and deeper beds. Under the conditions of existence of stabilized channel drains delimiting the shoreline zone, alternating outflows and depressions occurred in the longitudinal profile. A system of linear cascades of basins was created, which were formed in the deep zones and isolated from each other by shallows. The underground recharge may also be the factor favoring the preparation and stabilization of the deepest zones of the basins of the avulsion lakes. Especially in gorges areas, water-bearing layers, the drainage of which allows to maintain full watering of the lake basins throughout the year, can be often intersected.

Anastomotic lake basins were shaped by the processes resulting from the adaptation of the flow of flooding waters to the decreasing slope of the valley bottom (most often sections located before its narrowing or topographic obstacle). The lower transport efficiency of the bed (resulting from the lower velocity of flowing water) led to swelling of water on the floodplain terrace during flooding. At that time, alternative (supplementary) beds were created. Such organization of the outflow, in conditions of the high variability of flows, helped to increase the transport efficiency of the beds and faster outflow of river waters throughout the year. Significant lengthening of the basins (beds) in relation to their width does not favor the limnic functioning of these forms. Only a few basins can be considered anastomotic lakes. The condition of the functioning of the flow of potamic waters through the basin must be met while maintaining the zones of standing waters or waters with very slow motion.

Division by supply direction

The origin of the floodplain lake determines the manner and rate of supplying the basin with the parent river water, and during the potamophase, most of the floodplain lakes have a flowing character. Depending on the direction of supplying waters in relation to the slope of the valley bottom, there are four hydrological types of floodplain lakes [37]. Confluent supply is mentioned when the direction of flowing river water (supplying the lake basin) is consistent with the longitudinal gradient of the river (Fig. 6.4a). This type of lakes is characterized by the highest dynamics of water exchange in the period of potamophase.

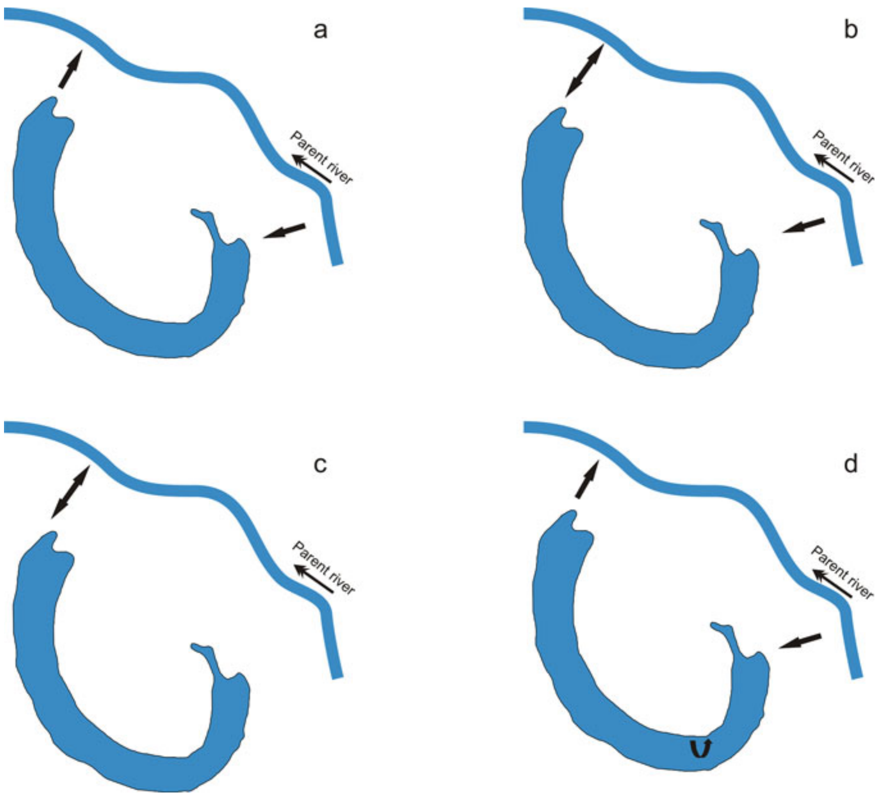

Fig. 6.4 Hydrological types of floodplain lakes: **a** confluent, **b** contrafluent–confluent, **c** – contrafluent, and **d** profundal

The inflow of river water in floodplain lakes with a contrafluent type of supply takes place through one arm of the lake, located on the lower side of the river water (Fig. 6.4c). In the reservoirs with this type of supply, the process of slower (than in confluent lakes) water exchange with the river is observed. In deep lake basins (e.g., avulsion lakes), apart from confluent supply, constantly high underground water supply is observed. These lakes belong to the profundal hydrological type (Fig. 6.4d). There were also cases of river water inflow through two arms of the floodplain lake, first from the lower and then from the upper water side. In the first phase of potamic recharge, the lake water masses are pushed into the central part of the basin, and after connecting the basin with the river by the second arm, they change direction in accordance with the inclination of the river bed. It is a complex contrafluent–confluent way of lakes supplying (Fig. 6.4b).

Confluent, (Latin *confluentia* "floating," *confluere* "floating together") recharge of floodplain lakes takes place consequently in relation to the slope of the valley. The supply of confluent lake basins, from the upper side of the river water, results from the local relations between the shape of the surface of the modern meander belt and the geometry of the river bed. Potamophase in such lakes begins when the flow of the river, which corresponds to the shore point, is exceeded. The direction of flooding waters in the valley and river waters is consequent, and the amount of supply to the basins of floodplain lakes is a result of the elevation of the ceiling of the crevasse splay (limnological effective rise – LER). Limnological Effective Rise (Fig. 6.5) is, therefore, a layer of water measured on the crevasse glyph that feeds the basin (most commonly given in centimeters). In the case of contrafluent lakes, a subsequent or obsequent direction of feeding waters in relation to the river bed is observed, which results from the system of local landform features. Contrafluent supply is activated when the relative height of the dike isolating the lake basin from the river, from the lower water side is lower than from the upper water side.

Mixed hydrological type occurs in the case of supplying the floodplain lakes with two arms (contrafluent–confluent). At the beginning inflow occurs from the lower water side, and after some time also through the second arm (from the upper water

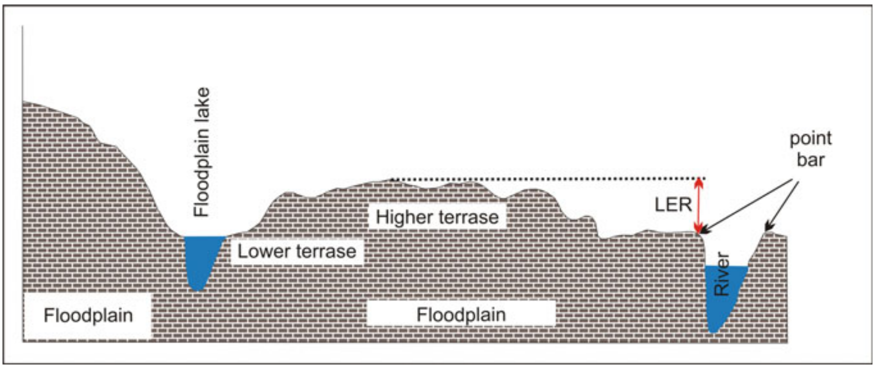

Fig. 6.5 Limnological effective rise

side). This form of basins supply occurs only when there is a difference in the value of limnological effective rise of crevasses (from the upper and lower side of the water in the river). Potamophase begins with contrafluent inflow of river waters and “old” waters pushing deep into the basin. Confluent recharge and the change of direction of basin supply starts after crossing the shore point, at the height of upper water crevasse.

Division by the manner of water exchange

The basins of the floodplain lakes are particularly dynamic ecological systems in which there is a constant exchange of matter and energy. The classic pattern of water exchange rate in the basin assumes its uninterrupted movement within the entire bowl (CSR – Continuously Stirred Reactor) [38]. The rate of water exchange in the basin results primarily from the characteristics of the basin, e.g. geological structure, relief, surface of the basin, and the bathymetry of the basin itself [39]. In the Polish scientific literature, there are two types of water exchange in relation to lakes: horizontal and vertical, and a situation where the role of these forms of exchange is so variable that none of them is dominant. In the world literature, the rate of water exchange is generally determined on the basis of the ratio of the capacity of the lake basin to the volume of the supply (in the case of nondrainage lakes). However, the capacity of the basin to the drainage (in the case of outflow lakes) or the capacity of the basin to the sum of the supply and drainage (in the case of flowing lakes) has always been implemented. The role of genetic forms of supply in terms of groundwater resources (base flow) or quick flow component of the supply is relatively rarely described in the literature.

There are three types of floodplain lakes due to the way of water exchange; evaporation-dominated, exchange-dominated and flood-dominated [40]. In the case of evaporation-dominated lakes, the vertical form of water exchange in the basin is dominant. The largest share in the revenue side of the water balance is precipitation, while the evaporation is the largest share in the expenditure side. Lakes of this type have short-lived potamophase, and for most of the year, the hydrological condition of the lake is determined by the resources of the catchment.

In flood-dominated lakes, the quantity and quality of water in the lake basin is determined by river recharge. The duration of potamophase in a hydrological year often exceeds six months, which is conducive to equalization of water levels in the reservoir during the year. Long-lasting potamic recharge also determines the physicochemical parameters of waters, which are similar to the waters of the parent river [24]. The most difficult to identify is the type of exchange-dominated lakes, due to the lack of threshold values of, e.g. evaporation or outflow, or the duration of potamophase and limnophase. The functioning of such lakes is shaped by both extrazonal potamic factors and interzonal factors of the catchment.

So far, no precise and objective criterion has been developed for the division of floodplain lakes due to water exchange. Two criteria can be adopted to objectively assign floodplain lakes to a specific type:

Direct methods

Comparison of the size of expenditure side the balance equation of the basin (evaporation and outflow), the dominance of which would indicate evaporation or flood-dominated lake type. The absence of clear dominance of one of the components may mean that it belongs to a transition type.

Determination of the lake type, based on the water residence time in the lake, regardless of how it is calculated. Lakes with a long residence time are evaporation-dominated reservoirs, whereas fast flushing is characteristic of flood-dominated lakes. The group of transitional lakes requires the determination of the limits of the range of variability.

Indirect methods

- Method of recharge. In the case of direct supplying of floodplain lake basin with potamic waters, one deals with the flow type. When potamic recharge takes place through a basin of another lake or a system of such lakes (cascade), one deals with transitional lakes, while if the recharge with river waters is episodic or does not occur, then these are evaporation-dominated lakes.
- Location of the lake basin. The flow type includes the lakes located in the modern meandering belt or within the lower floodplain terrace. Transitional lakes occur within the floodplain higher terraces, whereas the waters under the edge of the terraces are usually evaporation-dominated reservoirs.
- Bathymetric parameters. For example, the ratio of the lake surface to its maximum depth, or the ratio of the shoreline development to the mean depth. The high value of the first quotient is usually characteristic for evaporation-dominated lakes, whereas the low value for flood-dominated lakes. The remaining lakes constitute an intermediate class. Determination of the range of variability should be established individually for different river valleys. In the case of the ratio of the coefficient of shoreline expansion and the average lake depth, the values >1 are characteristic for flood-dominated type, about 1 transitional type and <1 evaporation-dominated type.
- Linking the origin of the floodplain lake with the way it is supplied. Oxbow and avulsion lakes in the vast majority belong to the group of flood-dominated lakes. The anastomotic lakes are most often transitional lakes, while the inter-levee lakes are evaporation-dominated lakes.

Division by water hydrochemistry

The quality parameters of the floodplain lake waters result from the period of their functioning cycle (potamophase, limnophase, flooding). During the potamophase, the parent rivers transform the quality of the lake waters in a short period of time as a result of intensive exchange. During overbed flows of the parent river, multiple mixing of waters in the basin takes place. Dynamic supply of allochthonous river waters determines the ionic composition of lake waters often for many months, and hydrochemical processes of catchments of the lakes are of little importance. In the period of limnophase, the physical and chemical parameters of the waters of the floodplain lakes are determined by the supplying waters of the own catchment. The quality of lake waters is then determined by atmospheric precipitation, surface and underground inflow (hypodermic and from a deeper groundwater table). In turn, the flooding is an important but only cyclical episode in flood ecosystems, during which lakes are only the recesses of submerged flood terraces [41]. General hydrochemical relationships resulting from the cycle of successive potamophases and limnophases and their effect on the quality of valley waters can be expressed with the β index. It is the ratio of Ca^{2+} cation concentration to the sum of Cl^- and ${SO_4}^{2-}$ anions concentrations [42]. Calcium, as a product of calcium carbonate dissociation processes, is treated as a geogenic ion, typical for the natural environment with a significant share of carbonate sediments. Sulfates and chlorides, being good migrants, are an indicator of the degree of anthropogenic transformation of the environment. The percentage quotient of the limnic and fluvial index β $\left(F = \frac{\beta_{\text{lakes}}}{\beta_{\text{rivers}}}\right)$ is the basis for determining the similarity or difference in the quality of these two environments. On this basis, the following groups of lakes can be distinguished:

Minor – lakes with a low F-value. The waters of these lakes have a higher share of anthropogenic components than in the waters of the parent river.
Maior – lake waters have a lower share of anthropogenic ions than that of the parent river. In this case, the quality of lake waters is shaped by processes related mainly to chemical denudation of the sediments of the reservoir's basin.
Integralis – lakes showing an apparent similarity in the size of lake and river β indices. Potamic supply is the main factor shaping the quality of lake waters. The limits of the F index ranges for the distinguished lake types are the arithmetic mean ± half of the standard deviation. When the distribution of quality parameters of the analyzed lake waters corresponds to the normal distribution, the defined limits divide the area of the variability of the index value into three ranges, the narrowest of which is the middle range (*integralis*). This is due to the need to emphasize the hydrochemical similarity of limnic and potamic waters. The value [F] below 85% means a transformation of lake waters in the direction of pollution growth and belonging to type 3 (*minor*). The opposite situation (F-value > 115%) is represented by waters of lakes of natural hydrogeochemical character, the quality of which is shaped by the supply from the own catchment. The values [F] in the range of 115–85% correspond to type 2 (*integralis*).

The way of connection between the lake and the parent river and the forms of supplying the lake basins constituted the basis for distinguishing three types of lakes within each of the lake types. Interzonal lakes (IZ) are lakes with a hydrologically dominant role of the reservoir own catchment area. When the area of lake recharge is a catchment area of the parent river, one deals with extrazonal reservoirs (EZ). The third group of mixozonal reservoirs (MZ) are those lakes in which there is no clear dominance of a particular type of catchment.

6.4.2 Anthropogenic Lakes

A separate group of lakes are anthropogenic lakes, which were created as a result of artificial regulation procedures [43]. These are the lakes located on a flood plain, which were created mainly as a result of cutting off the side arms of the river from the main river bed or closing the water space between the groynes as a result of regulatory works carried out. These lakes are often referred to as quasi-ox-bows or post-regulation reservoirs. The isolation of a lateral river bed or a fragment of the river itself results from a process aimed at narrowing the main river bed [44]. The scope of work carried out, and the type of regulation structures used to play an important role. The diagram of regulation works in the river is presented in Fig. 6.6.

River regulation includes: strengthening riverbank, works in the river bed and in the floodplain area, including flood protection. The regulation belongs to the group of hydrotechnical works, which have been carried out on a large scale and for a long time. From the very beginning, their aim was to make fuller use of the rivers and to protect the population against the threat that they may pose to the adjacent areas under extreme conditions.

The regulation of rivers according to the designed course of the river bed route is carried out with the use of appropriate regulatory structures. Such structures may be heavy or light. Heavy regulatory buildings are constructions built on a permanent basis, ensuring the durability of their construction at all water levels encountered on a given river. These structures include groynegroynes, longitudinal and transverse dams, breakages and edge bands. Light regulatory structures are those that can be easily and quickly built and, if necessary, dismantled. An example of such a structure can be different types and sizes of fences [45, 46] (Fig. 6.6).

Depending on the degree of river bed narrowing and the regulatory structures used, anthropogenic lakes may be formed in different ways. Authors [17, 47] distinguished the following methods of anthropogenic lakes formation (Fig. 6.7):

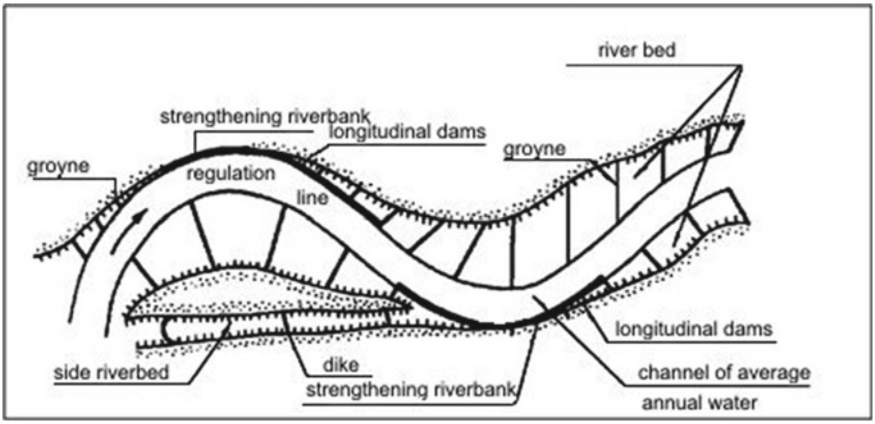

Fig. 6.6 Distribution of heavy regulation structure in a river [45]

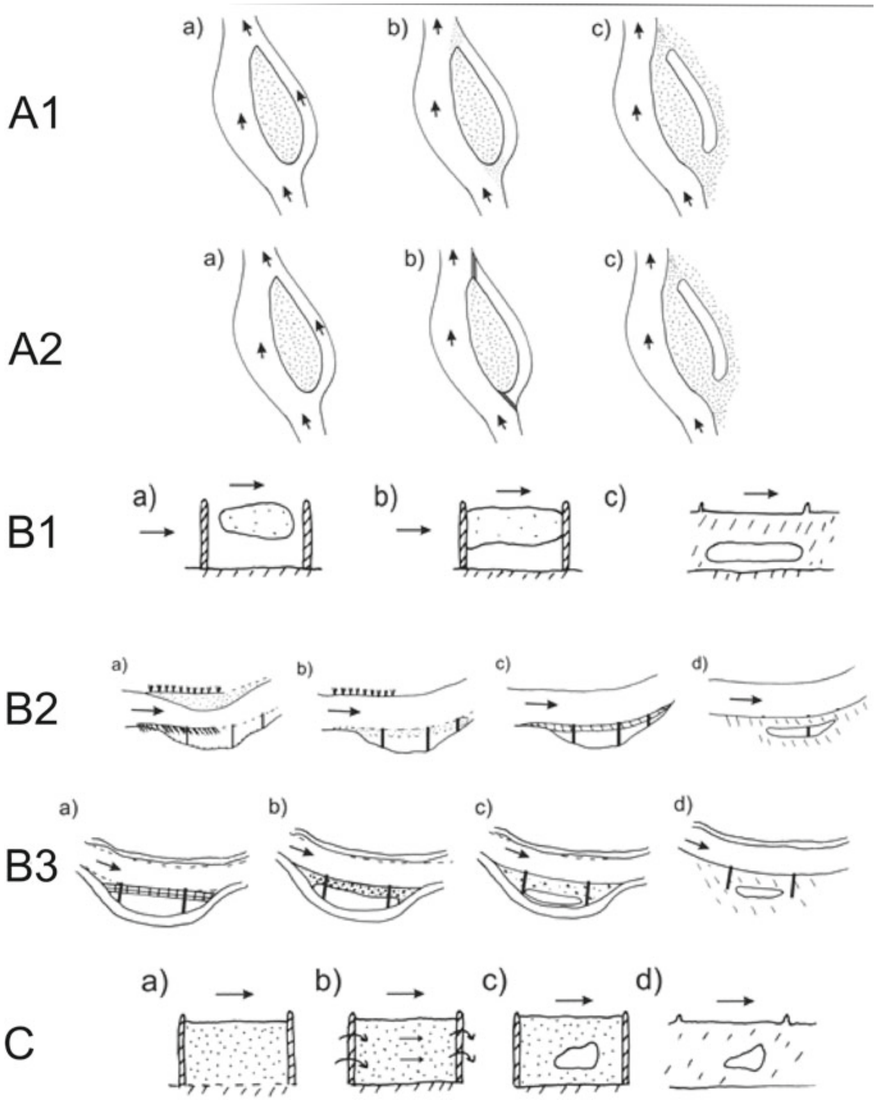

Fig. 6.7 Steps of post-regulatory reservoirs creation [17, 47]

Created as a result of river arms cutting off from the main river bed

The cutoff can occur naturally by backfilling with debris carried by the river (on one or both sides) as a result of stream diversion. In turn, the artificial cutoff is the result of closing a branch (also on one or both sides) as a result of breakage, construction of river groynes or transverse dams. A cutoff arm that had closure on one side could be used as a relief canal or work canal.

Created as a result of closing the water space between the groynes

Construction of the groynes perpendicularly to the banks of the river bed changes the existing hydrodynamic conditions as a result of a change in the course of the bed and river streams. Near the groyne heads, river streams collapse and the dragged debris is deposited in their "shade" [48]. Three mechanisms of this process can be distinguished:

- natural accumulation of material. Sandbanks formed parallel to the shore separate the water spaces cutoff from the main river bed. Gradually, the sandbanks are fixed by vegetation, while the cutoff water surfaces are continuously reduced and shallow.
- forced accumulation. It leads to a partial transformation of the spaces excluded from the active river bed into the land area. This applies especially to sections where the space between the groynes was large, and the dragged debris movement is observed in the watercourses. In the space between the groynes, at different distances from the shore, fascine mattresses or wicker curtains were usually placed at the bottom of the rivers, which slow down the speed of the flowing water and encourage the depositing of the retained material.
- artificial landing. When the space between the groynes is shallow, the land is strengthened with vegetation planting, most often with willow seedlings.

Created as a result of the floodplain erosion

This process usually occurs during floods. When the water level in the river is high, previously accumulated material is eroded and washed away. A basin is created in the place where the material is eroded by the river, and it is filled with river water.

Taking into account the nature of the inflow or outflow to lakes in regulated river valleys, a simple and complex hydrographic system can be distinguished [47].

The simple system includes single reservoirs (Fig. 6.8):

A flow lakes

A1 along the axis:

(a) with gravitational inflow and outflow,
(b) with regulated inflow and outflow,
(c) with gravitational inflow and regulated outflow,
(d) with regulated inflow and outflow.

A2 asymmetric, in close vicinity there is inflow and outflow of water:

(a) with gravitational inflow and outflow,
(b) with regulated inflow and gravitational outflow,
(c) with gravitational inflow and regulated outflow,
(d) with regulated inflow and outflow.

B lake with inflow in the form of a trench or channel from the flood plain

(a) gravitational inflow

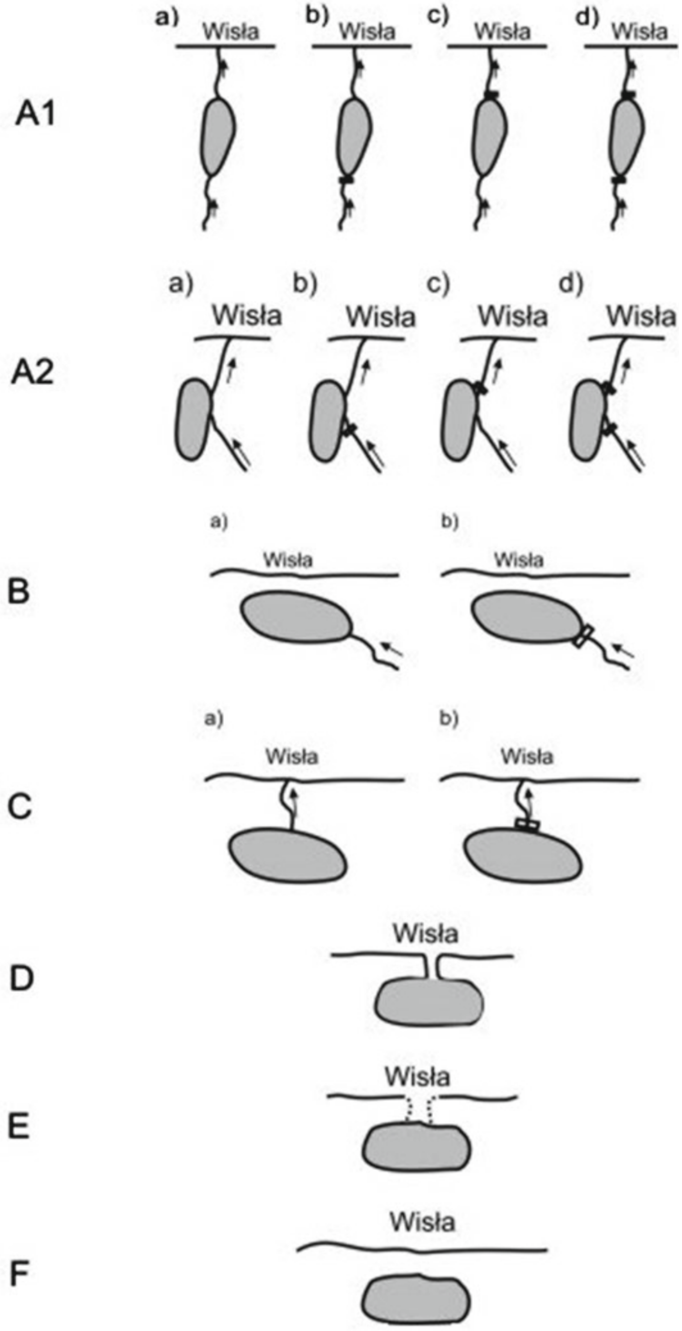

Fig. 6.8 Examples of a lake and parent river connectivity [47]

   (b) inflow regulated by means of a pumping station or a flap.

C lake with outflow toward the river

   (a) gravitational outflow
   (b) regulated outflow.

D lake without surface outflow, isolated from the river
E lake permanently connected with the river
F lake periodically connected with the river.

The complex system is a system of several (at least 2) lake basins, which are connected by means of a narrow isthmus. As a result of dams constructions, one reservoir was divided into several smaller ones. Breaks in the dams systems occurred later, which led to the connection of some of the reservoirs. Lakes with a simple system may occur within this type.

The formation and functioning of anthropogenic floodplain lakes are determined by the type and scope of river bed regulation works. The river regulation is generally defined as hydrotechnical activities (with the use of appropriate structures) aimed at creating conditions for the formation of a uniform bed of a river with gentle meandering arches and fixed cross-sections for three characteristic stages: low water (LW), medium (MW) and high (HW). Measures to achieve this aim are: concentration of the stream, consolidation of the shore, straightening of excessively sharp curves of the river, extension of excessive narrowing, i.e., creation of conditions for the free flow of ice to avoid dangerous blockages, as well as creation and maintenance of a constant depth necessary for the proper flow [45].

The appearance of a large number of anthropogenic reservoirs in river valleys was connected with the systematic regulation of major rivers in Poland, which began in the nineteenth century. Lack of maintenance and renovation of neglected regulatory buildings caused their technical condition, as well as the whole regulatory system, was constantly deteriorating. Debris was deposited in the inter-groyne zones, and new water reservoirs were created. In places where river groynes were destroyed, blurring was created in existing, already settled inter-groyne spaces. These deformations widened as a result of the swelling wave and further erosion of the reservoir. Therefore, such waters appeared most often after the passage of large floods, which meant that these are relatively young objects.

6.5 Studies and Bathymetric Plans of Selected Floodplain Lakes in Poland

The lakes of river valleys are one of the fastest growing types of water reservoirs and at the same time the most perishable forms in the landscape. The highest disappearance rate was observed in the case of artificially cutoff anthropogenic lakes [49]. The studies on floodplain lakes in Poland were carried out to a different extent (hydrological, hydrochemical, bathymetric). They included lakes located in the valleys of

Fig. 6.9 The location of selected floodplain lakes in Poland

large rivers, e.g. the Vistula [47, 50], Odra [51], Warta [52], Obra [53], Bug [37], as well as Biebrza, Łyna, Drwęca [49].

The floodplain lakes in Poland are poorly recognized in terms of the geometry of basins. Significantly more publications concern biodiversity concerning both the composition and variability of species in the lake waters in the Słupia [54], Biebrza [55], Vistula [56], Warta [57], and Łyna [58].

Bathymetric maps of selected floodplain lakes together with their location have been presented in Figs. 6.9, 6.10, 6.11, 6.12 and 6.13.

6.6 Changes in Water Relations of Floodplain Lakes

The water relations of lakes located in river valleys are a result of the degree of transformation of the natural environment of their catchment areas. In natural and quasi-natural valleys, the water balance of the lake basins results from the way they are supplied (confluent, contrafluent, profundal, etc.) and their functional period (potamophase or limnophase). In general, it can be stated that the valleys of the

Fig. 6.10 The location of floodplain lakes in the Bug River Valley

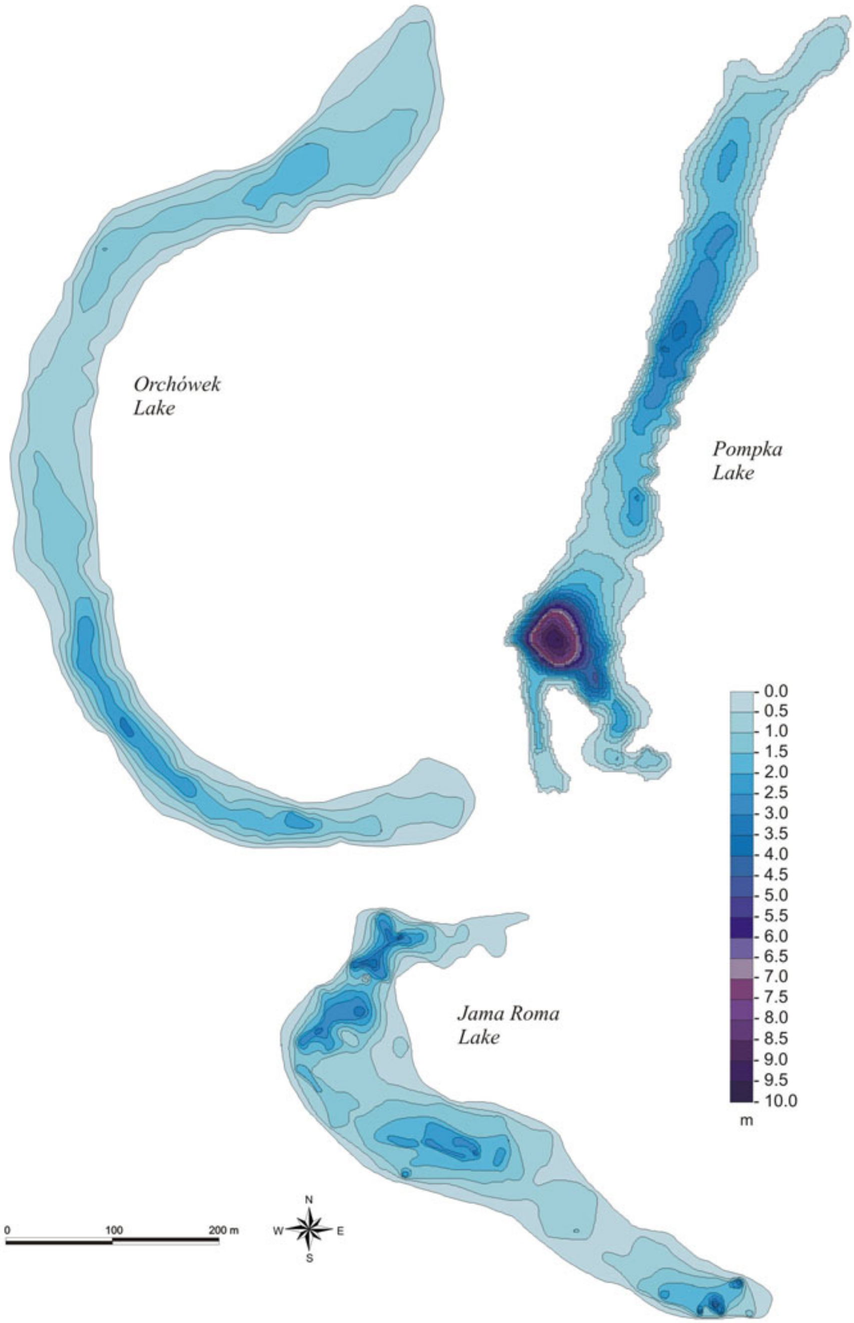

Fig. 6.11 Bathymetric scans of selected floodplain lakes in the Bug River Valley

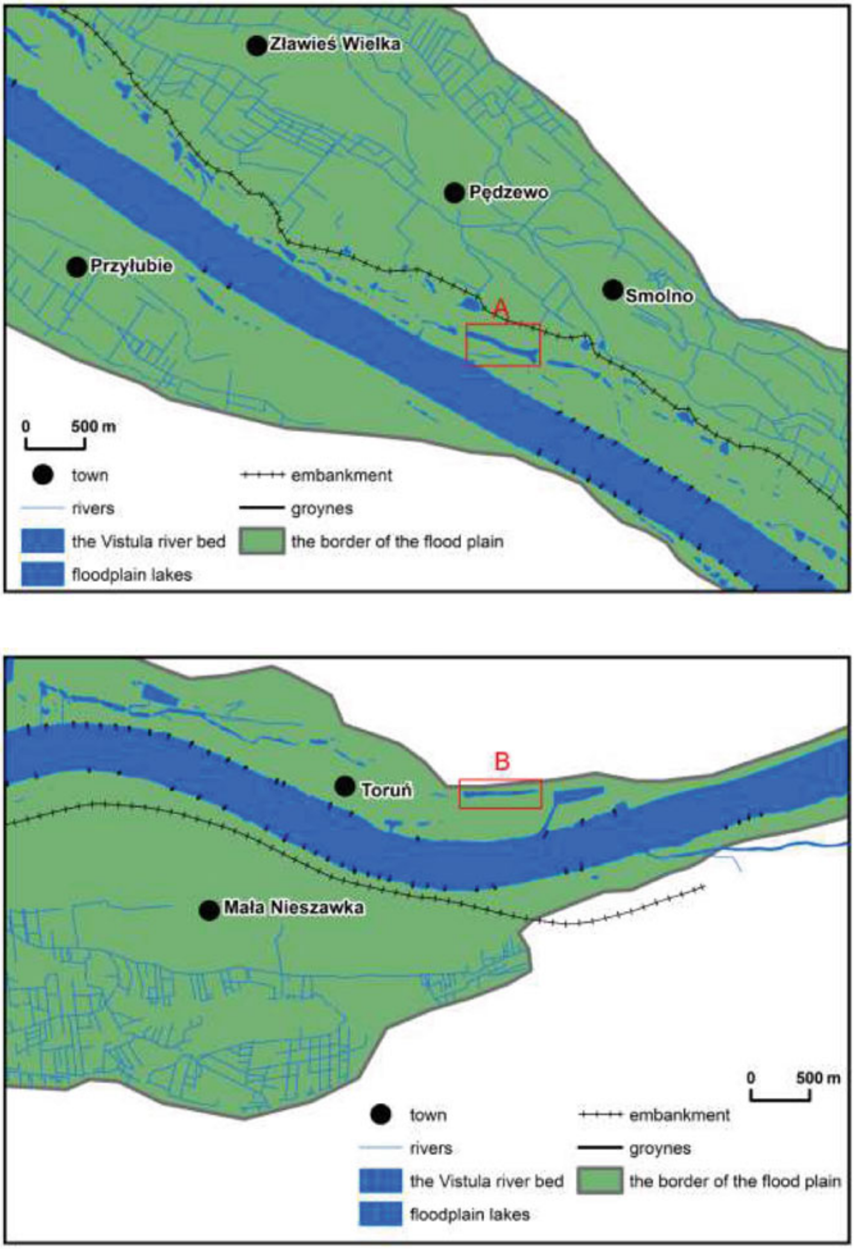

Fig. 6.12 Location of selected floodplain lakes in the Vistula River Valley (A-Smolno, B-Martówka)

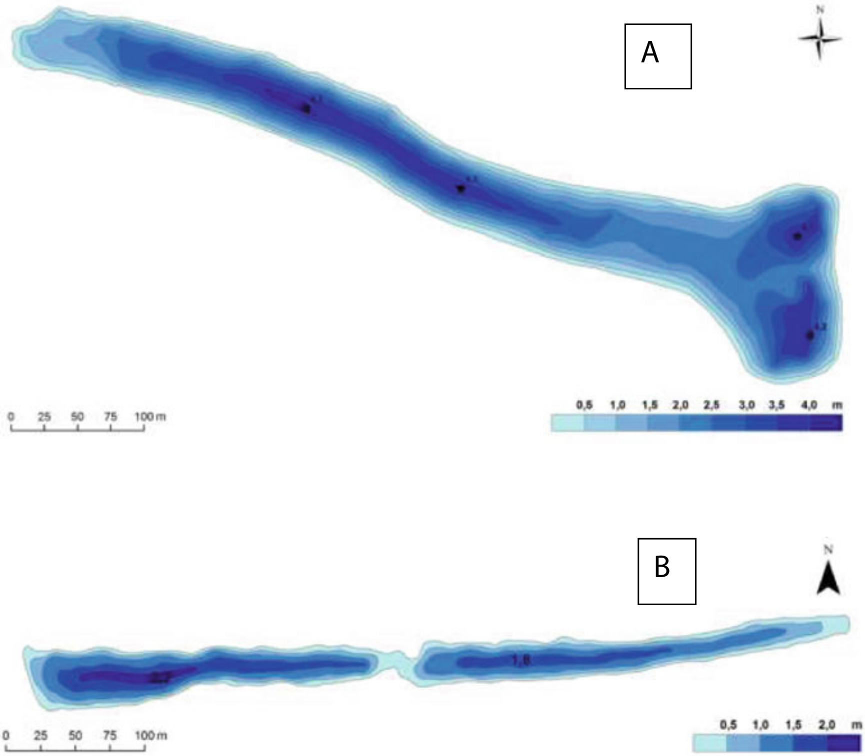

Fig. 6.13 Bathymetric scans of selected floodplain lakes in the Vistula River Valley (A-Smolno, B-Martówka)

largest rivers in the eastern part of Poland (e.g., Lower San, Lower Wieprz, Middle and Lower Bug, Middle and Lower Narew, Biebrza, Pisa) belong to the areas with relatively low anthropopression. The lakes in their valleys are numerous, and the degree of transformation of water relations in their lymnophasic drainage basins should be described as moderate or small. The western wing of the Vistula basin and the Odra basin is characterized by an increase in hydrotechnical interventions in river valleys. The effects of the main regulatory works contributed to changes in the surface of lakes. Hydrotechnical works also affect the problem of lake water quality in the hydrochemical (ionic composition) and hydrobiological sense (composition and biomass of phytoplankton, zooplankton and microplankton).

A good example of lake surface changes is the Vistula valley. There are some problems with defining the shoreline of objects, especially in the case of basins connected and forming compact complexes. However, such changes were the subject of research mainly on the regulated section of the Vistula (from Włocławek to Tczew). Studies of various details concerned both short and long sections of the valley [44, 47, 59]. They also included changes in the hydrographic network of the Vistula from the nineteenth century until 2010 (the Schroetter's map from the nineteenth century, Karte des Deutschen Reiches from the beginning of the twentieth century and a contemporary map from the beginning of the twenty-first century).

6.7 Summary

The lakes of the river valleys are very diverse reservoirs. High variability of morphometric, hydrochemical and hydrobiological as well as ecological and landscape parameters make them attractive. Moreover, they are young reservoirs subject to dynamic processes of disappearance. Although they are a very numerous group of lakes, their degree of recognition is relatively low. The small area and capacity of the basins are conducive to anthropogenic transformations. They are often backfilled, their shore zone is destroyed, and they are often the receivers of waste. Some floodplain lakes (both natural and anthropogenic ones) are used for recreation as swimming pools, fishing grounds, canoeing routes. Due to their natural values (often unique), they also have significant educational potential. The floodplain lakes allow to preserve the diversity of habitats and constitute habitats of fauna and aquatic flora. Bearing in mind the general values of floodplain lakes, active forms of lake protection and lake restoration projects can be found more often.

6.8 Recommendations

A complex mechanism of the functioning of floodplain lakes (limnophase and potamophase) and their specific environmental role (in terms of hydrochemistry and hydrobiology) require particular approach when management practices are concerned. Due to a high susceptibility of floodplain lakes on human pressure, both quantitative and qualitative protection activities are highly recommended.

In terms of quantitative issues, natural or quasi-natural type of water alimentation should be maintained. It is visible in a consistency occurrence of both periods and paths of water alimentation with a natural relation between floodplain lake and the river. In practice it means that both long-lasting potamophases or long-lasting limnophases may be observed. It often brings about high variability of water stages dynamic during the functional periods. Thus, water budget which is typical for a particular floodplain lake should be established by implicating duration of both potamophases and limnophases of the water body in question.

Qualitative approach to floodplain lakes should be focused on maintaining both typical for particular lake ionic composition and natural hydrobiological conditions of its water. It may be achieved by controlled water input from the river during the limnophase period, using drains, pipes or ditches.

Moreover a quality of the lake's catchment environment should be recognized. It is important in terms of influencing lake water quality during the limnophase period.

It is natural that water quality of floodplain lake observed during potamic supply (and afterwards) significantly differs than ionic composition formed during limnophase period.

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