Dammed lakes – Present state of knowledge and research requirements

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Abstract: The paper presents the current state of knowledge on dammed lakes in Poland and identifies the crucial research necessities in this area. The analysis of documents concerning dammed lakes and information obtained from institutions responsible for water management in Poland were the basis for a preliminary qualitative and quantitative assessment of dammed lakes located in north-west Poland. This allowed the identification of the necessary directions to be taken in the study of dammed lakes. In many cases, the indicated directions are innovative and have high potential for application.

Key words: dammed lake, hydrotechnical construction, small retention programmes

Introduction

Since the late 20th century, a considerable increase in the number of dammed lakes has been observed. They are created by raising the water level by means of a movable weir (or less frequently, a fixed weir) or water gate usually installed near the outlet from the lake.

The principal purpose of lifting the lake water level is to increase water storage capacity as a measure against the increasing frequency of drought occurrences (hydrological droughts in particular) thus mitigating drought impacts on ecosystems and water management. The practice of lake damming is one of the crucial elements of the so-called small retention problem often referred to in key documents at national and regional levels.

Scarce available data (mostly unpublished) indicate that in the period of 1997-2005, 139 lakes in Poland were dammed increasing their total surface area by 2586 ha (source: Ministry of Agriculture and Rural Development, after Mioduszeowski and Pierzgalski 2009). Consequently,

the storage capacity of lakes was enhanced by a total of 54.5 Mm³ (Mioduszeowski and Pierzgalski 2009). This result was ca. 20% higher compared to artificial reservoirs, almost four times higher than water storage increase in fish ponds and almost 6-fold higher in comparison to channel storage resulting from the implementation of field drainage systems and main drainage systems. This fact indicates the primary function of lakes in the implementation of the small retention programme in Poland. Furthermore, the average unit cost of water storage increase in 1997-2005 was the lowest for lakes at 0.21 PLN m⁻³ (i.e. artificial reservoirs – 8.40 PLN m⁻³, fish ponds 3.27 PLN m⁻³) (Mioduszeowski and Pierzgalski 2009).

The increase in lake storage capacity is still an on-going process in the second decade of the 21st century. According to the assumptions made, by 2015, water storage capacity will have reached ca. 263 Mm³ (source: Ministry of Agriculture and Rural Development, after Mioduszeowski and Pierzgalski 2009). This estimate does not seem to be accurate since in the Warmia-Masuria Voivodeship alone, water storage capacity of lakes

is planned to increase by 183 Mm³ (WZMiUW 2007) and in the West Pomerania Voivodeship by at least 37.2 Mm³ within the same timeframe (ZZMiUW 2008). Similar inconsistencies or lack of relevant information were found in other documents and regions in Poland. The “Programme of small scale retention for the Warmian-Masurian Voivodeship for the period of 2006-2015” states that the total area to be flooded by dammed lakes will reach 83.6 thousand ha in this period (WZMiUW 2007).

The present knowledge of the problem indicates that the planned increase in lake storage capacity in the entire country will not be accomplished. Nonetheless, the issue of lake damming is of such importance that it requires research that would allow its range and impact on physico-chemical and biological processes in lakes and potential changes in lake ecosystems to be estimated. Such research is being carried out by the authors.

The review of scarce literature and unpublished materials prepared for the central and regional governments indicates that lake damming has a positive impact on lake ecosystems and the adjacent area. According to ichthyologists, higher water levels in lakes contribute to a significant increase in fish production. Furthermore, dammed lakes are a much better habitat for stenothermic fish (e.g. Salmonidae and freshwater whitefish), which are adapted to low temperatures and tolerate a narrow temperature range. However, there is no evidence in the literature that raising the lake water level by several tens of centimetres, i.e. within the mean annual water level fluctuation range, causes an increase in the ratio of cold water mass to total water volume in the lake. There is no data describing the increase in the littoral surface area in particular dammed lakes and its effects on lake trophic status. This is one of the reasons why in particular cases there are negative opinions concerning the effects of lake damming.

Dammed lakes and the effects of damming require structured data, research, analyses and estimates. The authors hope that their work will contribute to at least a partial explanation of diverse problems related to lake damming.

Methods and study area

The aim of the work is to present and to analyse the current knowledge on dammed lakes and to identify the most important directions of their study. This required the study of technical, legal and environmental documents concerning lake damming, scientific publications, statute law, unpublished reports and studies of dammed lakes, lake damming permits under the Water Act and small retention programmes of the voivodeships in Poland.

A database of dammed lakes has been created on the basis of, among others, surveys sent to different institutions which, according to the authors, should be concerned with the operation and maintenance of both retaining devices and dammed lakes. Information and data provided by these institutions allowed a preliminary quantitative and spatial distribution assessment of dammed lakes to be carried out. Furthermore, information on changes in the basic parameters of lakes resulting from their damming and technical data of some water lifting structures were obtained.

This article discusses lakes located in the area of Poland within the range of the last glacial period. However, for the purpose of a more detailed and precise discussion of selected issues related to lake damming, the work focuses on the north-west part of Poland, which includes five voivodeships: West Pomeranian Voivodeship, Pomeranian Voivodeship, Kuyavian-Pomeranian Voivodeship, Greater Poland Voivodeship and Lubusz Voivodeship. The institutions responsible for water management are assigned to each particular administrative region.

Results and discussion

A dammed lake is a natural lake where the water level was raised by means of a hydrotechnical structure usually located at the lake outflow. By damming a lake, the available storage capacity is regulated (increased retention) depending on damming height, which is determined separately for each lake. Table 1 presents examples of resulting storage capacities as a function of damming heights of selected lakes in Poland. It can be noted that Lake Pakość has the largest available storage capacity (47.7 Mm³) and damming height (4.90 m) in Poland.

Hydrotechnical constructions are defined as constructions equipped with technical devices and installations used in water management and implement-

Table 1. Storage volume and damming height of selected lakes in Poland (Depczyński and Szamowski 1999, with minor changes).

No.	Lake	Region	Available storage capacity	Damming height
			[Mm ³]	[m]
1	Pakość	Greater Poland Lakeland	47.7	4.90
2	Rajgrodzkie	Masurian Lakeland	31.7	2.05
3	Necko	Lithuanian Lakeland	27.7	3.36
4	Miedwie	Szczecin Lakeland	27.5	0.70
5	Gopło	Greater Poland Lakeland	21.2	0.95
6	Jeziorak	Łąwa Lakeland	18.0	2.35
7	Serwy	Lithuanian Lakeland	11.0	1.86
8	Dzieżgoń	Łąwa Lakeland	9.0	1.70
9	Urszulewskie	Chełmno-Dobrzyń Lakeland	9.0	1.50
10	Gołdopiwo	Masurian Lakeland	8.5	2.25

ed for the purpose of regulation of water resources and their exploitation (Journal of Laws of 2007, No 86, Item 579). They are built for protection against the destructive power of water or for the purpose of water use. Hydrological constructions used only for protection against the destructive power of water include stream-regulating structures used for river control and flood control (levees). Constructions that enable the storage and use of water are barrages. A barrage consists of a dam, gates and constructions that use water (Depczyński and Szamowski 1999). A damming

structure is therefore any hydrotechnical construction that allows water, liquid or semi-liquid substances to be raised above the level of the surrounding area or reservoir (Journal of Laws of 2007, No 86, item 579). The most common damming structures used in lakes are weirs and water gates (Fig. 1, Fig. 2).

Although generally lake damming is considered to be a positive practice, its effects do raise concerns. The literature on the subject gives several examples of beneficial impacts of lake damming such as the following: increment of water resources, increased volume

Fig. 1. Movable weir at the outlet of Lake Osiek, 2009

Fig. 2. Movable weir at the outlet of Lake Dzieżgoń, 2011

of stored water within a catchment, rising groundwater level (thus increasing groundwater resources), increased moisture level in hydrogenic habitats, reduced surface water runoff and an overall improved water balance. Lake damming fulfils specific purposes, the effects of which have to be seen as beneficial: lowered flood risk, decreased frequency of low flows, water supply for urban and rural areas, agriculture, industry (including mills), power plants etc., and creating recreational space on the lake and its surroundings. Artificially raising the water level in a lake has a positive impact on “ecotonic zones” – by increasing biodiversity, overall improvement of both the environmental status and quality of surface waters.

Any human interference in the environment brings both positive and negative effects. The negative effects of lake damming include the possibility of local flooding, disruption of debris movement in rivers, disturbed migration of fish and swamping of adjacent areas (lakes with low shores). In the case of reversing the swamped areas to their previous status, several indirect negative effects of lake damming emerge such as, for example, creation of drainage systems thus lowering groundwater levels, decreasing groundwater resources, desiccation of surrounding areas and increased inflow of non-point source pollution in the event of reflooding the desiccated adjacent areas. The negative impacts of lake damming on the lacustrine ecosystem also include the decline of “un-

derwater meadows” resulting from high fluctuations of the water level, increased infusion of phosphorus and nitrogen compounds from sediments, decreased population of littoral vegetation – natural “biofilters” – increased transport of non-point source pollutants, negative changes in “ecotonic zones” – decreasing biodiversity, disturbing the general environmental equilibrium and, contrary to positive effects, deterioration of surface water quality.

The literature on the subject, therefore, presents an ambiguous attitude towards the effects of lake damming on the lacustrine ecosystem and surrounding areas.

Review of Polish literature

In the literature on the subject of dammed lakes, the most notable positions include works on water damming impacts on the ecological processes of lakes (Gołdyn 1990), changes in lake ecosystems using the example of Lake Lubikowskie (Tonder 1993) and changes in lake water levels using the example of Lake Wielki Bytyń (Staniewska-Zątek 1992).

The issues of degradation resulting from damming and the potential to improve the status of water using the examples of Lake Pakoskie and Lake Gopło (Jańczak et al. 1999; Jańczak et al. 2001; Jańczak et al. 2002) and theoretical retention capacity of large lakes in Poland (Jańczak et al. 2004) were also discussed in depth.

The biggest changes resulting from lake damming in Poland took place in Great Masurian Lakes. The changes occurred in several stages between the 16th and 19th centuries. The water level in lakes was lifted by the use of weirs and several sluices. The main purpose of the damming was not to increase retention but to create an inland navigation route connecting the basins of the Vistula and Pregola Rivers. This resulted in a considerable increase in lake area and the creation of new reservoirs (Dąbrowski 2001).

Research into lake damming in the context of hydrological changes in the Masurian lakes was carried out by Marszelewski and Adamczyk (2004), and in Lakes Gopło and Bachotek by Skowron (2002), Dorożyński and Skowron (2002), Skowron and Dorożyński (2004).

The subject of the effects of lake damming on the littoral zone was discussed by Nowak and Grześkowiak (2010) and Grobelska (2004, 2006, 2007).

The literature review shows that the number of publications on the topic of the effects of damming on lakes is rather small. The number of unpublished materials is much larger but very often such sources are difficult to access. These materials usually discuss particular lakes. Relatively speaking, much information can be found in works concerning the implementation of small retention programmes. However, the information there usually relates to the plans of lake damming in particular voivodeships. While much attention is devoted to small retention programmes in Poland, there is a considerable lack of exhaustive analysis of the subject of lake damming. There is no comprehensive work indicating which lakes are dammed, no materials on lake damming on a local, regional and national scale, no studies that would determine the effect of damming on the condition of lakes. This leads to the conclusion that in Poland there is no synthetic study of impacts of damming on water resources and condition of lakes.

Small retention programmes

Basic legal acts related to the issues of lake damming include the following:

- The Water Framework Directive – Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy,
 - Water Law – Act of 18 July 2001 on Water Law (Journal of Laws of 2012, Item 145 as amended),
 - Construction Law of 7 July 1994 (Journal of Laws of 2010, No. 243, Item 1623 with later amendments),
 - Nature Conservation Act of 16 April 2004 (Journal of Laws of 2009 No. 151, Item 1220, as amended),
 - Regulation by the Minister of the Environment of 20th April 2007, On the technical requirements for hydrotechnical structures and their location (Journal of Laws of 2007, No 86, Item 579),
 - Regulation of the Minister of Agriculture and Rural Development of 30 December 2004, On the procedures of registering water bodies, water management facilities and ameliorated land (Journal of Laws of 2005, No. 7, Item. 55),
 - Regulation of the Minister of the Environment of 17 July 2006, On the scope of water management guidelines (Journal of Laws of 2006, No 150, Item 1087),
- The agreement of 21 December 1995 between the Minister of Agriculture and the Food Industry and the Minister of Environmental Protection, Natural Resources and Forestry on cooperation within the programme of small retention,
- The agreement of 11 April 2002 between the Minister of Agriculture and Rural Development, the Minister of the Environment, the President of the Agency for Restructuring and Modernization of Agriculture and the National Fund for Environmental Protection and Water Management on cooperation for the development of small retention and the implementation of pro-ecological methods of water retention.
- The agreement signed on 21 December 1995 between the Minister of Agriculture and the Food Industry and the Minister of the Environment, Natural Resources and Forestry on cooperation for small water retention activities resulted in the development of small water retention programmes to the year 2015 in each voivodeship. These programmes were updated after the introduction of a new administrative division in Poland in 1997 and after the next 7 years, the first assessment of the implementation of the programme was conducted (Kowalewski 2004). According to the assessment, lake damming constituted the basic component of the small retention programmes providing the highest increase in water resources while requiring the least investment on the national scale (Table 2). Unjustifiably, lake damming is an underestimated practice often of marginal importance. It probably results from the fact that constructing water reservoirs is a spectacular process receiving much public attention. Construction of a water reservoir translates into an incomparably higher in-

Table 2. Implementation of small retention programmes in Poland in 1997-2003 (after Kowalewski 2004)

Basic components	Retention increase	Costs
	[Mm ³]	[M PLN]
Dammed lakes	46.5	10.4
Water reservoirs	37.3	231.9
Fish ponds	14.2	42.6
Channel retention	8.2	76.4
Other	1.0	3.1
Total	107.2	364.4

crease in retention capacity over a small period of time but also into high investment costs and, quite often, social and economic losses.

In the period of 1997-2003, 135 lakes were dammed, which incremented water retention by 46.5 Mm³. This is only 22.4% of the total number of objects planned to be dammed and 17.6% of the retention capacity planned to be achieved by 2015 (Table 3). It is, therefore, to be expected that in the next few years, there will be a rapid increase in the number of dammed lakes.

Table 3. Implementation and planned effects of lake damming within the small retention programme in Poland (after Kowalewski 2004)

Dammed lakes	Number of objects	Increment of retention
		[M m ³]
Completed in 1997-2003	135	46.5
Planned results by 2015	602	262.9

Inventory of dammed lakes – preliminary results

In order to examine the actual progress made in building water lifting constructions and to assess the probability of achieving the goals set by small retention programmes in a particular area, the authors conducted a preliminary inventory of dammed lakes and water lifting constructions in the area of north-west Poland. For this purpose, the main institutions responsible for water management in Poland were asked to allow access to environmental information. The requests, containing also a survey, solicited basic information on dammed lakes i.e.: the lake's name, its localization, volume and area of the lake before and after the damming, retention increment, available storage capacity. The request for technical data of water lifting constructions was also included, i.e.: type,

width, height, construction date, date of the most recent renovation and the current technical condition of the construction.

The collected data allowed a database to be created using the Geographic Information System (GIS) of dammed lakes and water lifting constructions located in north-west Poland. The database contains essential information on the locations of dammed lakes and water lifting structures, the number of dammed lakes, date of water lifting in a given lake, type of hydrotechnical structure and technical data of those structures. This allowed the creation of maps of spatial distribution of dammed lakes and water lifting structures in north-west Poland. A preliminary analysis of localizations of dammed lakes in the studied area shows that the percentage of such lakes in the total number of lakes is significant. However, not all dammed lakes were included. The information on the damming of some lakes can be found only in the literature or it is the authors' own knowledge.

The most information on dammed lakes was obtained from the Regional Boards of Land Reclamation and Water responsible for the development and implementation of small retention programmes. To a large degree, the data are incomplete or insufficient for a thorough analysis. It appears that the greatest problem is the lack of sufficient data on the localization of hydrotechnical water lifting structures and their poor technical condition. Furthermore, it is quite difficult to access the relevant water permits, which are scattered in many institutions or are missing altogether. Hydrotechnical structures not operating as intended or poorly maintained can negatively affect the environment, e.g. cause local flooding. The most dangerous situations occur where water is lifted without the required permits. There are cases of unlawfulness and in the event of damage to the lake and its surrounding area that should be compensated, no responsible parties are to be found. It is mainly in cases of such lakes that compiling accurate data is very difficult and it will be necessary to carry out thorough field research where all required parameters of water lifting structures will be measured and their technical condition assessed.

Study necessity

In the time of high interest in water retention increment, it seems that there is a considerable need for a study of both dammed lakes and water lifting structures. It is necessary to create a database of

dammed lakes and to provide a uniform inventory system for such lakes.

From the national water management point of view, the identification of changes in morphometric parameters of lakes resulting from damming, and of changes in lake water resources caused by damming as well as the determination of water retention capacity in dammed lakes, including retention on local, regional and national levels as well as within the catchment system, need to be carried out.

Since the lakes are required to achieve a good ecological status, the determination of changes in lake water quality caused by damming must be considered a priority. A study of this issue will allow the impact of lake damming on their ecological status to be assessed. The changes to the dynamics and hydrological and hydrochemical regime of dammed lakes should be characterized as well as the effects of lake damming. Also, the positive and negative impacts of damming on lakes need to be identified.

Should negative impacts of damming be found, it will be necessary to propose possible solutions for mitigating such effects and also possible changes (amendments) of regulations promoting rational use of lakes to prevent the decline and abuse of water resources and quality of lakes.

Completion of the aforementioned studies, analyses and assessments will provide the basis for the first synthetic work on dammed lakes in Poland. The conclusions of this study could be significant groundwork for successive lake damming projects.

The presented issue is innovative and has potential for application. So far, there have been a number of works attempting to produce an inventory of dammed lakes and water lifting structures. In the near future, work related to changes in water resources and physico-chemical and biological changes in the water of dammed lakes will begin. The hydrological analysis and the study of lake quality will include a representative group of dammed lakes. The selected lakes are located in north-west Poland. The analysis will include periods before and after damming. Historical data and authors' own studies will allow changes occurring in lakes as the result of damming to be analysed to the greatest extent possible. Historical data are made available by the Institute of Meteorology and Water Management – National Research Institute, the Inland Fisheries Institute and Voivodeship Inspectorates for Environmental Protection.

Conclusion

Dammed lakes have not been – so far – studied using one uniform method. The majority of case studies do not include assessments of lake damming impacts on qualitative and quantitative changes in lake water. No database containing information about dammed lakes exists. The exact number of dammed lakes in a particular region, catchment or part of Poland is not known. The required permits to build water lifting structures are stored by different institutions, which makes it difficult to collect uniform documentation on dammed lakes. Given this state of affairs, it seems imperative to systematize all the information and to assess the impacts of damming on lakes. Such a necessity also arises in the context of intensified discussions on the effects of lake damming. The debates are often based on presumptions rather than the actual data and research results. There is no doubt that at present a comprehensive study of dammed lakes and analysis and assessment of impacts of damming on water resources and quality of lakes are urgently and justifiably needed.

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