Ecological Engineering 95 (2016) 714–722

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Can we stop the degradation of lakes? Innovative approaches in lake restoration

Julita A. Dunalska*, Grzegorz Wiśniewski

Department of Water Protection Engineering, University of Warmia and Mazury in Olsztyn, Prawocheńskiego str. 1, 10-719 Olsztyn, Poland

ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form 30 June 2016
Accepted 23 July 2016
Available online 1 August 2016

Keywords:
Urban lakes
Water quality
Recreation
Lake protection
Lake restoration

ABSTRACT

We studied an urban, flow-through lake with a large total catchment area, in the context of implementing complex protection and restoration methods in the shoreline zone and within the lake's basin. The study was found that the annual total load of nutrients was 4 688 kg P and 50 652 kg N, which – when converted to the lake's unit area – corresponded to 8.2 g P m^{-2} y^{-1} and 88.4 g N m^{-2} y^{-1}. Taking into account the surface inflows alone, the current actual phosphorus load of the lake is over 20-fold higher than the permissible one. An additional source of phosphorus is the lake's bottom sediments, which is confirmed by the negative balance of this element (−2 882.5 kg P y^{-1}). Despite the polymictic type of the lake, oxygen deficits may appear near its bottom, which intensify the internal enrichment process. At present, the primary production in the lake is extremely large, which is indicated by a very high oxygen content (the maximum value of 230%) coinciding with a very high pH value (around 9.7 at both sites) as well as a high chlorophyll *a* and seston content (158 mg m^{-3} and 30.6 mg dm^{-3} at sites S-1, 176 mg m^{-3} and 33.4 mg dm^{-3} at sites S-2, respectively), and a low visibility of Secchi disc (around 0.5 m at both sites). At such advanced trophy of the lake and high content of phosphorus (TSI(TP) = 100), it is impossible to stop the rapidly progressing degradation of this water body without man's intervention. The only possible way to eliminate allochthonous sources of pollutants is by constructing a system of pipelines and waterproof walls for transporting pollutants outside the lake's catchment. Selection of adequate technological solutions must be preceded by a detailed analysis of hydrological and morphometric properties of the water body, parameters of its catchment and the potential use of lake water in the context of economic calculations. An innovative approach may involve self-oxygenation of lake waters by supplying some of a lake's surface inflow water to the lake's bottom. This method can assist in improving oxygen conditions, which to a large extent will reduce the internal supply. It can also be a supporting method in the process of phosphorus inactivation with the use of safe ferrous coagulants, whose efficiency of phosphorus precipitation and immobilization depends on the oxygen content.

1. Introduction

Under natural conditions, development of phytoplankton and macrophytes, which represents primary production, is regulated either by possible deficit of one of the chemical components or by a specific pattern of the physical or hydrochemical conditions of the aquatic environment. This is a mechanism of self-regulation of water ecosystems. Eutrophication, which in essence means enrichment of the mineral nutrient base or a change in the physical conditions of the surroundings to ones which stimulate photosynthesis and matter cycling, can disrupt the equilibrium and intensify primary production (Carpenter, 2005, 2008; Istvánovics, 2009). Water eutrophication accelerates due to growing amounts of nutrients imported to water from point sources of discharge of household, industrial and farm wastewater as well as agricultural runoffs (Barlow et al., 2005; Ellwood et al., 2009; Zhang et al., 2010). More intensive agricultural production necessitated a search for increasingly more efficient agrotechnical methods. Application of large quantities of artificial fertilisers enhances the yielding of crops but simultaneously becomes a considerable source of nitrogen and phosphorus in surface waters. Amounts of nutrients running off from fields depend on the type of plant cover, soil structure, i.e. mechanical properties and permeability, the sloping angles of shores as well as the amount and character of precipitation

* Corresponding author.
E-mail address: julitad@uwm.edu.pl (J.A. Dunalska).

http://dx.doi.org/10.1016/j.ecoleng.2016.07.017
0925-8574/

(Dunalska, 2011a; Grabowska et al., 2014; Fraterrigo and Downing, 2008; Malmaeus and Håkanson, 2004).

For maintaining a good ecological state of waters, it is essential to limit the import of pollutants from the catchment. This requires a detailed review of the wastewater management in the lake's catchment, followed by making an inventory and calculating a balance of pollutants originating from point, non-point, linear and atmospheric sources. Next, it is important to determine what amounts of these nutrients are allowable in the lake (Jeppesen et al., 2007; Peterson et al., 1999; Søndergaard et al., 2001; Welch et al., 1980). Elimination of point pollutants (household greywater and sewage, industrial wastewater, rainwater carried to either the lake or its tributaries through water collectors) is a fundamental step in any lake protection programme. However, non-point pollution sources are much more difficult to control. They include wastewater from villages lacking sewage systems which enter lakes through soil, confined groundwaters, field drainage ditches, defective septic tanks and cesspools, etc. Any effort to limit an import of contaminants from such sources requires to pay special attention to single household greywater and sewage treatment systems and to construct local and collective water treatment plants (WTPs). Area pollution is mainly caused by agricultural activity, and therefore can be controlled through a variety of methods adjusted to particular catchments, their physiographic and soil characteristics, the current management of a given area and hydrographical conditions. All approaches aim at closing the circulation of water and nutrients within an area dedicated to agricultural production and limiting their transfer to adjacent land. What is particularly important for protection of water bodies is the proper land management in immediate surroundings of lakes or rivers. Protective barriers should be created of plant assemblages, which inhibit migration of nutrients (McDowell et al., 2006; Muirhead et al., 2011; Redding et al., 2008; Tanner et al., 2005). For years, water bodies have fallen 'a victim' of irrational human activity. Today, it is necessary to combine several methods in order to halt the process of rapid degradation of lakes. By just reducing the influx of nutrients from external sources, good results can only be achieved when dealing with weakly or moderately eutrophic lakes. Badly degraded lakes may not respond to it, most often because they have an internal supply of nutrients. Bottom sediments of heavily eutrophic lakes store huge quantities of both phosphorus and nitrogen, which – at least theoretically – are an inexhaustible source of these elements (Marsden, 1989; Søndergaard et al., 2003; Welch and Cooke, 2005). Both the internal supply of nutrients and the fact that flow-through lakes have a constant delivery of nutrients from the total catchment via surface inflows make an efficient restoration of such water bodies extremely difficult and expensive. Our objective in this research project was to develop innovative concepts and complex protection and restoration measures that would improve the water quality of heavily degraded lake. A lake situated in urban surroundings was chosen for our study. It is a flow-through lake, which receives waters from a total catchment area of over 100 km^2. Detailed analyses of hydrological as well as physicochemical parameters of waters were done, including the lake's inflows and a surface outflow. Based on the analytical results, thermal and oxygen profiles were elaborated, the current trophic status of the lake determined and loads of nutrients from external sources estimated. Finally, the phosphorus and nitrogen balance were calculated.

2. Material and methods

2.1. Study site

Wierzysko Lake lies in the basin of the rivers Wierzyca and Vistula and belongs to the Kashubian Lake District, which is situated in the macro-region called the Eastern Pomeranian District (Kondracki, 2011). It is an urban lake, located within the town limits of Kościerzyna. Two rivers flow through the lake: the Wierzyca and the Bibrowa. This is a glacial lake, presenting characteristics of a ribbon lake. The longer axis runs from the north-east to the south-west (NE-SW). Morphologically, this is a single-basin lake with no distinguishable sink basin (local depth). The maximum depth of 6 m occurs in several sites, centrally in the lake (Fig. 1). More detailed morphometric parameters of the lake are given in Table 1.

The total catchment basin of Wierzysko Lake covers 131.82 km^2 (Fig. 2). The land within the catchment is mostly used for agriculture and residential purposes (the town Kościerzyna as well as some small villages and settlements), while the share of forested land is small. Among parameters which describe the land relief, the most distinguishing are the slope gradient (11.57‰) and the elevation difference (132.8 m) in the catchment. These values of the said parameters are typical of lake districts in northern Poland (Kondracki, 2011). The lake's direct catchment covers 111.61 ha. The types of land cover found there are mostly forests (70.92 ha), arable land (14.18 ha) and urban land (11.83 ha) (Table 2).

2.2. Water sample collection

Physicochemical properties of Wierzysko Lake were determined in an annual cycle, taking into account all plant growing seasons (October 2013, November 2013, April 2014, June 2014, August 2014). Samples were taken from the surface and bottom layers at two stations located w middle (S-1) and north-east (S-2) part of the lake (Fig. 3). In addition, in October 2013, November 2013, December 2013, March 2014, April 2014, June 2014, August 2014 and October 2014, the measurements were made of the hydrochemical parameters of water in the surface inflows and outflow

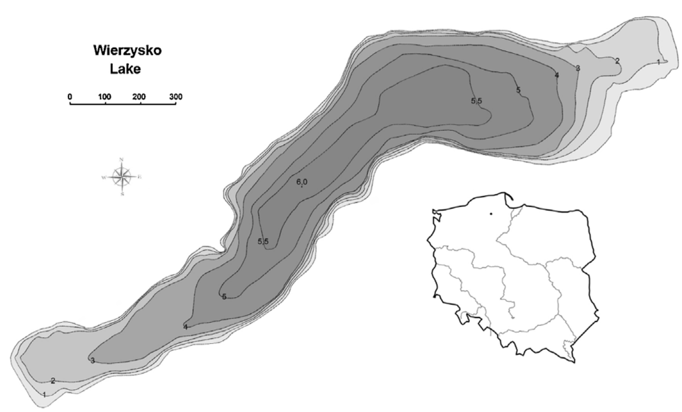

Fig. 1. Bathymetric maps of Wierzysko Lake.

Table 1
Morphometric parameters of Wierzysko Lake.

Parameter	
Geographical coordinates	54°6′21″N 17°59′24″E
Elevation of average water table (m AMSL)	146.4
Lake surface (ha)	57.32
Maximum depth (m)	6.0
Average depth (m)	3.7
Relative depth	0.0079
Depth indicator	0.62
Volume (in thousand m^3)	2 118.3
Maximum length (m)	2 110
Maximum width (m)	410
Average width (m)	272
Elongation indicator	5.1
Coastline length (m)	5 150
Shoreline expansion indicator	1.9