

Changes in Water Resources of Polish Lakes as Influenced by Natural and Anthropogenic Factors

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Abstract

Processes of lake shrinkage as a result of the action of natural and anthropogenic factors in recent decades have been considerably accelerated. On the other hand, lake capacities may have increased as a consequence of damming. These changes are typically analyzed in relation to changes in lake area, while horizontal and vertical components are excluded. The aim of this study was to assess changes in morphometry in several lakes in central western Poland and to determine changes in water resources in selected lakes as a result of changes in their morphometry. These changes were analyzed based on archival data concerning the area and capacity of lake basins, collected from studies prepared by the Institute of Inland Fisheries in the early 1960s and current bathymetric studies. These investigations showed that within approx. 50 years a considerable decrease was recorded in the area of the analyzed group of lakes, amounting to 14.8% (i.e., 172.6 ha). As a result of changes in the area and shallowing of lakes, the water resources stored in lakes decreased by a total of 7.7%, which amounts to 3.6 million m³. Referring to the factors determining the above-mentioned transformations, it was found that both climatic and anthropogenic conditions were disadvantageous. While in the study period no trends were observed for changes in precipitation, a significant increase in temperature was found, thus contributing to increased evaporation. This situation was compounded by human activity connected with land reclamation operations or agricultural activity.

Keywords: lake disappearance, bathymetry changes, lake shallowing

Introduction

Northeastern central Europe is characterized by a considerable number of lakes [1]. These lakes play an important role in the preservation of water resources and

biodiversity, while they also are significant for economic activity [2]. Their occurrence is connected with the limits of the last Weichselian glaciation. In the case of Poland there are more than 7,000 natural lakes with an area of min. 1 ha [3]. They are located mainly within three large lake districts: Pomerania, Wielkopolsko-Kujawskie, and Masuria.

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Postglacial lakes have been evolving since they were formed, which in the end results in their shrinkage. The rates of these processes vary and generally depend on morphometric characteristics of the lakes, the size and character of catchment use, climatic conditions, etc. [4-7]. The process of lake shrinkage may be the result of a lake basin filling with deposits and fluctuations of water levels. In the latter aspect a particular role is played by human activity, which through, e.g., land reclamation operations in the catchment may have a marked effect on fluctuations in water tables and their continuous lowering. In extreme cases we have observed a drastic reduction of their area or complete discharge of water from lakes [4-5].

Data obtained so far, based on the analysis of changes in the area, indicate that the mean forecasted age of lakes in Poland is approx. 2000 years [8]. Thus it is a short period in the geological scale. Moreover, it needs to be remembered that lake basins, being three-dimensional objects, are also subject to the process of lake shrinkage connected with their shallowing. In view of several functions served by lakes in the natural environment – both in relation to its natural elements (water cycle, microclimate, biodiversity, etc.) as well as artificial ones related with human life (agricultural irrigation, industry, tourism, etc.) – it is obvious that lakes should function in the environment for the longest possible period, serving the above (and other) roles to the greatest possible extent. A significant problem is connected with water deficits observed in different regions of the world [9-11], and lakes may constitute considerable reservoirs of readily available water, in contrast, e.g., to underground waters. Poland is a country with the least amount of water resources in Europe [12] – comparable to those of Egypt. At least for this reason it is essential to have detailed information on water resources deposited in lakes and the changes affecting them.

The aim of this study was to 1) determine in a comprehensive manner the changes in lakes, covering the horizontal and vertical components connected with their contemporary evolution and 2) to determine changes in water resources of selected lakes in the Wielkopolska region as a result of changes in their morphometry.

Material and Methods

This paper presents an analysis of changes in the area and capacity of 18 lakes located in west-central Poland (Fig. 1). The location of lakes to a considerable extent overlaps with the area of the lowest water resources in Poland. Low precipitation and relatively high air temperature result in a situation when the mean specific discharge in many regions is as low as $2\text{-}2.5 \text{ dm}^3 \cdot \text{km}^2 \cdot \text{s}^{-1}$ [13]. A key aspect in the selection of the lakes was related to the bathymetric studies by the Institute of Inland Fisheries in Olsztyn (IRŚ) prepared in the 1960s. The analyses of changes in area of the lakes was based on data given in the bathymetric charts of the institute and on 1:50,000 hydrographic maps of Poland from the early 21st century.

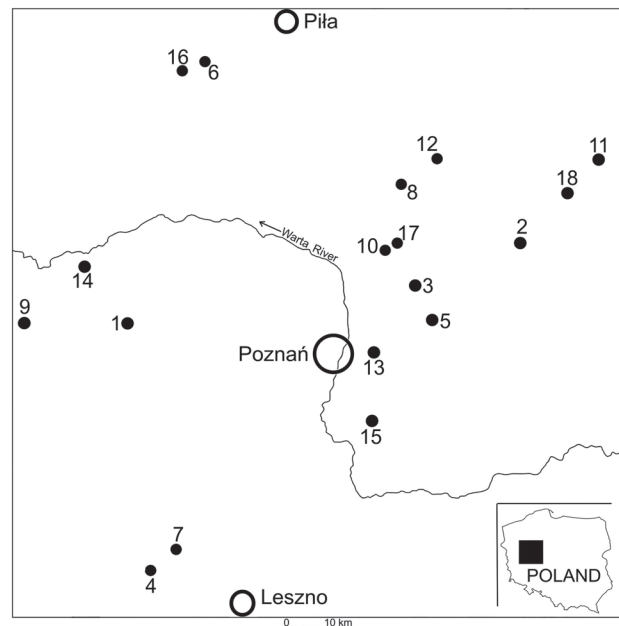


Fig. 1. Locations of analyzed lakes: 1 – Konińskie, 2 – Mielno, 3 – Turoślawskie, 4 – Linicjusz, 5 – Biezdruchowo, 6 – Sarcze, 7 – Wielkie, 8 – Łęgowskie, 9 – Pszczewskie, 10 – Włókna, 11 – Kierzkowskie, 12 – Łeknieńskie, 13 – Swarzędzkie, 14 – Ławickie, 15 – Skrzyńka, 16 – Straduń, 17 – Maciejak, and 18 – Gąsawskie.

In the determination of bathymetry for the analyzed lakes we applied the method presented by Choiński et al. [14].

Measurements were taken in 2013 and 2014 using a Garmin Fishfinder 100 sonar and a GPS Garmin GPS 12

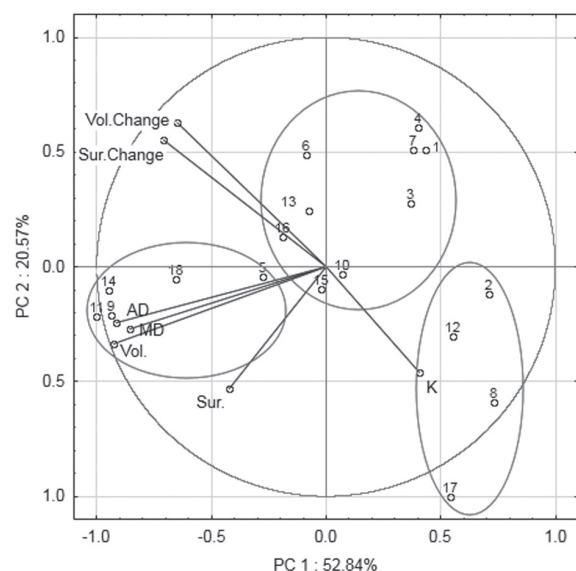


Fig. 2. Distribution of the analyzed lakes in the system of the first two principal components (PC1 and PC2) based on morphological parameters.

Abbreviations: Vol. Change – lake volume changes, Sur. Change – lake area changes, AD – average depth, MD – maximum depth, Vol. – volume, Sur. – lake area, K – shoreline development index, 1-18 – studied lakes.

Table 1. Selected morphometric parameters of analyzed lakes in two studied time periods.

Lake number	Lake name	1950s/1960s			Early 21 st century		
		Surface	Volume	Average depth	Surface*	Volume	Average depth
		[ha]	[mln m ³]	[m]	[ha]	[mln m ³]	[m]
1	Konińskie	24.2	0.4	1.7	23.0	0.3	1.3
2	Mielno	26.1	0.6	2.3	18.1	0.4	2.2
3	Turoslawskie	32.9	0.8	2.6	25.7	0.7	2.7
4	Linicjusz	37.5	0.4	1.3	30.0	0.4	1.3
5	Biezdruchowo	48.8	2.8	5.7	37.8	2.6	6.9
6	Sarcze	51.1	1.9	3.7	48.9	1.9	3.9
7	Wielkie	51.2	0.6	1.3	40.0	0.5	1.3
8	Łęgowskie	68.4	1.2	1.8	43.5	0.8	1.8
9	Pszczewskie	68.7	6.5	9.5	61.6	5.7	9.3
10	Włókna	74.4	2.4	3.2	60.7	2.2	3.6
11	Kierzkowskie	77.3	6.1	8.0	72.2	5.8	8.0
12	Łeknieńskie	85.2	1.3	1.6	56.9	0.9	1.6
13	Swarzędzkie	90.0	2.1	2.3	81.4	2.3	2.8
14	Ławickie	90.1	6.5	7.3	82.8	6.4	7.7
15	Skrzynka	91.5	3.1	3.4	72.1	2.6	3.6
16	Straduń	96.7	3.0	3.2	90.5	2.8	3.1
17	Maciejak	59.0	1.7	2.7	61.2	1.7	2.8
18	Gąsawskie	99.0	5.7	5.8	93.1	5.4	5.8
	Average	1172.1	47.1	3.7	999.5	43.4	3.9

*area of lakes by Czarnecka et al. [13]

receiver. In view of the fact that the Institute was sounding the lake bottoms using a sounding line in order to eliminate the measurement error resulting from the application of a different methodology (echo sounder), results were verified by comparing echo sounder measurements with the results provided by the sounding line. Lake capacity was determined according to Penck's method, in which the lake basin is equivalent to a set of truncated pyramids closed with a cone.

Principal component analysis (PCA) was employed to investigate differences between lakes based on morphological parameters. All statistical analyses were performed using Statistica (StatSoft, Poland) software.

Results

The analysis of 18 lakes in Wielkopolska showed that their shrinkage rates vary. Based on morphological parameters and the rate of disappearance in the PCA diagram, lakes were classified into three groups (Fig. 2). The first two factors identified 73.41% total variation. The first group comprised four lakes characterized by the greatest change in capacity and area, i.e., Lakes

Mielno, Łęgowskie, Łeknieńskie, and Maciejak. The other distinguished group with the greatest capacity or depth included five lakes: Biezdruchowo, Miejskie, Kierzkowskie, Ławickie, and Gąsawskie. The other lakes with a varied overgrowth rate or shallowing rate as well as differing in morphometric parameters comprised the other group.

Data concerning changes in morphometry of the investigated lakes in relation to the main parameters are given in Table 1. In the analyzed period of approx. 50 years we have been observing a considerable transformation of lake ecosystems. We need to stress a considerable reduction of lake area by a total area of 172.6 ha, which constitutes a decrease in relation to the initial status by as much as 14.8%. The greatest area shrinkage was found in Lake Łęgowskie (36.4%) (Fig. 3). In turn, the smallest shrinkage was recorded in Lake Sarcze (4.3%).

As a result of the reduced area and the simultaneous process of shallowing, a decrease was observed in water resources stored in the analyzed lakes. Jointly for all lakes we observed a reduction of water resources by 3.6 million m³, which constitutes 7.7% decreased capacity in relation to the 1950s. For comparison, the total water resources of lakes in Poland amounts to ca. 20 km³. The greatest

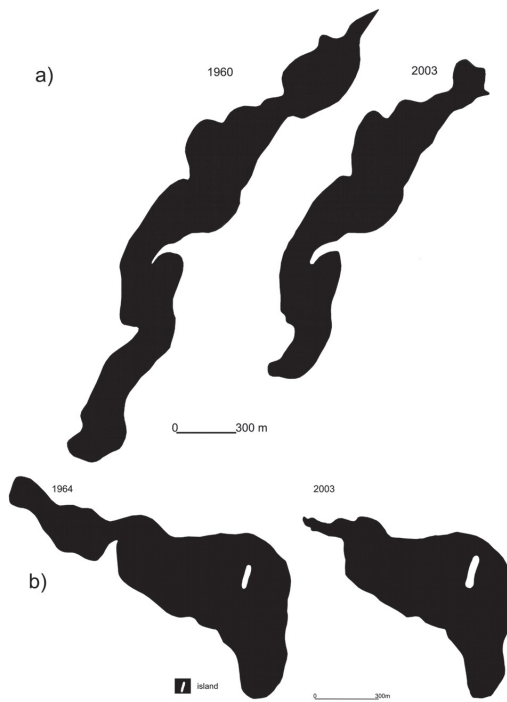


Fig. 3. Selected examples of changes in lake area: a) Lake Łęgowski, b) Lake Biezdruchowo.

depletion of water resources was recorded for Lakes Łęgowski and Mielno (Fig. 4), which in both cases was as much as 33%. Mean depth (calculated as a ratio of lake capacity to its area) specified jointly for all lakes increased by 0.2 m, which is a result of the considerable reduction of their area.

The greatest changes in bathymetry of lakes were observed within the shallowest isobaths. Analyses showed a shift in individual isobaths toward the centre of lakes. In the case of Lake Mielno we may consider the narrowing between the two basins – where the continuity of the 1 m isobath is broken – as the characteristic site. In turn, in the case of Lake Biezdruchowo the characteristic site may be identified as the area of an island whose growth has contributed to considerable changes in the distribution of isobaths. In both cases the predominant volume of shallowing was approx. <math><0.5\text{ m}</math>.

Discussion

Problems of contemporary morphometric changes in lakes are extensively investigated in different parts of the world, comprising both analyses of their area [15-20] and bathymetry [21-25]. The rates and scales of these transformations vary. Comparable findings to those reported in this study (e.g., due to climatic conditions and the scale of anthropopressure) were given in earlier studies concerning lakes in Poland, conducted in various periods and for a varied numbers of water bodies. They may be referred both to changes in area [26-30] and bathymetry [31-35]. In both cases they are consistent and thus they

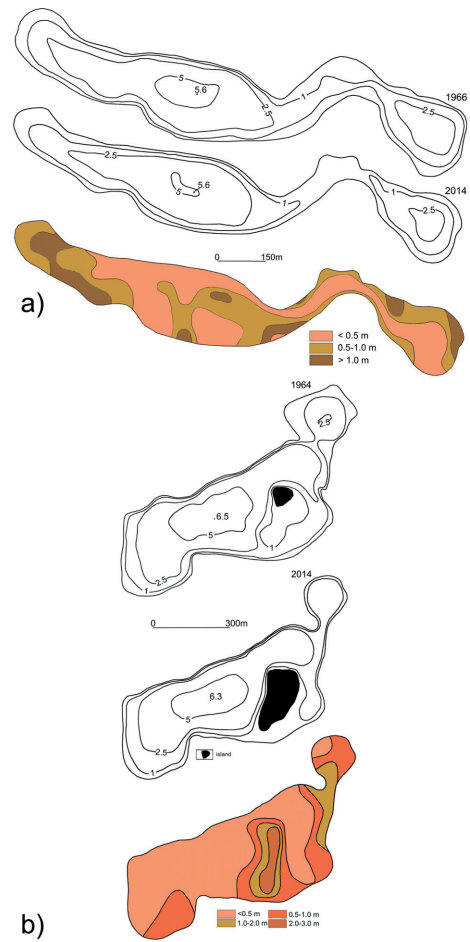


Fig. 4. Changes in bathymetry and shallowing of lakes: a) Mielno, b) Turostowo.

confirm that we are observing successive reductions of lake area and depletion of water resources.

In spatial terms (i.e., referring to the region or individual catchments) it is frequently difficult to identify factors responsible for changes in lake area and bathymetry. It is essential to definitely specify processes influencing fluctuations of water levels. Bonacci et al. [36], when referring to changes in water levels in Lake Dojran, stressed that it is not easy to specify what determines them, whether it is climatic factors or whether they are caused by human activity. This statement may be considered universal in many other cases. Moreover, monitoring sites of hydrological conditions located in the vicinity of drainage networks [37] additionally hinders determining causes of water level changes.

Analyses of changes in climatic conditions for the Poznań weather station (located in the central part of the analyzed area) in the period investigated in this study are presented in Fig. 5 [based on 38-39].

We see from the graphs presented above that over the entire multiannual period no significant trend was observed for changes in precipitation, and that a marked increase in air temperature was recorded. This increase at the Poznań station is consistent with the course of air temperature in other regions of Poland, and it is directly

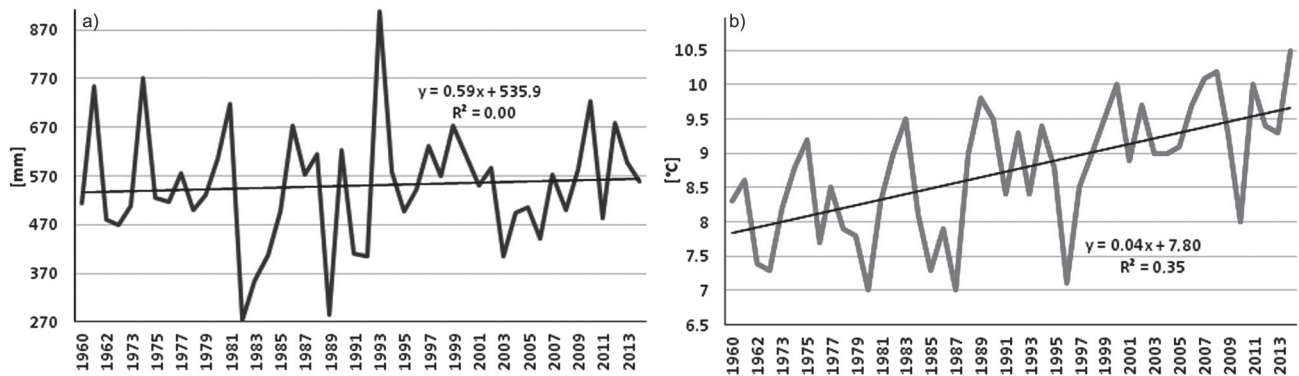


Fig. 5. Fluctuations in precipitation a) and air temperature b) for the Poznań weather station in 1960-2014 [based on 38-39].

reflected in the elevation of lake water temperatures [40]. Such a situation affects changes in the components of the water balance of the lakes. Kędzióra [41] stated that for Wielkopolska (i.e., the area where most lakes in this study are located) in the years 1996-2006 evaporation from the water surface increased from 600 to 1,000 mm. In turn, Chmal [42], when investigating evaporation from the water surface of Lake Sławskie (located approx. 20 km from analyzed lakes Linicjusz and Wielkie) in 2007 stated that it was greatest in June and amounted to 114.3 mm. In the same month the precipitation total for Leszno station (approx. 40 km from Lake Sławskie) was 47.5 mm (en.tutiempo.net). Thus the deficit was considerable and amounted to almost 67 mm.

Another element contributing to changes in water levels and thus changes in lake area is connected with human activity. Water bodies whose catchments have been affected by drainage operations differ markedly from neighboring lakes in terms of transformation processes [43-44]. The greatest intensity of large-scale drainage operations in Poland was observed in the 19th century. As a result, water levels dropped considerably in many lakes (also in the study area), occasionally leading to their

complete drainage [7]. Among the analyzed lakes, over the course of decades a marked decrease in water levels (amounting to 1.1 m) was recorded in Lake Maciejak (Fig. 6).

Optimal assumptions for hydroengineering works should ensure regulation of water relations so that it may be possible to discharge waters in the case of their excess and facilitate their retention during shortages. In the case of lakes, dual control may be executed thanks to the damming infrastructure located on the watercourses flowing out of these lakes (weirs, gates). In the set of lakes analyzed in this study there are several on which such a practice was applied, e.g., lakes Łęgowskie, Konińskie, Straduń, and Swarzędzkie.

The effect of hydroengineering structures on stopping the decrease in lake area and water resources in the above-mentioned cases may not be definitely evaluated. Despite the potential to maintain the assumed water level, area decreased in all lakes. Moreover, except for Lake Swarzędzkie (Fig. 7), a reduction of water resources was also recorded.

Situations in which the area was also reduced (apart from the potential stabilization of water levels) need to be associated with their overgrowth. This process is relatively common [45-46] and, as indicated by the situations described in this study, it affects even those lakes in which the water level is regulated artificially. An example of vegetation succession is presented in Fig. 8.

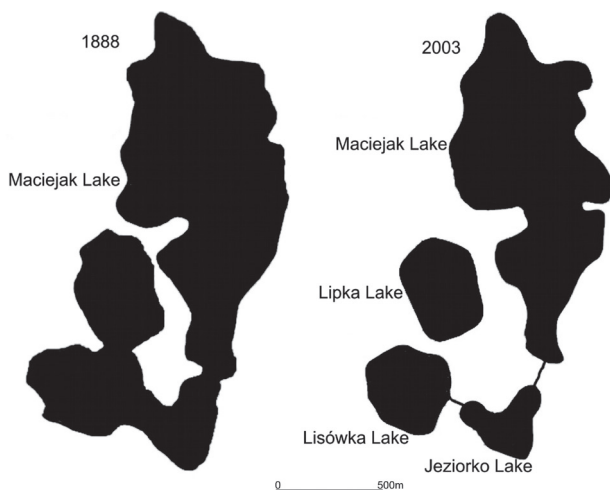


Fig. 6. Division of Lake Maciejak into several water bodies in the period 1888-2003.



Fig. 7. A weir in Lake Swarzędzkie; in the background is considerable vegetation succession.



Fig. 8. The overgrowing Lake Mielno.

The scale and rate of lake overgrowth, next to direct human interference, is connected with the lowering of water levels in lakes (i.e., when water damming on a larger scale is rather exceptional), and thus the exposure of the shallower sections of the littoral zone has been considerably accelerated by the inflow of biogens from agricultural sources [47]. This manifestation of the human impact on lake ecosystems was limited, e.g., at Poland's accession to the European Union. The need to standardize legal regulations in Poland to conform to EU requirements (e.g., the Nitrate Directive) was connected with the reduction of the influx of nitrogen and phosphorus compounds, although obviously it has not eliminated them completely. Moreover, the growth of aquatic vegetation may be stimulated by the secondary supply of lakes, where, e.g., as a result of resuspension of deposits, biogens are again introduced to the pelagic zone and this contributes to the deterioration of the trophic state. Internal supply is frequently the main component of the presence of nutrients in water [48-50]. Due to the deforestation of central Poland dating back several centuries, in most cases the analyzed lakes are located in catchments with predominant agricultural areas with intensive farming systems. Even lakes situated in areas legally protected in many cases may be degraded. Pasztaleniec and Kutyla [51], when analyzing 92 lakes located in national and landscape parks, stated that only 50% of them had at least good ecological status, while the others were classified as moderate, poor, or bad.

Other intermediate forms of human impact on the functioning of lakes are also connected with human activity in the catchment and they are manifested, e.g., in the lowering of groundwater levels. A complicated problem related both to the indirect human impact together with the accompanying adverse changes in natural conditions was presented by Przybyłek and Nowak [52]. Those authors found that both mining-related drainage and adverse climatic conditions are responsible for the lowering of water levels in lakes in central Poland (the Gnieźnieńskie Lake District).

Conclusions

The analysis of the area and bathymetry presented in this paper for the group of around a dozen lakes located in west central Poland indicates that in a period of approximately 50 years we have observed their considerable transformation, most noticeably in the marked decrease in their area and water resources stored in lake basins. The achieved results show a 1.7% reduction of lake surfaces and a nearly two times lower reduction of water resources, amounting to 7.9%. These results indicate that the reduction of lake surfaces is more significant than lake shallowing. These changes, due to the functions served by lakes in the natural environment, need to be considered undesirable. A particularly important role is played by the successive decrease in the water storage capacity of lakes. It is particularly crucial in view of the recently observed and increasing hydrological and extreme weather processes (floods, droughts). Lakes, due to their high retention potential, have a stabilizing effect in such situations in their catchments.

When discussing changes in lake area and bathymetry we need to be aware that they are a natural element of their evolution. In the case of analyzed lakes this evolution is accelerated by human activity and climate change. However, it is nevertheless difficult to identify causes for morphometric changes taking place in lakes. An exception in this case is provided by lakes subjected to the direct process of water regulation, which clearly and definitely indicates causes for changes in their area and bathymetry.

The scale of changes in bathymetry due to a lack of comparable data for a larger set of lakes is still insufficiently clarified. Lake sounding as a result of its labor intensity is most typically undertaken on single lakes or a set of several water bodies. These data need to be considered valuable, as thanks to them it is possible to determine changes in lakewater resources in Poland, and as a result identify current water resources in our country.

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