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Retrospective ties of Lake Kalotė with the Baltic Sea and the Akmena-Danė River, western Lithuania

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Abstract. The network of streams is one of the most active and dynamic factors reforming the relief and landscape. Together with the global factors of climate formation and trends of neotectonic movement, the streams are naturally and by means of the anthropogenic factor joining or re-joining the catchments the area of which is changeable. The aim of this research was to reveal in greater detail the development of the Lithuanian Baltic Sea coastal landscape with focus on Lake Kalotė outflows surface runoff within two coastal catchments, the catchment of Pajūris Rivers and the Akmena-Danė River sub-catchment, in time and space. That is important even nowadays under the climatic challenges and anthropogenic pressure in the coastal areas rich with lakes and small streams. The methods used were the analysis of old maps and aero-photo material, geological-geomorphological, hydrological, land reclamation and soil data obtained in the area of the Pajūris Regional Park and Klaipėda district municipality, supplemented with the results of recent land surface and soil surveys, drone technique and ArcGIS. As a result the possible scenarios of Lake Kalotė outflows surface runoff directions from the 17th to the beginning of the 21st century were prepared with the evidence of periods with lake's bifurcation regime.

Keywords: *outflows; surface runoff; bifurcation regime; catchment; sub-catchment; flow scenarios*

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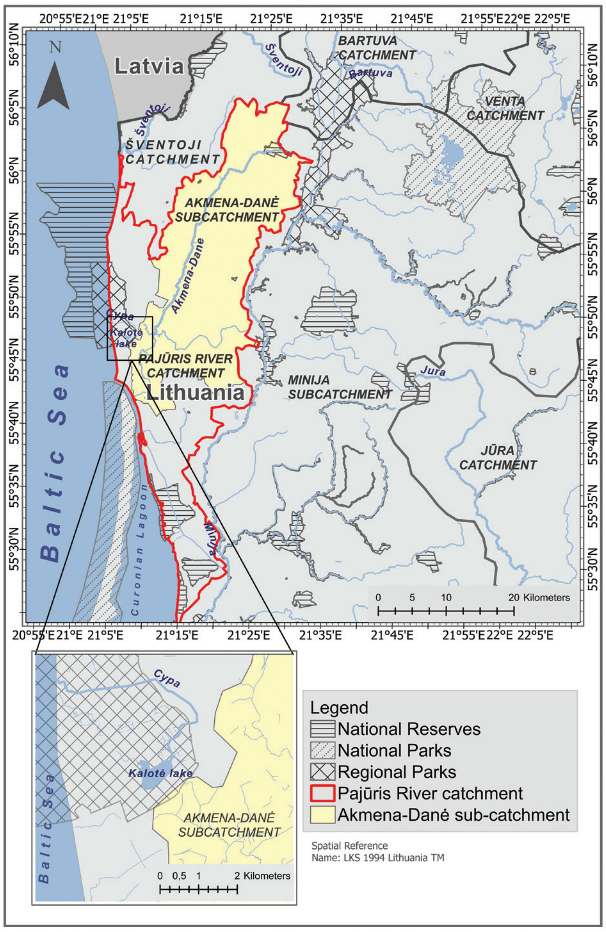
INTRODUCTION

Lithuania is located in the Baltic Sea catchment area which belongs to a large EU marine and coastal environment. Marine waters make 6,437 km^2 or 9.6% of the total country land and water area (HELCOM 2017; Wise Marine... 2022). Two large river catchments were formed in this coastal area: the catchment of Pajūris (seacoast) Rivers with no main stream and the Akmena-Danė River sub-catchment (Fig. 1). The coastal landscape can be considered to be the developing polystructural and polyfunctional natural-anthropogenic structure, where water factors are the most active and dynamic (May 1976; Basalykas 1986; Turner *et al*. 2001; Antrop 2005). According to the position in the watershed, lakes can be divided into those which are located in the border areas of river catchments and those which aren't (Bieliukas 1961; Beven, Wood 1983; Ludwig, Mauser 2000). The studied Lake Kalotė can be attributed to the lakes of the first group.

The Akmena-Danė River ends in the Klaipeda Strait within the Klaipėda city (Taminskas *et al*. 2011;

Bučienė *et al*. 2019; Bučienė, Kuisė 2019; Čepienė *et al*. 2022). The old Curonian hydronym for this river was the 'Dangė' (Demereckas 2002; Žiemytė 2010) which can be found in the old maps and historian texts. The anthropogenic pressure in the Pajūris Regional Park (Pajūris RP) is mostly evident by the increase of the built-up area and development of fishery, agriculture and tourism-recreation activities (HELCOM 2017; Paplauskis 2022). It differs from low by the coastal line from the Karklė village towards Lake Pla-

a



b

Fig. 1 Map with location of the catchment of Pajūris rivers (within red borders) and the Akmena-Danė sub-catchment (area in yellow); the studied site of Lake Kalotė and its recent outflow, the Cypa River (a); photo of the north-western side of Lake Kalotė (b)

Table 1 Type of documents compiled and used for the current research

Type of documents	Explanation
Old maps	The main information sources were from Klaipeda museums, historian books, Klaipeda university departments and libraries (paper-copies), as well as from David Rumsey Collection (available from the Internet): https://www.davidrumsey.com/luna/servlet/detail/RUMSEY~8~1~289569~90061658:Composite-Map--Karte-von-Ost-Preuss; https://www.landkartenarchiv.de/tk100_sonderkarten.php?qhttps://www.oldmapsonline.org/map/geoportost/BV042518395 and https://www.geoportal.lt/map/Žemėlapių_fondai/Istoriniai/ In total, 23 maps were studied of which 9 were selected for this paper (see in Figs 4, 5, 6, 7)
Aero-photo material	Mainly from the WWII period and second half of the 20th century available at: Antrojopasauliniokarometųa erofotonuotraukos (arcgis.com)
Reports on land reclamation, land cover, soil types and texture	Data of local land reclamation projects and soil surveys fulfilled from 1960 to 1986 in the kolhozes of Klaipeda district and archived at the Agriculture Department of Klaipeda District Municipality https://www.klaipeda_rajono_savivaldybe.lt; from books (LTSR Žemės kadastras 1979; Žemės kadastras 1989); Reports of Pajūris RP available at: https://www.pajuris.info/index.php?option=com_content&view=article&id=74%3Aekologins-problemos-parke&catid=36%3Agamta&Itemid=83&lang=lt
Geological data	Database of Geological Survey of Lithuania with a description of 49 boreholes in the vicinity of Lake Kalotė and nearby settlements (https://www.lgt.lt/epaslaugos/elpaslauga.xhtml)
Hydrographic data	From the books (Lietuvos TSR upių kadastras1959; Gailiušis *et al*. 2001; Kilkus, Stonevičius 2011) and Gamtos katalogasKalotėsežeras (Klaipėdosrajone) – Vandenstelkiniai (vilnius21.lt)

cis under conservation regime to higher in palve ecosystems and agroecosystems with densely populated Kalotė, Zeigiai, Normantai and Karklė villages.

The boreal forests stretching in more than 30% of the area constitute the main type of land cover at the Lithuanian coast. A small part of land cover is used for agricultural needs, but urbanization is rapidly increasing in the region (Verkulevičiūtė-Kriukienė *et al.* 2021) due to the nearness of the Baltic Sea, Klaipėda city with the seaport, and Palanga resort town. The present-day conditions and processes on the coast are important because they are the key to the past, even if the present does not function in the same way (Kalnina 2001). The aim of this research was to reveal in greater detail the development of Lithuania's Baltic Sea coastal landscape with focus on the direction of the outflow of Lake Kalotė within two coastal catchments – the catchment of Pajūris Rivers and the Akmena-Danė River sub-catchment – in space and over a large timescale – from the second part of the 17th to the beginning of the 21st century.

METHODS

The main methods used in this research were the analysis of old maps supplemented with historian texts, as well as compilation of other data sources (Table 1). In addition, recent field researches, as well as soil and geodesy surveys were made in the area round Lake Kalotė using drilling technique and a spade to 1.5–2.0 m depth and EMLID Reach RS+ (https://globalgpssystems.com/brand/emlid/). The results of a recent soil texture and land surface survey were compared with earlier obtained data. Drone technique was used for supplementing the studied site data with photo and video material.

THE RECENT AND PALEOGEOGRAPHIC SITUATION AT THE CONTINENTAL COAST OF LITHUANIA

The natural physical background of the coastal landscapes of Lithuania is represented by several large structures such as the shallow Baltic Sea offshore (up to 20 m isobaths), beach, primary dunes, range of dunes, and the palve – a plain landform extending directly after the range of dunes (Basalykas 1965; Gudelis 1998; Gelumbauskaitė 2000; Stančikaitė 2004; Kabailienė 2006; Gelumbauskaitė, Šečkus 2005; Molodkov *et al.* 2010; Paškauskaitė, Šinkūnas 2014; Bitinas, Damušytė 2019). The territory of the Pajūris RP occupies 5,865 ha in total, of which the area under conservational regime takes 2,630 ha (LIFE09 NAT/LT/000234 Inventory…; Paplauskis 2022). Lake Kalotė surface area in different sources is documented differently: from about 47 ha (Gudelis 1998), 50.6 ha (Restauruotinų Lietuvos ežerų… 2009) and 51.4 ha (Kalotės ežeras. VLE… 2006). Nowadays, the lake is located in the catchment of Pajūris Rivers, 22.09 ± 0.01 m a. s. l. (authors' measurements in September 2022) about 2 km eastward from the seacoast.

The terrain around Lake Kalotė was formed by the deglaciation of the Upper Nemunas (Late Weichselian) Glaciation and Holocene approximately 11,000–12,000 BP (before present). The melting waters were distributed within depressions of the relief of the paleocoast and crossed by streams flowing to the previous Baltic Sea or Lake stage (Basalykas 1965; Česnulevičius 1999; Molodkov *et al.* 2010; Baltijos jūros krantų... 2014; Borzenkova *et al*. 2015; Bitinas, Damušytė 2019). To the north and northeast of Lake Kalotė, the relief is formed from the material released from the body of the glacier at the edge of the glacier – moraine sediments. Southwest of Lake Kalotė, the basin that was lying between the slabs of dead ice formed a huge glaciolacustrine kame plateau. Thus, unique relief of Lake Kalotė was formed between semi-passive and dead ice fields. After ice melting, the relict lakes were formed. Lake Kalotė is recognised as one of this type of lakes with mostly round or horseshoe shape, shallow (average depth about 1.0 m, max depth 2.4 m) and with regular shores (Garunkštis 1988; Gudelis 1998).

THE MAIN FEATURES OF RELIEF, HYDROGRAPHY, GEOLOGY AND SOIL IN THE STUDIED SITE

The recent relief around Lake Kalotė distinguishes by a few features such as: the highest top reaches about 40.3 m a. s. l. in the south-eastern part of the lake's shore (the top of EF profile in Fig. 2); the highest point in the northern part is about 30.9 m, and the lowest reaches 21.6 m (CD profile in Fig. 2). A comparison of water level altitude in Lake Kalotė measured in September 2022 with the German data from the 1912/1916 geological map (Topogr. Aufnahmedes Kònigl. Preuβ. Generalstabes 1912) has shown a small rise – about +50 cm of water level (from 21.6 m a. s. l. in 1916 to 22.09 m a. s. l. in 2022) due to climatic conditions, sedimentation, etc. The relief is lowering from north to west, from the lake to the Baltic Sea, where the only recent outflow, Cypa stream, is flowing (Table 2) and from north to east towards the Akmena-Danė River sub-catchment (see Fig. 2).

The Bevardis Rivulet is the only inflow of Lake Kalotė. Its headwaters are found in the north-western side of the lake in the freshwater tree-dominated wetland of the Kukuliškiai forest. The discharge of the Bevardis Rivulet is seasonally fluctuating from zero

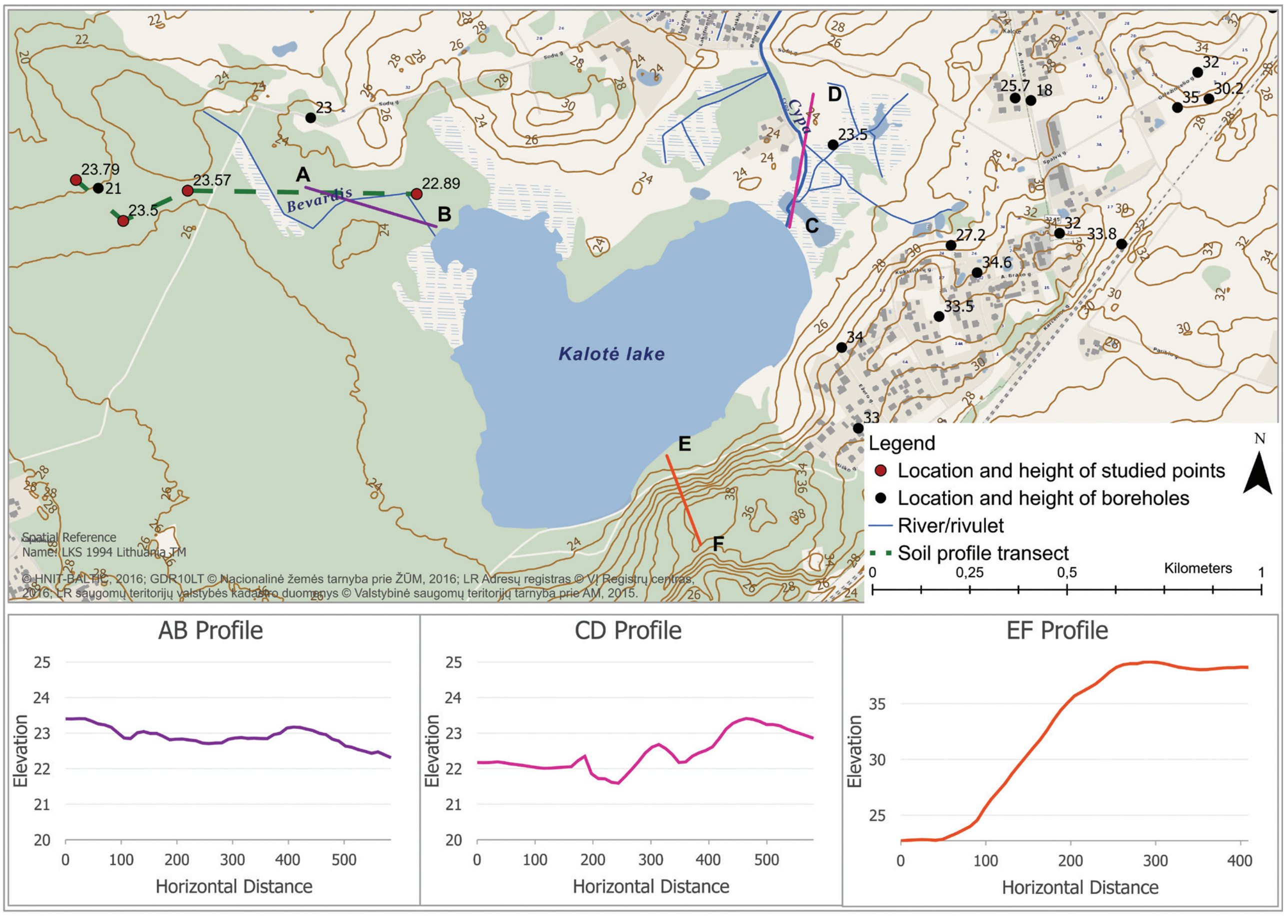


Fig. 2 The relief of surroundings of Lake Kalotė with AB, CD and EF profiles. Horizontal distance expressed in m, elevation in m a. s. l.

Table 2 The main geographic data of the recent outflow and inflow of Lake Kalotė

Parameters	The Cypa (outflow)	The Bevardis (inflow)
Coordinates of sources/elevation in m a. s. l.	55.788757, 21.114849/22.09	55.788229, 21.101379/23.90
Coordinates of the mouth/elevation in m a. s. l.	55.806442, 21.066004/0.08	55.790731, 21.092249/22.09
Length in km	6.1	0.67
Surface runoff module in $l\ s^{-1}\ km^{-2}$	8.5*	nd

*– taken from the drainage system plans archived at the Department of Agriculture of Klaipeda District Municipality; nd – not determined.

in dry summer months to maximum in early spring and late autumn.

The characteristics of the recent terrain with points of geological boreholes and textural composition of underground layers of the studied site can be observed in Figs 3a and 3b. The abundant material of till was dominating in the studied profiles and particularly in the upper parts of most boreholes near the lake. But approaching the Baltic Sea, situation was different: in the northern borehole (60533), like in the rest of boreholes closer to the lake, till was dominating on the land surface, while in the southern one (16006) fine-grained sand was found overlying clay and till. The presence of fine-grained sand on the top of the profile seemingly is the remain of previous intensive aeolian processes taking place between the Baltic Sea and kame plateau. The prevailing soil types around the lake were Arenosols, Gleysoils and Histosols formed on the morainic, sea and lacustrine deposits. The upper 10–28 cm soil horizon was made of dark grey and yellow sand, and the overlaying B horizon (80–90 cm thickness) was made of yellow to light grey sand with clear attributes of gleysation. The average level of ground water in the transect close to the lake was about 94 cm down the soil surface. The dark peat layer was found at the 167 cm depth from the soil surface on the average.

TIES OF LAKE KALOTĖ WITH THE BALTIC SEA AND THE AKMENA-DANĖ RIVER DURING CENTURIES

Among historian maps, the map by J. Narūnavičius-Naronskis of 1670 can be recognised as the oldest one with an evident picture of Lake Kalotė and its out-

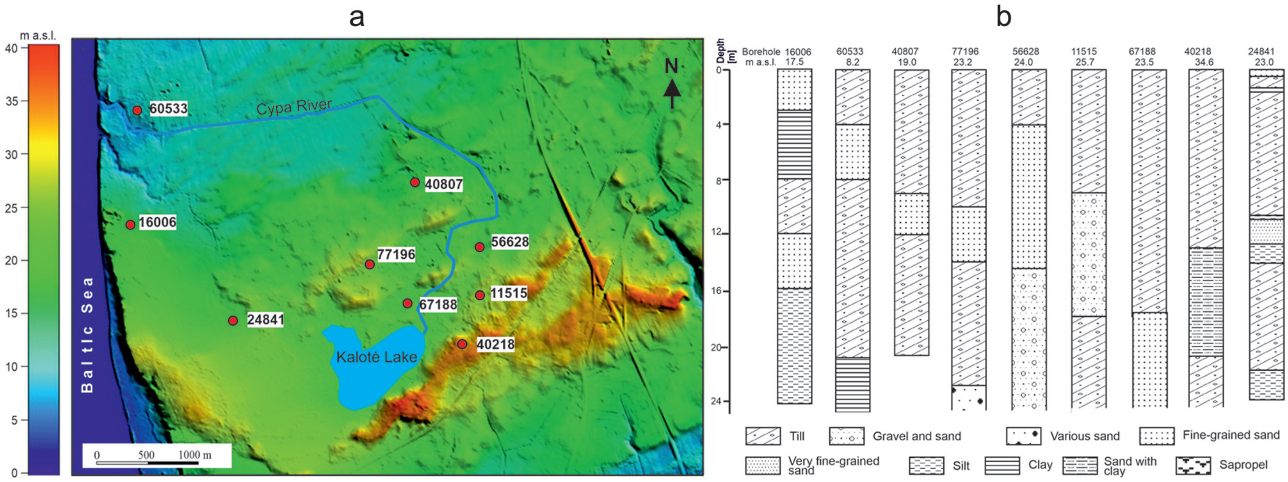


Fig. 3 The surface of the surroundings of Lake Kalotė. Images are shaded-relief DEMs. The copyright of the DEMs belongs to the National Land Service under the Ministry of Agriculture of the Republic of Lithuania and the Geological Survey of Lithuania (a). Structure of the upper part of Pleistocene deposits in the vicinity of Lake Kalotė (b)

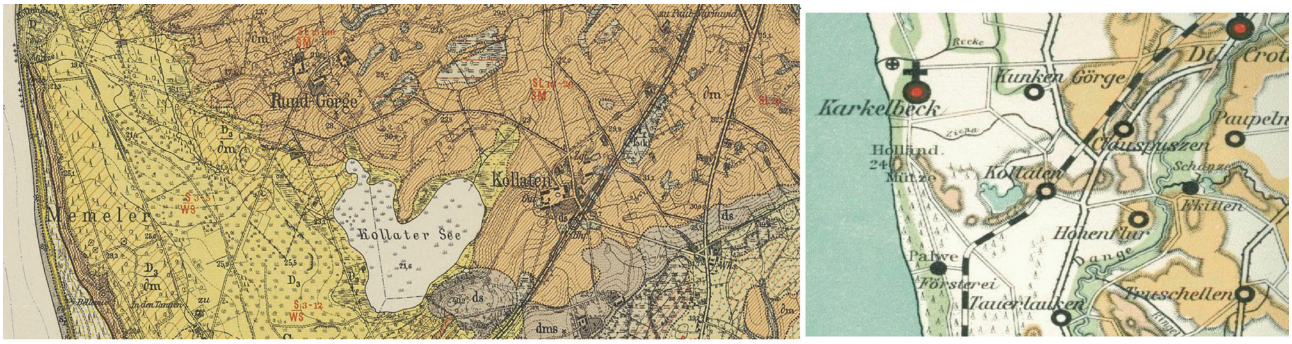
Fig. 4 A fragment of map M 1:100,000 from 1670 made by J. Narūnavičius-Naronskis. Photo made from the map is presented at the Museum of the History of Lithuania Minor in Klaipeda

flows (Fig. 4). The map clearly shows that an outflow from Lake Kalotė north to west enters directly the Baltic Sea. The other outflow from north to east towards the Dūmešis River, the tributary of Akmena-Danė River sub-catchment, can be also seen though not clearly. Thus, it seemed that during the 17th century there might have existed two outflows of Lake Kalotė: one with a more regular surface runoff to the sea, and the other to the Akmena-Danė sub-catchment, with a periodical surface runoff. This shows that in the 17th century Lake Kalotė might have had a bifurcation regime, carrying surface runoff to two different catchments. The map also shows the range of sandy dunes that extended along the coast up to the Memel (Klaipėda) town, thus the landscape there was open with very few forests. Such conditions were favourable for intensive aeolian processes. Most probably, due to the intensive sand drifts in the 17–18th century the north to north-west outflow stream to the Baltic Sea (Fig. 5, map from 1796–1802) stopped and a large sand massive formed in the territory between the sea and the western part of Lake Kalotė.

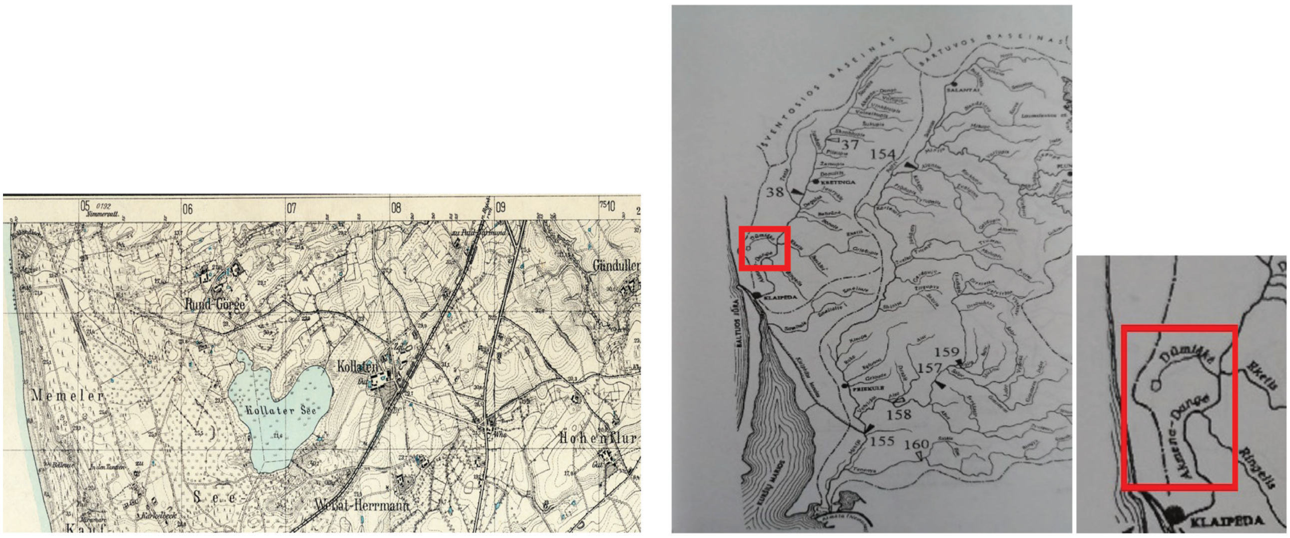
At the same time, the second outflow with north to east flow direction continued to transfer the surface runoff to the Akmena-Danė sub-catchment between the end of the 18th century and later periods up to the most of the 20th century. But the map of 1849 showed a different situation again. There was one outflow from Lake

1796-1802 1:160 000 1849 1: 200 000

Fig. 5 The outflow of Lake Kalotė to the Dūmešis River, the tributary of the Akmena-Danė River, and to the Baltic Sea: fragments from maps in 1796–1802 and 1849. The red rectangular marks two outflow branches formed from one
Sources: Composite Map: Karte von Ost-Preussen nebstPreussischLitthauen und West-Preussen – David Rumsey Historical Map Collection (1802); Reymann´s Special-KarteNr.B Klaipeda, Litauen (dt. Memel) (1849)



1912/1916 1: 25 000 1938 1:350 000



1942 1:25 000 1959 1:300 000

Fig. 6 The fragments from maps of 1912/1916, 1938, 1942 and 1959 with the Dūmiškė outflow reaching the Akmena-Danė sub-catchment (within red rectangular).
Sources: Topogr. Aufnahmedes Königl. Preuβ. Generalstabes 1912. Geologische Karte von Preuβen und benachbarten Bundesstaaten 1912/1916; Kartevomnördlichen Memelland.1938 European Map https://www.flickr.com/photos/27639553@N05/4135034165/; Reichuniversität Posen Geographisches Institut 1942 https://www.landkartenarchiv.de/tk100_sonderkarten.php?q; Lietuvos TSR upių kadastras (1959)

Kalotė’s north-eastern shore, but about 1.5 km from the headwaters it was divided into two branches: one continued towards the Akmena-Dangė River sub-catchment via the Dūmešis River, and the second with west to north-west turn directly reached the Baltic Sea. Thus, the bifurcation regime of Lake Kalotė, though from one outflow, continued. In the 20th century, the outflow of Lake Kalotė was running both directions depending on the year and seasonal water input level (Fig. 6).

This distribution of surface runoff was probably the result of both natural (the position of the lake according to watershed boundaries, relief, soil/ground permeability, aeolian processes) and particularly anthropogenic factors, since during the 19th century the formation of drainage tranches in the nearby farmer fields and household areas was common and the network of roads as well as homesteads became denser. The planting of trees was also increasing then.

The map of 1938 showed the surface runoff of the outflow named Cypa (Ziepa in German language) for the first time. It was flowing from north to north-west again and reached directly the Baltic Sea, not connecting with the Akmena-Danė sub-catchment. The same flow direction can also be seen from a more detailed topographic map in 1942. However, after the WWII, the watershed map showed the outflow stream direction towards the Akmena-Danė sub-catchment again, but the outflow was named the Dūmiškė River (Lietuvos TSR upių kadastras 1959). However, particularly large changes occurred in the 70s and 80s of the 20th century (Fig. 7).

A very distinguished situation with the outflow surface runoff was observed in 1968: the outflow then did not reach the Akmena-Danė sub-catchment or the Baltic Sea. Seemingly, climatic conditions then were drier and warmer than in previous decades. The last large changes in the studied site occurred in 1976–1986 when the Cypa River was straightened and directly entered the Baltic Sea again. That was a time when a large soviet land reclamation and drainage projects campaign took place in Lithuania to intensify agriculture development. At the same time, the increased urbanization and intensive road network building between the lake and the Akmena-Danė River closed the surface runoff outflow formation eastwards.

POSSIBLE SCENARIOS OF LAKE KALOTĖ OUTFLOWS DIRECTIONS DURING A FEW LAST CENTURIES

An overview of analysed cartographic material (maps and aero-photos) allowed drawing possible scenarios of the main changes in the outflows surface runoff directions (Fig. 8). During the 17th cen-

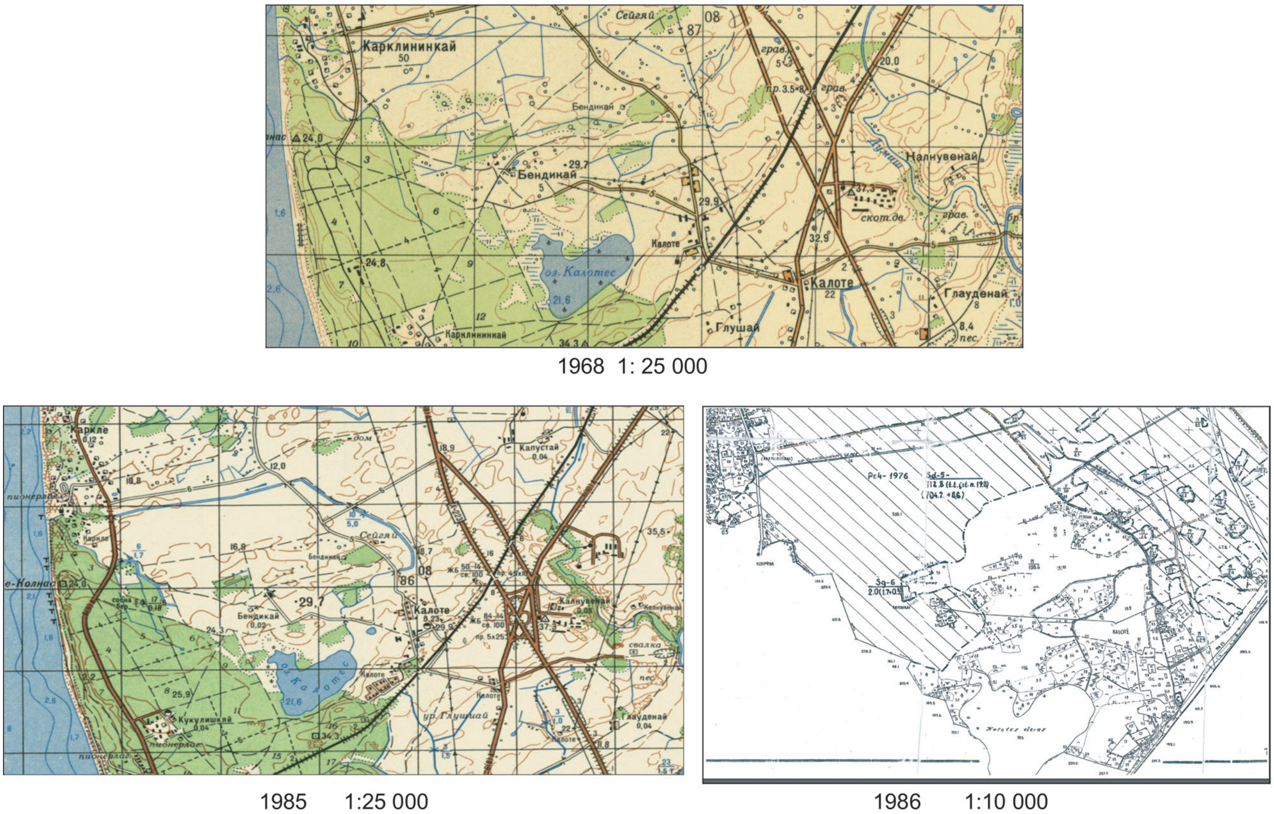


Fig. 7 The outflow of Lake Kalotė presented in the maps from 1968, 1985 and the fragment of the kolhoz ‘’Girkaliai” drainage systems plan in 1986.
Sources: https://www.geoportal.lt/map/Žemėlapių_fondai/Istoriniai/; https://maps.vlasenko.net/smtm100/n-34-007.jpg; a copy of the drainage system plan from 1986 was taken from the archives https://www.klaipeda_rajono_savivaldybe.lt

tury, there were two outflows of Lake Kalotė flowing different directions: from north to west towards the Baltic Sea and from north to east to the Akmena-Danė River sub-catchment, thus there was a naturally formed bifurcation regime. Later, during the 18th and the first half of 19th century with intensification of sand drifts and increase in anthropogenic activities (farming, digging of tranches and ponds, building of roads, railway and other infrastructure), the outflow from Lake Kalotė to the Baltic Sea stopped. Instead, another outflow towards the Akmena-Danė River via the Dūmešis tributary continued to flow. In the middle of the 19th century, two different branches of outflow surface runoff were discovered again: one from north to east (towards the Akmena-Danė sub-catchment) and the other directly to the Baltic Sea towards the west. This time, differently from the situation in the 17th century, the headwaters of outflow were located in one place, but the bifurcation regime still continued to take place. During the 20th century, the outflow surface runoff directions were even more changeable than in the 19th century, but most of the time the outflow was directed to the Akmena-Danė sub-catchment. Since the 1980s, urbanization started to increase with the establishment of the gardeners' community "Ežeras" in the upper reaches of the Cypa River and the extension of private households in Kalotė, Zeigiai, Kunkiai, Normantai and Karklė settlements.

With global climate warming, it is expected to face more extreme situations in the coastal areas. Most probably, dry and hot weather will occur more frequently in this area in summers. In such conditions, the surface runoff of the Cypa outflow might not reach the Baltic Sea, and if it does reach, it will not be able to recover its water quality because of large anthropogenic pressure from settlements and single households. A detailed environmental monitoring supplemented with a proper sewage water management system should be a priority in the studied site.

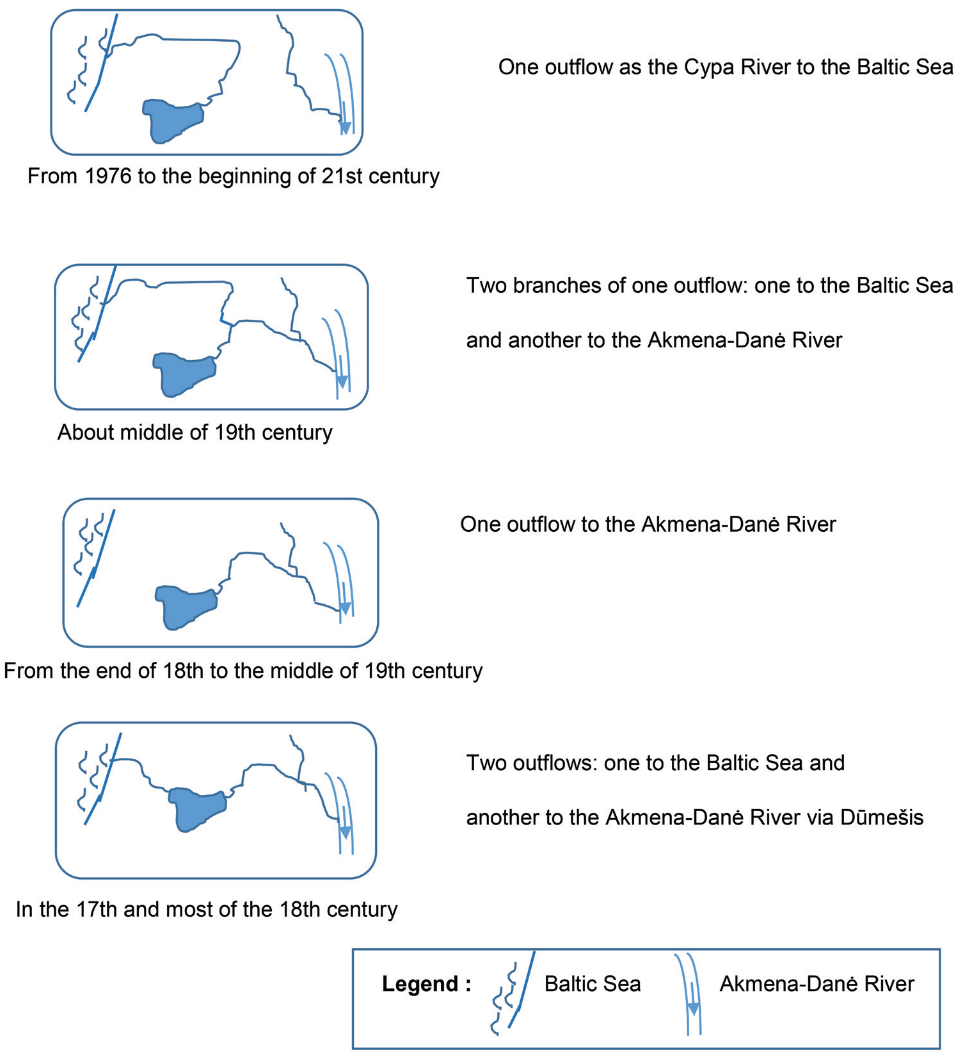


Fig. 8 Possible scenarios of the formation of surface runoff of Lake Kalotė outflows during the 17^{th} – 21^{st} centuries based on the analysed maps and compilation of research material

DISCUSSION

Though Lithuania is small in area, the division of country's territory into river catchments and sub-catchments is rather complicated (Directive 2000/60/EC of the European Parliament... 2000). According to the data of lake monitoring during 1948–2003, the tendency of water level was to fluctuate at the same medium level of ±20–25 cm depending on climatic factors (Irbinskas, Jablonskis 2004). Probably this statement can be relevant to the earlier centuries, when human activities on landscape were less pronounced. This is also in correspondence with our results of historian map analysis, proving that the water level of Lake Kalotė was slightly increasing due to intensive sedimentation processes. The processes of sedimentation and bogging are typical of such a lake with a rather thick sapropel and peat layer (Krevš *et al.* 2002; Restauruotinų Lietuvos... 2009).

The lakes with two outflows that run into different drainage basins can be attributed to the bifurcation lakes (Sikder *et al.* 2023; Holbrook, Howe 2018). The studied Lake Kalotė could be considered a natural bifurcation lake in the periods with a high water stand due to the climate wetting in its history till the middle of the 19th century, when the anthropogenic factor was insufficient yet.

Different historian sources and drawings as well as recent archaeological surveys (Zembrickis 2002; Demereckas 2018; Urbonaitė-Ubė, Ubis 2018; Minkevičius *et al*. 2020) confirm the fact of increased sand drifts during the 16–18th centuries up to the beginning of the 19th century, what we have observed from the compilation of old cartographic material. It was concluded, for example, that "the winter of 1607 was extremely severe, the Baltic Sea was covered completely by ice. The total 17th century was named "the small glacial period" with extreme winds, frequency of hurricanes and low temperatures" (Galvonaitė 2019).

In the 20th century, the anthropogenic factor became decisive as compared with the natural factors. In general, urbanization inspires great changes in watershed hydrology (Chin 2006) including declines in the natural filtering capacity of river systems (e.g., channelization of headwater streams, loss of floodplains and wetlands), drainage of fields and regulation of flows due to the construction of dams and impoundments. Such changes have resulted in globally altered watershed sediment and solute export (Meybeck, Vorosmarty 2005; O'Driscoll *et al.* 2010). With the 21st century, due to the anthropogenic modification of the hydrological cycle by deforestation, urbanization and irrigation, water resources have been overexploited, degraded and wasted, resulting in higher risks to human health, economic and social development as well as to the functioning of ecosystems and the preservation of the environment (Zalewski *et al.* 2001; Meyer *et al.* 2005; Kaushal *et al.* 2014). Some mentioned challenges have already arisen in the studied environment with Lake Kalotė and Cypa outflow, thus the near-future research has to be focused on the practical solutions improving the health of ecosystems in the coastal landscape, particularly while maintaining the water quality of densely stretched small streams. Still there is an open question about Lake Kalotė outflows other than Cypa, which could directly reach the Baltic Sea during the last centuries and about reliable hydronyms of the outflows of Lake Kalotė in earlier centuries. It is evident that the hydronyms of the outflows were changing from unknown in the historical maps of Prussia administration times to Šaltupis or Gaigalupė (Pėteraitis 1992; Lietuvių enciklopedija 1 Tomas 1957), Gindulė and Dūmiškė (Lietuvos TSR…1959; Gailiušis *et al.* 2001), Ziepa (Plicken auf der Karte des Kreises Memel 1936) and Cypa after 1986 (https://maps.vlasenko.net/smtm100/n-34-007.jpg) . One version should be checked about the so-called Kalotė rivulet which was described in the book "Žvejų kaimelio kronika" with many stories written from the memories of local fisherman family members (Aleknavičius 2010).

CONCLUSIONS AND FURTHER RESEARCH

The analysis of old maps allows concluding that the situation with outflows from Lake Kalotė has been changeable from the 17th to the beginning of the 21st century due to the natural and anthropogenic reasons. The headwaters and flow directions of outflows were different in different time periods. Lake Kalotė being on the border of the catchment of Pajūrio Rivers and the Akmena-Danė sub-catchment in the 17th–18th centuries, with two different outflows might be considered a natural bifurcation lake with a more regular surface runoff flowing to the Baltic Sea. The climatic conditions and open landscape were favourable for the aeolian processes. As a result, the surface runoff of an outflow with north-west direction stopped. In the middle of the 19th century, however, two separate branches of surface runoff formed from the headwater of the second north-eastern outflow: one was flowing westwards to the Baltic Sea and the other continued flowing eastwards to the Akmena-Danė sub-catchment. These changes in surface runoff formation and distribution were mostly the result of the anthropogenic factor, and since then two outflow directions were in balance. Thus, the lake continued with the bifurcation regime under the high-water input supply. During the 20th century, however, the direction towards the Akmena-Danė River sub-catchment became more regular. The observed situation with no runoff outflow according to the map from 1968 was probably the result of a few dry decades.

From the eighties of 20th century due to the large land reclamation and stream straightening campaign, the Cypa River has become the only outflow of the Kalotė Lake directed to the Baltic Sea, and the lake has lost the bifurcation regime.

With the 21st century the situation requires more attention to be given to the self-purification capacities of small streams and surface runoff water quality in the coastal landscapes, because, firstly, urbanization and recreation are increasing in the area. Secondly, with the global climate warming more frequent extreme situations are expected, which can reduce the surface runoff of small streams during summer months, and thus the conservation regime in certain coastal ecosystems and areas might be disturbed.

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