KAUNAS
UNIVERSITY OF
TECHNOLOGY

DARIUS JAKIMAVIČIUS

Changes of Water Balance Elements of the Curonian Lagoon and their Forecast Due to Anthropogenic and Natural Factors

Summary of Doctoral Dissertation
Technological Sciences, Environmental Engineering (04T)

2012, Kaunas

KAUNAS UNIVERSITY OF TECHNOLOGY
LITHUANIAN ENERGY INSTITUTE

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KAUNO TECHNOLOGIJOS UNIVERSITETAS
LIETUVOS ENERGETIKOS INSTITUTAS

DARIUS JAKIMAVIČIUS

KURŠIŲ MARIŲ VANDENS BALANSO ELEMENTŲ POKYČIAI IR JŲ PROGNOZĖ DĖL GAMTINIŲ BEI ANTROPOGENINIŲ VEIKSNIŲ

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INTRODUCTION

The hydrological regime of water bodies, as well as this lagoon, is influenced by climate. Recently much attention is being paid to the impact of climate change on physical geographical factors. These processes cause changes in river runoff and rise of the global sea-level. The Curonian Lagoon is also influenced by the anthropogenic factors due to activities of Klaipeda State Seaport Authority (KSSA), situated in a strait between the Curonian Lagoon and the Baltic Sea. Dredging of the Klaipėda port entrance channel influences water exchange between the mentioned water bodies, and consequently more and more salt water inflows to relatively fresh water body. The question is, whether climate change and the port activity have impact on the hydrological regime of the Curonian Lagoon? Up to now only analysis of separate elements (such as river inflow, water level, climate factors, i.e. precipitation field, wind speed, which influence evaporation and air temperature) changes of water balance of the Curonian Lagoon was performed. There is no research analysing water balance of the Curonian Lagoon and changes of its elements in a long time period, as no forecast of this phenomena for 21st century is presented. Till now in the scientific studies that analysed changes of water exchange between the Baltic Sea and the Curonian Lagoon, the influence of the port activity was emphasized. However there is no study about this change due to the natural factors in the 21st century. In this doctoral dissertation it was estimated that the rise of the sea-level, increasing difference of the water levels between the Baltic Sea and the Curonian Lagoon, as well as decreasing river runoff will significantly change water exchange between these two water bodies, and the salt water inflow can negatively affect the conditions of the Curonian Lagoon ecosystem.

In order to evaluate the changes of the Curonian Lagoon hydrological regime, the water balance of the lagoon for the period of 1960–2009 was calculated. Changes of the water balance elements in the 21st century were forecasted using hydrological modelling, ECHAM5 and HadCM3 global and RCAO–E and RCAO–H regional climate model data under A2, A1B, B1 and B2 greenhouse gas emissions scenarios. Analysis of the data from such a long time period gave an opportunity to assess variation of hydrological regime in the context of the climate change and to present possible forecasts for the 21st century.

In this work the database of hydrological and meteorological data was created and used for comprehensive analysis of hydrological regime of the Curonian Lagoon. By using statistical analysis methods, hydrological modelling and prognostic climate change data, the changes of total river inflow, precipitation, evaporation and water exchange between the Baltic Sea and the Curonian Lagoon in 1960–2009 were analysed and forecasted for the 21st century.

Relevance of Doctoral Dissertation

This work is relevant from scientific and practical points of view. The created methodology for water balance calculation can be used for other water bodies. The estimated water balance enables to identify hydrological changes of the Curonian Lagoon due to global processes (climate change), as well as local anthropogenic activities (dredging of the port entrance channel), and forecast possible changes in future.

Object of Doctoral Dissertation

The Curonian Lagoon and the water balance elements of the Curonian Lagoon: river inflow to the lagoon, water exchange between the Baltic Sea and the Curonian Lagoon (outflow from the lagoon to the sea and inflow from the sea to the lagoon), precipitation on the surface of the lagoon and evaporation.

Aim of Doctoral Dissertation

To evaluate changes of water balance of the Curonian Lagoon and to assess its possible tendencies in 21st century using the hydrometeorological database, mathematical models of climate and sea-level change, statistical analysis methods and hydrological modelling.

Goals of Doctoral Dissertation are the following:

1. To create a methodology for calculation of water balance of the Curonian Lagoon for two different time periods: 1960–2009 and 2011–2100.
2. To calculate water balance of the Curonian Lagoon for 1960–2009 and to analyse its changes in the context of climate change and anthropogenic factors.
3. To forecast the Curonian Lagoon water balance and the tendencies of its changes in the 21st century applying the created model of the Nemunas runoff and the data of various climate and sea-level change scenarios.
4. To evaluate uncertainty of the calculation of the Nemunas runoff model and the Curonian Lagoon water balance using SUSA software package.
5. To assess changes of factors (water exchange between the Curonian Lagoon and the Baltic Sea) that limit Klaipėda Port activities under climate change conditions.

Hypothesis (the defence of Doctoral Dissertation)

Both natural and anthropogenic factors have a substantial influence on the change of the water balance elements of the Curonian Lagoon. Over the past decades river inflow to the Curonian Lagoon is decreasing and water exchange between the Baltic Sea and the Curonian Lagoon is changing. In the 21st century inflow from the Baltic Sea is going to increase due to climate change, therefore it will be necessary to implement environmental measures in order to develop Klaipėda Port and to protect the ecosystem of the Curonian Lagoon.

Scientific novelty and application of Doctoral Dissertation

The methodology was prepared, according to which a forecast (in the 21st century) of water balance of the Curonian Lagoon and its elements, including runoff at the mouth of Nemunas, were presented in this Doctoral Dissertation for the first time. In order to evaluate the hydrological changes of the lagoon in the past, the author improved the calculation methodology of the lagoon water balance and computed river inflow in a daily step by estimating the discharges of the Nemunas at Smalininkai and other rivers inflowing below. For the first time in Lithuania the uncertainty analysis of the water balance elements was performed. The obtained knowledge about the changes of hydrological regime of the Curonian Lagoon will be valuable for Klaipėda Port development and for justifying environmental measures.

Publications

4 publications in the journals of the Institute for Scientific Information (ISI) and 7 presentations in Lithuanian and international conferences on the subject of Doctoral Dissertation.

2. METHODOLOGY

The Curonian Lagoon is a complex system; its water balance depends on river inflow to the Curonian Lagoon, the water level difference between the Baltic Sea and the Curonian Lagoon, permeability of the port entrance channel, climate elements (air temperature, precipitation, wind speed and direction in respect of the port gates). In the 21st century the global climate warming strongly influences natural systems causing to increase air temperature and sea-level, changing annual distribution of precipitation and river runoff. Anthropogenic impact on the Curonian Lagoon is made by changing the permeability of the port entrance channel. Due to the simultaneous occurrence of global and local anthropogenic impacts, hydrological regime, as well as water balance, of the Curonian Lagoon changes.

This doctoral work consists of two parts: 1) calculation of water balance of the Curonian Lagoon; 2) forecasting of water balance of the Curonian Lagoon according to global sea-level and climate change scenarios.

The water balance of the Curonian Lagoon for 1960–2009 is calculated according to a scheme, presented in Figure 2.1. Following this scheme, water balance income and losses, as well as uncertainties of the water balance calculations using SUSA software package are estimated.

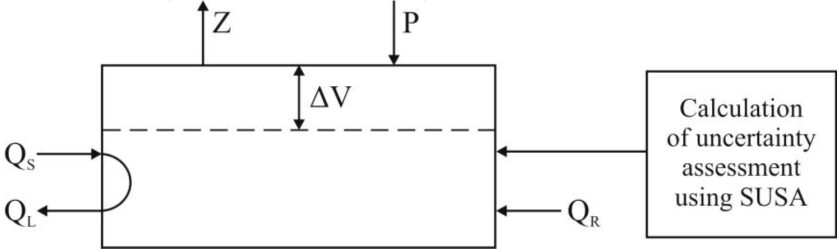

Fig. 2.1. A principled scheme of water balance of the Curonian Lagoon

Forecast calculations of water balance of the Curonian Lagoon for 2011–2100 were performed similar to that of 1960–2009, but using output data of global climate change models and sea-level rise projections. According to output data of ECHAM5 and HadCM3 models under A2, A1B and B1 emission scenarios river inflow was simulated, precipitation and evaporation were calculated (Fig. 2.2). Sensitivity and uncertainty of the Nemunas runoff model parameters were assessed using SUSA software package. Water exchange between the Baltic Sea and the Curonian Lagoon for the period 2011–2100 was forecasted considering the projections of sea-level rise and the Curonian Lagoon level rise in 1960–1990.

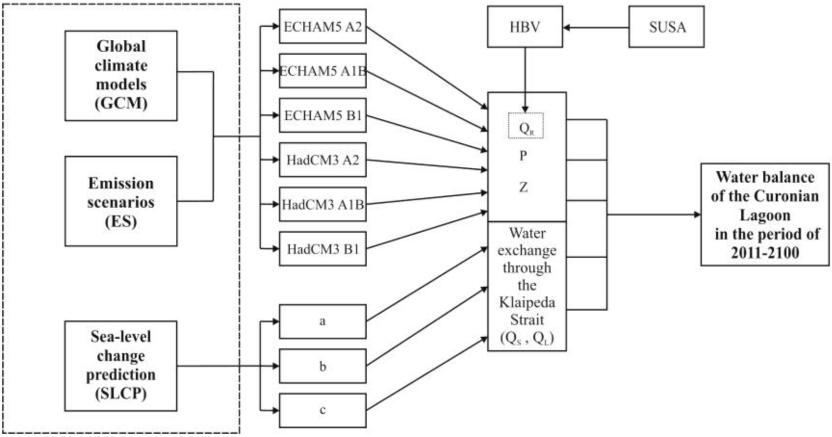

Fig. 2.2. The evaluation scheme of climate change impact on water balance of the Curonian Lagoon in the period 2011–2100

2.1. Methodology of calculating water balance of the Curonian Lagoon

Water balance. The water balance equation can be used for evaluation of the impact of natural and anthropogenic factors on water exchange processes. Water balance can be considered as a method for evaluation of water exchange processes in a pond as well as a level of hydrometeorological investigation of a pond. The water balance of the Curonian Lagoon analysed in this work is described as follows:

$$(Q_R + P - Z) + (Q_S - Q_L) = \Delta V \tag{1}$$

where Q_R – river inflow to the Curonian Lagoon, P – precipitation on the surface of the Curonian Lagoon, Z – evaporation from the Curonian Lagoon, Q_S – inflow from the Baltic Sea to the Curonian Lagoon, Q_L – outflow from the Curonian Lagoon to the Baltic Sea, ΔV – change in the volume of the Curonian Lagoon.

The income of the water balance consists of precipitation, river and sea water inflow to the lagoon, whereas losses comprise of outflow from the lagoon to the sea and evaporation.

River inflow. Daily discharges of the rivers Nemunas, Šešupė, Šešuvis, Jūra, Minija, Akmena–Danė and Deimena of the period 1960–2009 were used to calculate river inflow. The Deimena that inflows to the Curonian Lagoon, discharges were calculated according to the Šešupė data. The calculations were performed by the methodology improved by the author using the direct measurement data of water gauging stations (WGS) and analogy methods. Discharge at WGS, where measurements are taken, was recalculated for the river mouth (multiplying by appropriate coefficients obtained according to the catchment area ratio between WGS and river mouth) and then recalculated from the mouth to the lagoon (taking into account the inflow time).

Precipitation and evaporation. Precipitation that fell on the surface of the lagoon in the period of 1960–2009 was calculated according to the data of Klaipėda, Nida and Ventė meteorological stations (MS). The total amount of precipitation entering the lagoon was computed using the monthly amounts of the mentioned MS data and weighed stations coefficients estimated by Thiessen polygon method. The direct measurement data of evaporation from the lagoon surface does not exist. Therefore evaporation was calculated applying empirical formulas based on hydrometeorological elements measured at Nida MS.

For the calculation of **volume change,** daily data of river inflow and mean water level in the lagoon at Juodkrantė were used. The water surface area of the lagoon was assessed according to the relation between water level and surface area. When ΔH is calculated and daily data of the lagoon water surface area are available, the variation of the lagoon volume can be estimated. According to the daily data of volume variation and total river inflow, water exchange between the sea and the lagoon can be calculated. These discharges are computed deducting total river inflow from the volume change. The negative discharge means that water flows from the Curonian Lagoon to the Baltic Sea, and the positive one shows the opposite flow direction.

Uncertainty analysis of the calculation of water balance elements of the Curonian Lagoon was performed applying SUSA (SUSA – *Software System for Uncertainty and Sensitivity Analysis*) package. The data of river inflow to the Curonian Lagoon (Q_R), amount of precipitation (P) and evaporation (Z) were selected for this analysis as they were computed by direct measurement data. The volume change is calculated as a result of water balance, therefore sensitivity and uncertainty analysis for this element was not performed.

2.2. Creating of the Nemunas runoff hydrological model

HBV is a technique of rainfall-runoff modelling used to calculate the total water balance in a catchment. The main HBV equation is:

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + V] \qquad (2)$$

where *P* – precipitation, *E* – evapotranspiration, *Q* – runoff, *SP* – snow pack, *UZ* – upper groundwater zone, *LZ* – lower groundwater zone, *V* – lake or dam volume.

Model computations are performed in three steps: 1. Estimation of precipitation amount that falls to the ground; 2. Estimation of the slope runoff; 3. Evaluation of runoff in watercourse and runoff transformation.

For calibration of hydrological model many parameters that depend on the local conditions are used. The correct selection of calibration parameters determines reliability of the results. Calibration process has to be performed until the correlation coefficient R is greater than 0.8 and the total deviation is the least. Using HBV, hydrological models of the separate Nemunas catchment parts were created, then calibrated and validated. After that individual subcatchments are integrated to the Nemunas hydrological model. Hydrometeorological information of the period of 1961–1990 (according to World Meteorological Organisation this period is considered as climate norm) was used for the model creation. The period of 1961–1975 was selected for the model calibration, whereas the period of 1976–1990 was used for validation.

The calibration procedure of the Nemunas hydrological model consisted of changing the model parameters. Uncertainty and sensitivity analysis of the Merkys and Neris hydrological models parameters was performed applying SUSA. The results will enable to assess the impact of the individual parameters on discharge calculations more accurately.

2.3. Methodology of calculating water balance of the Curonian Lagoon for the 21st century

Water balance of the Curonian Lagoon was calculated using equation 1 and prognostic data of climate change (Fig. 2.2). We have presented projections of the temperature and precipitation in the Nemunas river basin for the 21st century according to conclusions of the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change as well as the results of output data of ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios.

These data were used to compute the Nemunas inflow to the lagoon in 2011–2100, the amount of precipitation entering the lagoon and evaporation from the lagoon water surface.

The mean daily water level of the Curonian Lagoon is necessary for estimation of water balance. Water level of the Curonian Lagoon was forecasted according to RCAO–E and RCAO–H models under A2 and B2 emission scenarios. It was estimated that the lagoon water level can increase from 0.87 mm/ year (according to scenario (a)) to 4.65 mm/ year (according to scenario (c)). After evaluation of the water level rise of the Curonian Lagoon in 1961–1990, scenario (b) was prepared according to which water level in the Curonian Lagoon in the 21st century will increase by 4.02 mm/year. Using (a), (b) and (c) scenarios of the level rise in the Curonian Lagoon and the data of water level of the baseline period (1961–1990) the lagoon water level was forecasted for the 21st century.

3. CREATION OF HYDROMETEOROLOGICAL DATABASE

The following data were used for estimation of water balance of the Curonian Lagoon: river discharges, water levels of the Curonian Lagoon and the Baltic Sea, air temperature, water surface temperature, soil temperature, precipitation amount, wind speed, water vapour pressure, moisture deficit, duration of ice cover on the Curonian Lagoon. Daily data of 11 WGS were used to calculate river inflow and water exchange between the Baltic Sea and the Curonian Lagoon (Fig. 3.1). Monthly mean data of Klaipėda, Ventė and Nida MS were used to calculate precipitation amount that falls on the surface of the Curonian Lagoon and evaporation from the Curonian Lagoon water surface (Fig. 3.1). The database in MS Excel was created for processing and storage of the mentioned information.

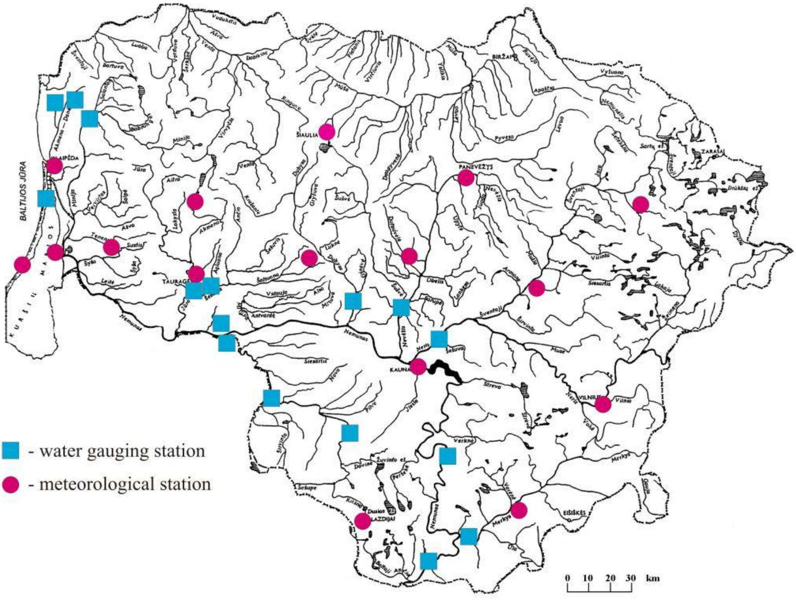

Fig. 3.1. Distribution of meteorological and water gauging stations

Daily discharges of 10 WGS, daily precipitation and air temperature data of 14 MS were used to create the Nemunas hydrological model applying HBV model (Fig. 3.1).

Air temperature and monthly precipitation data derived from ECHAM5 and HadCM3 models under A2, A1B and B1 emission scenarios were used to forecast water balance of the Curonian Lagoon for the period 2011–2100. Prognostic data of 14 MS, data of 1961–1990 and downscaling method were applied to calculate daily mean data from mean monthly output data of climate change scenarios. In such a way obtained prognostic values of precipitation and temperature data were used to simulate the Nemunas inflow and to compute water balance. Water level data of the lagoon of the forecast period are necessary for calculation of water exchange between the Baltic Sea and the Curonian Lagoon. Therefore daily water level data of the Baltic Sea at Klaipėda and Pionersk as well as analogical data of the Curonian Lagoon at Juodkrantė of the period 1961–1990 were used. The evaluation of water level rise in the Curonian Lagoon in the period of the climate norm enabled to determine the relation between water levels of the Curonian Lagoon and the Baltic Sea. According to sea-level rise projections, three possible scenarios (0.87 mm/year, 4.02 mm/year, and 4.65 mm/year) of the Curonian Lagoon level change in 2011–2100 were computed.

4. LONG-TERM WATER BALANCE OF THE CURONIAN LAGOON IN THE CONTEXT OF CLIMATE CHANGE AND ANTHROPOGENIC FACTORS

4.1. Water balance

River inflow is the largest part of water balance income, therefore it is very important to evaluate it accurately. River inflow is calculated at a day interval in the period of 1960–2009. In the investigated period, the average annual river inflow was 21.784 km^3/year and it fluctuated between 13.967 km^3/year (in 1969) and 30.041 km^3/year (in 1980) (Fig. 4.1).

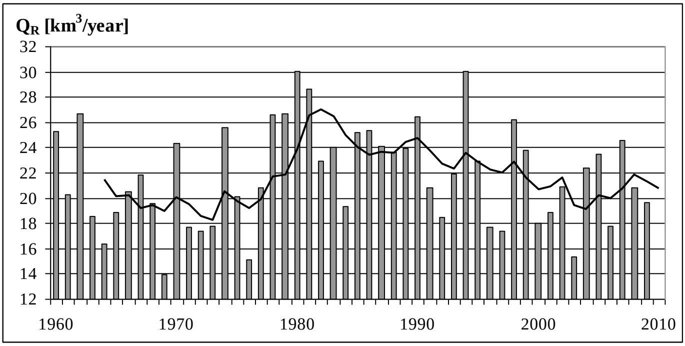

Fig. 4.1. River inflow to the Curonian lagoon in the period of 1960–2009

After the application of Mann-Kendall test and 5-year moving averages method, it was determined that the trend of river inflow to the lagoon is positively significant (with a reliability of 95 %) until 1982, and from 1983 the river inflow is decreasing, but the decrease is not statistically significant. With a small decrease of runoff, its annual distribution changes notably. The analysis of annual distribution of runoff was performed for separate 10-year periods: 1960–1969, 1970–1979, 1980–1989, 1990–1999 and 2000–2009. It was evaluated what part (in %) of the annual runoff the seasonal run-off in different periods composed (Fig. 4.2). In the investigated period, summer runoff fluctuated between 14.9 % and 16.9 %. The autumn season runoff changed the most – between 18.8 % and 22.1 %. The largest fluctuations are observed in the runoff distribution of the winter and spring seasons. A significant change of runoff occurred comparing the periods of 1960–1969 and 1970–1979: in winter runoff increased by 3.7 % and in spring it decreased by 6.5 %. After the comparison of the part of the total river runoff into the lagoon that occurred in the winter and spring seasons in the beginning and the end of the studied period, a significant redistribution of runoff was observed. In the period of 1960–1969, the difference between winter and spring was 24.2 % (20.5 % in winter, 44.7 % in spring), while in the period of 2000–2009 it was only 3.3 % (30.1 % in winter, 33.4 % in spring). Such change of distribution of long-term total river runoff to the

Curonian Lagoon indicates that the spring floods are occurring earlier, the maximum discharges are measured earlier and their values are decreasing.

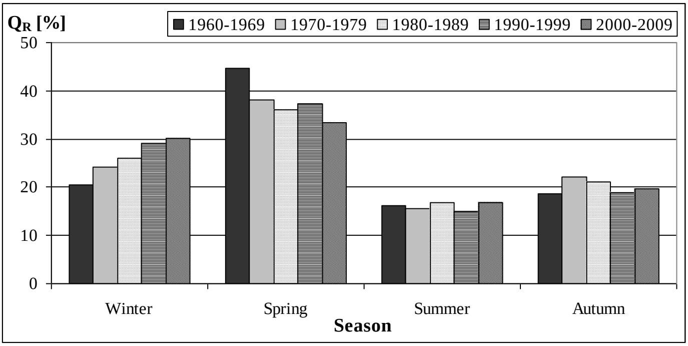

Fig. 4.2. Distribution of seasonal runoff, %

In the period of 1960–2009, the average annual amount of precipitation was 1.199 km^3. The amount of precipitation increased slightly during this period. After the application of Mann-Kendall test, it was determined that the trend of the amount of precipitation is positively significant (with a reliability of 90 %). The average evaporation in the period of 1960–2009 is 1.007 km^3/year. Evaporation is very closely related to wind speed, which increased until 1982 and decreased from 1983. After the application of Mann-Kendall test for the analysis of wind speed measured in the Nida MS, it was estimated that the trend of wind speed for the period until 1982 is positively significant (with a reliability of 99 %), while for the period from 1983 it is negatively significant (with a reliability of 99.9 %).

The calculated average long-term runoff from the Curonian Lagoon to the Baltic Sea in the period of 1960–2009 (Q_L) was 27.642 km^3/year (Fig. 4.3), and the runoff trend for this period is positively significant.

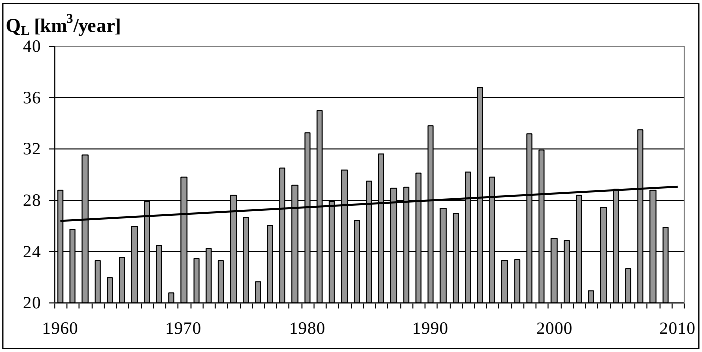

Fig. 4.3. Runoff from the Curonian Lagoon to the Baltic Sea (Q_L) in the period of 1960–2009

The average long-term inflow from the Baltic Sea to the Curonian Lagoon (Q_S) was 6.171 km^3/year. The analysis of the long-term inflow from the Baltic Sea to the Curonian Lagoon (Q_S) indicates that the inflow is increasing (Fig. 4.4). The dredging of Klaipeda port entrance channel changes its permeability. Therefore it is relevant to understand how Q_L and Q_S changed during the investigated period and if this alternation is related not only to the dredging of the port entrance channel, but with environmental changes (climate change) as well.

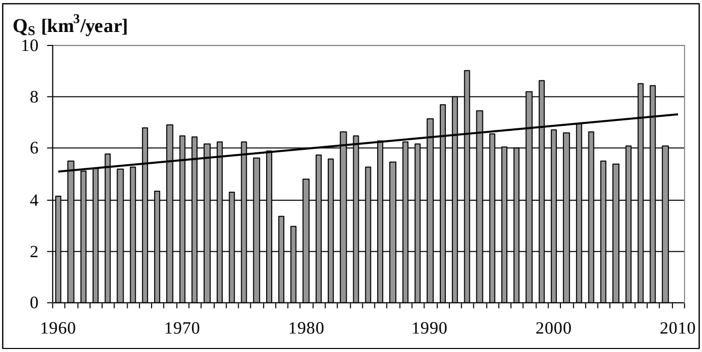

Fig. 4.4. Inflow from the Baltic Sea to the Curonian Lagoon (Q_S) in the period of 1960–2009

When analyzing the inflow from the Baltic Sea to the Curonian Lagoon, two equal periods (1963–1982 and 1983–2002) were compared (Fig. 4.5). The 1981–1982 dredging of the Klaipeda port was chosen as the reading point. The river inflow during these periods is 21.169 km^3/year in 1963–1982 and 22.468 km^3/year in 1983–2002, a change of only 5.8 %.

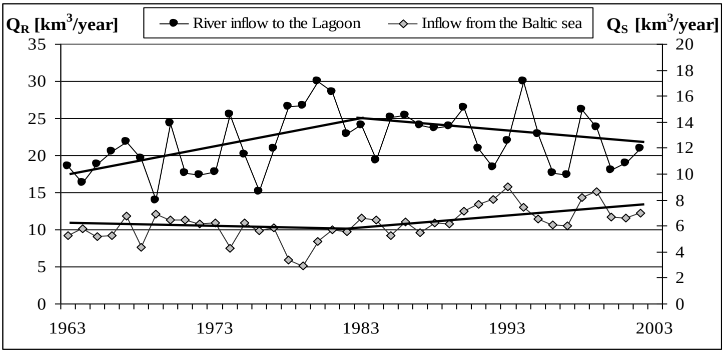

Fig. 4.5. Change of inflow from the Baltic Sea to the Curonian Lagoon and river inflow to the Lagoon in 1963–2002

The results showed that the inflow from the Baltic Sea into the Curonian Lagoon in the period of 1963–1982 is smaller by 20.6 % than in the period of 1983–2002. After the application of Mann-Kendall test, it was determined that until 1982 there is an insignificant decrease (statistically insignificant), while from 1983 the trend is positively significant (with a reliability of 90 %). Such change of inflow could not be determined only by the dredging of the port, because the permeability of the entrance channel was increased by 10 %. An important factor that determines the direction of inflow is the difference of water level between the Baltic Sea and the Curonian Lagoon. The level of the Baltic Sea changes due to global anthropogenic influence, while the level of the Curonian Lagoon is influenced by local anthropogenic activity (dredging of the port fairway).

Changes of inflow from the Baltic Sea to the Curonian Lagoon were influenced by envinronmental-anthropogenic factors: the fluctuation of the Baltic Sea water level; the change of the river hydrological regimes due to anthropogenic activity and climate change; the increased permeability of Klaipeda port entrance channel.

The water balance of the Curonian Lagoon in the period of 1960–2009 is presented in Table 4.1.

Table 4.1. Water balance of the Curonian Lagoon during the period of 1960–2009 (in km^3).

Balance elements	**Month**												**Annual**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
River inflow, **(Q_R)**	1.937	1.778	2.816	3.580	1.848	1.225	1.141	1.131	1.123	1.418	1.831	1.955	**21.784**
Inflow from sea to lagoon, **(Q_S)**	0.485	0.322	0.288	0.235	0.327	0.478	0.510	0.550	0.666	0.778	0.899	0.634	**6.171**
Precipitation, **(P)**	0.088	0.062	0.066	0.059	0.066	0.094	0.120	0.135	0.129	0.140	0.133	0.107	**1.199**
Income	**2.509**	**2.162**	**3.170**	**3.874**	**2.241**	**1.797**	**1.771**	**1.817**	**1.919**	**2.335**	**2.863**	**2.696**	**29.153**
Runoff from lagoon to sea, **(Q_L)**	2.425	2.272	2.984	3.932	2.299	1.524	1.537	1.668	1.748	2.159	2.524	2.557	**27.642**
Evaporation**,** **(Z)**	0.023	0.020	0.031	0.055	0.115	0.155	0.174	0.163	0.119	0.073	0.047	0.032	**1.007**
Losses	**2.448**	**2.292**	**3.015**	**3.988**	**2.415**	**1.679**	**1.711**	**1.830**	**1.867**	**2.225**	**2.589**	**2.589**	**28.648**
Change in volume	**0.001**	**-0.010**	**-0.050**	**0.031**	**0.078**	**0.023**	**-0.033**	**-0.015**	**-0.023**	**0.025**	**-0.046**	**0.056**	**0.037**
Error	**0.061**	**-0.121**	**0.206**	**-0.144**	**-0.252**	**0.095**	**0.092**	**0.001**	**0.075**	**0.085**	**0.320**	**0.051**	**0.468**

4.2. Evaluation of water balance uncertainty applying SUSA software

The uncertainties of water balance of the Curonian Lagoon emerge when the measurements of water balance elements are executed. Errors of measurement parameter have influence on accuracy of calculation of water balance elements. In this study, measured hydrometeorological parameters are river inflow (Q_R), amount of precipitation (P) and evaporation (Z). Using SUSA, 100 different sets of water balance elements (Q_R, P and Z) were composed for every calculated year from 1960 to 2009. According to these sets of input parameters, water balances of the Curonian Lagoon and the volume changes (ΔV) in the long term period were calculated. The influence of river inflow, precipitation and evaporation for the calculated changes of the Curonian Lagoon volume is presented in Figure 4.6.

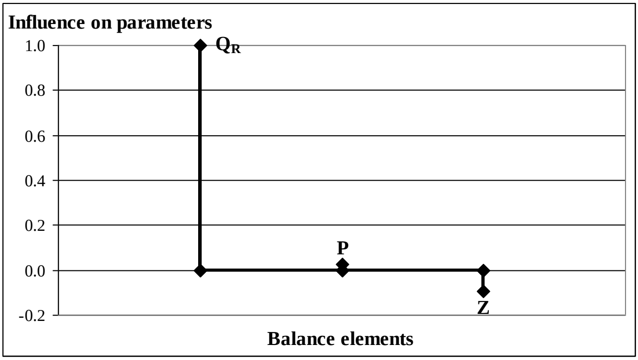

Fig. 4.6. Impact of water balance elements on the calculation of water balance of the Curonian lagoon (Q_R – river inflow, P – precipitation, Z – evaporation)

The larger the absolute value of the parameter sensitivity coefficient is, the more important that parameter is and has a greater impact on the model result. As can be seen from Fig 4.6, the most important balance element that influences the accuracy of the calculation of water balance of the Curonian Lagoon is the river inflow to the Curonian Lagoon. The average influence of this parameter is 1.0. Other water balance elements are less important. The average influence of precipitation and evaporation is respectively 0.02 and -0.1. Such a different influence of water balance elements to the accuracy of the calculation of water balance of the lagoon can be explained by the values of river inflow, precipitation and evaporation, as the value of river inflow is 18 times greater than the value of precipitation and 22 times greater than the value of evaporation. Therefore the influence of river inflow to the calculation of water balance of the Curonian Lagoon is significantly greater than the influence of precipitation and evaporation.

5. CREATION OF HYDROLOGICAL MODEL FOR THE NEMUNAS CATCHMENT AREA

The aim of the hydrological model was to model the inflow of the Nemunas to the Curonian Lagoon in the period of 2011–2100. The Nemunas from Druskininkai (selected as a starting point) to the mouth has been splitted to the separate stretches successively connecting the catchments of the Merkys, Neris, Nevėžis, Dubysa, Šešupė, Jūra and Minija (Fig. 5.1).

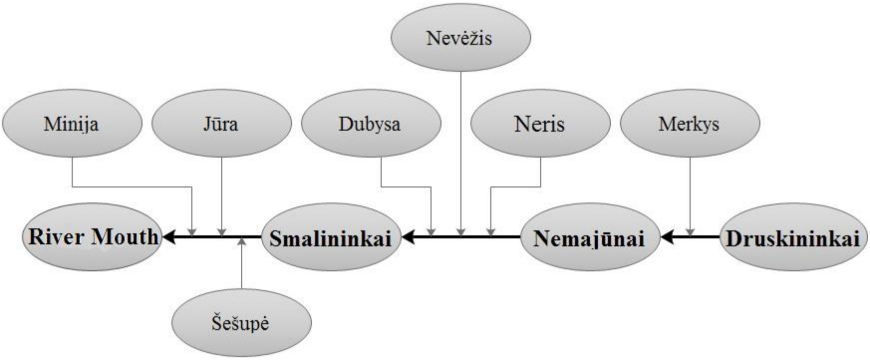

Fig. 5.1. The scheme of the Nemunas hydrological model

After integration of the separate subcatchments into one entirety, calibration of the model was started. Model calibration was performed changing 16 model parameters. The period of 1961–1975 was selected for the calibration (Fig. 5.2a). The correlation coefficient between simulated and calculated discharges for calibration period was R=0.88, and *accdif*, i.e. accumulated difference between simulated and calculated discharges, was 0.07 mm. Such results allow to state that the model calibration was successful. The correlation coefficient for validation period (1976–1990) was R=0.84, and accumulated difference between simulated and calculated discharges, was -188 mm (Fig. 5.2b). Taking into account a long model validation period (1976–1990), accumulated difference is not significant. Considering the model calibration and validation results, it can be concluded that the model is suitable to make forecast of the Nemunas inflow in the 21st century according to predicted climate change scenarios.

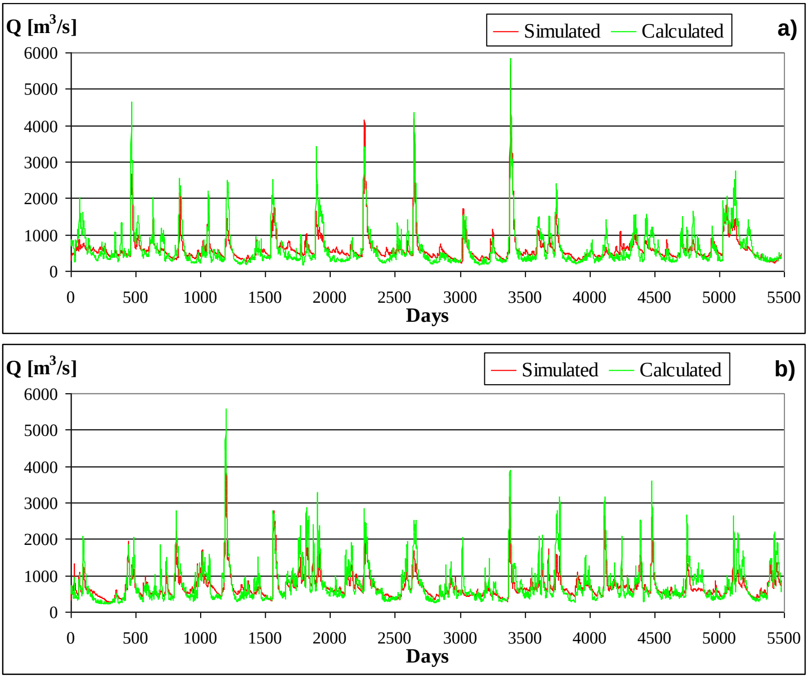

Fig. 5.2. Comparison of simulated and calculated discharge of the Nemunas at its mouth: a) in calibration period (1961–1975), b) in validation period (1976–1990)

The quality and success of river hydrological model calibration depends on the correct selection of model parameters. The influence of hydrological model parameters on the modelling results (the runoff of the Nemunas catchment tributaries – the Neris and Merkys) was assessed applying uncertainty and sensitivity analysis (SUSA software). The sensitivity analysis of model parameters during the selected hydrological periods (spring flood, winter and autumn flash floods, low water) over a year was performed, because some parameters have greater influence on floods and flash floods and some can better describe the runoff during the low water period. During spring flood the results of hydrological model depended on the calibration parameters that describe snowmelt and soil moisture storage, while during the low water period – the parameter that determines river underground feeding was the most important.

6. PREDICTION OF WATER BALANCE ELEMENTS OF THE CURONIAN LAGOON ACCORDING TO DIFFERENT CLIMATE AND SEA-LEVEL CHANGE SCENARIOS

6.1. Analysis of air temperature and precipitation amount in the Nemunas catchment according to different climate change scenarios

Air temperature and precipitation amount are the main climate elements that form river runoff. Prognostic air temperature and precipitation amount data derived from ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios were used for modelling of river inflow.

Air temperature. The mean projected air temperature in the periods of 2011–2040, 2041–2070 and 2071–2100 according to different models and emission scenarios is presented in Figure 6.1. In accordance to the output data of ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios, the increase of air temperature was estimated by the data of 14 MS. In the period of 2011–2100 the annual air temperature in the Lithuanian part of the Nemunas catchment area is supposed to change from 7.1 °C to 11.4 °C (Fig. 6.1a), in winter – from -1.4 °C to 3.6 °C (Fig. 6.1b), in spring – from 6.5 °C to 11.5 °C (Fig. 6.1c), in summer – from 16.5 °C to 20.3 °C (Fig. 8.1d) and in autumn – from 7.1 °C to 10.9 °C (Fig. 8.1e). In the period of 2011–2100 annual air temperature is going to be higher up to 5.3 °C, in winter – 6.7 °C, in spring – 5.7 °C, in summer and spring – 4.0 °C if compared to the air temperature of the baseline period.

Precipitation. Not only evaluation of the annual amount of precipitation is important, but also its distribution among different seasons. In Figures (6.1 a–j) total annual and seasonal amounts of precipitation are presented and compared to the mean values of 1961–1990 and six scenarios. The projected annual amount of precipitation for 2011–2100 according to all investigated scenarios will fluctuate in a range of 656–784 mm (Fig. 6.1f), in winter – 137–196 mm (Fig. 6.1g), in spring – 137–183 mm (Fig. 6.1h, in summer – 203–250 mm (Fig. 6.1i) and in autumn – 154–195 mm (Fig. 6.1j). The annual amount of precipitation will be up to 5.8 % comparing to the baseline period. Higher than the baseline period amount is expected to be in winter and spring, up to 29.6 % and 14.4 % more precipitation respectively. In winter and autumn seasons the decrease of the amount of precipitation is predicted, down to 29.6 % and 14.4 % less than in the baseline period respectively.

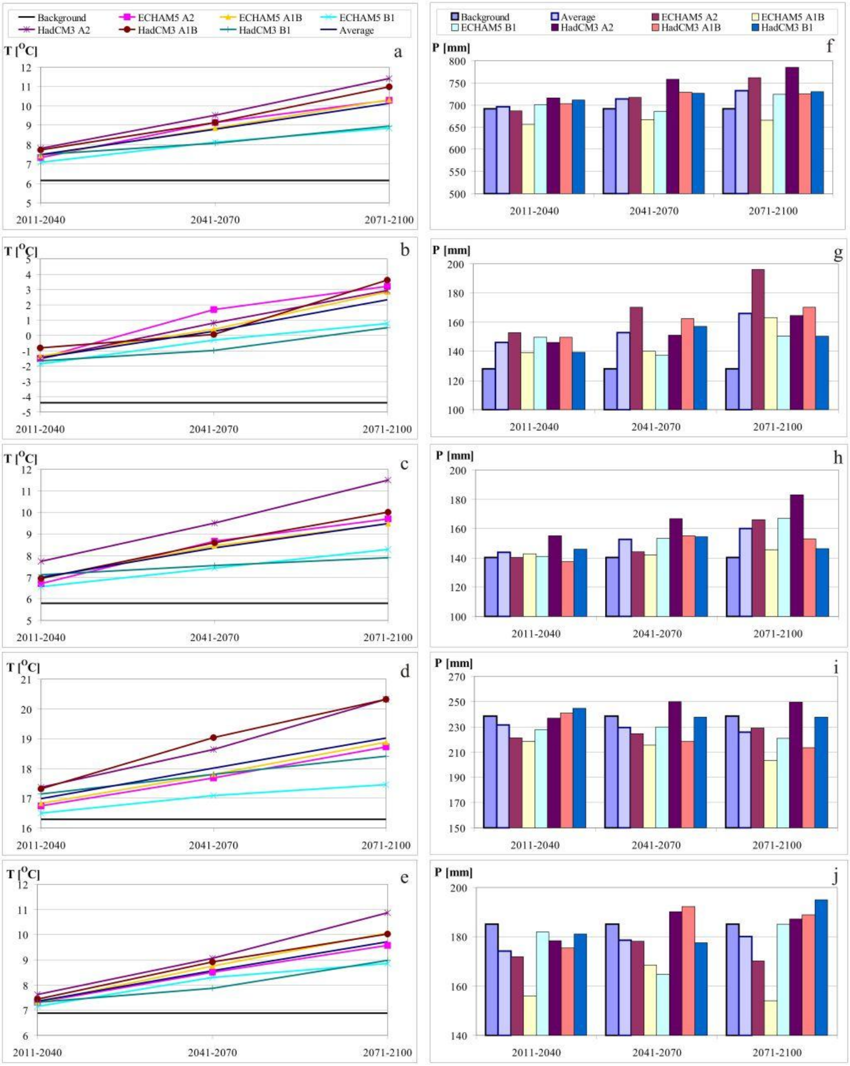

Fig. 6.1. The projected changes of air temperature (T, °C) and precipitation (P, mm) in 2011–2040, 2041–2070 and 2071–2100: **a** and **f** annual, **b** and **g** in winter, **c** and **h** in spring, **d** and **i** in summer, **e** and **j** in autumn

6.2. The Nemunas runoff according to different climate change scenarios in the 21st century

The model of the Nemunas runoff to the Curonian Lagoon was created applying HBV software package as well as the discharge, precipitation and temperature data of the period of 1961–1990. The Nemunas total inflow to the Curonian Lagoon in 21st century was simulated according to the output data of ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios. The obtained results were compared with the runoff of the baseline period (Fig. 6.2)

In 2011–2100 the Nemunas discharge to the Curonian Lagoon will increase to 5.4 % in winter, whereas it is supposed to decrease in spring, summer and autumn to 40.5 %, 1.7 % and 21.8 % respectively.

During the first period (2011–2040) discharges of spring floods are going to get lower, a part of the runoff will move from spring to the winter season. In this period two floods are projected: one at the end of winter and another in the middle of spring (Fig. 6.2). The discharge of winter flood will vary in a range of 752–1110 m^3/s and will be equal to 880 m^3/s in average according to 6 scenarios. Spring flood is expected to be higher than winter flood: 1122 m^3/s in average (837–1385 m^3/s). It was estimated that spring floods will exceed winter floods (up to 242 m^3/s), but they will be less than in the baseline period, when the mean flood discharge was 1861 m^3/s. The projected mean runoff will increase in summer and decrease in autumn if compared to the baseline period. In the period of 2041–2070 significant spring floods are expected only according to HadCM3 B1 scenario, when flood discharges will increase to 1183 m^3/s in average. According to the rest of 5 scenarios floods are going to occur only in February. During winter flood discharge will vary from 706 m^3/s to 1119 m^3/s. In 2041–2070 summer and autumn discharges will be smaller than in the baseline period. In 2071–2100 spring floods are going to move to the winter season, while flood peaks will decrease by half. The maximum discharge of such floods will vary from 704 m^3/s to 1047 m^3/s. Runoff in summer and autumn is supposed to get smaller than in the baseline period.

The projected extreme values of runoff are very important for investigation of the annual runoff change. It was estimated that in the period of 2011–2100 mean maximum discharges according to 6 scenarios are going to be by 61.4 % less than in the baseline period. The flood peaks will move from spring to winter. Such runoff changes can be explained by the increase of air temperature (Fig 6.1b) and amount of precipitation (Fig. 6.1g) in the winter season. Temperature in winter increases, more often it becomes positive, therefore precipitation falls in the form of rain and reaches the rivers sooner by forming the earlier flood.

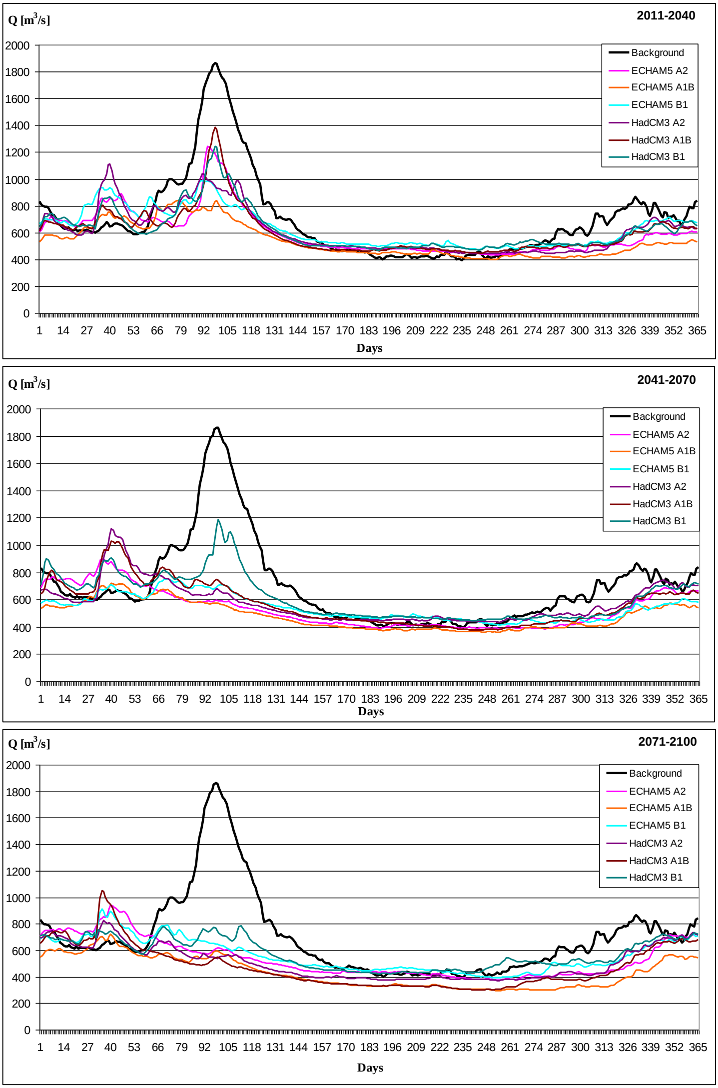

Fig. 6.2. Simulated mean daily discharge of the Nemunas river inflow to the Curonian Lagoon for the periods of 2011–2040 (a), 2041–2070 (b) and 2071–2100 (c) according to emission scenarios (A2, B1, A1B) and global climate models (HadCM3, ECHAM5) compared with discharge of the baseline period of 1961–1990.

6.3. Analysis of water balance elements of the Curonian Lagoon according to different climate and sea-level change scenarios in the 21st century

Water balance of the Curonian Lagoon for 21st century. was calculated by dividing the investigated period to three thirty-year periods: 2011–2040, 2041–2070 and 2071–2100. River runoff, precipitation and temperature were estimated as the mean values of 6 scenarios in a certain thirty-year period. As a result, three possible water balances of the Curonian Lagoon were proposed according to three different sea-level rise scenarios (Table 6.1).

River inflow makes the most significant part of water balance income. In the baseline period (1961–1990) it was 22.084 km^3/year in average. The simulation results indicated the runoff decrease; according to the mean value of 6 scenarios it will reach 18.886 km^3/year in 2011–2040, 17.372 km^3/year in 2041–2070 and 16.236 km^3/year in 2071–2100.

Figure 6.3 shows the analysed river runoff distribution in the different periods. It was estimated that the winter river runoff comprised 24.2 % of the annual amount in the baseline period, 28.0 % in 2011–2040, 30.9 % in 2041–2070 and 32.9 % in 2071–2100. The spring river runoff made 38.8 % of the annual amount in the baseline period, 34.4 % in 2011–2040, 28.5 % in 2041–2070 and 27.2 % in 2071–2100. The summer river inflow to the lagoon formed 15.9–16.0 % of the annual amount and 19.3–20.0 % in 2011–2100. In autumn during both the baseline and 2011–2100 periods river runoff changed insignificantly and comprised 21 % of the annual amount in average. The obtained results allow confirming an assumption that runoff changes between the winter and spring seasons are going to decrease. In summer runoff will slightly increase, whereas in autumn it will remain unchanged.

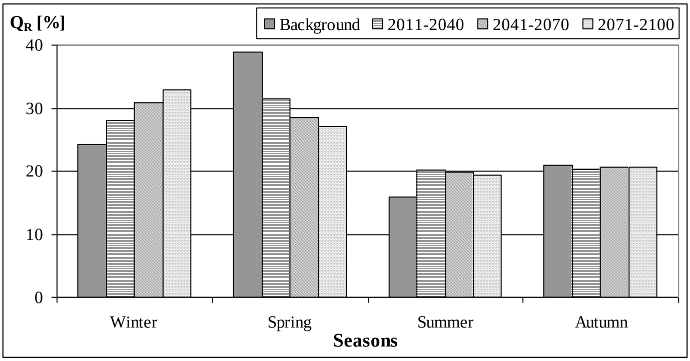

Fig. 6.3. River inflow to the Curonian Lagoon during different seasons according to six emission scenarios (% from the annual amount)

Annual variation of precipitation and evaporation is determined by constantly changing climate. Precipitation makes the least part of water balance income, but it cannot be ignored. The mean annual amount of precipitation that falls on the surface of the Curonian Lagoon in the baseline period equals 1.157 km^3. According to the mean values of ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios, 1.155 km^3/year amount of precipitation will fall down on the lagoon in 2011–2040, 1.172 km^3/year – in 2041–2070 and 1.201 km^3/year – in 2071–2100 in average. It is projected that the amount of precipitation will increase in winter and spring, decrease in summer and be close to the one of the baseline period in autumn.

Evaporation is the least element of water balance losses. About 1.052 km^3 of water was evaporated per year in average during the baseline period. According to 6 emission scenarios, the average annual amount of evaporation from the Curonian Lagoon will consist of 1.075 km^3 in 2011–2040, 1.152 km^3 – in 2041–2070 and 1.228 km^3 – in 2071–2100. If compared to the baseline period, the greatest differences of evaporation were estimated in winter, less – in spring and summer and the least – in autumn.

Water exchange between the Baltic Sea and the Curonian Lagoon is a water balance element that is the most difficult to measure. For this reason it is calculated using water balance equation (equation 2). Water exchange between the sea and the lagoon was computed according to 3 sea-level rise scenarios: (a) 0.87 mm/year; (b) 4.02 mm/year; (c) 4.65 mm/year. Sea-level rise scenario (b) is the most possible (Fig. 6.4); it is based on water level change in the Curonian Lagoon in 1961–1990.

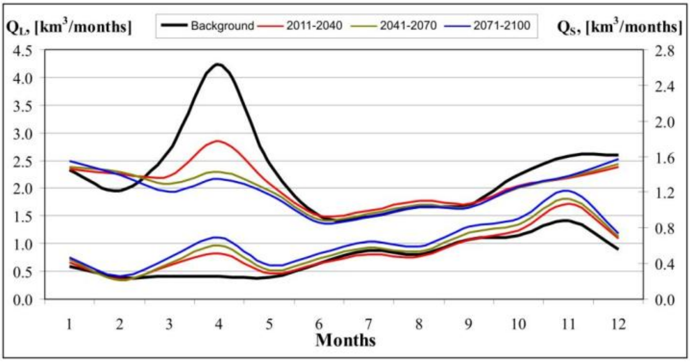

Fig. 6.4. Change of outflow to the sea from the lagoon ($Q_{L,}$ curves in the upper part of the figure) and inflow from the sea to the lagoon (Q_S, curves in the lower part of the figure) in 2011–2100

It was estimated that according to scenario (b) the outflow from the Curonian Lagoon to the Baltic Sea will gradually decrease: by 24.996 km^3/year –

in 2011–2040, 24.042 km^3/year – in 2041–2070 and by 23.708 km^3/year – in 2071–2100. The outflow is expected to decrease by 9 % in 2011–2040, 12.5 % – in 2041–2070 and by 13.7 % – in 2071–2100 comparing to the baseline period. According to sea-level rise scenario (b), the inflow from the sea to the lagoon will increase: it will reach 6.399 km^3/year in 2011–2040, 6.972 km^3/year – in 2041–2070 and 7.708 km^3/year – in 2071–2100 in average. The inflow from the sea to the lagoon is expected to be greater by 13.0 %, 18.4 % and 36.2 % respectively, if compared to the baseline period.

Review of the simulation results of water exchange between the Baltic sea and the Curonian Lagoon according to sea-level rise scenario (b) allows to state that rising sea-level will less influence outflow from the lagoon to the sea, but it will be determinated for the increase of the inflow from the sea to the lagoon.

The projection of water balance of the Curonian Lagoon for the periods of 2011–2040, 2041–2070 and 2071–2100 is presented in table 6.1. Water balances of the periods of 1961–1990 and 1960–2009 are also shown for the comparison.

Table 6.1. Water balance of the Curonian lagoon in the periods of: 1961–1990, 1960–2009, 2011–2040, 2041–2070, 2071–2100.

Sea-level change scenarios	**Period**	**Water balance elements**							
		Q_R	**Q_L**	**Q_S**	**P**	**Z**	**ΔV**	**Error**	**Maximum allowable error**
	1961–1990	22.084	27.467	5.658	1.157	1.052	0.018	0.380	1.123
	1960–2009	21.784	27.642	6.171	1.199	1.007	0.037	0.468	0.810
(a)	2011–2040	18.883	24.870	6.239	1.155	1.075	0.015	0.317	0.562
	2041–2070	17.372	23.625	6.527	1.172	1.152	0.016	0.277	0.590
	2071–2100	16.236	22.915	6.855	1.201	1.228	0.019	0.130	0.665
(b)	2011–2040	18.883	24.996	6.399	1.155	1.075	0.015	0.351	0.572
	2041–2070	17.372	24.042	6.972	1.172	1.152	0.012	0.309	0.632
	2071–2100	16.236	23.708	7.708	1.201	1.228	0.018	0.190	0.699
(c)	2011–2040	18.883	25.022	6.429	1.155	1.075	0.014	0.355	0.572
	2041–2070	17.372	24.160	7.113	1.172	1.152	0.016	0.328	0.607
	2071–2100	16.236	23.863	7.907	1.201	1.228	0.015	0.238	0.714

7. IMPACT OF KLAIPĖDA STATE SEAPORT ON WATER BALANCE OF THE CURONIAN LAGOON

Klaipėda seaport has been known since 1252. The main factor that limited port activity was shallow fairway. In order to ensure the normal functioning of Klaipėda State Sea Port, dredging works of the port entrance channel are performed, the new quays are constructed and the old ones are reconstructed. In 1853 the maximum depth of the fairway was only 7 m, in 1932 – 10 m, in 1996 – 12 m, in 2010 – 12–14.5 m. Since 1996 intensive dredging works of Klaipėda port entrance channel has began. The dredging works influence Klaipėda strait permeability which changes have impact on water balance of the Curonian Lagoon. The changes of the entrance channel permeability have increased the salt water inflow from the sea to the lagoon. Implementing the port development projects, environmentalists have an attitude that permeability of Klaipėda port entrance channel cannot be increased more than 10 % compared to the level of 1996. A possibility of the port dredging is left, but then the increased permeability should be compensated by other measures, for instance, by installing pierses or constructing new quays. Currently it is planned to dredge Klaipėda port fairway to the depth of 14.5 m. Environmental impact assessment of dredging of navigation channel of Klaipėda State Sea Port showed that if environment protection measures were implemented, the permeability of Klaipėda Strait would increase by 10.4 % when there is outflow from the Curonian Lagoon to the Baltic Sea and by 8.5 % when there is inflow from the Baltic Sea to the Curonian Lagoon.

The changes of probability of the inflow from the sea to the lagoon in the period of 2011–2100 according to different sea-level rise scenarios comparing to the baseline period are relevant for the development of the port activities. Such projection would help to evaluate possible changes of the Klaipėda Strait permeability due to climate change in the 21st century.

According to sea-level change scenario (b), in the period of 2011–2040 salt water inflow of 95 % probability will be greater by 32.7 %, inflow of 50 % probabillity will increase by 11.2 % and inflow of 5 % probability – by 21.6 % if compared to the baseline period inflow values (Fig. 7.1). In 2041–2070 the projected inflows of the mentioned probabilities is going to be 48.5 %, 20.2 %, 29.8 % and in 2071–2100 – 66.4 %, 30.9 %, 39.5 % respectively. In the period of 2011–2100 especially great changes of the salt water inflow are possible if inflow has 95 and 5 % probability and the least changes will occur – if inflow from the Baltic Sea to the Curonian lagoon has 50 % probability. These inflow changes are projected according to the data of climate and sea-level change scenarios on condition that the strait permeability is not going to be changed. Evaluation of the sea water inflow changes is necessary for Klaipėda port development, because this inflow can increase by 39.7 % only due to climate change.

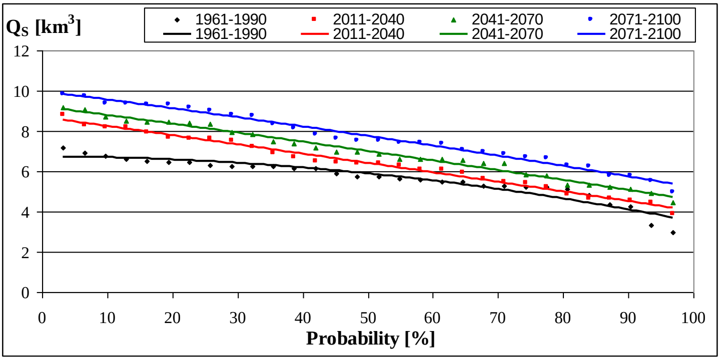

Fig. 7.1. The probability distribution of the inflow from the Baltic Sea according to sea-level rise scenario in comparison to the period of 1961–1990

8. CONCLUSIONS

1. In Doctoral Dissertation the original methodology was created, according to which the already occurred changes of water balance of the Curonian Lagoon over the past 50 years were evaluated and a forecast of water balance for the 21st century was performed. Analysis and projection of water balance elements of the Curonian Lagoon revealed that in the recent decades and the 21st century river inflow to the Curonian Lagoon decreases and water exchange between the Baltic Sea and the Curonian Lagoon changes. In the 21st century growing of the salt water inflow from the Baltic Sea will influence the ecosystem of the Curonian Lagoon. Variation of water exchange due to climate change has to be taken into account during Klaipėda port development (fairway dredging).
2. According to calculation of multi-annual (1960–2009) water balance of the Curonian Lagoon, total river inflow is 21.784 km^3/year, precipitation– 1.199 km^3/year, evaporation – 1.007 km^3/year. Water exchange between the Baltic Sea and the Curonian Lagoon consisted of the sea water inflow to the lagoon (6,171 km^3/year) and fresh water outflow from the lagoon to the sea (27.642 km^3/year).
3. In the period of 1960–2009 significant changes of the river runoff to the Curonian Lagoon during a year were determined. River runoff is increasing in winter and decreasing in spring, therefore runoff is getting more evenly distributed among the seasons. Such changes are caused by the increase of air temperature in the cold period. In 1960–2009 water inflow from the Baltic Sea to the Curonian Lagoon was rising, this can be related to climate change and Klaipėda port development.
4. Uncertainty analysis of water balance elements showed that river inflow has the greatest influence (equal to 1.0 according to Spearman correlation) on the results (volume change of the Curonian Lagoon), whereas precipitation (0.02) and evaporation (-0.1) are much less important. In order to get more accurate results of water balance of the Curonian Lagoon, special attention should be paid to the precise evaluation of river inflow.
5. Water balance of the Curonian Lagoon in the 21st century was calculated according to ECHAM5 and HadCM3 global climate models under A2, A1B and B1 greenhouse gas emission scenarios as well as sea-level rise scenarios (a), (b) and (c) for the periods of 2011–2040, 2041–2070, 2071–2100. In the 21st century the mean annual air temperature in the Lithuanian part of the Nemunas catchment area is supposed to increase by 4.0 °C, in winter – 6.7 °C, in spring – 3.7 °C, in summer – 2.7 °C and in autumn – 2.8 °C if compared to the baseline period values. In the 21st century annual amount of precipitation will increase by 5.8 %, in winter and spring – by 29.6 % and 14.4 %, whereas in summer and autumn will decrease by 5.6 % and 2.7 % if compared to the baseline period precipitation values.

6. The Nemunas hydrological model was created for the modelling of river inflow to the Curonian Lagoon. The uncertainty analysis of hydrological model parameters revealed that FC (maximum soil moisture storage) was the most important calibration parameter during all seasons. Influence of the other parameters changed depending on the season: snowfall correction factor (sfcf) was significant in spring, exponent in formula for drainage from soil (beta) – in autumn, recession coefficient for lower response box (k4) – in winter. Therefore during calibration and validation of the created models a special attention should be paid to the appropriate selection of these parameters.
7. River inflow to the Curonian Lagoon was simulated using the Nemunas hydrological model and the output data of climate change models. The projection is made that at the end of the 21st century according to the mean values of six scenarios, the annual Nemunas inflow to the Curonian Lagoon is expected to be less by 25.9 % comparing to the baseline period. Analysis of runoff in different seasons revealed that runoff will increase by 9.0 % in winter, but it will get less in spring, summer and autumn by 55.8 %, 25.3 % and 56.3 % respectively if compared to the Nemunas runoff in the baseline period. Analysis of predicted maximum and minimal discharges of the Nemunas at the end of the 21st century showed that the mean extremal discharges will be less than in the baseline period, runoff is going to be more smoothed during a year.
8. Analysis of the change of projected water balance elements indicated decrease of river inflow to 25.9 %, increase of evaporation to 25.1% due to air temperature rise, insignificant increase of precipitation (to 3.8 %), decrease of outflow from the Curonian Lagoon to the Baltic Sea of 16.6 % if compared to the baseline period values. Evaluation of the sea water inflow changes is necessary for Klaipėda port development, because this inflow can increase by 39.7% only due to climate change.

THE LIST OF SCIENTIFIC PUBLICATIONS ON THE SUBJECT OF THE DISSERTATION

Publications in the journals of the Institute for Scientific Information (ISI Web of Science):

1. **Jakimavičius, Darius**; Kovalenkovienė, Milda. Long-term water balance of the Curonian Lagoon in the context of anthropogenic factors and climate change // Baltica. ISSN 0067-3064. 2010, vol. 23, no. 1, p. 33–46.
2. Gailiušis, Brunonas; Kriaučiūnienė, Jūratė; **Jakimavičius, Darius**; Šarauskienė, Diana. The variability of long–term runoff series in the Baltic Sea drainage basin // Baltica. ISSN 0067-3064. 2011, vol. 24, no. 1, p. 45–54.
3. Kriauciuniene, Jurate; **Jakimavicius, Darius**; Sarauskiene, Diana; Kaliatka, Tadas. Estimation of uncertainty sources in the projections of Lithuanian river runoff // *Stochastic Environmental Research and Risk Assessment*. 2012. DOI: 10.1007/s00477-012-0608-7. IF-1,523 (2011).
4. **Jakimavicius, Darius**; Kriauciuniene, Jurate. Climate change impact on the water balance of the Curonian Lagoon // *Water resources*. [**accepted 13 June 2012**]

Conference material:

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REZIUME

Vandens telkinių, šiuo atvejų Kuršių marių, hidrologinį režimą veikia klimatas. Pastaruoju metu dažnai kalbama apie klimato kaitos įtaką fiziniams geografiniams veiksniams. Dėl klimato kaitos kinta upių nuotėkis, kyla pasaulinio vandenyno lygis. Visi šie pokyčiai yra klimato kaitos pasekmė. Kuršių marios taip pat patiria ir antropogeninį poveikį dėl Klaipėdos valstybinio jūrų uosto (KVJU), įsikūrusio sąsiauryje tarp Kuršių marių ir Baltijos jūros, veiklos. Gilinant Klaipėdos uosto įplaukos kanalą, keičiasi vandens apykaita tarp Baltijos jūros ir Kuršių marių, vis daugiau druskingo vandens priteka į sąlyginai gėlą vandens telkinį. Kyla klausimas, kokiu mastu klimato kaita bei uosto veikla turi įtakos Kuršių marių hidrologiniam režimui. Iki šiol buvo analizuota tik atskirų Kuršių marių vandens balanso elementų, tokių kaip upių prietakos, vandens lygio, klimatinių rodiklių, t.y. kritulių lauko, išgaravimą įtakojančio vėjo greičio ir oro temperatūros, kaita. Tyrimo, kuriame būtų analizuojama ilgo laikotarpio Kuršių marių vandens balanso bei jo elementų kaita ir pateikiama jų prognozė XXI a., nebuvo. Mokslininkai iki šiol analizuodami vandens apykaitos tarp Baltijos jūros ir Kuršių marių pokyčius akcentuodavo uosto veiklos įtaką, tačiau iki šiol nėra mokslinių darbų, kaip ši apykaita XXI a. keisis dėl gamtinių procesų. Šiame darbe nustatyta, kad kylantis pasaulinis jūros lygis ir dėl to didėjantis vandens lygių skirtumas tarp Baltijos jūros ir Kuršių marių bei mažėjanti upių prietaka reikšmingai pakeis vandens apykaitą tarp šių dviejų vandens telkinių. Padidėjusi druskingo vandens prietaka gali neigiamai veikti Kuršių marių ekosistemos gyvavimo sąlygas.

Norint įvertinti Kuršių marių hidrologinio režimo pokyčius, apskaičiuotas 1960–2009 m. laikotarpio marių vandens balansas. Pasitelkus hidrologinį modeliavimą, ECHAM5 ir HadCM3 globalių bei RCAO–E ir RCAO–H regioninių klimato modelių duomenis pagal A2, A1B, B1 ir B2 šiltnamio dujų emisijų scenarijus (plačiau 1.5 skyrius), prognozuota Kuršių marių vandens balanso elementų kaita XXI amžiuje. Ilgo laikotarpio Kuršių marių vandens balanso elementų analizė leido įvertinti hidrologinio režimo pokyčius klimato kaitos fone bei pateikti galimas vandens balanso kitimo prognozes XXI a.

Šiame darbe sudaryta hidrologinių ir meteorologinių duomenų bazė, pagal kurią buvo atlikta išsami Kuršių marių hidrologinio režimo analizė. Naudojant statistinės analizės metodus, hidrologinį modeliavimą bei prognostinius klimato kaitos duomenis išanalizuoti suminės upių prietakos, kritulių, išgaravimo bei vandens apykaitos tarp Baltijos jūros ir Kuršių marių pokyčiai tiriamuoju 1960–2009 m. laikotarpiu bei sudaryta jų prognozė XXI a.

Darbo aktualumas

Šis darbas aktualus moksliniu ir praktiniu požiūriais. Parengtą vandens balanso skaičiavimo metodiką galima taikyti ir kitiems vandens telkiniams. Apskaičiuotas vandens balansas sudarys galimybę identifikuoti Kuršių mariose įvykusius hidrologinius pokyčius dėl globalių procesų (klimato kaitos) ir lokalios antropogeninės veiklos (uosto įplaukos kanalo gilinimo) bei prognozuoti galimus jų pokyčius ateityje.

Darbo objektas

Kuršių marios bei Kuršių marių vandens balanso elementai: upių prietaka į marias, vandens apykaita tarp Baltijos jūros ir Kuršių marių (prietaka ir nuotėkis), krituliai ant marių paviršiaus bei išgaravimas.

Darbo tikslas

Naudojant sukauptą hidrometeorologinių stebėjimo duomenų bazę, klimato ir jūros lygio kaitos matematinius modelius, statistinės analizės metodus bei hidrologinį modeliavimą įvertinti įvykusius Kuršių marių vandens balanso pokyčius ir nustatyti galimas jo kitimo tendencijas XXI amžiuje.

Darbo uždaviniai:

1. Parengti Kuršių marių vandens balanso skaičiavimo metodiką dviems skirtingiems laikotarpiams: 1960–2009 m. ir 2011–2100 m.
2. Apskaičiuoti 1960–2009 m. laikotarpio Kuršių marių vandens balansą ir išanalizuoti jo pokyčius klimato kaitos bei antropogeninių veiksnių fone.
3. Taikant sukurtą Nemuno nuotėkio modelį bei įvairių klimato ir jūros lygio kaitos scenarijų duomenis prognozuoti Kuršių marių vandens balansą ir jo kitimo tendencijas XXI a.
4. Įvertinti Nemuno nuotėkio modelio ir Kuršių marių vandens balanso skaičiavimo neapibrėžtumus taikant SUSA programinę įrangą.
5. Įvertinti Klaipėdos uosto plėtrą ribojančių veiksnių (vandens apykaitos tarp Kuršių marių ir Baltijos jūros) pokyčius klimato kaitos sąlygomis.

Ginamas disertacijos teiginys

Kuršių marių vandens balanso elementų kaitai esminės įtakos turi tiek gamtiniai, tiek antropogeniniai veiksniai. Per pastaruosius dešimtmečius bei XXI amžiuje mažėja upių prietaka į Kuršių marias ir keičiasi vandens apykaita tarp Baltijos jūros ir Kuršių marių. XXI a. prietaka iš Baltijos jūros didės dėl klimato kaitos, todėl gamtosaugos priemonės bus būtinos plečiant Klaipėdos uostą ir saugant Kuršių marių ekosistemą.

Darbo naujumas ir pritaikomumas

Darbe parengta metodika, pagal kurią pirmą kartą pateikta Kuršių marių vandens balanso bei jo elementų, įskaitant ir Nemuno nuotėkio ties žiotimis, prognozė (XXI amžiuje). Siekdamas įvertinti marių hidrologinius pokyčius praeityje, autorius patobulino marių vandens balanso skaičiavimo metodiką, pagal kurią upių prietaka apskaičiuota paros intervalu vertinant Nemuno ties Smalininkais ir žemiau jų įtekančių upių debitus. Pirmą kartą Lietuvoje atlikta vandens balanso elementų neapibrėžtumo analizė. Gautos naujos žinios apie

Kuršių marių hidrologinio režimo pokyčius bus naudingos plečiant Klaipėdos uostą ir pagrindžiant gamtosaugos priemones.

Publikacijos

Disertacinio darbo tema paskelbtos 4 publikacijos mokslinės informacijos instituto (ISI) pagrindinio sąrašo leidiniuose. Pristatyti 7 pranešimai respublikinėse bei tarptautinėse konferencijose.

IŠVADOS

1. Darbe sukurta originali metodika, pagal kurią įvertinti jau įvykę Kuršių marių vandens balanso pokyčiai per pastaruosius 50 metų ir atlikta vandens balanso prognozė XXI amžiuje. Išanalizavus Kuršių marių vandens balanso elementų pokyčius ir jų prognozę nustatyta, kad per pastaruosius dešimtmečius bei XXI a. mažėja upių prietaka į Kuršių marias ir keičiasi vandens apykaita tarp Baltijos jūros ir Kuršių marių. XXI a. didėjanti druskingo vandens prietaka iš Baltijos jūros turės įtakos Kuršių marių ekosistemai, todėl plečiant Klaipėdos uostą (gilinant farvaterį), būtina įvertinti vandens apykaitos pokyčius dėl klimato kaitos.
2. Apskaičiavus daugiametį (1960–2009 m.) Kuršių marių vandens balansą gauta, kad suminė upių prietaka yra 21,784 km^3/m., krituliai 1,199 km^3/m., išgaravimas 1,007 km^3/m. Vandens apykaitą tarp Baltijos jūros ir Kuršių marių sudarė Baltijos jūros vandens prietaka į Kuršių marias (6,171 km^3/m.) ir gėlo vandens nuotėkis iš Kuršių marių į Baltijos jūrą (27,642 km^3/m.).
3. 1960–2009 m. laikotarpiu nustatytas žymus upių nuotėkio į Kuršių marias persiskirstymas per metus. Žiemos sezono upių nuotėkis didėja, o pavasario – mažėja, todėl nuotėkis tolygiau pasiskirsto tarp sezonų. Šiuos pokyčius sukėlė šaltojo laikotarpio temperatūros didėjimas. 1960–2009 m. laikotarpio vandens prietaka iš Baltijos jūros į Kuršių marias didėjo. Prietakos iš Baltijos jūros į Kuršių marias didėjimas sietinas su klimato kaita ir Klaipėdos uosto plėtra.
4. Vandens balanso elementų neapibrėžtumo analizė parodė, kad didžiausią įtaką galutiniam rezultatui (Kuršių marių tūrio pokyčiams) turi upių prietaka (įtaka yra 1,0 pagal Spearmano koreliaciją), o kur kas mažesnę įtaką – krituliai (0,02) ir išgaravimas (-0,1). Norint tiksliau apskaičiuoti Kuršių marių vandens balansą, ypatingą dėmesį reikėtų atkreipti į upių prietakos įvertinimą, nes šio parametro įtaka rezultatams yra didžiausia.
5. XXI a. Kuršių marių vandens balansas buvo apskaičiuotas pagal ECHAM5 ir HadCM3 globalius klimato kaitos modelius ir A2, A1B, B1 emisijų bei (a), (b) ir (c) jūros lygio kilimo scenarijus 2011–2040 m., 2041–2070 m., 2071–2100 m. laikotarpiams. Darbe nustatyta, kad per XXI a. Nemuno baseino teritorijoje vidutinė metinė oro temperatūra padidės 4,0 °C, žiemos sezono – 6,7 °C, pavasario sezono – 3,7 °C, vasaros sezono – 2,7 °C ir rudens sezono –

2,8 °C palyginti su foninio laikotarpio oro temperatūra. Per XXI a. metinis kritulių kiekis padidės 5,8 %, žiemos ir pavasario sezonų – didės 29,6 % ir 14,4 %, vasaros ir rudens – sumažės 5,6 % ir 2,7 % palyginus su foninio laikotarpio kritulių kiekiu.

6. Nemuno hidrologinis modelis sukurtas upių prietakai į Kuršių marias modeliuoti. Atlikus hidrologinio modelio parametrų neapibrėžtumo analizę nustatyta, kad modeliuojant Nemuno baseino upių debitus visais metų sezonais reikšmingiausias kalibravimo parametras buvo FC (maksimalus drėgmės atsargų dirvožemyje sluoksnis). Kitų parametrų įtaka keitėsi priklausomai nuo sezono: pavasarį reikšmingas sniego kiekio pataisos koeficientas (sfcf), rudenį – nuotėkio, susiformuojančio iš gruntinio vandens, eksponentės rodiklis (beta) ir požeminio baseino recesijos koeficientas (k4), žiemą – k4. Todėl kalibruojant ir validuojant kuriamus modelius, ypatingą dėmesį reikėtų skirti tinkamam šių parametrų parinkimui.

7. Upių prietaka į Kuršių marias sumodeliuota pagal klimato kaitos modelių išvesties duomenis. Prognozuojama, kad XXI a. pabaigoje pagal šešių scenarijų vidurkį metinis Nemuno nuotėkis į Kuršių marias bus 25,9 % mažesnis negu foniniu laikotarpiu. Išanalizavus nuotėkio pasiskirstymą atskirais sezonais nustatyta, kad žiemos laikotarpiu nuotėkis didės iki 9,0 %, o pavasario, vasaros ir rudens – mažės atitinkamai iki 55,8 %, 25,3 % ir 56,3 %, palyginus su foninio laikotarpio Nemuno nuotėkiu. Ištyrus maksimalius ir minimalius prognozuojamus Nemuno debitus XXI a. pabaigoje nustatyta, kad, palyginti su foniniu laikotarpiu, vidutiniai maksimalūs ir minimalūs debitai mažės, nuotėkis taps labiau išlygintas metų eigoje.

8. Išanalizavus XXI a. prognozuojamų vandens balansų elementų kaitą nustatyta, kad, lyginant su foniniu laikotarpiu, upių prietaka mažės iki 25,9 %, dėl kylančios oro temperatūros išgaravimas didės iki 25,1 %, kritulių kiekis didės nedaug (iki 3,8 %), nuotėkis iš Kuršių marių į Baltijos jūrą sumažės iki 16,6 %. Plečiant Klaipėdos uostą XXI a. būtina įvertinti prietakos iš Baltijos jūros į Kuršių marias pokyčius, nes vien dėl klimato kaitos ši prietaka gali padidėti iki 39,7 %.

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