

# Formation of Groundwater Runoff in Nemunas RBD (Lithuania)

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**Abstract** – One of the goal for the preparation of Nemunas RBD management plan is to provide a description of the current state of RBD, including the assess of groundwater discharge into surface water bodies. Groundwater discharge into surface water bodies in Nemunas RBD was carried out in four independent mathematical models for individual groundwater bodies (GWB). Models included shallow groundwater, surface water and deeper laying confined aquifers. The obtained results later were combined. Transmissivity values and recharge rates of shallow groundwater aquifer have been revised by mathematical modelling. Sources of groundwater runoff formation, i. e. an input of groundwater flow from the unconfined aquifer and deeper confined aquifers into surface water bodies, were evaluated. In addition groundwater discharge variation throughout the river length was itemized.

**Keywords:** groundwater model, groundwater runoff, groundwater body, river basin

## I. INTRODUCTION

Since Lithuania joined the European Union, the water bodies should be handled and stored outside the administrative rules, but in accordance with natural hydrological boundaries of river basins. Lithuanian rivers are combined into four river basin districts (RBD): Nemunas, Venta, Daugava and Lielupe. Each RBD developed river basin district management plans and programme of implementation measures. Description of the current state of RBD, summarized results of the analysis of influential human activity, information on water protection goals and their justification and others must be presented in the management plan (Nemunas RBD management plan, 2010). In order to provide the necessary information for management plans, one of the challenges is to quantify the groundwater discharge into surface water bodies. The easiest way to assess groundwater discharge into surface water is the division of the genetic hydrograph of the river. In Lithuania for the first time this kind of work related to Nemunas RBD was made in 1968 [9]. The analysis of different methods of hydrograph division revealed that in Lithuanian weather conditions and in the absence of extensive alluvial terraces, which could accumulate more significant quantities of water during the flood, groundwater discharge can be measured with sufficient accuracy by the minimum 30 day average flow value. These data are presented in hydrological works [1]. However, this method gives insufficient information for a number of practical problems. First, the groundwater discharge can be measured only in those basins or their parts, where the hydrological stations are settled. It is usually related to river basins of the second sequence, in exceptional cases of

the third one. Second, it is difficult to specify groundwater discharge variations through the entire length of river, which is essential analyzing the impact of diffused pollution on surface water bodies. Third, it is impossible to assess the contribution of confined aquifers groundwater discharge directly. All listed problems are solved more effectively using methods of mathematical modelling.

## II. LOCATION

Nemunas RBD consists of Nemunas River basin part located in the territory of Lithuania, Lithuanian coastal river basin, part of Prieglius River basin located in the territory of Lithuania, Lithuanian part of Curonian Lagoon and Baltic Sea coastal waters (Fig. 1).

Nemunas RBD area is 97,928 km<sup>2</sup>. Nemunas RBD (excluding assigned coastal and transitional water) area is 47.814 km<sup>2</sup> in Lithuania territory. Taking into account areas of basins, the longest and the largest tributaries of Nemunas River in Lithuania are Merkys, Neris, Nevezis, Dubysa, Sesupe, Jura and Minija.

## III. METHODOLOGY

Nemunas RBD surface water basin and sub-basin boundaries do not coincide with the boundaries of GWB. For this reason, the quantification of groundwater discharge into surface water bodies was carried out by using mathematical models of groundwater flow in particular GWB, surface water bodies and deeper situated confined aquifers, later combining the received results. Four mathematical models of groundwater-surface water interaction in Nemunas RBD were made. They include the following GWB (Fig. 2.):

- GWB of Upper-Middle Devonian deposits, Stipinai GWB of Upper Devonian deposits, Kėdainiai – Dotnuva GWB;
- GWB of Upper-Lower Cretaceous deposits, GWB of Permian-Upper Devonian deposits, Suvalkija GWB;
- GWB of Quaternary deposits of South-Eastern Lithuania, GWB of the middle reaches of the Neris, GWB of the sandy south-eastern plain, GWB of the Nemunas and the Neris, and of the lower reaches of the Nevėžis;
- GWB of Western Samogitian Quaternary deposits.

The software of s U.S. Geological Survey MODFLOW2005 [2] was used for creation of GW flow mathematical models for all mentioned GWB. The licensed software of U.S. Environmental Simulations Inc. company Groundwater Vistas Enterprise v5 [4] was used for the management of the mentioned above software, as well as for the graphic depiction and analysis of the results.

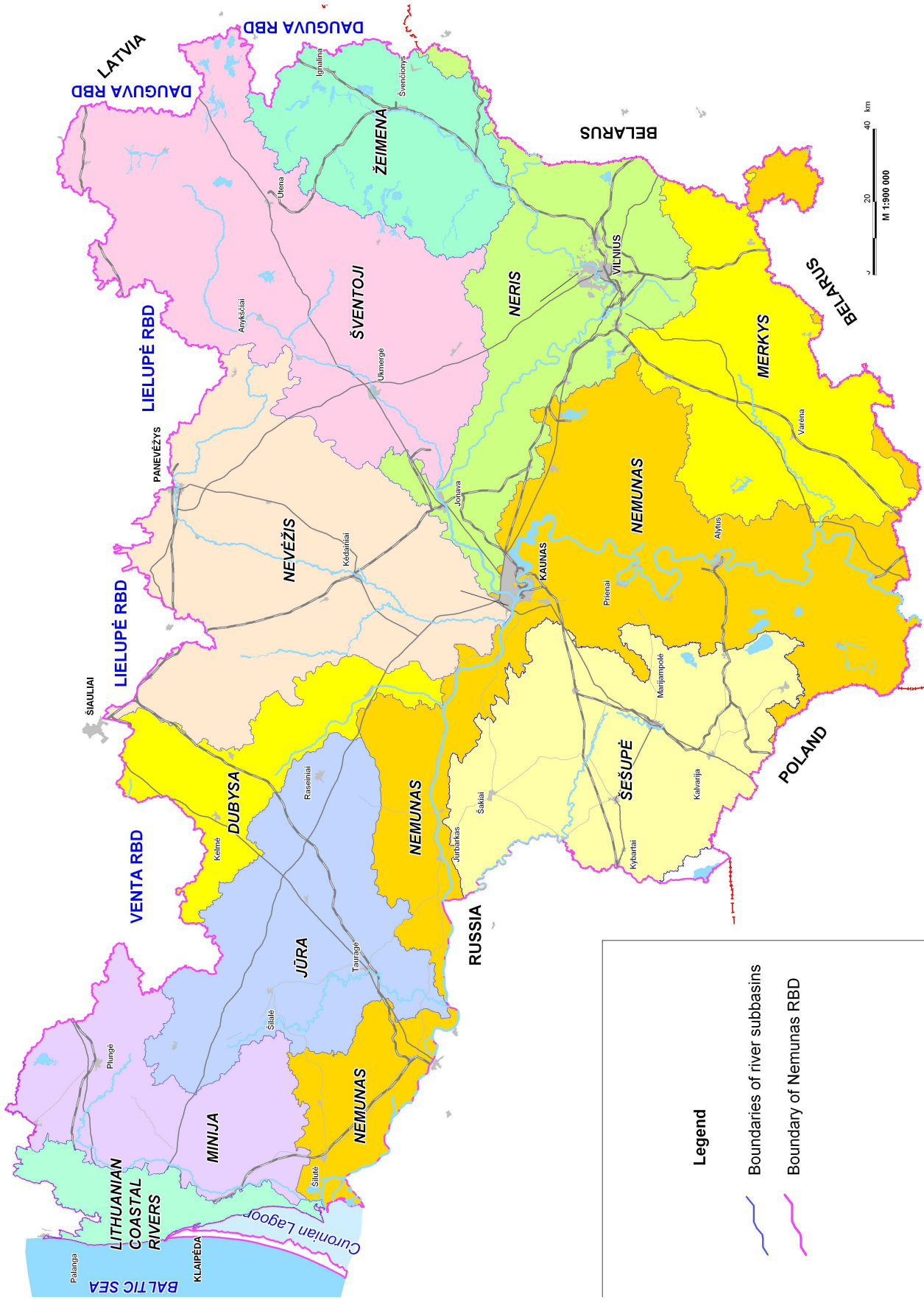


Fig. 1. Rivers subbasins within Nemunas RBD

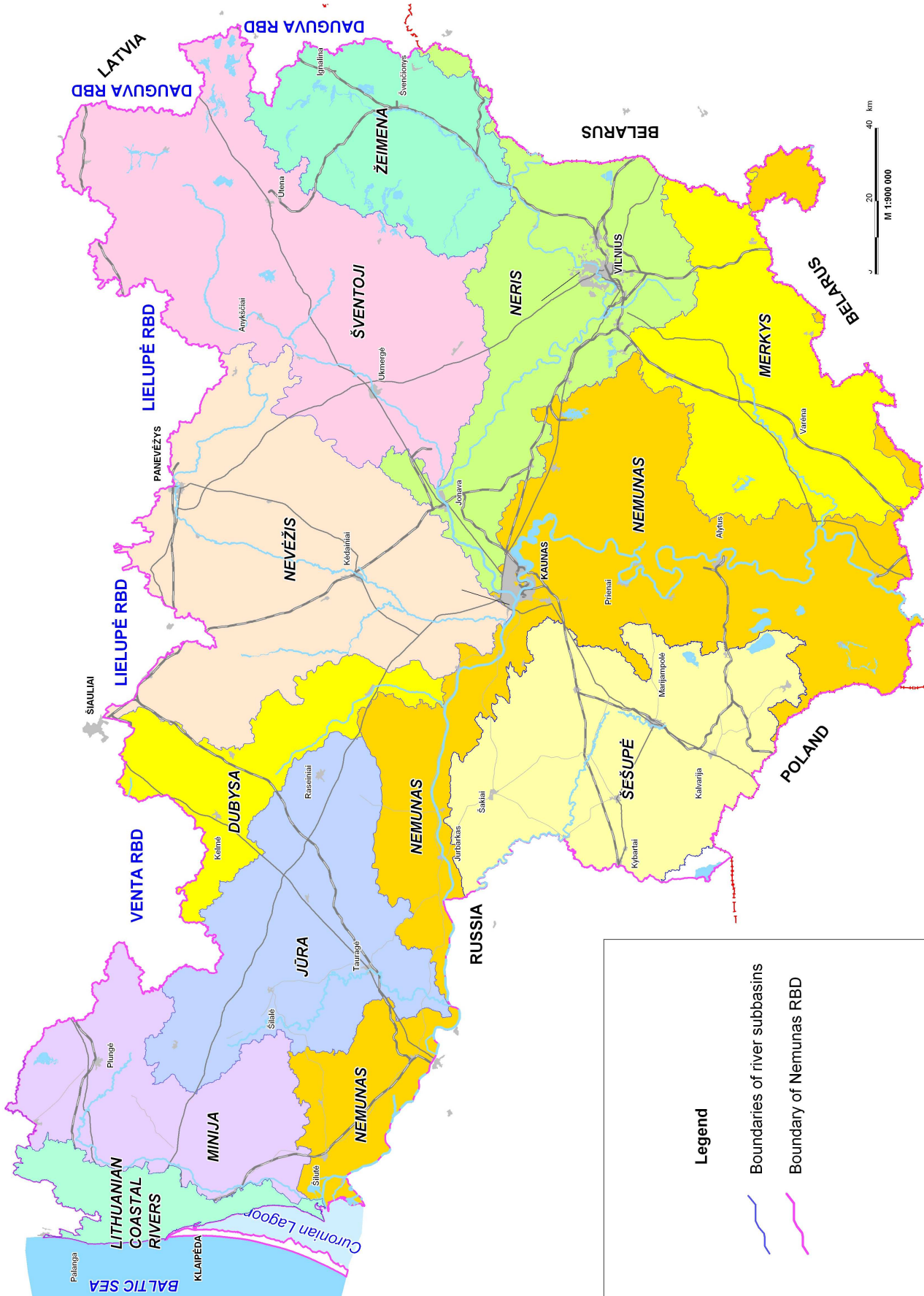


Fig. 2. Groundwater bodies within Nemunas RBD

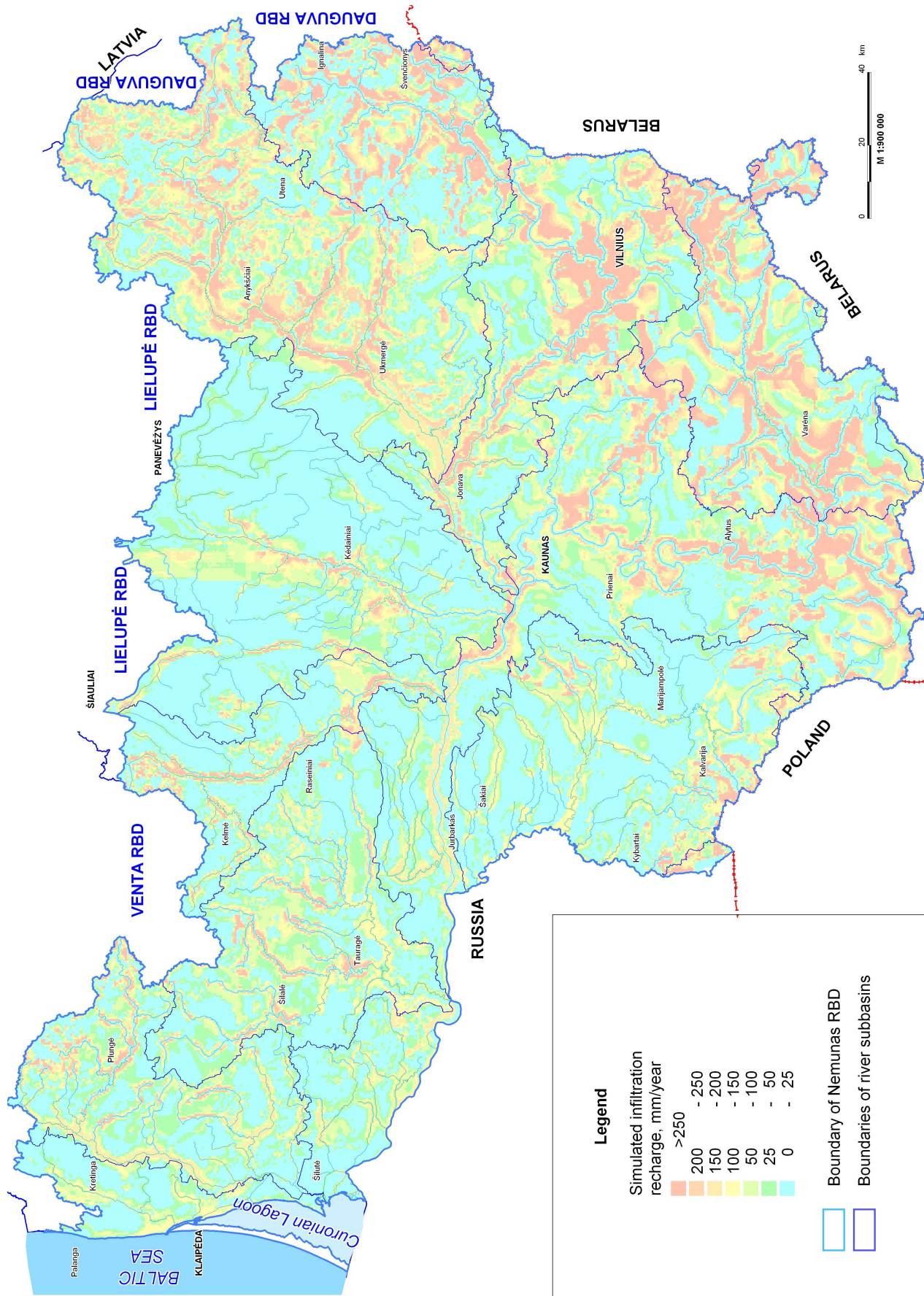


Fig. 3. Simulated infiltration recharge of shallow groundwater

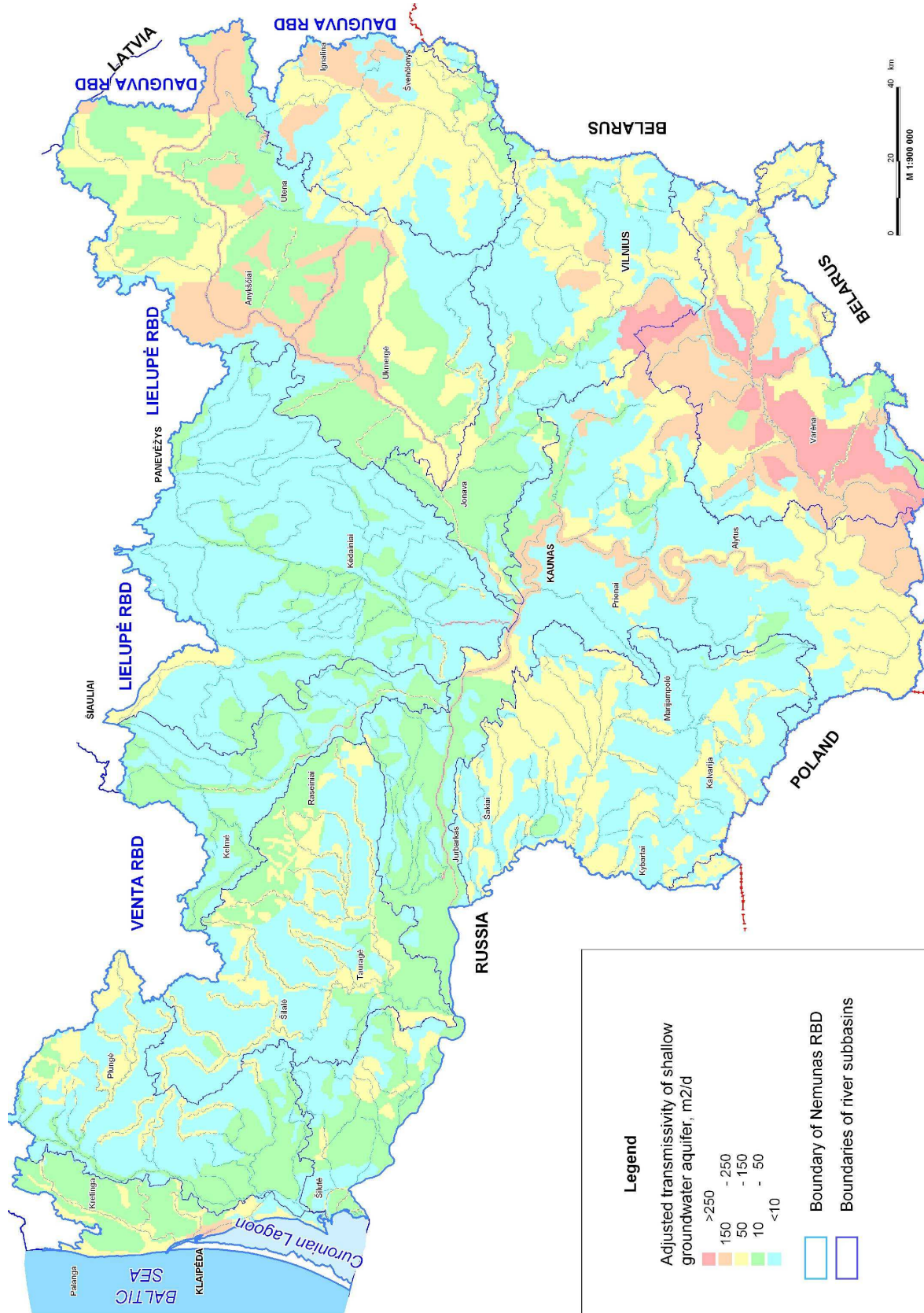


Fig. 4. Adjusted transmissivity of shallow groundwater aquifer



For quantification of surface and groundwater quantity changes caused by the exploitation of deeper laying confined aquifers, all major productive confined aquifers were included into the above mentioned mathematical models. A special methodology, created in the Riga Technical University Environmental Modelling Centre and self-proved in a number of objects, was used for shallow groundwater recharge simulation. Its essence is that the landscape elevation serves as the 1<sup>st</sup> type boundary condition and rate of infiltration flow in each active model block is obtained by selecting size of conductivity in unsaturated zone between landscape elevation and shallow groundwater level [5], [6]. In mathematical models territory of each GWB is divided into rectangular blocks 500x500 m.

#### IV. RESULTS

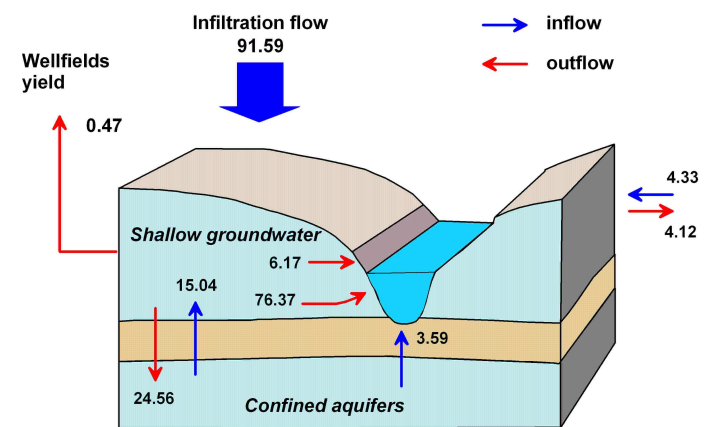
During models calibration values of unconfined aquifer transmissivity and infiltration recharge of unconfined aquifer have been adjusted and specified (Fig. 3 and 4). Simulated groundwater level of shallow aquifer, received using the adjusted values of the above mentioned parameters, is presented in Figure 5.

The highest altitudes of shallow groundwater level are in Medininkai and Suduva (up to 250–270 m abs. a.), Middle Zemaiciu (up to 170–190 m a. s. l.), Aukstaiciu (up to 200–220 m a. s. l.) highlands. Shallow groundwater flows to valleys of the largest rivers as Nemunas, Neris, Sventoji, Dubysa, Sesupe, Merkys, Zeimena and others river valleys and discharges there. Shallow groundwater level in the Middle Lithuanian Plain is in 20–40 m and in the Baltic coast it is in a few meters above sea level (Fig. 5).

The biggest infiltration rate into the unconfined aquifer is in the areas, where sand of different origin and different grain size as well as sand with gravel and pebble are spread. Adjusted values of transmissivity of these types of soil often are up to 50–200 m<sup>2</sup>/d and sometimes it exceeds 250 m<sup>2</sup>/d

(Fig. 4). In these areas infiltration recharge of shallow aquifer usually exceeds 100 mm per year (Fig. 3). In the areas, where glacial sandy and clay loam are spread, adjusted values of transmissivity are up to 10 m<sup>2</sup>/d and infiltration recharge in most cases do not exceed 50 mm per year (Fig. 3, 4). In the areas, where limnoglacial clay is spread, values of transmissivity are up to 1 m<sup>2</sup>/d and modules of infiltration recharge often are negative, i. e. groundwater does not refill, but decrease because of evaporation and plant transpiration. Modules, received in models of infiltration recharge are very close to the data received during long term monitoring, carried out in the year 1961–1972 [9].

In the whole modelled territory there is an intense interchange taking place between shallow groundwater and surface water bodies as well as between shallow groundwater and confined aquifers of GWB, which forms groundwater



resources and runoff (Table 1, Fig. 6).

Fig. 6. Simulated balance of formation of shallow groundwater resources and groundwater runoff to surface water bodies in Nemunas RBD (mm per year)

TABLE 1

SIMULATED BALANCE OF FORMATION OF SHALLOW GROUNDWATER RESOURCES AND GROUNDWATER RUNOFF TO SURFACE WATER BODIES IN NEMUNAS RBD

| Inflow                                 |                         |                  | Outflow   |                           |                   |
|--|-------------------------|------------------|---|---------------------------|-------------------|
| Source                                 | Quantity                |                  | Source  | Quantity                  |                   |
|  | m <sup>3</sup> /d       | mm/year          |   | m <sup>3</sup> /d         | mm/year           |
| Infiltration recharge                  | 11,972,080              | 91.59            | Outflow in slopes of surface water bodies valleys | 806,950                   | 6.17              |
| Water inflow from surface water bodies | 97,290                  | 0.74             | Groundwater runoff                                | 10,451,500<br>(469,372)** | 79.96<br>(3.59)** |
| Water inflow from confined aquifers    | 2,435,070<br>(469,372)* | 18.63<br>(3.59)* | Outflow to confined aquifers                      | 3,210,800                 | 24.56             |
| Water side-inflow                      | 565,890                 | 4.33             | Water side-outflow                                | 539,010                   | 4.12              |
|  |                         |                  | Wellfields yield                                  | 62,070                    | 0.47              |
| <b>Total:</b>                          | <b>15,070,330</b>       | <b>115.29</b>    | <b>Total:</b>                                     | <b>15,070,330</b>         | <b>115.29</b>     |

According to the modelling data, in the territory of Nemunas RBD total recharge of unconfined aquifer with the given wellfield yield (average daily yield in the year 2007–2008) slightly exceeds 15 million m<sup>3</sup>/d (115.29 mm per year). The greater part of it (79.4%) consists of infiltration recharge (almost 12 million m<sup>3</sup>/d or 91.59 mm per year) and mainly all other part of recharge is an inflow from confined aquifers that are situated deeper. According to the modelling data, the greatest infiltration recharge of shallow groundwater is in sub-basins of Merkys, Zeimena and Neris (150–180 mm per year), the lowest, just 30 mm per year, is in sub-basin of Nevezis (Fig. 2).

Groundwater runoff in Nemunas RBD is formed by two sources, i. e. direct outflow of shallow groundwater to surface water bodies and confined water inflow through the hardly

permeable deposits that cover the aquifer (Table 2). The last one covers only the part of inflow which proceeds in the area of river or lake bottom. The other part of confined water inflow gets in to the shallow water and along with infiltration recharge forms its flow.

In Nemunas RBD only 20% of confined water inflow directly gets into surface water bodies and formates a part of surface runoff. The rest of the confined water inflow (80%) gets into the unconfined aquifer and takes part in formatting its resources and flows to the surface water bodies as a part of shallow groundwater runoff (Table 2).

The greater part of groundwater runoff (95.5%) is formatted by shallow groundwater as a mix of precipitation and inflow of confined groundwater from deeper layers (Table 3).

TABLE 2

INFLOW OF CONFINED GROUNDWATER FROM DEEPER AQUIFERS TO THE SHALLOW GROUNDWATER AQUIFER AND SURFACE WATER BODIES

| River basin/<br>subbasin | Inflow of confined groundwater through the hardly permeable deposits, that cover the layer, m <sup>3</sup> /d |   |                           |   |           |
|--------------------------|---|---|---------------------------|---|-----------|
|                          | Into shallow groundwater aquifer  |   | Into surface water bodies |   | Total     |
|                          | m <sup>3</sup> /d   | part of total inflow of confined groundwater, % | m <sup>3</sup> /d         | part of total inflow of confined groundwater, % |           |
| Coastal rivers           | 1,690   | 95.48   | 80                        | 4.52  | 1,770     |
| Minija                   | 68,200  | 91.67   | 6,200                     | 8.33  | 74,400    |
| Jura                     | 79,790  | 94.65   | 4,510                     | 5.35  | 84,300    |
| Nemunas                  | 434,130   | 76.39   | 134,170                   | 23.61   | 568,300   |
| Sesupe                   | 132,940   | 90.17   | 14,490                    | 9.83  | 147,430   |
| Merkys                   | 187,470   | 75.15   | 61,980                    | 24.85   | 249,450   |
| Neris                    | 496,500   | 86.12   | 80,040                    | 13.88   | 576,540   |
| Zeimena                  | 103,550   | 64.41   | 57,210                    | 35.59   | 160,760   |
| Sventoji                 | 298,120   | 76.47   | 91,730                    | 23.53   | 389,850   |
| Nevezis                  | 150,000   | 88.93   | 18,680                    | 11.07   | 168,680   |
| Dubysa                   | 13,160  | 97.92   | 280                       | 2.08  | 13,440    |
| Prieglius                | 148   | 98.67   | 2                         | 1.33  | 150       |
| Nemunas RBD total        | 1,965,698   | 80.72   | 469,372                   | 19.28   | 2,435,070 |

TABLE 3

SOURCES OF GROUNDWATER RUNOFF INTO SURFACE WATER BODIES FORMATION IN NEMUNAS RBD

| River basin/<br>subbasin | Simulated<br>groundwater<br>runoff, total<br>m <sup>3</sup> /d | Source of runoff formation, m <sup>3</sup> /d            |                                     |   |                                     |
|--------------------------|--|--|-------------------------------------|---|-------------------------------------|
|                          |  | Outflow of shallow groundwater into surface water bodies |                                     | Inflow of confined groundwater into surface water bodies through the hardly permeable deposits that cover the layer |                                     |
|                          |  | m <sup>3</sup> /d  | part of total groundwater runoff, % | m <sup>3</sup> /d   | part of total groundwater runoff, % |
| Coastal rivers           | 70,050   | 69,970   | 99.89                               | 80  | 0.11                                |
| Minija                   | 440,920  | 434,720  | 98.59                               | 6,200   | 1.41                                |
| Jura                     | 482,120  | 477,610  | 99.06                               | 4,510   | 0.94                                |
| Nemunas                  | 2,139,810  | 2,005,640  | 93.73                               | 134,170   | 6.27                                |
| Sesupe                   | 496,670  | 482,180  | 97.08                               | 14,490  | 2.92                                |
| Merkys                   | 1,725,660  | 1,663,680  | 96.41                               | 61,980  | 3.59                                |
| Neris                    | 1,707,170  | 1,627,130  | 95.31                               | 80,040  | 4.69                                |
| Zeimena                  | 1,019,810  | 962,600  | 94.39                               | 57,210  | 5.61                                |
| Sventoji                 | 1,747,190  | 1,655,460  | 94.75                               | 91,730  | 5.25                                |
| Nevezis                  | 376,420  | 357,740  | 95.04                               | 18,680  | 4.96                                |
| Dubysa                   | 225,750  | 225,470  | 99.88                               | 280   | 0.12                                |
| Prieglius                | 19,930   | 19,928   | 99.99                               | 2   | 0.01                                |
| Nemunas RBD              | 10,451,500   | 9,982,128  | 95.51                               | 469,372   | 4.49                                |

Direct confined groundwater inflow into surface water bodies through the hardly permeable deposits that cover the layer formates only 4.5% of groundwater runoff. The biggest inflow is taking place in rivers, where valleys are deep (Nemunas, Neris, Sventoji, Zeimena), as it is the reason, why conditions for the confined groundwater runoff are better inside boundaries of valleys and in some places direct confined groundwater discharge from upper-laying confined aquifers is possible. Lower inflows of confined groundwater are in sub-basins of rivers, which are mostly in recharge area of deeper confined aquifers (Jura, Minija, Dubysa) and in river sub-basins, where deeper confined aquifers are well isolated from surface water by regional confining beds (Coastal river basin) (Table 3).

According to modelling data, in Nemunas RBD the biggest groundwater runoff into rivers is in sub-basins of Merkys, Zeimena and Neris (average intensity is 4–5 and more l/s for 1 km<sup>2</sup>), a little lower runoff is in sub-basins of Sventoji, minor tributary of Nemunas and in the basin of Prieglius (average intensity is approximately 3 l/s for 1 km<sup>2</sup>), the lowest runoff is in Nevezis sub-basin (Table 4).

TABLE 4

SIMULATED GROUNDWATER RUNOFF INTO SURFACE WATER BODIES IN NEMUNAS RBD

| Basin/<br>subbasin | Area,<br>km <sup>2</sup> | Simulated runoff,<br>m <sup>3</sup> /d | Groundwater runoff<br>intensity, l/s for 1 km <sup>2</sup> |                                |           |
|--------------------|--------------------------|--|--|--------------------------------|-----------|
|                    |                          |  | Perennial*   | Of the year<br>1993–2007<br>** | Simulated |
| Coastal rivers     | 1,002                    | 70,050                                 | <1   | 0.93                           | 0.81      |
| Minija             | 2,940                    | 440,920                                | 1.65   | 2.17                           | 1.74      |
| Jura               | 4,005                    | 482,120                                | 1.33   | 1.65                           | 1.39      |
| Nemunas            | 9,175                    | 2,139,810                              | 2.65   | 2.60                           | 2.70      |
| Sesupe             | 4,770                    | 496,670                                | 1.03   | 1.20                           | 1.21      |
| Merkys             | 3,799                    | 1,725,660                              | 5.16   | 5.08                           | 5.26      |
| Neris              | 4,267                    | 1,707,170                              | 3.56   | 4.58                           | 4.63      |
| Zeimena            | 2,775                    | 1,019,810                              | 4.45   | 4.27                           | 4.25      |
| Sventoji           | 6,789                    | 1,747,190                              | 3.02   | 3.42                           | 2.98      |
| Nevezis            | 6,140                    | 376,420                                | 0.66   | 0.79                           | 0.71      |
| Dubysa             | 1,966                    | 225,750                                | 1.14   | 1.35                           | 1.33      |

Results, given in the table 4, reveal that values of groundwater runoff, received in the model, are close enough to the values, received using other methods – in most cases they are intermediate between perennial means of groundwater runoff intensity and values received using MIKE BASIN model.

Modelling results reveal that groundwater runoff in the territory of Nemunas RBD is distributed unevenly and its input for the total river runoff in different sub-basins rather differs. The biggest input is in the sub-basin of Merkys, where perennial mean of total river runoff intensity is approximately 8 l/s for 1 km<sup>2</sup> [1]. The groundwater runoff (intensity 5.26 l/s

for 1 km<sup>2</sup>) formates 65% of total river runoff of sub-basin. A little lower groundwater runoff input for the total river runoff into river is in the sub-basin of Zeimena, as it covers 55% (intensity 4.25 l/s for 1 km<sup>2</sup>) of total river runoff (intensity 7.8 l/s for 1 km<sup>2</sup>). This input is much lower in sub-basins of other rivers. Groundwater runoff formates 36% of total river runoff in sub-basin of Sventoji and 19.4% in sub-basin of Dubysa. Whereas in sub-basin of Nevezis, where shallow groundwater is situated mostly in poorly permeable till and poor infiltration recharge prevails, the input is even lower, only approximately 13% river runoff.

Values of groundwater runoff modules given in the Table 5 generally describe groundwater outflow into rivers and other groundwater bodies in the whole territory of river basin or sub-basin. Values of shallow groundwater outflow rate and their distribution in every modelled river through the entire length of river depending on unconfined groundwater filtration parameters and flow gradient are presented in Fig. 7. As the size of calculated block of the model is 0.5x0.5 km, numbers given in the map show the rate of shallow groundwater outflow in the 500 m length riverbed section. According to the modelling results, the greatest values of shallow groundwater outflow rate are in Merkys, Zeimena, Sventoji, in a 500 m length riverbed section in many cases they are up to 0.025–0.05 m<sup>3</sup>/s (25–50 l/s) and more. A little lower outflow rates are in Neris, Dubysa and main tributaries of Sventoji, such as Virinta, Siesartis and others. According to the modelling data, the lowest outflow rate of shallow groundwater into surface water bodies are in sub-basin of Nevezis. Lower than 0.001 m<sup>3</sup>/s (1 l/s) modelled values prevails there (Fig. 7).

## CONCLUSIONS

- At regional level evaluation of groundwater runoff in Nemunas RBD using mathematical modelling was carried out for the first time. Groundwater runoff evaluation was carried out in 4 mathematical models that cover different groundwater basins. Later results obtained in these models were combined.
- During the modelling process filtration parameters of shallow groundwater aquifer and its infiltration recharge were revised. It was found that in sandy areas transmissivity of shallow groundwater is over 50 m<sup>2</sup>/d, and infiltration recharge - 100 mm per year. In the areas, where glacial sandy and clay loam are spread, adjusted values of transmissivity are up to 10 m<sup>2</sup>/d and infiltration recharge in most cases do not exceed 50 mm per year.
- During the modelling process sources of groundwater runoff formation, i. e. an input of groundwater flows from the shallow groundwater aquifer and deeper laying confined aquifers, were evaluated. It was found that only 20% of confined water inflow directly gets into surface water bodies and formates a part of surface runoff, while the rest of the confined water inflow (80%) gets into the shallow groundwater aquifer and takes part in formatting its resources. The greater part of groundwater runoff (95.5%) is formatted by shallow groundwater as a mix of precipitation and inflow of confined groundwater from

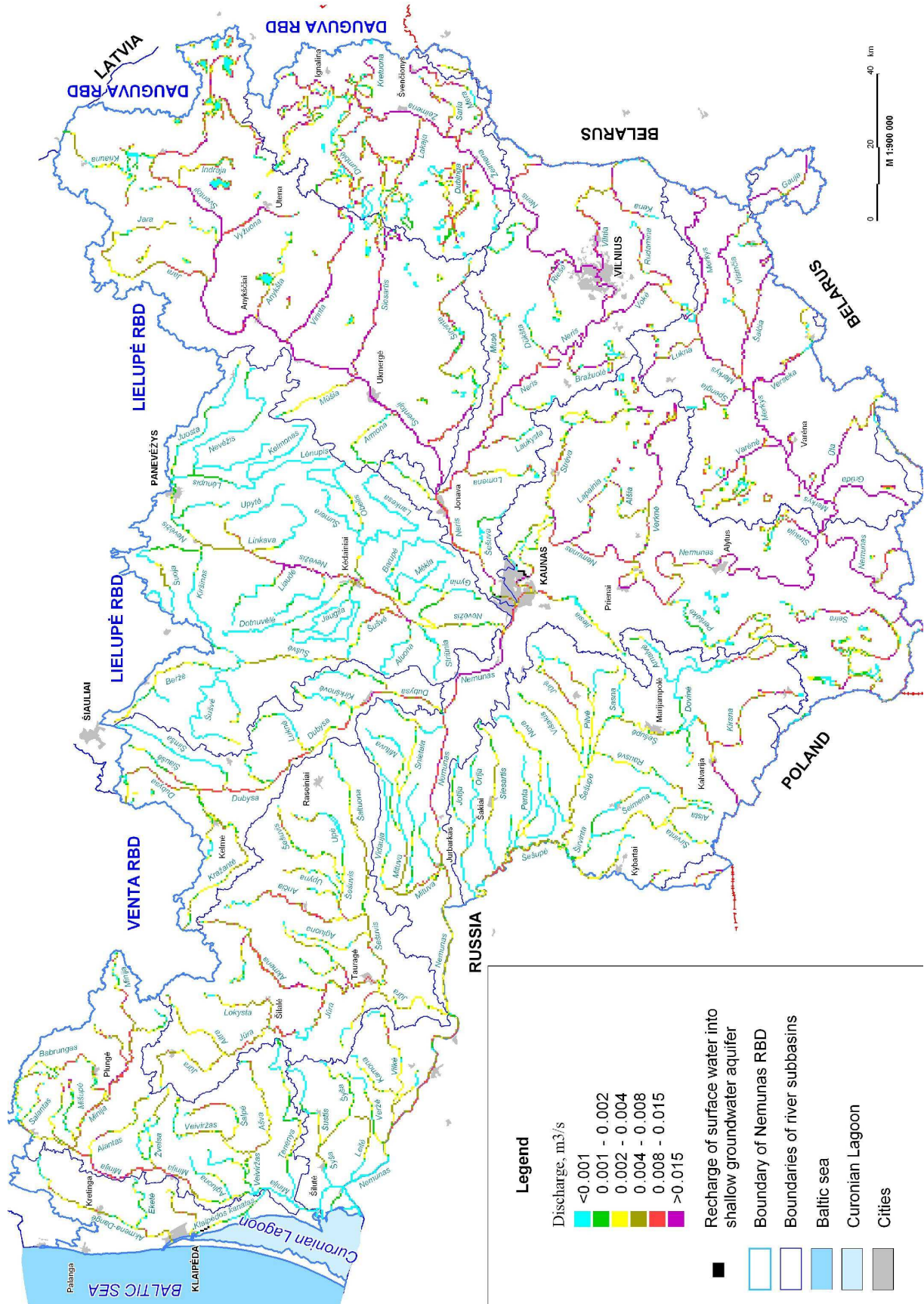


Fig. 7. Simulated discharge of shallow groundwater into surface water bodies

deeper layers. Meanwhile, direct confined groundwater inflow into surface water bodies through the hardly permeable deposits that cover the layer formates only 4.5% of groundwater runoff.

- Modelling results of shallow groundwater outflow into surface water bodies were applied to evaluate impact of diffused pollution in this aquifer on surface water bodies.

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WEB site: <http://www.grota.lt>

#### **Anicetas Štuopis, Marius Gregorauskas, Algirdas Domasevicius. Pazemes ūdens pieteces veidošanās Nemunas baseinā (Lietuvā)**

Nemunas upes sateces baseinam (NSB) ir sagatavots tā apsaimniekošanas plāns. Sagatavojot šo plānu, bija jānovērtē NBS pazemes plūsmu raksturs, tajā skaitā gruntsūdeņu pieteces. Šo vērtējumu pirmo reizi izdevās iegūt ar matemātiskās modelēšanas metodēm. Izmantojot četrus modeļus, kuri bija izveidoti atsevišķām baseina daļām, modelēšanas procesā tika precizēti pirmkvartāra ūdens slāņa parametri un infiltrācijas barošana. Noskaidrots, ka smilšu apgabalim ūdensvadāmības koeficients pārsniedz 50 m<sup>2</sup>/dienn un infiltrācijas barošana – 100 mm/gadā. Mālainajos apgabalos ūdensvadāmības koeficients nav lielāks par 10 m<sup>2</sup>/dienn, bet infiltrācija 100 mm/gadā. Modelēšanas rezultāti apstiprina, ka 20% spiediena gruntsūdeņu pārtiek uz virszemes ūdeņiem, bet atlikusī daļa (80%) noplūst pirmajā (augšējā) horizontā un piedalās tā resursu veidošanā. Nemunas NSB vidēji 95% no pazemes ūdens plūsmas veido gruntsūdeņi. Tikai 4.5% no plūsmas veido pārtece caur sprostsļāņiem. Pazemes plūsmas modelēšanas rezultāti izmantoti, lai novērtētu izkliedētā pazemes ūdens piesārņojuma ietekmi uz virszemes ūdens objektiem.

#### **Аницетас Штуопис, Мариус Грегораускас, Адгирдас Домашевичюс. Формирование стока подземных вод в районе бассейна реки Неман (Литва)**

Для района бассейнов рек Немана (РБР) подготовлен план управления. При подготовке этого плана одним из заданий было описание текущего состояния РБР, в том числе и количественная оценка стока подземных вод. Оценка подземных вод в региональном плане РБР Немана впервые осуществлялась методами математического моделирования, путем использования четырех математических моделей, которые рассматривают отдельные бассейны подземных вод. В этих моделях получаемые результаты затем были объединены. Во время моделирования РБР были уточнены фильтрационные параметры грунтового водоносного слоя и инфильтрационное питания. Определено, что на песчаных площадях залегания коэффициент водопроницаемости превышает 50 м<sup>2</sup>/сут., а инфильтрационное питания – 100 мм в год. На площадях распространения гляциальных суффлюк и супеси коэффициент водопроницаемости в основном не превышает 10 м<sup>2</sup>/сут., а инфильтрационное питание – 100 мм в год. Моделированием было установлено, что только 20% притока напорных вод прямо попадают в поверхностные водоемы и формируют часть поверхностного стока, оставшаяся часть напорной подземной воды (80%) перетекает в грунтовой водоносный слой и участвуют в формировании его ресурсов. В РБР Немана в среднем 95,5% подземного стока формирует грунтовая вода как смесь атмосферных осадков и притекающей напорной воды. Прямой приток напорной воды через слабопроницаемые слои формирует только 4,5% подземного стока. Моделированием полученные результаты стока подземных вод использованы для оценки воздействия рассеянного загрязнения грунтового водоносного слоя на поверхностные водоемы.