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KONCEPTUĀLĀ HIDROLOĢISKĀ MODEĻA METQ PILNVEIDE URBĀNĀS HIDROLOĢISKĀS ATBILDES VIENĪBAS IZVEIDEI UN SEG EMISIJU MODELĒŠANAI

THE IMPROVEMENT OF THE CONCEPTUAL HYDROLOGICAL MODEL METQ WITH THE URBAN HYDROLOGICAL RESPONSE UNIT AND GHG EMISSION MODELLING

zinātnes doktora grāda

zinātnes doktore (Ph.D.) inženierzinātnēs un tehnoloģijās

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ANOTĀCIJA

Vairāk nekā puse pasaules iedzīvotāju dzīvo urbānajās teritorijās. Iedzīvotāju skaita un urbanizācijas līmeņa palielināšanās liek arvien vairāk domāt par ilgtspējīgu resursu, tajā skaitā ūdens, apsaimniekošanu un adaptāciju klimata pārmaiņām. Zemes lietojuma veida maiņa, īpaši urbanizācija, būtiski ietekmē hidroloģiskos procesus. Urbānās teritorijas ne tikai rada papildus piesārņojuma slodzi un samazina ūdens resursus, bet arī veido ūdensapgādes un kanalizācijas infrastruktūru, kā arī attīsta plūdu aizsardzības sistēmas. Eiropas Savienībā plūdu riska mazināšanas pasākumus nosaka Plūdu Direktīva 2007/60/EC, kas nosaka dalībvalstīm veikt plūdu riska novērtēšanu un apdraudēto teritoriju kartēšanu. Izpratne par urbāno teritoriju hidroloģisko režīmu pašlaik tiek veidota un attīstīta, izmantojot monitoringa datus un modelēšanas piedāvātās iespējas, taču lai izmantotu modelēšanas rīkus, ir nepieciešami vismaz divu dekāžu hidroloģiskā režīma ikdienas novērojumu dati. Urbāno sateces baseinu hidroloģisko procesu modelēšana ir sarežģīta dēļ sadrumstalotās vides, specifisko hidroloģisko režīmu un lietus režīmu urbānajā vidē. Pasaulē hidroloģiskie modeļi tiek bieži izmantoti ekoloģisko komponenšu modelēšanā. Parīzes nolīguma un Eiropas Zaļā kursa kontekstā ir nepieciešams attīstīt SEG emisiju modelēšanas iespējas Latvijā.

Promocijas darbā ir izvirzīta hipotēze, ka konceptuālajā hidroloģiskajā modelī METQ ir iespējams integrēt urbāno hidroloģisko atbildes vienību, un konceptuālais hidroloģiskais modelis METQ var tik izmantots SEG emisiju modelēšanai no augsnēm.

Promocijas darba mērķis ir pilnveidot konceptuālo hidroloģisko modeli METQ, integrējot urbāno hidroloģisko atbildes vienību, un sagatavot datubāzi un konceptuālo risinājumu SEG emisiju no augsnēm modelēšanai, izmantojot konceptuālajā hidroloģiskajā modelī METQ ietverto hidroloģisko aprēķinu augsnes aktīvajā slānī, gruntsūdenī un ar to saistītajā kapilārajā pacelšanās slānī.

Promocijas darbā veiktās teorētiskās iestrādes sniedz padziļinātu ieskatu hidroloģiskā cikla komponenšu izmaiņās urbānajās vidēs, kā arī sniedz teorētisko pamatu dažādu modelēšanas algoritmu izstrādei urbānajās hidroloģiskajās atbildes vienībās. Papildus ir analizētas SEG modelēšanas iespējas, izmantojot hidroloģiskos modeļus, kas ļauj tuvākajā nākotnē attīstīt dislāpekļa oksīda, ogļskābās gāzes un metāna modelēšanas rīkus, kas ļaus SEG emisiju aprēķinu metodikai pāriet uz *Tier3* pieeju (nacionālā līmenī tiek modelētas SEG emisijas), kurā tiek ņemtas vērā reģionālās, klimatiskās un ģeomorfoloģiskās īpatnības.

Praktisku nozīmi hidroloģisko procesu modelēšanā sniedz konceptuālajā hidroloģiskajā modelī METQ iebūvētā urbānā hidroloģiskā atbildes vienība, kas ļauj modeli izmantot sarežģītu ūdenssaimniecības jautājumu risināšanā, piemēram, klimata pārmaiņu un zemes lietojuma veida maiņas kumulatīvo ietekmes kvantifikāciju, tādējādi sniedzot teorētisku pamatu hidrotehnisko būvju reglamentējošo normatīvo regulējumu atjaunošanai, kas iekļautu adaptāciju klimata pārmaiņām. Izstrādātie konceptuālie risinājumi SEG emisiju modelēšanai no augsnēm ļauj attīstīt modelēšanas rīku, ar kuru būs iespējams novērtēt SEG emisiju apjomus no augsnēm un izvērtēt dažādu SEG emisiju no augsnēm samazinošo pasākumu efektivitāti, kā arī veikt kompleksu novērtējumu augsnes SEG emisiju bilancei.

Šis promocijas darbs sastāv no desmit tematiski vienotām zinātniskajām publikācijām.

ABSTRACT

More than half of the world's population live in urban areas. Increasing population and urbanisation levels make it more and more likely to think about the management of sustainable resources, including water, and adaptation to climate change. Changing the use of land, particularly urbanisation, has a significant impact on hydrological processes. Urban areas not only create additional pollution pressures and reduce water resources, but also build water supply and sewer infrastructure and develop flood protection systems. In the EU, flood risk mitigation measures are set out in Flood Directive 2007/60/EC, which requires Member States to carry out flood risk assessments and mapping of endangered areas. Awareness of the hydrological regime of urban areas is currently being developed and developed using monitoring data and modelling capabilities, but at least two decades of hydrological daily observation data is needed to use modelling tools. The modelling of the hydrological processes of the urban catchment areas is complicated due to the fragmented environment, the specific hydrological regime and the rain regime in the urban environment. In the world, hydrological models are often used in the modelling of ecological components. In the context of the Paris Agreement and the European Green Deal, it is necessary to develop modeling capabilities for GHG emissions in Latvia.

In the research, it is hypothesised that the urban hydrological response unit can be integrated into the conceptual hydrological model METQ, and the conceptual hydrological model METQ can be used to simulate GHG emissions from soils.

The aim of the study is to improve the conceptual hydrological model METQ by integrating the urban hydrological response unit and to prepare a database and conceptual solution for modelling GHG emissions from soils using the hydrological calculation included in the conceptual hydrological model METQ of the active layer of soil, groundwater and the associated capillary take-off layer.

Theoretical research provide an in-depth insight into the changes in hydrological cycle components in urban environments, as well as the theoretical basis for the development of various modeling algorithms in urban hydrological response units. In addition, GHG modelling capabilities have been analysed using hydrological models enabling the development in the near future of nitrous oxide, carbon dioxide gas and methane modeling tools that will allow the methodology for calculating GHG emissions to go to the *Tier3* approach (national models on GHG emissions), which takes into account regional, climatic and geomorphological conditions.

A practical role in the modelling of hydrological processes is provided by the urban hydrological response unit built into the conceptual hydrological model, which allows the model to be used to address complex water management issues, such as the cumulative impact quantification of climate change and land use patterns, thereby providing a theoretical basis for the renewal of regulatory frameworks regulating hydrotechnical structures, which include: adaptation to climate change. The developed conceptual solutions to modelling GHG emissions from soils allow for the development of a modelling tool that will allow the assessment of soil GHG emissions and the assessment of the effectiveness of various soil-reducing GHG emissions measures, as well as the carrying out of a complex assessment of the soil GHG emissions balance.

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PUBLIKĀCIJU SARAKSTS

Promocijas darbs balstīts uz desmit publikācijām, uz kurām atsauces tekstā veidotas, izmantojot romiešu ciparus:

I. **Grinfelde, I.**, & Bakute, A. (2017). The Local Parameters Sensitivity of Urban Hydrological Response Unit of Conceptual Hydrological Model METQ. In Raupeliene, A (Ed.), 8th International Scientific Conference Rural Development 2017: Bioeconomy challenges (pp. 599–604). https://doi.org/10.15544/RD.2017.075 ***(indeksēta WoS datubāzē)***.

II. **Grinfelde, I.**, & Bakute, A. (2017). Urban Hydrological Response Unit Parameter Calibration and Verification for Conceptual Hydrological Model METQ. In Engineering for Rural Development (Vol. 16, pp. 1117–1122). https://doi.org/10.22616/ERDev2017.16.N236 ***(indeksēta SCOPUS un WoS datubāzēs).***

III. **Grinfelde, I.**, Bakute, A., Steinberga, K., & Pilecka, J. (2017). The Changes of Lake Hydrological Cycle: A Case Study of Lake Usma in Latvia. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM (Vol. 17, pp. 655–662). https://doi.org/10.5593/sgem2017/31/S12.082 ***(indeksēta SCOPUS un WoS datubāzēs).***

IV. **Grinfelde, I.**, Bakute, A., Pilecka, J., Berzina, L., & Vebere, L. L. (2019). The Impact of Landscape Structure of Catchment area on Lake Hydrology. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM (Vol. 19, pp. 569–576). https://doi.org/10.5593/sgem2019/3.1/S12.073 ***(indeksēta SCOPUS un WoS datubāzēs).***

V. Bakute, A., **Grinfelde, I.**, Pilecka-Ulcugaceva, J., Liepa, S., & Siltumens, K. (2021). The Land Use and Climate Change Impact on Lake Usma Hydrological Regime. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM (Vol. 21, pp. 159–165). https://doi.org/10.5593/sgem2021V/3.2/s12.24 ***(indeksēta SCOPUS un WoS datubāzēs).***

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IX. Liepa, S., Butenaite, D., Bakute, A., **Grinfelde, I.**, & Pilecka-Ulcugaceva, J. (2021). Composition of the Isotopes of Nitrous Oxide in the Clay Soil at Different Moisture Conditions. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM (Vol. 21, pp. 59–66). https://doi.org/10.5593/sgem2021V/4.2/s19.a09 ***(indeksēta SCOPUS un WoS datubāzēs).***

X. **Grinfelde, I.**, Pilecka-Ulcugaceva, J., Bakute, A., Berzina, L., & Liepa, S. (2021). The Conceptual Framework of GHG Module Integration in Conceptual Hydrological Model

In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM (Vol. 21, pp. 361–368). https://doi.org/10.5593/sgem2021/4.1/s19.60 ***(indeksēta SCOPUS un WoS datubāzēs).***

AUTORA IEGULDĪJUMS

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I.	IG	IG	IG	IG, AB	IG, AB	90%
II.	IG	IG	IG	IG, AB	IG, AB	90%
III.	IG	IG	IG, KŠ	IG	IG, AB, JP	85%
IV.	IG	IG, JP	IG, LLV	IG	IG, AB, LB	75%
V.	IG	IG, AB	IG	IG	IG, AB	75%
VI.	IG	IG, JPU	IG, LLV	IG	IG, AB, KS	75%
VII.	IG	IG, KV,	IG, KZ	IG	IG, LB	80%
VIII.	IG	IG	IG, KV	IG, KV,	IG, KV, JP, OF, LB	75%
IX.	IG	IG, JPU	IG, SL	IG, DB	IG, SL, DB, AB	75%
X.	IG	IG, JPU	IG, SL	IG	IG, AB, LB	90%

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PROMOCIJAS DARBA APROBĀCIJA

Promocijas darba pētījumos iegūto rezultātu aprobācijā var izdalīt četrus būtiskus posmus, kas atspoguļo pētījuma nozīmīgumu un konceptuālā hidroloģiskā modeļa METQ turpmākās attīstības perspektīvas. Promocijas darba pētījuma rezultāti un iestrādes ir izmantotas vairākos fundamentālo un lietišķo pētījumu projektos. Par promocijas darba rezultātiem ir sagatavotas un publicētas vairākas publikācijas, kas tieši saistītas ar promocijas darba pētījumu un ir vērstas uz tālāku konceptuālā hidroloģiskā modeļa METQ pilnveidi un izmantošanu SEG emisiju modelēšanā no augsnēm. Ziņojumi konferencēs un diskusijas ļāva identificēt esošās problēmas un veikt precīzāk mērķētus modeļa uzdevumus. Izglītojošais darbs ļauj modeļa izmantošanas iespējas paplašināt un nodot zināšanas topošajiem zinātniekiem un nozares speciālistiem.

Projekti

Promocijas darba izstrādes laikā ir ņemta dalība 31 projektā.

1. 2016. Climate KIC ES Ietvara programmas projekts; Eksperts
2. 2017. – 2019. Rīgas jūras līča integrēta slāpekļa apsaimniekošanas sistēma ES Kopienas iniciatīvas INTERREG projekts Projekta vadītāja
3. 2017. – 2020. Klimata izmaiņas lauksaimniecībā Starptautiskas organizācijas mērķfinansēts izglītības projekts Eksperte
4. 2018. Aramzemes un ilggadīgo zālāju apsaimniekošanas radīto siltumnīcefekta gāzu (SEG) emisiju un oglekļa dioksīda (CO_2) piesaistes uzskaites sistēmas pilnveidošana un atbilstošu metodisko risinājumu izstrā Pētniecības (zinātnisko izstrāžu) līgumdarbs (pakalpojuma līgums) ar Latvijas vai ārvalstu uzņēmumiem, organizācijām (komersantiem) Pētniece
5. 2018. – 2019. Inovatīva degradēto teritoriju reģenerācija pārrobežu reģionu ilgtspējīgai attīstībai ES Kopienas iniciatīvas INTERREG projekts Pētniece
6. 2018. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā Valsts pārvaldes iestādes finansēts projekts Pētniece
7. 2018. – 2021. Latvijas Lauksaimniecības universitātes pārvaldības pilnveide (ES28) ES struktūrfondu projekts izglītības programmas direktors
8. 2018. – 2019. Atsevišķu pārvaldes uzdevumu deleģēšanas izpilde Valsts pārvaldes iestādes finansēts projekts Pētniece
9. 2018. SEG gāzu mērījumi LIFE purvu atjaunošanas projektā (tēma L269) Starptautiskās zinātniskās pētniecības projekts Projekta vadītāja
10. 2018. Lauksaimniecības sektora siltumnīcefekta gāzu un amonjaka emisiju aprēķina metodiku aktualizācija samazināšanas pasākumu kvantitatīvai novērtēšanai Valsts pārvaldes iestādes finansēts projekts Projekta vadītāja
11. 2018. Gruntsūdens līmeņa mērījumu datu verifikācija un interpretācija kopšanas ciršu izmēģinājumu objektos (L271) Pētniecības (zinātnisko izstrāžu) līgumdarbs (pakalpojuma līgums) ar Latvijas vai ārvalstu uzņēmumiem, organizācijām (komersantiem) Projekta vadītāja
12. 2018. Ineraktīva ūdenssaimniecība ES Kopienas iniciatīvas INTERREG projekts Eksperts
13. 2018. Ziņojums par gaisa piesārņojošo vielu emisiju aprēķināšanu un sagatavošanu no lauksaimniecības sektora par 2017. gadu Valsts pārvaldes iestādes finansēts projekts Pētniece
14. 2018. TAIEX-EIR PEER 2 PEER Eiropas Teritoriālās sadarbības programmas projekts Eksperts
15. 2018. – 2020. Par Svētes upes atveseļošanas plāna sagatavošanu un ieteikumu izstrādi upes krastu un upes pieguļošo teritoriju apsaimniekošanai Pašvaldības finansēts projekts Projekta vadītāja
16. 2018. Gruntsūdens līmeņa mērījumu datu verifikācija un interpretācija kopšanas ciršu izmēģinājumu objektos Pētniecības (zinātnisko izstrāžu) līgumdarbs (pakalpojuma līgums) ar Latvijas vai ārvalstu uzņēmumiem, organizācijām (komersantiem) Projekta vadītāja
17. 2019. Lēmumu pieņemšanas atbalsta sistēmas izstrāde ziemas kviešu lapu un vārpu slimību ierobežošanai. LAD4 ES struktūrfondu projekts Pētniece
18. 2019. TAIEX Eiropas komisijas kaimiņvalstu un paplašināšanās sarunu tīklojums AGR 67812 Cits Eiropas komisijas u.c. institūciju izglītības projekts Eksperte
19. 2019. – 2022. Augsnes ķīmiskā sastāva ietekme uz SEG emisijām no lauksaimniecībā izmantojamās zemes LLU pētniecības projekts projekta vadītāja
20. 2019. TAIEX Eiropas komisijas kaimiņvalstu un paplašināšanās sarunu tīklojums ETT 67476 Cits Eiropas komisijas u.c. institūciju izglītības projekts Eksperte

21. 2019. TAIEX Eiropas komisijas kaimiņvalstu un paplašināšanās sarunu tīklojums ETT 68655 Cits Eiropas komisijas u.c. institūciju izglītības projekts Eksperte
22. 2020. – 2021. Pārrobežu projekti VBF. tēma INT11 - "Ūdens resursu ilgtspējas veicināšana vietas pievilcības un tūrisma attīstībai Rēzeknes un Ostrovas pārrobežu teritorijās Eiropas Teritoriālās sadarbības programmas projekts pētniece
23. 2021. Meliorācijas ietekmes novērtēšana klimata pārmaiņu (plūdu riska) mazināšanā (S401) Valsts pārvaldes iestādes finansēts projekts pētniece
24. 2021. Lēmumu pieņemšanas atbalsta sistēmas izstrāde ziemas kviešu lapu un vārpu slimību ierobežošanai Valsts pārvaldes iestādes finansēts projekts pētniece
25. 2021. Aramzemes un ilggadīgo zālāju apsaimniekošanas radītās siltumnīcefekta gāzu (SEG) emisijas un oglekļa dioksīda (CO_2) piesaistes uzskaites sistēmas pilnveidošana un atbilstošu metodisko risinājumu izst Pētniecības (zinātnisko izstrāžu) līgumdarbs (pakalpojuma līgums) ar Latvijas vai ārvalstu uzņēmumiem, organizācijām (komersantiem) pētniece
26. 2021. – 2022. Hidroloģiskās situācijas monitoringa veikšana par veikto darbību (pārbūves) ietekmi uz hidroloģisko situāciju Valsts nozīmes ūdensnoteku Valgundes 1. vasaras poldera kanālu ŪSIK Jelgavas novadā, un pi Valsts pārvaldes iestādes finansēts projekts projekta vadītāja
27. 2021. – 2022. Jaunāko tehnoloģiju izmantošana nezāļu ierobežošanai laukaugu sējumos integrētajā audzēšanas sistēmā Valsts pārvaldes iestādes finansēts projekts pētniece
28. 2021. – 2023. Klimatu saudzējošas lopkopības sistēmas ES struktūrfondu projekts pētniece
29. 2017. – 2018. Zināšanas Inter-Baltic partnerības apmaiņā par turpmāko reģionālo aprites ekonomikas sadarbību Zviedru institūta finansēts projekts Projekta vadītāja
30. 2018. – 2019. Amonjaka emisiju mērījumu veikšana lauka apstākļos un ziņojuma sagatavošana Komersanta pasūtīts pētījums Projekta vadītāja
31. 2018. – 2019. Baltijas Jūras Reģiona universitāšu tīkla stiprināšana ainavu ilgtspējības un atkritumu apsaimniekošanas jomā Zviedru institūta finansēts projekts Projekta vadītāja

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5. Rudovica, V., Rotter, A., Gaudêncio, S. P., Novoveská, L., Akgül, F., Akslen-Hoel, L. K., **Grinfelde, I.** … Burlakovs, J. (2021). Valorization of Marine Waste: Use of Industrial By-Products and Beach Wrack Towards the Production of High Added-Value Products. Frontiers in Marine Science, 8. https://doi.org/10.3389/fmars.2021.723333

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7. Valujeva, K., Pilecka-Ulcugaceva, J., Skiste, O., Liepa, S., Lagzdins, A., & **Grinfelde, I**. (2022). Soil Tillage and Agricultural Crops Affect Greenhouse Gas Emissions from Cambic Calcisol in a Temperate Climate. Acta Agriculturae Scandinavica Section B: Soil and Plant Science, 72(1), 835–846. https://doi.org/10.1080/09064710.2022.2097123
8. Burlakovs, J., Jani, Y., Kriipsalu, M., **Grinfelde, I**., Pilecka, J., & Hogland, W. (2020). Implementation of New Concepts in Waste Management in Tourist Metropolitan areas. In IOP Conference Series: Earth and Environmental Science (Vol. 471). https://doi.org/10.1088/1755-1315/471/1/012017
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Ziņojumi konferencēs

Promocijas darba izstrādes laikā ir sniegti 177 ziņojumi starptautiskās zinātniskās konferencēs, no kuriem 65, kas norādīti sarakstā zemāk, ir tieši sasitīti ar promocijas darba pētījuma tēmu.

1. Effect of soil physical properties on N_2O isotope formation. Sindija Liepa, Kristaps Siltumens, Jovita Pilecka-Ulcugaceva, **Inga Grinfelde**, Dace Butenaite, 22nd International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 04-10 July, 2022. Bulgarian Academy of Sciences Albena, 2022.
2. The calculation algorithm of nitrous oxide emissions from soils integration into the conceptual hydrological model METQ. **Inga Grinfelde**, Anda Bakute, Jovita Pilecka-Ulcugaceva, International congress on sustainable development in the human environment-current and future challenges ICSDEV 2022, Alanya, Turkey, 19-22 october 2022. Bydgoszcz University of Science and Tehnology Ananya, 2022.
3. Effect of soil physical properties on N_2O isotope formation. Sindija Liepa, Kristaps Siltumens, Jovita Pilecka-Ulcugaceva, **Inga Grinfelde**, Dace Butenaite, Linnaeus ECO-TECH 2022, 13th International conference "Establishment of cooperation between companies and institutions in the Nordic countries, the Baltic Sea region and the world", Kalmar, Sweden, November 21-23, 2022. Linnaeus University Kalmar, 2022.
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61. Peat extraction impact on hydrological regime of high moss. Agris Bodnieks, **Inga Grinfelde**, 9th International scientific conference "Students on their way to science", (undergraduate, graduate, post-graduate students), April 25, 2014.
62. Sensitivity test of hydrological model METQ. Karlis Deikovskis, **Inga Grinfelde,** 9th International scientific conference "Students on their way to science", (undergraduate, graduate, post-graduate students), April 25, 2014.
63. Assessment of water body overgrow using GIS technologies: case study of lake Usma. Zane Sarkane, **Inga Grinfelde,** 9th International scientific conference "Students on their way to science", (undergraduate, graduate, post-graduate students), collection of abstracts, April 25, 2014.
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Akadēmiskais darbs

Promocijas darba izstrādes laikā iegūtās zināšanas un iestrādnes tiek izmantotas Latvijas Biozinātņu un tehnoloģiju universitātes un citu augstākās izglītības iestāžu, pamatstudiju studentu, maģistrantu un doktorantu zinātniskajos darbos. Promocija darba iestrādņu integrācija izglītojošā darbā ir apkopota 1.1. tabulā, kur krāsojums atbilst konceptuālā hidroloģiskā modeļa METQ pilnveides soļiem kas grafiski prezentēti 1.3. un 2.1. attēlos.

1.1.tabula **Promocija darba iestrādņu integrācija izglītojošā darbā**

N.p.k.	Aktivitāte	Konceptuālā hidroloģiskā modeļa METQ izmantošana
1.	Studiju kurss Inženierhidroloģija 3 KP	Izpratnes veicināšana par hidroloģiskajiem procesiem, īpaši pavasara paliem
2.	Studiju kurss Hidroloģiskā modelēšana 3 KP	Iepazīstas ar modeļa struktūru un galvenajiem darbības principiem.
3.	Studiju kurss Upju baseinu apsaimniekošana I 2 KP un II 2 KP	Iepazīstas ar modeļa struktūru un galvenajiem darbības principiem.
4.	Studiju kurss Hidroloģisko procesu modelēšana 4 KP	Iepazīstas ar modeļa struktūru un galvenajiem darbības principiem. Apgūst parametru kalibrāciju.
5.	Studiju kurss Zinātniskā darba pamati II 2 KP	Modelis tiek izmantots dažādos pētījumos.
6.	Doktora darbs Arta Bārdule "Mikro- un makroelementu plūsmas īscirtmeta apšu hibrīdu (Populus tremuloides Michx. x Populus tremula L.) kokaugu stādījumā lauksaimniecības zemē".	Konceptuālais hidroloģiskais modelis METQ tika izmantots, lai modelētu augu barības vielu noteces apjomu no kokaugu stādījumiem (Bardule, Grinfelde, Lazdina, Bardulis, & Sarkanabols, 2018)
7.	Maģistra darbs Kristīne Šteinberga "Usmas ezera hidroloģiskā režīma ilgtermiņa izmaiņas".	Konceptuālais hidroloģiskais modelis METQ tika izmantots, lai modelētu Usmas ezera ūdens līmeņa izmaiņas
8.	Maģistra darbs Anna Kuduma "Mazo HES hidroekonomiskā modeļa adaptācija Latvijā".	Konceptuālais hidroloģiskais modelis METQ tika izmantots, lai modelētu Usmas ezera
9.	Maģistra darbs Sabīne Oficiere "Sateces baseina apsaimniekošanas ietekme uz ezeru hidroloģisko režīmu".	Konceptuālais hidroloģiskais modelis METQ tika izmantots, lai modelētu Usmas ezera ūdens līmeņa izmaiņas
10.	Maģistra darbs Dace Butenaite "N_2O izotopu mērījumu veikšana augsnes paraugiem laboratorijas apstākļos".	Izstrādāta metodika N_2O izotopu mērījumiem no augsnēm
11.	Maģistra darbs Anete Anna Zālīte "Augsnes apstrādes un audzētās kultūras ietekme uz SEG emisijām māla augsnēs".	Sagatavota SEG emisiju datu bāze METQ modeļa pilnveidei.
12.	Maģistra darbs Luīze Lepiksone N_2O veidošanās procesa izpēte augsnēs ar dažādu organiskās vielas saturu	Pētīta N_2O izotopu izcelsme organiskajās augsnē
13.	Maģistra darbs Sindija Liepa Izotopu izmantošanas iespējas N_2O avotu identifikācijai no augsnēm	Izstrādāta metodika N_2O izotopu avotu identifikācijai no augsnēm

1.IEVADS

Vairāk nekā puse pasaules iedzīvotāju dzīvo urbānajās teritorijās un ANO iedzīvotāju migrācijas prognozes rāda, ka 2030. gadā to īpatsvars parsniegs 80% (United Nations, 2019). Iedzīvotāju skaita un urbanizācijas līmeņa palielināšanās liek arvien vairāk domāt par ilgtspējīgu resursu, tajā skaitā ūdens, apsaimniekošanu un adaptāciju klimata pārmaiņām (Saedi, Sharifi, Saremi, & Babazadeh, 2022).

Zemes lietojuma veida maiņa, īpaši urbanizācija, būtiski ietekmē hidroloģiskos procesus (Ajjur & Al-Ghamdi, 2022). Urbānās teritorijas ne tikai rada papildus piesārņojuma slodzi un samazina ūdens resursus, bet arī tajās veido ūdensapgādes un kanalizācijas infrastruktūru, kā arī attīsta plūdu aizsardzības sistēmas (Crawford et al., 2022; Hernández-Hernández, Olcina, & Morote, 2020). Spēcīgu lietusgāžu gadījumā urbānās teritorijās veidojas lokāli plūdi, kas kļūst arvien intensīvāki un atkārtojas arvien biežāk (J. Chen, Hill, & Urbano, 2009; Kang, Park, & Singh, 1998; X. Li et al., 2022; Mark, Weesakul, Apirumanekul, Aroonnet, & Djordjević, 2004; Schmitt, Thomas, & Ettrich, 2004). Plūdos visbiežāk cieš vai zaudē dzīvību iedzīvotāji no sabiedrības nabadzīgākajām grupām, kā arī tiek nodarīti materiālie zaudējumi, kas mērāmi vairākos miljardos dolāru (Abdeljaber, Adghim, Abdallah, Ghanima, & ALjassem, 2022; Jonkman & Vrijling, 2008; Kron, Steuer, Löw, & Wirtz, 2012). Eiropas Savienībā plūdu riska mazināšanas pasākumus nosaka Plūdu Direktīva 2007/60/EC (European Parliament, 2007), kas nosaka dalībvalstīm veikt plūdu riska novērtēšanu un apdraudēto teritoriju kartēšanu.

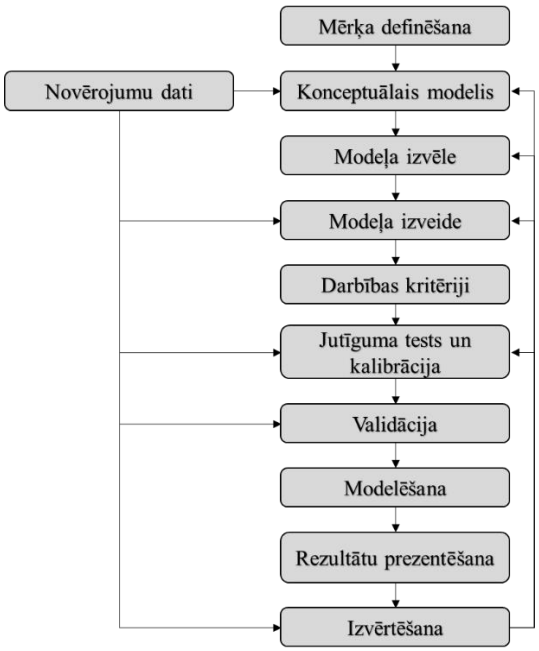
Izpratne par urbāno teritoriju hidroloģisko režīmu pašlaik tiek veidota un attīstīta, izmantojot monitoringa datus un modelēšanas piedāvātās iespējas, taču lai izmantotu modelēšanas rīkus, ir nepieciešami vismaz divdesmit gadu hidroloģiskā režīma dati (DeFries & Eshleman, 2004; Delleur, 2003; T. D. Fletcher, Andrieu, & Hamel, 2013; Praskievicz & Chang, 2009; Zhong et al., 2022). Urbāno sateces baseinu hidroloģisko procesu modelēšana ir sarežģīta sadrumstalotās vides, specifisko hidroloģisko režīmu un urbānajā vidē raksturīgu hidroloģisko procesu dēļ (Meng, 2022; F Rodriguez, Andrieu, & Zech, 2000). Urbānā vide rada hidroloģiskā cikla izmaiņas un tajā pašā laikā ļoti jutīgi reaģē uz hidroloģiskā cikla izmaiņām visa sateces baseina teritorijā. Bach 2014, pētījums atklāj, ka ir nepieciešams klasificēt urbāno sateces baseinu integrētos modeļus un tos klasificēt pēc integrācijas pakāpes (Bach, Rauch, Mikkelsen, McCarthy, & Deletic, 2014; Q. Zhou, Luo, Qin, Su, & Ren, 2022), lai reducētu modeļa aprēķina rezultātu nenoteiktību, ko rada urbānās vides heterogenitāte. Pašlaik notiek diskusijas par ūdens aprites cikla universālas koncepcijas vai metodoloģijas izstrādi sateces baseina līmenī (Q. Zhou et al., 2022).

Hidroloģisko procesu mainība un atkarība no klimata un ģeomorfoloģiskajiem apstākļiem, kā arī antropogēnajiem faktoriem, mūsdienu hidrologiem sniedz izaicinājumu prognozēt un paredzēt iespējamo hidroloģisko procesu dinamiku laikā un telpā. Modeļi ar augstu telpisko izšķirtspēju ir ar sarežģītiem aprēķinu algoritmiem un nepieciešams salīdzinoši liels un blīvs novērojumu datu apjoms, kas bieži vien nav pieejams, tādējādi ietekmējot modeļa rezultātu nenoteiktību. Modeļa rezultātu nenoteiktību samazināšanai ieteicams izvēlēties mērķim un pieejamiem datiem atbilstošu modelēšanas rīku. Starptautiskā hidroloģijas zinātnieku asociācija (IAHS) ir izvirzījusi kopumā divdesmit trīs neatbildētus jautājumus hidroloģijas jomā, kas jāmēģina risināt nākamajā desmitgadē, tajā skaitā jautājumi, kas tieši saistīti ar promocijas darbā izvirzīto mērķi (Blöschl et al., 2019), respektīvi, hidroloģisko modeļu izmantošana hidroloģiskā cikla izmaiņu prognozēšanā mainīga klimata un zemes lietošana veida apstākļos, urbanizācijas ietekme uz hidroloģiskā cikla izmaiņām, ūdens pārvaldības ietekme pārtikas ķēdēm tajā skaitā SEG emisijām no antropogēnām ekosistēmām.

Latvijas teritorijā lielākā daļa ūdens objektu ir ar antropogēno ietekmi, un antropogēnajām slodzēm reģionā ir tendence palielināties. Kā piemēru var minēt straujo pilsētu attīstību, mežsaimniecības un lauksaimniecības intensifikāciju.

1.1. Hidroloģisko procesu modelēšanas pamatprincipi

Modelēšanas process sākas ar skaidri definētu modeļa izveides mērķi (skat.1.1att). Šis solis dod izpratni par to, kura tipa modelēšanas sistēma palīdzēs atrisināt vai vismaz gūt padziļinātu izpratni par problēmu. Nākamais solis ir, pamatojoties uz izvirzīto mērķi, izveidot sistēmas konceptuālo modeli. Šī procedūra bieži vien aizņem vairāk laika un resursu, jo jānosaka modelētās sistēmas robežas, jāapkopo pieejamie dati, studējot literatūru, jāiepazīstas ar līdzšinējo pieredzi šādu vai līdzīgu problēmu risināšanā, kā arī jāapseko sateces baseins, lai gūtu pilnīgu priekšstatu par objektu un risināmo problēmu. Papildus definētajam mērķim, pieejamie dati ir noteicošais faktors modeļa sarežģītības pakāpes izvēlē. Modeļa izvēle ir stadija, kurā tiek izvēlēts jau esošs modelis, modificēts vai papildināts jau esošs modelis, vai arī izveidots pilnīgi jauns modelis.



1.1.att. **Hidroloģisko procesu modelēšanas pamatprincipi**

Hidroloģijas aprēķinu veikšanā un hidroloģisko procesu modelēšanā ir nepieciešams atrast līdzsvaru starp apjomīgu (masīvu) datu ietilpīgu modeļu rezultātu un vienkāršotu modeļu ticamību, kā arī, izmantojot neatkarīgas metodes (savas metodes), jo vienmēr ir nepieciešams pārliecināties, ka modelētie lielumi ir korekti un atbilst reālajai situācijai. Ņemot vērā, to, ka hidroloģisko modeļu klāsts ir ļoti plašs visbiežāk tiek ņemts un pielāgots jau esošs modelis. Galvenie noteicošie faktori ir izmaksas un modeļa lietošanas vienkāršība. Modeļa izveide ir tā stadija, kad modelēšanas platformā tiek ievadīti dati un uzstādīti modelēšanas platformas parametri. Darbības kritēriju uzstādīšana notiek ar mērķi novērtēt modelēto un novēroto rezultātu sakritību. Jutīguma analīze ir process, kura laikā tiek izvērtēta modeļa nenoteiktība (identificētas nenoteiktības), kas saistītas ar modelēšanas procesu, gan saistībā ar modeļa struktūru, gan uzstādīto parametru vērtībām. Šis solis palīdz ranžēt parametrus, kuri tiek kalibrēti, īpaši tas attiecas uz modeļiem ar lielu kalibrējamo parametru skaitu. Modeļa kalibrācija ir process, kura laikā tiek atrasti optimālie parametru lielumi, kas ļauj modelim aprēķināt lielumus pēc iespējas tuvāk novērotajiem datiem.

Modeļa validācija ir process, kurā tiek pārbaudīts vai citam periodam modelis spēj aprēķināt ar tādu pašu precizitāti, kā kalibrācijas periodam. Paredzēšana, pielietojot kalibrēto modeli, ir process, kurā aprēķināta paredzamā nākotnes klimata scenāriju ietekme uz sateces baseina hidroloģisko režīmu. Pie nemainīgiem sateces baseina apstākļiem un parametriem tiek pārbaudīti dažādi scenāriji. Iegūto rezultātu prezentācija ir viens no svarīgākajiem posmiem, un

to var darīt dažādos veidos, kā ziņojumu, prezentāciju vai pat animāciju. Iegūto rezultātu saprotama prezentācija ir viens no galvenajiem stūrakmeņiem, lai panāktu vienošanos īpašnieku starpā, kā arī palīdzētu politikas veidotājiem, dažādos līmeņos. Savukārt izvērtēšana *(postaudit)* ir vēl viens veids, kā veikt modeļa validāciju konkrētam sateces baseinam. Šo soli parasti veic vairākus gadus pēc modelēšanas. Validēšana izpaužas tādā veidā, ka tiek salīdzināti modelētie dati ar novērotajiem datiem, tādējādi pārbaudot modeļa precizitāti. Ja rezultāti nav pietiekami, tiek pārskatīts konceptuālais modelis un veikta modeļa uzlabošana. Modeļa izveides pamatprincipi tika izmantoti gan urbānās hidroloģiskās atbildes vienības integrācijai konceptuālajā hidroloģiskajā modelī METQ, gan SEG emisiju no augsnēm aprēķina konceptuālo risinājumu izstrādē.

1.2. Urbāno hidroloģisko procesu modelēšana

Urbānie hidroloģiskie modeļi galvenokārt ir izveidoti trīs galveno mērķu sasniegšanai:

1) urbanizācijas ietekmes izvērtēšana uz dabisko ūdens aprites ciklu un papildus zināšanu uzkrāšana par komplekso sistēmu;
2) mērījumu datu iztrūkuma novēršana un izaicinājumu pārvarēšana, kas saistīta ar heterogēno un sarežģīto ūdens aprites sistēmu;
3) urbāno teritoriju nākotnes scenāriju izvērtēšana risku identificēšanai, kas saistīti ar klimata pārmaiņām un urbanizācijas straujo pieauguma tempu, kā vienu no galvenajiem var minēt plūdu risku.

Urbāno teritoriju iedzīvotājiem viena no galvenajām pamatvajadzībām ir tīra un droša dzeramā ūdens apgāde un notekūdeņu novadīšana, tāpēc tika attīstīti modeļi, kas ļauj modelēt ūdensapgādes un kanalizācijas tīklu. Nākamais urbāno hidroloģisko modeļu attīstības posms ir saistīts ar drošību, piemēram, plūdu un piesārņojuma risku izvērtēšanu (Price, 2011). Hidrauliskie modeļi spēj kalkulēt *De Saint Venant* plūsmas vienādojumus pie ļoti augstas izšķirtspējas, tomēr telpiskā dimensija šiem modeļiem paliek mākslīgi radītajā vidē un nespēj izvērtēt hidroloģiskos apstākļus urbānajos sateces baseinos. Šie modeļi fokusējas uz noteiktu hidroloģisku un hidroķīmisku fenomenu un tāpēc nespēj izvērtēt urbāno ūdens aprites ciklu kopumā. Papildus šiem modeļiem ir nepieciešamas vairākas robežvērtības, piemēram, ienākošās virszemes plūsmas, jo pilns hidroloģiskais cikls šajos modeļos netiek simulēts. (V G Mitchell & Diaper, 2005; O'Loughlin, Huber, & Chocat, 1996) pētījumos norāda, ka mūsdienās būtu nepieciešams integrēt modeļus ar dažādām laika un telpas skalām, lai varētu atbilstošā līmenī modelēt pilnu ūdens aprites ciklu sateces baseinā. Šajā nodaļā ir sniegts ieskats līdzšinējā pieredzē urbāno hidroloģisko procesu modelēšanā. Tikai daļa no analizētajiem modelēšanas rīkiem ir sākotnēji paredzēti urbānajiem sateces baseiniem, lielākā daļa ir sākotnēji veidoti dabiskajiem sateces baseiniem un vēlāk pielāgoti urbānajiem sateces baseiniem.

Hidroloģiskie modeļi galvenokārt tiek klasificēti pēc laika un telpas skalas. Ir divas atšķirīgas pieejas urbāno hidroloģisko procesu modelēšanā: pirmā ir urbanizācijas pētīšana sateces baseina robežās, savukārt otra pieeja ir hidroloģiskā modeļa izveide pilsētas robežās. Modeļi, kas aptver lielāku teritoriju par 10 km^2, tiek definēti, kā sateces baseina modeļi, un modeļi, kuros izmantotā teritorija ir mazāka par 10 km^2, tiek definēti kā pilsētas modeļi. Lai sniegtu lielāku izpratni par urbāno hidroloģisko modeļu pielietošanu, urbānās hidroloģijas pētījumi, kuros tika pielietoti modeļi, var tikt sagrupēti pēc laika dimensijas, telpas dimensijas un modeļa tipa.

Modeļu pielietojums var tikt iedalīts 5 nosacītās grupās:

1) robustie modeļi – šī pieeja ir vienkāršota un ir izmantojama ar ļoti ierobežotu ienākošo datu apjomu, dod priekšstatu par caurplūduma izmaiņām laikā, taču šajā pieejā netiek sniegta telpiskā informācija;
2) fizikālie modeļi ar apakšbaseiniem – šajos modeļos, balstoties uz topogrāfisko informāciju, tiek izdalīti apakšbaseini ar līdzīgu zemes virsmas segumu, piemēram, meži,

lauksaimniecības zeme, urbānās teritorijas utt. Izmantojot šo pieeju, tiek sniegta pamatinformācija par katru apakšbaseinu, taču trūkst detalizēta telpiskā informācija, jo telpiskais sadalījums ir kvantitatīvs, bez telpiskās dimensijas (Bergström, 1992; Krams & Ziverts, 1993);

3) hidroloģiskās atbildes vienības modeļi – tipisks piemērs ir SWAT modelis, kur aprēķini tiek balstīti uz ģeomorfoloģiskajiem datiem, kas kombinēti ar virsmas augstuma atzīmēm (Arnold & Fohrer, 2005; Arnold, Srinivasan, Muttiah, & Williams, 1998). Šajā pieejā hidroloģiskās atbildes vienības tiek grupētas pēc līdzīgām ģeomorfoloģiskajām un zemes pārklājuma pazīmēm, tādējādi veicot precīzākus aprēķinus, taču, tiklīdz ir izveidotas, aprēķinu grupas ar kopējām pazīmēm, telpiskā dimensija zūd un izejas informācija attiecas uz visu hidroloģisko atbildes vienību;
4) fizikāli telpiskie modeļi – šajā pieejā tiek izmantotas GIS kartes un attālinātās izpētes tehnoloģijas, hidroloģiskie raksturlielumi tiek modelēti aprēķina režģī. Šādu modeļu detalizācija ir tieši atkarīga no aprēķina režģa izmēra, ka arī katrai šūnai nepieciešamā datu apjoma un detalizācijas pakāpes;
5) urbāno hidroloģisko elementu modeļi – šie modeļi ir būvēti, lai analizētu urbānā caurplūduma izmaiņas laikā un telpā. Katra modeļa pieeja ir atšķirīga, taču kopējā iezīme ir izvēlēta urbānā sateces baseina elementu kopa, kas pietiekoši precīzi apraksta urbānā sateces baseina heterogenitāti, bet tajā pašā laikā ir homogēna attiecībā pret hidroloģiskajiem procesiem viena elementa ietvaros (Grimmond & Oke, 1991; Mackay & Last, 2010; V Grace Mitchell, McMahon, & Mein, 2003; Morris, Rueedi, Cronin, Diaper, & DeSilva, 2007; Fabrice Rodriguez, Andrieu, & Morena, 2008; Y. Zhou, Wang, Gold, & August, 2010).

Modeļi var tikt sagrupēti pēc izmantotā laika soļa garuma. Laika dimensija variē no 30 sekundēm līdz vienam gadam, taču 90% no visiem gadījumiem laika dimensija ir viena diena vai mazāks laika periods. Papildus izmantotās metodes var tikt sadalītas divās grupās pēc telpiskās izplatības: aprēķina režģa pieeja un pārējie, kas tika izmantoti vairāk nekā 60% gadījumu. Tik plašai šo modeļu daudzveidībai ir vairāki iemesli: pirmkārt, ir vienkāršāk palielināt apakšbaseinu skaitu ar vienādām īpašībām, otrkārt, robustie modeļi ļauj vienu sateces baseinu uztvert, kā vienu vienību ar līdzīgām pazīmēm, treškārt, urbāno hidroloģisko elementu pieeja ļauj iekļaut ļoti detalizētu telpisko informāciju. Ir divas izteikti atšķirīgas pieejas urbāno hidroloģisko procesu modelēšanā.

Modeļu pielietošana sateces baseina līmenī aptver visu laika un telpas skalas diapazonu, kā arī aprēķina režģa modeļus un pārējos modeļus. Galvenā tendence ir laika un telpas dimensijas nosacītas proporcionalitātes saglabāšana, proti, pie lielākas laika skalas ir lielāka telpiskā skala, savukārt robustajos modeļos galvenokārt dominē laika skala vienas dienas diapazonā;

Urbāno teritoriju modeļiem ir tendence grupēties aprēķina režģa grupā ar augstu telpisko izšķirtspēju un dažādām laika dimensijām, kā arī dažādo modelēšanas pieeju zonā ar dažādām laika skalām. Šo fenomenu var izskaidrot ar relatīvi mazo pētāmo teritoriju izmēru, kas nepieļauj lielu variāciju iespēju telpiskajā dimensijā, bet ļauj variēt ar laika dimensijas skalu. Pilsētas līmeņa modeļiem ir relatīvi smalkāka laika un telpas skala, salīdzinot ar urbāno sateces baseinu modeļiem. Vairāk nekā 50% no modeļiem, kuros pētāmā teritorija bija mazāka par 10 km^2, laika dimensijas skala ir 6 minūtes vai mazāka, savukārt telpas dimensija ir 5 m vai mazāka. Izpētes teritorijām, kas ir lielākas par 10 km^2, kā laika dimensijas skalā dominē 1 stunda un telpiskās dimensijas skalā dominē 30 m. Salīdzinot ar tradicionālajiem noteces modeļiem, šīs modeļu grupas izšķirtspēja abās dimensijās ir augstāka.

Pēdējo desmitgažu laikā ir strauji attīstījušās attālinātās izpētes un GIS tehnoloģijas, kas ir integrētas daudzos mūsdienu hidroloģiskajos modeļos. Lielākajā daļā urbānās hidroloģijas modelēšanas gadījumu ir integrēta vai izmantota GIS tehnoloģija. GIS tehnoloģijas tiek izmantotas šādiem mērķiem:

1) modeļu parametru un ievades datu pirmsapstrāde un pēcapstrāde;

2) telpisko datu apstrāde un vizualizācija;
3) sateces baseina identifikācija, ņemot vērā zemes virsmas augstumu topogrāfiju sadalījumu apakšbaseinos;
4) attālinātās izpētes datu integrācija modelī;
5) hidroloģisko atbildes vienību un hidroloģisko elementu identifikācija;
6) modeļu savietošanai platformā.

Vairāk nekā 80% gadījumu tiek izmantotas ArcView, ArcGIS, ArcInfo, ArcGIS-Python un GRASS programmu pakešu piedāvātās GIS iespējas. Visbiežāk GIS piedāvātās iespējas tiek izmantotas datu apstrādei un modeļu parametru noteikšanai. Digitālie virsmas modeļi un digitālie reljefa modeļi tiek izmantoti sateces baseina robežu noteikšanai (Gironás, Niemann, Roesner, Fabrice, & Hervé, 2010).

GIS tehnoloģiju attīstība veicina arī attālinātās izpētes datu izmantošanu hidroloģiskajos modeļos. Visbiežāk tiek izmantoti LIDAR dati, lai identificētu zemes lietojuma veidu, ūdens necaurlaidīgās virsmas un veģetācijas raksturu (Easton, Gérard-Marchant, Walter, Petrovic, & Steenhuis, 2007; Lee & Heaney, 2003; Y. Zhou et al., 2010). Tādiem pašiem nolūkiem tiek izmantoti satelītuzņēmumu dati (Berezowski, Chormański, Batelaan, Canters, & Van de Voorde, 2012; Dotto et al., 2011). Pamazām urbānajos hidroloģiskajos modeļos tiek integrēti nokrišņu radara dati (McColl & Aggett, 2007; Mejía & Moglen, 2010; Pan, Hou, Tian, Ni, & Hu, 2012; Thielen & Creutin, 1997; Vieux & Bedient, 2004). Lielākajā vairumā gadījumu tiek izmantoti satelītuzņēmumi, lai noteiktu vidējo sateces baseina sadalījumu hidroloģiskajās atbildes vienībās. Pamazām urbānajos hidroloģiskajos modeļos tiek izmantotas iespējas ko piedāvā zemes lietojuma veida, laika un telpas dimensijas (Im, Kim, Kim, & Jang, 2009; Verbeiren et al., 2013). Attālinātās izpētes tehnoloģijas tiek izmantotas digitālo virsmas modeļu izveidei (J. Chen et al., 2009; Fewtrell, Neal, Bates, & Harrison, 2011), netiešās summārās iztvaikošanas parametru noteikšanai izmantojot Lapu virsmas indeksu (*Leaf Area Index*) (Y. Zhou et al., 2010).

Urbānās hidroloģijas viens no stūrakmeņiem ir kolektoru, upju gultņu un rezervuāru hidrauliskā modelēšana. Var izdalīt četras galvenās aprēķinu metodikas virszemes noteces, lietus kanalizācijas, upju un notekūdeņu plūsmas dažādos hidrotehnisko būvju elementos:
1) lineārie un nelineārie, kā arī konceptuālie vienādojumi;
2) kinemātiskie, difūzie vai dinamiskie viļņu tuvinājumi, seklo ūdeņu vienādojumi, viendimensiju un divdimensiju *De Saint Venant* vienādojumi, turpmāk saukti hidrodinamiskā maršrutēšana;
3) vienības hidrogrāfs un ģeomorfoloģiskais vienības hidrogrāfs;
4) nezināmas metodes.

Lielākajā daļā gadījumu tiek modelēta upju gultņu hidraulika un dažos gadījumos arī lietusūdens un notekūdeņu kolektoru hidraulika. Urbānajā hidroloģijā liela nozīme ir virszemes noteces modelēšanai, taču lielākajā daļā gadījumu tiek izmantoti lineāri vienādojumi vai empīriskas formulas, un tikai nelielā daļā modeļu tiek izmantota hidrodinamiskā pieeja, kā arī tiek izmantota vienības hidrogrāfa pieeja vai, dažos gadījumos, virszemes noteces komponente netiek modelēta. Ļoti detalizētos fizikālajos modeļos ne vienmēr tiek ņemtas vērā lietus ūdens un notekūdeņu plūsmas.

Urbāno sateces baseinu hidroloģija atšķiras no klasiskās pilsētu hidraulikas galvenokārt ar mērogu. Detalizētu lietus ūdeņu un notekūdeņu plūsmu analīzi nav iespējams veikt hidroloģiskajos modeļos ar lieliem sateces baseiniem, tādēļ urbānajiem hidroloģiskajiem modeļiem ir nepieciešams izvēlēties integrētu aprēķina metodiku, kur ir diferencēts sarežģītības līmenis katrai plūsmas komponentei, piemēram, virszemes noteci var modelēt, izmantojot konceptuālo metodi, savukārt lietus un sadzīves kanalizācijai – hidrodinamisko metodi. Upes noteci, lietus ūdens savākšanas sistēmas un sadzīves kanalizācijas sistēmas nepieciešams modelēt, izmatojot plūsmas hidraulikas aprēķinus, taču bieži vien tiek izmantota vienkāršota gultņu forma (trapece utt.).

Procesu modeļi galvenokārt tiek veidoti, lai rastu atbildi uz kādu specifisku zinātniska vai praktiska rakstura jautājumu. Modelī fizikālo procesu simulēšana jāpakārto mērķim, tādēļ modeļa attīstītājiem jāizvēlas kurus hidroloģiskos procesus modelēt un modeļa detalizācijas līmenis saskaņā ar izvirzīto uzdevumu.

Visbiežāk tiek izmantota urbanizācijas ietekme uz infiltrāciju un noteces veidošanos, veidojot urbāno hidroloģisko atbildes vienību ar zemu infiltrāciju (Dixon & Earls, 2012; Valeo & Moin, 2000) vai izmantojot telpisko dimensiju, kur katram elementam ir atšķirīga infiltrācijas spēja (Verbeiren et al., 2013; Y. Zhou et al., 2010). Šādi modeļi palīdz izprast zemes lietojuma veida maiņas un necaurlaidīgo virsmu īpatsvara ietekmi uz hidroloģisko režīmu, un ir lielisks atbalsta instruments pilsētu attīstības stratēģiju izstrādē. Šāda tipa modeļi galvenokārt fokusējas uz virszemes noteces transformācijām, bet ne vienmēr izvērtē gruntsūdens līmeņa izmaiņas.

Šā tipa modeļu mērķis ir ūdens bilances invertējums urbānajās teritorijās. Pārsvarā tie ir mazi vai vidēji sateces baseini, un aprēķiniem tiek izmantoti urbānās hidroloģijas elementi. Šāda tipa modeļiem ir nepieciešama detalizēta informācija par sadzīves un industriālo ūdens patēriņu. Visbiežāk tiek simulētas lietus kanalizācijas plūsmas, notekūdeņu savākšanas un attīrīšanas sistēmas, infiltrācija sadzīves un lietus kanalizācijas tīklos, notekūdeņu attīrīšanas ietaises, sūkņu stacijas, gruntsūdens ieguves vietas, sadzīves un industriālā ūdens patēriņš, krājrezervuāru tilpums. Kā piemērus var minēt: Peri-Urban SYMHYD (Singh, Maheshwari, & Malano, 2009), CWB (*City Water Balance*) (Mackay & Last, 2010) un to priekšteči *Aquacycle* (V Grace Mitchell et al., 2003), un UVQ (*Urban Volume Quantity*) (Morris et al., 2007). Konceptuālie modeļi var tikt izmantoti, lai salīdzinātu dažādus ūdens resursu pārvaldības scenārijus (T. D. Fletcher et al., 2013). Visi iepriekšminētie modeļi sniedz lielisku atbalstu ūdens resursu pārvaldības politikas instrumentu izstrādē. Fiskālie procesi ir vienkāršoti, bet tie sniedz galveno informāciju par ūdens bilanci urbānajās teritorijās, tomēr tie nevar tikt izmantoti plūdu riska zonu vai gruntsūdens karšu izveidē.

Ļoti liels skaits komerciālo un brīvpieejas programmatūras ir pieejamas applūstošo teritoriju, pretplūdu aizsardzības sistēmu un lietus ūdens savākšanas sistēmu modelēšanai. Plūdu atkārtošanās biežumam un intensitātei ir pozitīva korelācija ar urbanizācijas līmeni. Applūstošās teritorijas ir ar lokālu raksturu un parasti tiek modelētas ar telpisko skalu no hektāra līdz 2 km^2. Galvenie fizikālie procesi ir virszemes notece, infiltrācija, ūdens plūsma lietus ūdens novadīšanas sistēmās un krājrezervuāros. Visbiežāk tie ir divdimensionāli un dažādi modificēti *De Saint Venant* vienādojumi (G. T. Aronica & Lanza, 2005; Fewtrell et al., 2011; Ogden, Raj Pradhan, Downer, & Zahner, 2011). Ir izmantots digitālais virsmas modelis ar augstu telpisko izšķirtspēju – *Semi-Urbanized Runoff Model* (SURF) modelis (Bellal, Sillen, & Zech, 1996; F Rodriguez et al., 2000). Gadījumos, kad nav pieejami topogrāfiskie dati, teritorija tiek pieņemta kā līdzena (J. Chen et al., 2009). Iepriekšminētajos piemēros tiek ņemta vērā lietus ūdens novadīšanas sistēma. Lietus ūdens savākšanas sistēma var tikt simulēta kā virtuālo hidraulisko elementu kopa, kur, katra lietusūdens uztveršanas aka uztver noteiktu daudzumu ūdens (G. Aronica & Cannarozzo, 2000). Dažos gadījumos ūdens plūsmu lietus ūdens savākšanas sistēmās var aprēķināt, izmantojot hidrauliskos aprēķinus un cauruļu caurvades spējas aprēķina līknes, kā piemēru var minēt SURF modeli (Bellal et al., 1996). Detalizētākai lietus ūdens savākšanas sistēmu matemātiskajai interpretācijai tiek izmantoti hidraulikas pamatprincipi un plūsmas transformācijas līknes, piemēram, modelī SURF (Bellal et al., 1996). Dziļākai lietus ūdens plūsmas aprēķinu detalizācijai izmanto *De Saint Venant* viendimensiju formu, kuru kombinē ar plūdu modeļiem, kuros iebūvēts lietus ūdens aprēķina algoritms, kā piemēram (Hsu, Chen, & Chang, 2000) izstrādātais modelis, kur SWMM (Huber, Dickinson, Barnwell Jr, & Branch, 1988) tika apvienots ar plūdu modeli. Neskaitot SWMM, vēl ir ļoti daudz dažādi lietus ūdens un kanalizācijas sistēmu modeļi, kurus iespējams izmantot urbānajās teritorijās, piemēram MUSIC (Dotto et al., 2011), InfoWORKS CS (Hurford, Maksimović, & Leitão, 2010), MOUSE (Thorndahl & Willems, 2008), un CANOE (Lhomme, Bouvier, & Perrin, 2004). Šie modeļi ļauj veiksmīgi modelēt plūsmas urbānajās sistēmās, kā arī ērti lietojami un pielāgojami konkrētam modelēšanas mērķim. Tajos ir integrēti moduļi, kas ļauj papildus

modelēt piesārņojumu. Kopumā šie modeļi tiek pozicionēti kā urbānie hidroloģiskie modeļi, taču jāmin daži trūkumi: nav iespējams modelēt hidroloģiju sateces baseina līmenī; dabiskie hidroloģiskie procesi ir vienkāršoti, un parasti tiek izmantoti kā ievades dati lietus kanalizācijas sistēmu modelēšanā; reti tiek ņemta vērā infiltrācija un gruntsūdeņu notece.

Ūdens bilance urbānajās augsnēs būtiski ietekmē pazemes un virszemes plūsmas sateces baseinā. Urbānajā vidē augsne ir būtiski izmainīta, kur pamatu konstrukcijas mijās ar pazemes infrastruktūras objektiem. Augsnes heterogēnais raksturs būtiski sarežģī modelēšanu un bieži vien pazemes plūsmu lēnais raksturs tiek pretstatīts plūdiem un tādējādi pazemes plūsmu kalkulācijas tiek vienkāršotas; tiek izmantoti vienkāršoti lineārās regresijas vienādojumi (Easton et al., 2007; Faulkner & Barber, 2009),fizikālā divdimensiju vai trīsdimensiju pieeja (Göbel et al., 2004; Jia, Ni, Kawahara, & Suetsugi, 2001). Urbāno augšņu filtrācija ir iekļauta (G. T. Aronica & Lanza, 2005) pētījumā, taču netiek risināta modelī, turpretim (Berthier, Andrieu, & Creutin, 2004) modelē urbāno augšņu ietekmi uz noteces veidošanos. Šajā pētījumā tiek ņemti vērā galvenie augsnes ietekmes veidi: kanalizācijas sistēmas drenē augsni, ja tīkli nav izbūvēti pietiekoši hermētiski; augsne zem ielām ir sablīvēta, kas izmaina pazemes ūdens plūsmas; ēku pamati parasti ir ūdensnecaurlaidīgi, kas būtiski maina pazemes ūdens plūsmu. Pazemes ūdens plūsmas tiek kalkulētas izmantojot *Richards* vienādojumus (Richards, 1931) ar noslēgtu elementu pieeju, savukārt kanalizācijas sistēmas tiek modelētas, izmantojot drenāžas aprēķinus. Šī modelēšanas pieeja ir izmantota ļoti mazam sateces baseinam – 0.05 kvadrātkilometriem. NEIMO modelī (Morris et al., 2007) tiek izmantots Darsī likums, lai aprēķinātu lietus un sadzīves kanalizācijas infiltrācijas un zudumus.

Urbānajos hidroloģiskajos modeļos, iekļaujot klimata parametrus, ir iespējams ņemt vērā urbānā mikroklimata ietekmi uz ūdens bilanci un urbanizācijas ietekmi uz hidroklimatoloģiju. Gandrīz visos modeļos tiek izmantoti nokrišņi, un lielā daļā modeļu ir iekļauta arī summārā iztvaikošana, temperatūra un sniega segas veidošanās un kušana (Lan Cuo, Lettenmaier, Mattheussen, Storck, & Wiley, 2008), dažos modeļos tiek ņemta vērā saules radiācija un siltuma plūsmas urbānajā vidē (Jia et al., 2001). Pašlaik modeļos netiek izmantota urbanizācijas ietekme uz nokrišņiem, kas ir plašs lauks pētījumiem. Summārā iztvaikošana modeļos tiek izmantota ar dažādu detalizācijas pakāpi, sākot ar summārās iztvaikošanas neņemšanu vērā dažādas intensitātes lietus gāžu simulācijas (J. Chen et al., 2009) vai, izmantojot empīriskas formulas (Chormanski, Van de Voorde, De Roeck, Batelaan, & Canters, 2008; V Grace Mitchell et al., 2003), līdz pat fizikālajām aprēķinu formulām kā *Penman–Monteith* vienādojumiem (Franczyk & Chang, 2009; Y. Zhou et al., 2010). SUES modelī (Grimmond & Oke, 1991; V G Mitchell, Cleugh, Grimmond, & Xu, 2008) tiek izmantota sarežģītāka pieeja, lai simulētu enerģijas bilanci urbānajā vidē, ņemot vērā antropogēnās siltuma plūsmas un siltuma akumulāciju urbānajos elementos, kā arī aerodinamiku un virsmu ietekmi. SUES modeļa trūkumi ir apjomīgā izejas datu kopa, no kuriem lielu daļu parametru ir grūti vai neiespējami nomērīt, kā arī tas neņem vērā augsnes mitruma un virszemes ūdeņu ietekmi uz summāro iztvaikošanu. Modelis ir ar ļoti augstu izšķirtspēju un var tikt izmantots no 0.2 līdz 30 km^2 lielās teritorijās.

Integrētie fizikālie modeļi ļauj modelēt urbānā sateces baseina noteci, balstoties uz hidroloģijas pamatprincipiem, ņemot vērā gan ūdens, gan enerģijas bilanci konkrētajā sateces baseinā, tomēr vēlme pēc iespējas detalizētāk aprakstīt hidroloģiskos procesus noved pie sarežģīta algoritma, kam ir nepieciešami lieli tehnoloģiskie resursi, palielināts izejas datu apjoms un rezultējas ar palielinātu nenoteiktību. Kā vienu no spilgtākajiem piemēriem var minēt URBS-MO (Fabrice Rodriguez et al., 2008). Izmantojot šo inovatīvo pieeju, hidroloģiskie procesi tiek modelēti UHE mērogā, kur:

1) *Penman-Monteith* vienādojumi tiek izmantoti summārās iztvaikošanas un lietus aiztures aprēķiniem;
2) trīsdimensiju vienādojumi kombinācijā ar vienkāršotiem vienādojumiem tiek izmantoti, modelējot piesātinātas grunts procesus;

3) infiltrāciju aprēķina lietus ūdens un sadzīves kanalizācijas sistēmās, izmantojot drenāžas aprēķinus;
4) virszemes plūsmu aprēķina, izmantojot urbāno GIUH, kas balstīta uz urbānajām GIS datubāzēm;
5) lietus ūdens kanalizācijas plūsmas tiek aprēķinātas, izmantojot *Muskingum–Cunge* algoritmu.

Kā trūkumu šādai pieejai var minēt, ka netiek ņemti vērā lietus un sadzīves notekūdeņu zudumi sistēmā, kā arī tiek izmantota Urbānā GIUH metode, kas kalkulē lineāru hidroloģiju visam sateces baseinam, kas var nebūt patiesa plūdu laikā. Modelis neļauj telpiski sadalīt ūdens plūsmas, tāpēc nav izmantojams plūdu zonu modelēšanā. Kā vienu no veiksmīgiem šīs modeļu grupas piemēriem var minēt (Göbel et al., 2004) izstrādāto modeli, kur tiek kombinēti trīs modeļi, kam katram ir specifisks mērķis:
1) ūdens bilances modelis GWNEU, lai aprēķinātu dabīgo augšņu gruntsūdeņu papildināšanos;
2) divdimensiju vertikālo plūsmu modeli HYDRUS_2D, lai modelētu infiltrāciju no urbānajām struktūrām;
3) un gruntsūdens plūsmu modeli SPRING.

Iepriekšminētajai modelēšanas pieejai, kā galveno priekšrocību, var minēt mērķtiecīgu specifisku fizikālo procesu modelēšanas iespēju, kas ļauj katram konkrētajam modelēšanas mērķim izvēlēties vispiemērotāko algoritmu, kā arī mainīt laika un telpas dimensiju izšķirtspēju. (Pan et al., 2012) izmanto slāņus un kombinē viendimensiju *Richards* vienādojumu vertikālajām gruntsūdens plūsmām; divdimensiju *De Saint Venant* vienādojuma difūzo formu virszemes plūsmai un viendimensiju dinamisko *De Saint Venant* vienādojumu ielām, kanalizācijas sistēmām un grāvju tīklam. Savukārt (Xiao, McPherson, Simpson, & Ustin, 2007) ņēma vērā augsnes un zemes virsmas savstarpējo mijiedarbību noteces veidošanās procesā, kā arī kalkulēja laistīšanas nepieciešamību, tādējādi būtiski uzlabojot urbāno teritoriju apsaimniekošanas efektivitāti.

Urbāno sateces baseinu hidroloģiskie modeļi ir daudz sarežģītāki par dabisko sateces baseinu hidroloģiskajiem modeļiem, jo simulē vairāk procesu nosacīti mazākā telpiskās dimensijas vienībā, tāpēc būtiski pieaug parametru un ievades datu apjoms (Chormanski et al., 2008; T. D. Fletcher et al., 2013; Gironás, Niemann, Roesner, Rodriguez, & Andrieu, 2009; Gironás et al., 2010; Grimmond & Oke, 1991; Hamdi, Termonia, & Baguis, 2011; Im et al., 2009; Mackay & Last, 2010; Morris et al., 2007; F Rodriguez et al., 2000; Singh et al., 2009; Xiao et al., 2007), kas savukārt aktualizē modeļu precizitāti un ticamību (Petrucci & Bonhomme, 2014; Vrebos, Vansteenkiste, Staes, Willems, & Meire, 2014). Konceptuālie modeļi nedod detalizētu telpas dimensiju, taču gadījumā, ja nepieciešams caurplūdums konkrētā vietā, šie modeļi ir precīzāki un palīdz izvairīties no pārlieku liela parametru apjoma (Vrebos et al., 2014). Daudzos gadījumos nav iespējams nodrošināt nepieciešamos ievades datus, un atbilstoša kalibrācija un validācija nav iespējama (G. T. Aronica & Lanza, 2005; Chormanski et al., 2008). Ir pierādīts, ka precīzi dati ar augstu laika un telpas izšķirtspēju uzlabo modeļu veiktspēju (Dotto et al., 2011; Hurford et al., 2010; Morris et al., 2007). Viena no iespējām uzlabot modeļa veiktspēju ir veikt kalibrāciju manuāli (G. Aronica & Cannarozzo, 2000; Hamel & Fletcher, 2014; Morris et al., 2007; Ogden et al., 2011; Pan et al., 2012; Vrebos et al., 2014) Dažos gadījumos tiek paralēli izmantotas manuālā un automātiskā kalibrācija (Berezowski et al., 2012; Franczyk & Chang, 2009), vai izmantotas vairākas automātiskās kalibrācijas metodes (Berthier et al., 2004; Dotto et al., 2011; Kleidorfer, Deletic, Fletcher, & Rauch, 2009; Mejía & Moglen, 2010; Petrucci & Bonhomme, 2014; F Rodriguez et al., 2000).

Urbānie integrētie modeļi ir sarežģīti un ietver ļoti daudz parametru. Pastāv vairākas pieejas šīs problēmas risināšanai.

Parametru skaita samazināšana: jūtīguma tests ļauj samazināt kalibrējamo parametru skaitu un identificēt tos parametrus, kas būtiski ietekmē modelēšanas rezultātus (Dotto et al., 2011; Kleidorfer et al., 2009; Krebs, Kokkonen, Valtanen, Setälä, & Koivusalo, 2014; Mejía &

Moglen, 2010; F Rodriguez et al., 2000; Fabrice Rodriguez, Andrieu, & Creutin, 2003; Vrebos et al., 2014). Daudzos gadījumos virsmas raupjuma koeficients un virsmas ūdens caurlaidība ir ar augstu jūtīgumu (Lan Cuo et al., 2008; Gironás et al., 2010; Lee & Heaney, 2003; Ogden et al., 2011; Fabrice Rodriguez et al., 2003). Telpiskā izšķirtspēja tiek minēta kā viens no galvenajiem nenoteiktību ietekmējošiem faktoriem (Fewtrell et al., 2011; Pan et al., 2012; Valeo & Moin, 2000). Saskaņā ar (Petrucci & Bonhomme, 2014) pārāk augsta telpiskā izšķirtspēja veicina parametru skaita palielinājumu. Citi autori savukārt uzskata, ka telpiskie dati ar augstu izšķirtspēju būtiski uzlabo modeļa veiktspēju un daļu no parametriem var definēt kā konstantes (Bellal et al., 1996; Gironás et al., 2010; Krebs et al., 2014; Lee & Heaney, 2003; Verbeiren et al., 2013; Y. Zhou et al., 2010).

Izmērāmi un fizikāli pamatojami parametri: liels skaits modeļu izmanto fizikālu pieeju. Saskaņā ar publicētajiem zinātniskajiem rakstiem šādiem modeļiem būtu jādod precīzāks rezultāts (Te Linde, Aerts, & Kwadijk, 2010), tie ir robusti (Fewtrell et al., 2011), ietver identificējamus parametrus ar optimālajām vērtībām (Vieux & Bedient, 2004), un to parametri spēj nodrošināt detalizētu un potenciāli precīzāku hidroloģisko procesu aprakstu (Jia et al., 2001). Fiziski izmērāmi parametri: (I) var palielināt izpratni par tipiskiem procesiem urbānajā vidē, tādiem kā BMPs (Xiao et al., 2007); (II) tā kā katrs modeļa parametrs ir attiecināms uz konkrētu procesu urbānajā vidē, šie parametri uzlabo manuālās kalibrācijas rezultātus (Morris et al., 2007); (III) galvenā priekšrocība ir parametra vērtību fizikālās robežas (Ogden et al., 2011). Papildus iepriekšminētajam, daudzu fizikālo parametru robežvērtības var pieņemt, izmantojot fundamentālo pētījumu rezultātus (Fabrice Rodriguez et al., 2008), savukārt virsmas raupjumu un citus parametrus ir iespējams viegli noteikt, apsekojot teritoriju (Lee & Heaney, 2003), tādējādi daļu parametru var klasificēt kā modeļa ieejas datus.

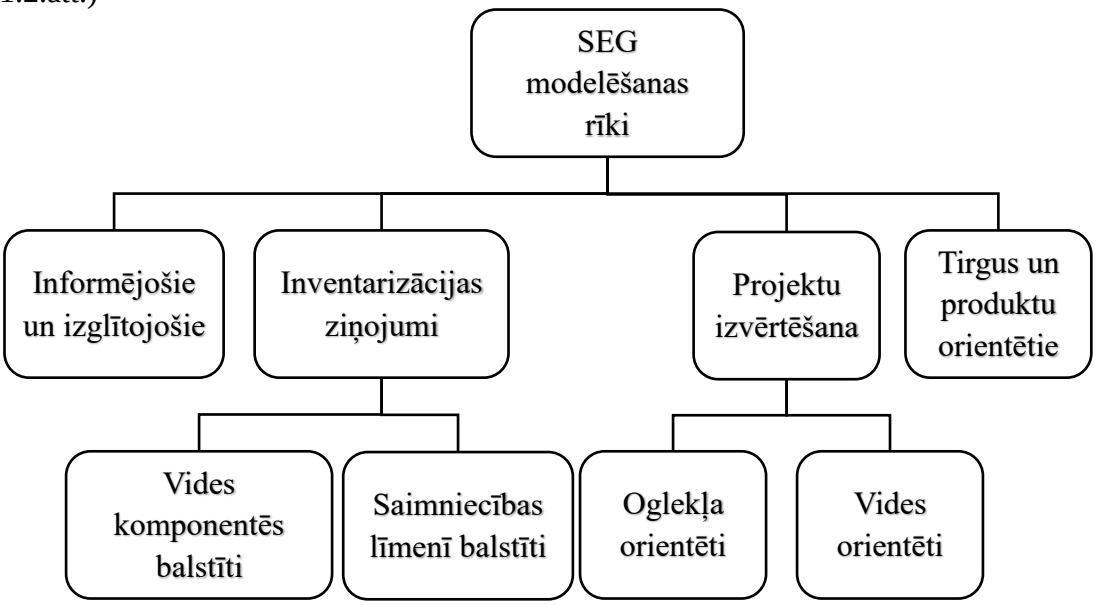
Kalibrācija un validācija: standarta metodes integrēto un telpisko urbāno modeļu kalibrēšanai un validācijai ir vienas mērķa funkcijas minimizēšana vai maksimizēšana, kas ir vienkārša, vai sarežģīta atlikumu forma starp novēroto un izmērīto upes caurplūdumu parēķina punktā (Berezowski et al., 2012; Lan Cuo et al., 2008; Franczyk & Chang, 2009; Hamdi et al., 2011; Im et al., 2009; Lhomme et al., 2004; Mejía & Moglen, 2010; V Grace Mitchell et al., 2003; Valeo & Moin, 2000; Verbeiren et al., 2013; Y. Zhou et al., 2010). Tiek izmantotas dažādas alternatīvas metodes modeļu kalibrācijai: (I) dažādu kalibrācijas algoritmu izmantošana viena modeļa kalibrācijai (F Rodriguez et al., 2000); (II) neatkarīgas kvantitatīvās un kvalitatīvās kalibrācijas metodes, (Kleidorfer et al., 2009; Petrucci & Bonhomme, 2014) ietverot virszemes noteces un notekūdeņu plūsmu validāciju (Singh et al., 2009); (III) pakārtota kalibrācija, piemēram, ūdensapgāde, lietusūdeņi un tad notekūdeņi (Mackay & Last, 2010); (IV) kalibrācija un validācija dažādām modeļa starpvērtībām, vai dažādu statistikas metožu izmantošana kalibrācijas rezultātu novērtēšanai, piemēram, dažādas statistikas metodes virszemes noteces kalibrācijas rezultātiem (Hamel & Fletcher, 2014); augsnes mitrums (Ogden et al., 2011; Xiao et al., 2007), augsnes mitrums un virszemes notece (Easton et al., 2007), virszemes notece un gruntsūdens līmeņi (Göbel et al., 2004; Fabrice Rodriguez et al., 2008), virszemes notece, gruntsūdens līmeņi, saules radiācija un augsnes temperatūra (Jia et al., 2001); gruntsūdens noteces gradients, kopējā gruntsūdens notece un apjoms (Berthier et al., 2004); virszemes ūdens dziļums plūdu modeļiem (J. Chen et al., 2009); telpiskā dimensija ūdens līmeņiem un virszemes notecei (Fewtrell et al., 2011); noteces mērījumi zaļajās urbānajās struktūrās (Morris et al., 2007).

1.3. SEG emisiju modelēšana no augsnēm

Klimata pārmaiņu mazināšana un oglekļa mazietilpīgas ekonomikas izveide ir viena no sešām pārmaiņām, kas jārealizē Eiropas Savienībā, lai sasniegtu ANO ilgtspējīgas attīstības mērķus (IAM). Paralēli IPCC izstrādātajām vadlīnijām SEG emisiju aprēķinu metodoloģijai ir izstrādāti daudzi SEG aprēķina rīki, lai novērtētu lauksaimniecības un mežsaimniecības praksi.

(Vincent Colomb et al., 2012) klasificē šos rīkus kā: kalkulatorus, protokolus, vadlīnijas un modeļus. Šajā apakšnodaļā galvenā uzmanība ir pievērsta modeļiem, kas izstrādāti SEG emisiju apjoma noteikšanai vai lauksaimniecības un mežsaimniecības emisiju samazinošo pasākumu izvērtēšanai.

SEG emisiju aprēķina instrumenti ir izstrādāti dažādiem mērķiem. Colomb kopā ar pētnieku grupu 2012. gadā izveidoja vienu no pirmajām SEG kalkulatoru klasifikācijām, kuras pamatā ir modeļa izmantošanas pieeja (V. Colomb et al., 2013; Vincent Colomb et al., 2012) (skat.1.2.att.)



1.2.att. **SEG emisiju modelēšanas rīku klasifikācija**

Modelis DairyWise ir empīrisks simulācijas modelis, kas integrē visas piena lopkopības saimniecības galvenās apakšsistēmas vienā kopējās saimniecības līmeņa modelī. Tas modelē CH_4, N_2O un CO_2 emisijas SEG emisiju apakš-modelī. *DairyWise* modelis tika izstrādāts, lai integrētu lauksaimniecības dzīvnieku apsaimniekošanu, vides un finanšu aspektus piena produktu ražošanai Nīderlandē, apvienojot esošos apakšmodeļus (Schils et al., 2007). Šis modelis ir vienas grupas izstrādāto esošo modeļu apkopojums. Šajos modeļos ietilpst *FeedSupply* un *GrassGrowth* modeļi. SEG emisijas aprēķina, izmantojot noklusējuma emisijas koeficientus. Modelis tiek izmantots kompleksiem pētījumiem SEG emisiju jomā un izmantots kā lēmumu pieņemšanas rīks (Hack-ten Broeke et al., 2019; Hutchings, Ozkan Gulzari, De Haan, & Sandars, 2018; Kolasa-Więcek, 2015).

Modelis DAYCENT ir bioķīmijas modeļa *CENTURY* ikdienas laika dimensijas versija. *DAYCENT* simulē C, N, P un S un SEG gāzu apmaiņu starp atmosfēru, augsni un augiem, kas rodas augu augšanas rezultātā, un tādām aktivitātēm kā dedzināšana, ganīšana, audzēšana, ražas novākšana un organiskā minerālmēslojuma izmantošana. *DAYCENT* pamatā ir process, ņemot vērā, kā apsaimniekošanas scenāriji ietekmē augsnes mitruma saturu, pH, nitrātu un amonija koncentrāciju un citas bioķīmiskās komponentes (Del Grosso et al., 2002; Parton, Hartman, Ojima, & Schimel, 1998; Parton et al., 2001). Modelis *DAYCENT* tiek plaši izmantots slāpekļa aprites cikla aprēķinos, īpaši reaktīvā slāpekļa noplūžu gruntsūdeņos un virszemes ūdeņos, un reaktīvā slāpekļa emisiju atmosfērā modelēšanai (Adler et al., 2018; M. Chen et al., 2019; Gao et al., 2018; Pepper, Del Grosso, McMurtrie, & Parton, 2005; Shang et al., 2019)

Modelis DNDC ir konceptuāls modelis oglekļa un slāpekļa bioģeoķīmisko procesu modelēšanai lauksaimniecības ekosistēmās, lai noteiktu oglekļa piesaisti, SEG gāzu emisijas, kultūraugu ražu un slāpekļa izskalošanos. Modelī *DNCD* ir integrēti *Nernst* (Butler, 1924) un *Michaelis–Menten* (Atkins & Nimmo, 1975; Chou, 1976; Sakoda & Hiromi, 1976)

vienādojumi, lai simulētu procesus, ko nosaka mikroorganismu metsbolismu (Changsheng Li, Frolking, & Frolking, 1992a; Deng et al., 2011; Giltrap, Li, & Saggar, 2010; C. Li, Frolking, Harriss, & Terry, 1994; C. Li, Narayanan, & Harriss, 1996). Notiek intensīvs darbs pie modeļa pilnveidošanas un papildu moduļu integrēšanas esošajā modelī (Abdalla, Song, Ju, Topp, & Smith, 2020; Budiman, Steiner, Topp, & Buerkert, 2020; Khalil, Fornara, & Osborne, 2020; Lai, Liu, Zhou, Zhu, & Liao, 2020; Shah, Li, Wang, & Collins, 2020; Smith et al., 2020; Zhao, Cao, Deng, et al., 2020; Zhao, Cao, Sha, et al., 2020; L. Zhou, Zhao, He, Flerchinger, & Feng, 2020).

Modelis FarmGHG ir izveidots ar mērķi aprēķināt SEG emisijas saimniecības līmenī, ieskaitot emisijas no iepirktajām precēm un materiāliem. Modelis *FarmGHG* ir veidots pamatojoties uz piena lopkopības paraugsaimniecību datiem. Modelī ir ietvers gan slāpekļa gan oglekļa cikls, kas ļauj aprēķināt bilances saimniecības līmenī, kā arī SEG emisijas CO_2 CH_4 un N_2O kā arī noplūdes NO_3^- un NH_3 veidā (Olesen, Rubæk, Heidmann, Hansen, & Børgensen, 2004; Schils et al., 2007).

Modelis IFSM ir veidots augkopības, piena lopkopības vai gaļas lopkopības saimniecības simulācijai. Saimniecības darbība tiek modelēta nākotnes perspektīvā, lai identificētu saimniecības darbības rādītāju ilgtermiņa ietekmi uz ekonomisko stabilitāti un vides kvalitāti. Modelis *IFSM* ir sarežģītāks nekā *DairyWise*, jo papildus SEG emisijām un CO_2 bilancei tas ļauj modelēt slāpekļa un fosfora zudumus un saimniecības ekonomiskos rādītājus. (Rotz, C Alan, Coiner, 2004; Rotz, 2018)

1.4. Urbāno hidroloģisko procesu un SEG emisiju modelēšanas iespējas Latvijā

Latvijā kopš 19.gadsimta ir izveidota nozīmīga un ilglaicīga fundamentālo pētījumu datu bāze, kas ļāva attīstīt hidroloģisko procesu modelēšanas algoritmus. Ir ļoti plaša ilglaicīgo pētījumu bāze par gruntsūdens līmeņu svārstībām un mitruma režīmu augsnē. Kā noslēdzošo posmu šo pētījumu ciklā var minēt konceptuālā hidroloģiskā modeļa METQ izveidi. Kam par pamatu ņemts gruntsūdeņu līmeņa prognozēšanas rīks METUL (Krams & Ziverts, 1993; Zīverts, 1976; A. Ziverts & Jauja, 1999; Ansis Ziverts, 1997). Modeļa kalibrācija un validācija ir pabeigta dabiskajos zemes lietojuma veidos, Latvijā tipiskajām hidroloģiskajā atbildes vienībām, taču nav veikta kalibrācija un validācija urbānajai hidroloģiskajai atbildes vienībai.

Pasaules pieredze rāda, ka lielākā daļa modeļu, kas izmantoti hidroloģisko procesu modelēšanā ir veidoti konkrētās zinātniskās grupās, kuru galvenais uzdevums ir nodrošināt nacionālā un lokālā līmeņa vajadzības pēc ticamām hidroloģiskajām prognozēm. Hidroloģisko procesu modelēšana ir nebeidzams process, kur, palielinoties datu pieejamībai un programmu nodrošinājumam, ir iespējas iekļaut arvien precīzākus aprēķina algoritmus. Tomēr, palielinoties modeļu datu ietilpībai un modeļa veiktspējas jaudai, ir jāizvērtē katra modeļa precizitātes rādītāji, jo neprecīzi izejas dati var novest pie nepieņemami augstas rezultātu nenoteiktības. Konceptuāli hidroloģiskie modeļi ir ļoti veiksmīgi pielietojami urbāno sateces baseinu hidroloģisko procesu modelēšanā, jo sniedz iespēju prognozēt caurplūdumu konkrētā gultnes vērumā ar augstu precizitāti. Konceptuālo hidroloģisko modeļu uzbūve, kas balstīta uz hidroloģisko atbildes vienību aprēķinu principiem ļauj veikt modeļa uzlabojumus un izstrādāt un integrēt aprēķinu algoritmā neierobežotu skaitu hidroloģisko atbildes vienību skaitu.

SEG Emisiju aprēķinu modeļi ir ļoti daudzveidīgi un balstīti uz atšķirīgiem principiem, kas katrs ir veidots ar konkrētu mērķi. Ja mērķis ir modelēt SEG emisijas no augsnes, tad viena no labākajām pieejām ir izmantot hidroloģiskos modeļus, kas balstīti uz konceptuālajiem hidroloģisko procesu modelēšanas principiem. SEG emisiju no augsnēm modelēšanas galvenie principi visām gāzēm ir cieši saistīti ar temperatūras un mitruma režīmu augsnē. Šos parametrus ir iespējams modelēt, izmantojot konceptuālo hidroloģisko modeli METQ, kas ir ar atvērtu kodu un ļauj izstrādāt un integrēt papildu parametrus un moduļus SEG emisiju no augsnēm modelēšanā. Lai uzsāktu urbānās hidroloģiskās atbildes vienības un SEG emisiju moduļu

integrāciju konceptuālajā hidroloģiskajā modelī METQ, ir nepieciešams aprakstīt modeļa galvenos algoritmus izprast modeļa darbības principus. Paralēli jāsagatavo informācija par SEG emisiju no augsnēm modelēšanas pamatprocesiem un apkopot pieejamo informāciju par papildus faktoru aprēķina algoritmu iekļaušanu modeļa algoritmu struktūrā.

Konceptuālais hidroloģiskais modelis METQ ir izveidots Latvijas Biozinātņu un Tehnoloģiju universitātes zinātnieku vadībā un aprobēts caurplūdumu kvantitatīvai novērtēšanai. Līdz šim izmantoto METQ konceptuālo modeli nav iespējams pielietot caurplūduma modelēšanai platībās ar urbānām teritorijām. Galvenais iemesls šim trūkumam ir tas, ka Latvijā līdz šim nav izveidots hidrometriskais postenis, kas monitorētu caurplūdumu urbānā sateces baseinā.

Konceptuālā modeļa METQ attīstība un pilnveidošana ir nepieciešama ne tikai caurplūduma kvantitatīvai analīzei, bet, papildus to pilnveidojot, ir iespējams veikt starpdisciplinārus pētījumus ekohidroloģijas apakšnozarē, kas pēta ūdens un ekosistēmas mijiedarbību. Vides inženierijā, kas risina difūzā piesārņojuma samazināšanas jautājumus, un SEG emisiju no augsnēm samazinošo tehnoloģiju ieviešanas jautājumus, kur ūdens saturam augsnē un gruntsūdens svārstībām ir viena no galvenajām lomām, piemēram, dislāpekļa oksīda emisiju rašanās procesos (Blöschl et al., 2019).

1.5. Promocijas darba mērķis

Promocijas darba mērķis ir pilnveidot konceptuālo hidroloģisko modeli METQ, integrējot urbāno hidroloģisko atbildes vienību, un sagatavot datubāzi un konceptuālo risinājumu SEG emisiju no augsnēm modelēšanai, izmantojot konceptuālajā hidroloģiskajā modelī METQ ietverto hidroloģisko aprēķinu augsnes aktīvajā slānī, gruntsūdenī un ar to saistītajā kapilārajā pacelšanās slānī.

1.6. Promocijas darba pētnieciskie uzdevumi

1. apkopot līdzšinējo pieredzi hidroloģisko procesu modelēšanā un modeļu izmantošanas iespējas urbāno hidroloģisko procesu un SEG emisiju no augsnēm modelēšanā;
2. izvērtēt urbānās hidroloģiskās atbildes vienības un SEG emisiju no augsnēm aprēķina algoritmu integrācijas iespējas konceptuālajā hidroloģiskajā modelī METQ;
3. izveidot konceptuālā hidroloģiskā modeļa METQ modelēšanas platformu ar integrētu urbānās hidroloģiskās atbildes vienību un tai izstrādāt algoritmu SEG emisiju no augsnēm aprēķina moduļu konceptuālo risinājumu;
4. izvērtēt konceptuālā hidroloģiskā modeļa METQ parametru jutīgumu urbānās hidroloģiskās atbildes vienības kalibrācijas un validācijas procesa optimizācijai;
5. sniegt ieskatu konceptuālā hidroloģiskā modeļa METQ izmantošanas iespējām klimata pārmaiņu un zemes lietošanas veidu maiņas ietekmes izvērtēšanā un caurplūdumu prognozēšanā;
6. izstrādāt konceptuālā hidroloģiskā modeļa METQ pilnveides scenāriju SEG emisiju no augsnēm modelēšanai, kas ietver moduļa algoritma izbūves koncepciju dislāpekļa oksīdam, metānam un ogļskābajai gāzei.

1.7. Promocijas darbā aizstāvamās tēzes

1. Konceptuālais hidroloģiskais modelis METQ ir piemērots urbānās hidroloģiskās atbildes vienības integrācijai un klimata pārmaiņu un zemes lietošanas veidu maiņas ietekmes izvērtēšanā un caurplūdumu prognozēšanā;

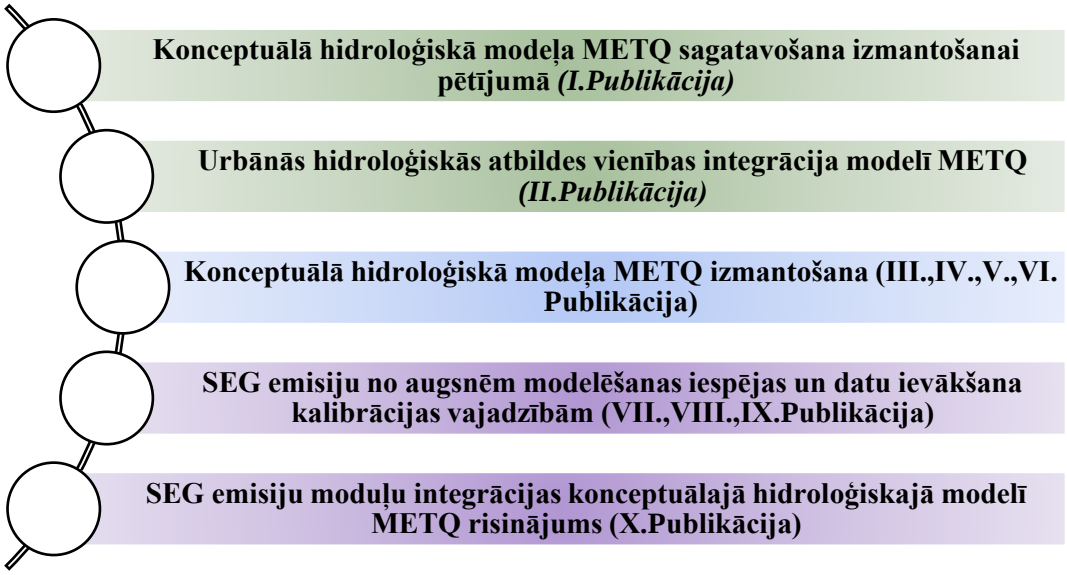
2. Konceptuālais hidroloģiskais modelis METQ ir piemērots dislāpekļa oksīda, metāna un ogļskābās gāzes potenciālo emisiju modelēšanai no augsnēm.

1.8. Promocijas darba novitāte

1. Apkopota līdzšinējā pieredzi hidroloģisko procesu modelēšanā un modeļu izmantošanas iespējas urbāno hidroloģisko procesu un SEG emisiju modelēšanā;
2. izvērtētas urbānās hidroloģiskās atbildes vienības un SEG emisiju aprēķina algoritmu integrācijas iespējas konceptuālajā hidroloģiskajā modelī METQ;
3. izveidota, lietotājam ērta, konceptuālā hidroloģiskā modeļa METQ modelēšanas platforma ar integrētu urbānās hidroloģiskās atbildes vienību un tai izstrādāts algoritms SEG emisiju aprēķina moduļu konceptuālajiem risinājumiem;
4. novērtēta konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas veiktspēja, izvērtēta autokalibrācijas algoritmu efektivitāte, veikta modeļa jutīguma analīze un urbānās hidroloģiskās atbildes vienības kalibrācija un validācija;
5. sniegts ieskats konceptuālā hidroloģiskā modeļa METQ izmantošanas iespējām klimata pārmaiņu un zemes lietošanas veidu maiņas ietekmes izvērtēšanā un caurplūdumu prognozēšanā, kā arī ūdenskrātuvju apsaimniekošanas pasākumu optimizācijai;
6. izstrādāti priekšlikumi konceptuālā hidroloģiskā modeļa METQ izmantošanai SEG emisiju no augsnēm modelēšanai.

1.9. Promocijas darba pētījuma uzbūve

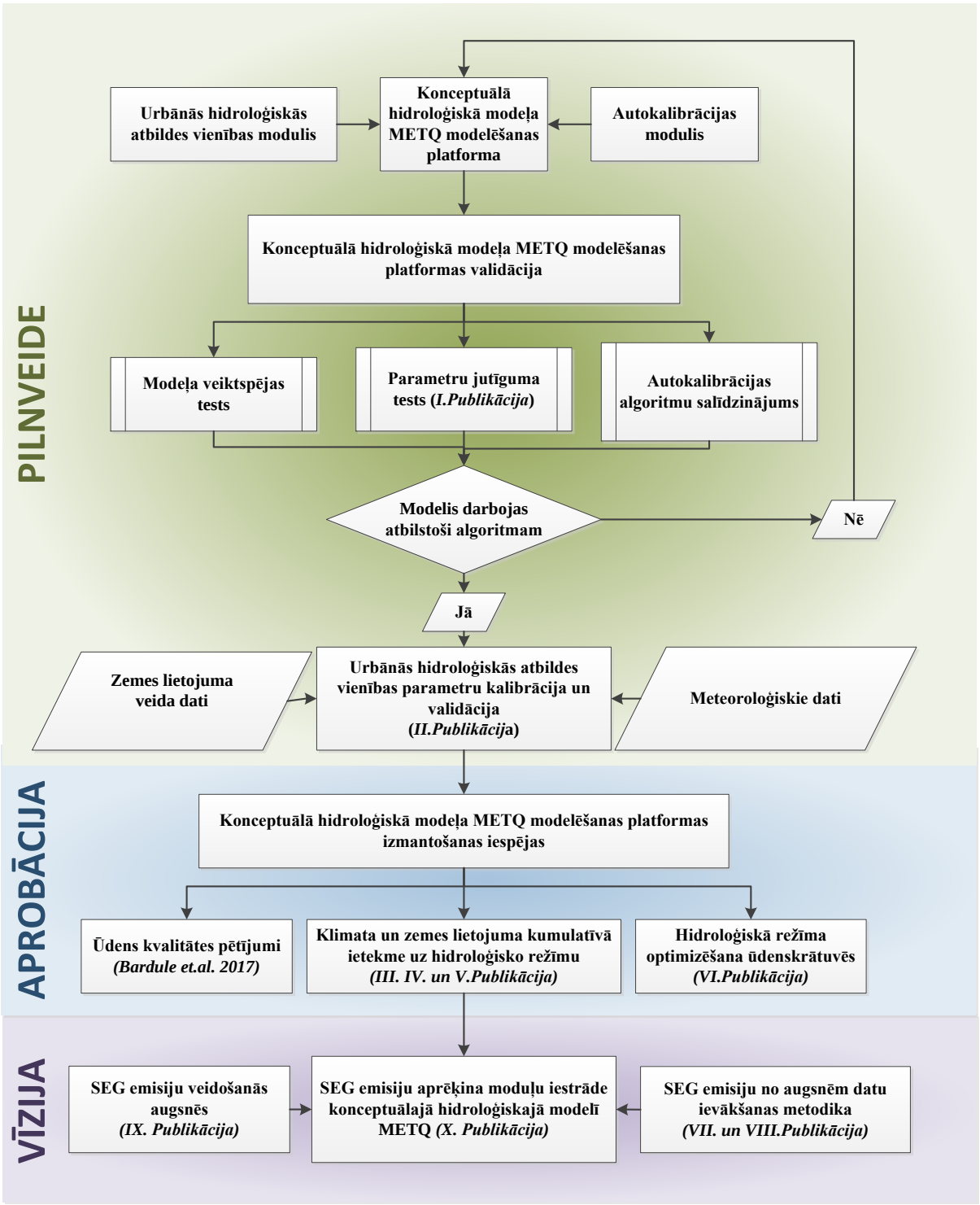
Promocijas darba pētījums veidots vairākās pakāpēs, lai saniegtu promocijas darbam izvirzīto mērķi (skat.1.3.att.). Pirmajā solī tika sagatavota modelēšanas platforma METQUL2012 ar iebūvētiem autokalibrācijas algoritmiem un iebūvētu urbāno hidroloģiskās atbildes vienību, kā arī veikts paremetru jutīguma tests. Otrajā solī tika veikta urbānās hidroloģiskās atbildes vienības kalibrācija un validācija. Trešajā solī konceptuālais hidroloģiskais modelis METQ tika izmantots klimata mainības un zemes lietojuma veida maiņas kompleksās ietekmes izvērtēšanā uz hidroloģisko režīmu. Ceturtajā solī tika apzinātas metodes SEG emisiju modelēšanai no augsnēm un sagatavota metodika gāzu mērījumu veikšanai modeļa kalibrācijas vajadzībām. Piektajā solī tika izstrādāta koncepcija SEG emisiju aprēķinu algoritmu integrācijai konceptuālajā hidroloģiskajā modelī METQ.



1.3.att. **Promocijas darba pētījuma galvenie soļi.**

2.MATERIĀLI UN METODES

Promocijas darbā izvirzītais mērķis ir sarežģīts, tādēļ pētījums tika sadalīts nosacīti piecos posmos. Pētījuma veikšanas konceptuālā shēma ir attēlota 2.1.att. Pirmajā posmā tika izstrādāta konceptuālā hidroloģiskā modeļa METQ modelēšanas platforma (Inga Grinfelde & Lauva, 2012). Otrajā posmā tika veikta modeļa verifikācija, autokalibrācijas algoritmu testēšana un veiktspējas salīdzināšana un parametru jutīguma tests (I.publikācija) un trešajā posmā tika veikta urbānās hidroloģiskās atbildes vienības parametru kalibrācija un urbānās hidroloģiskās atbildes vienības moduļa verifikācija (II.Publikācija).



2.1.att. **Konceptuālā hidroloģiskā modeļa METQ pilnveides plūsmas diagramma**

Ceturtajā posmā tika veikta Usmas ezera noteces modelēšana, lai izvērtētu zemes lietojuma veida un klimata mainības kumulatīvo ietekmi uz noteci (III.; IV. un V. Publikācija) un Tāšu ezera kompleksa modelēšana ar mērķi sniegt rekomendācijas ilgtspējīgai ezera apsaimniekošanai (VI.publikācija). SEG emisiju no augsnēm modelēšanas iespējas un datu ievākšana kalibrācijas vajadzībām (VII.; VIII. un IX.publikācija). SEG emisiju moduļu integrācijas konceptuālajā hidroloģiskajā modelī METQ risinājums (X.publikācija)

Promocijas darba izstrādes laikā tika ievēroti modelēšanas procesa pamatposmi, kas ļauj izsekot modeļa attīstībai un mazina kļūdu riskus modelī (skat. 1.1.att.).

2.1. Konceptuālā hidroloģiskā modeļa METQ sagatavošana izmantošanai pētījumā

Konceptuālais hidroloģiskais modelis METQ ir izveidots 1996. gadā (A. Ziverts & Jauja, 1996), kā modeļa METUL (Krams & Ziverts, 1993) modifikācija, kas ļauj ūdensteces baseinu sadalīt apakšbaseinos jeb hidroloģiskajās atbildes vienībās. Modeļa METQ96 aprēķina algoritms dod iespēju aprēķināt ikdienas caurplūdumu, izmantojot diennakts vidējās temperatūras, nokrišņu un mitruma deficīta novērojumus.

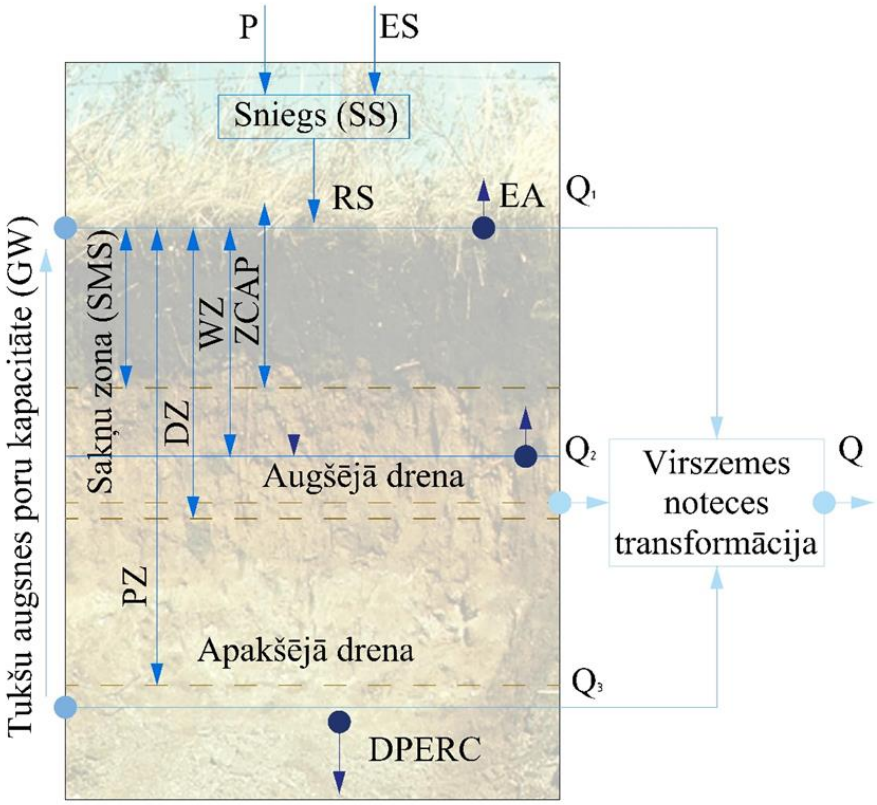
Konceptuālā hidroloģiskā modeļa METQ nākamā uzlabotā versija METQ0203 tika izstrādāta 2002. gadā. Modeli ieteicams lietot caurplūdumu modelēšanai baseiniem ar laukumu līdz apmēram 2000 km^2. Ūdensnotekām ar lielāku baseina laukumu ieteicams baseinu iedalīt daļbaseinos. Tomēr, ja mazākas upes baseinā ir liels ezers vai ūdenskrātuve, tad modelēšana vispirms veicama šī ezera vai ūdenskrātuves baseinam, bet baseina daļa lejpus šī ezera vai ūdenskrātuves ir modelējama kā atsevišķs daļbaseins.

Turpinot konceptuālā hidroloģiskā modeļa METQ pilnveidošanu, šī pētījuma ietvaros tika izveidota jauna un uzlabota modeļa versija METQUL2012, kas tika izstrādāta Latvijas Biozinātņu un tehnoloģiju universitātes Meža un ūdens resursu zinātniskajā laboratorijā, un ir pamats šī promocijas darba tapšanai. Modeļa galvenais papildinājums ir urbānās hidroloģiskās atbildes vienības integrācija aprēķina algoritmā (Bakute, Grinfelde, & Lagzdins, 2017; I. Grinfelde & Bakute, 2017; Inga Grinfelde & Lauva, 2012).

Pētījuma vajadzībām 2012.gada sākuma tika izveidota modelēšanas platforma METQUL2012(Inga Grinfelde & Lauva, 2012), kas atvieglo konceptuālā hidroloģiskā modeļa METQ kalibrāciju, validāciju un izmantošanu ikdienas caurplūduma aprēķiniem noteiktā laika vienībā. Modelēšanas platformas METQUL2012 izveidei par pamatu tika ņemta konceptuālā hidroloģiskā modeļa versija METQ0203. Papildus tika izveidots autokalibrācijas bloks, kur parametru kalibrācijai ir iespējams izmantot septiņus autokalibrācijas algoritmus (Neldera Mīda algoritms (*Nelder-Mead algoritm NEL*); Ģenētiskais algoritms (*Genetic algorithm GE*N); Levenberga Markuardta algoritms (*Levenberg-Marquardt algorithm LMA*); Kvazi-Ņūtona BFGS algoritms (*Quasi-Newton BFGS apgorithm*); Kvazi-Ņūtona DFP algoritms (*Quasi-Newton DFP apgorithm*); Fledčera konjuētā gradienta algoritms (*Conjugate gradient (FLETCHER) algorithm*); Polaka konjugētā gradienta algoritms (*Conjugate gradient (POLAK*) *alghorithm)*) (Broyden, 1969; W C Davidon, 1959; William C Davidon, 1991; R. Fletcher, 1970; R. Fletcher & Powell, 1963; Gilbert & Nocedal, 1992; Goldfarb, 1970; Inga Grinfelde & Lauva, 2012; Levenberg, 1944; Marquardt, 1963; Nelder & Mead, 1965; Nocedal, 1992; Polak & Ribière, 1969; Polyak, 1969; Powell, 1987; Shanno, 1970).

2.1.1. Konceptuā hidroloģiskā modeļa METQ uzlabojumi

Konceptuālā hidroloģiskā modeļa METQ noteces aprēķina konceptuālā shēma ir dota 2.2.att., kurā uzskatāmi tiek parādītas galvenās ūdens plūsmas. Ūdens bilances aprēķinos apjomīgs rādītājs ir ūdens uzkrājums hidroloģiskajā reakcijā, kā piemēram: sniega segā, augsnes aktīvajā slānī, gruntsūdenī un ar to saistītajā kapilārajā pacelšanās slānī.

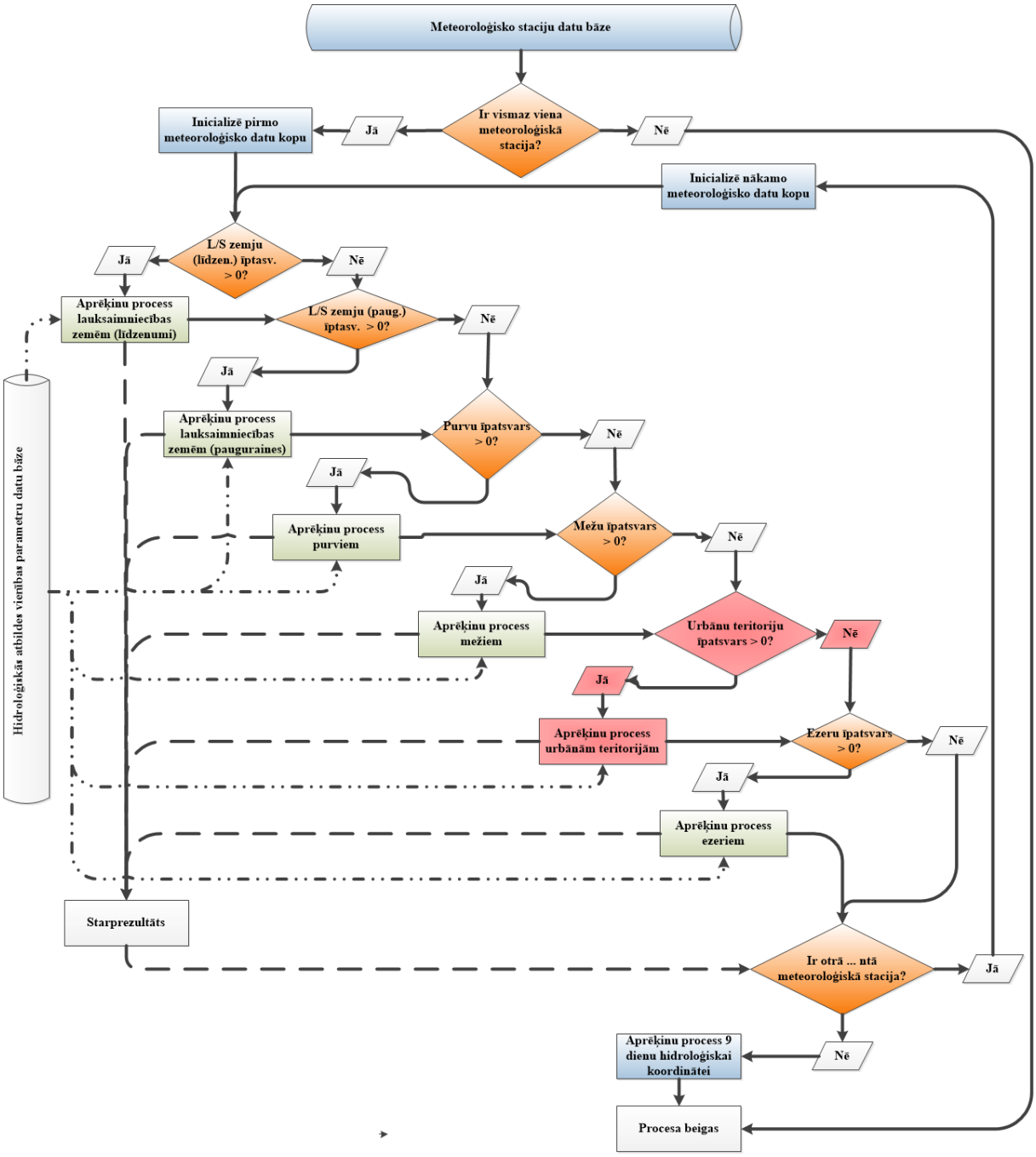


2.2.att. **Konceptuālā hidroloģiskā modeļa METQ hidroloģiskās atbildes vienības aprēķina principiālā shēma**

P– nokrišņi, mm dnn^{-1}; ES – iztvaikošana no sniega, mm dnn^{-1}; RS – lietu un sniega kušanas ūdens, mm dnn^{-1}; EA – iztvaikošana no augsnes aktīvā slāņa, mm dnn^{-1}; SMS – ūdens saturs augsnes aktīvajā slānī, mm; Z – dziļums no zemes virsas, cm; PZ – drenētā slāņa biezums, cm; Q_1, Q_2, Q_3 – noteces komponentes, mm dnn^{-1}; RCH – ūdens pārplūde no augsnes aktīvā slāņa uz gruntsūdens horizontu, mm dnn^{-1}; CAP – kapilārā pacelšānās, mm dnn^{-1}; SS – ūdens saturs sniegā, mm; GW – brīvo grunts poru tilpums, mm; DZ – augšējā slāņa biezums, cm; ZCAP – kapilārās pacelšanās augstums, cm; WZ – gruntsūdens dziļums, cm

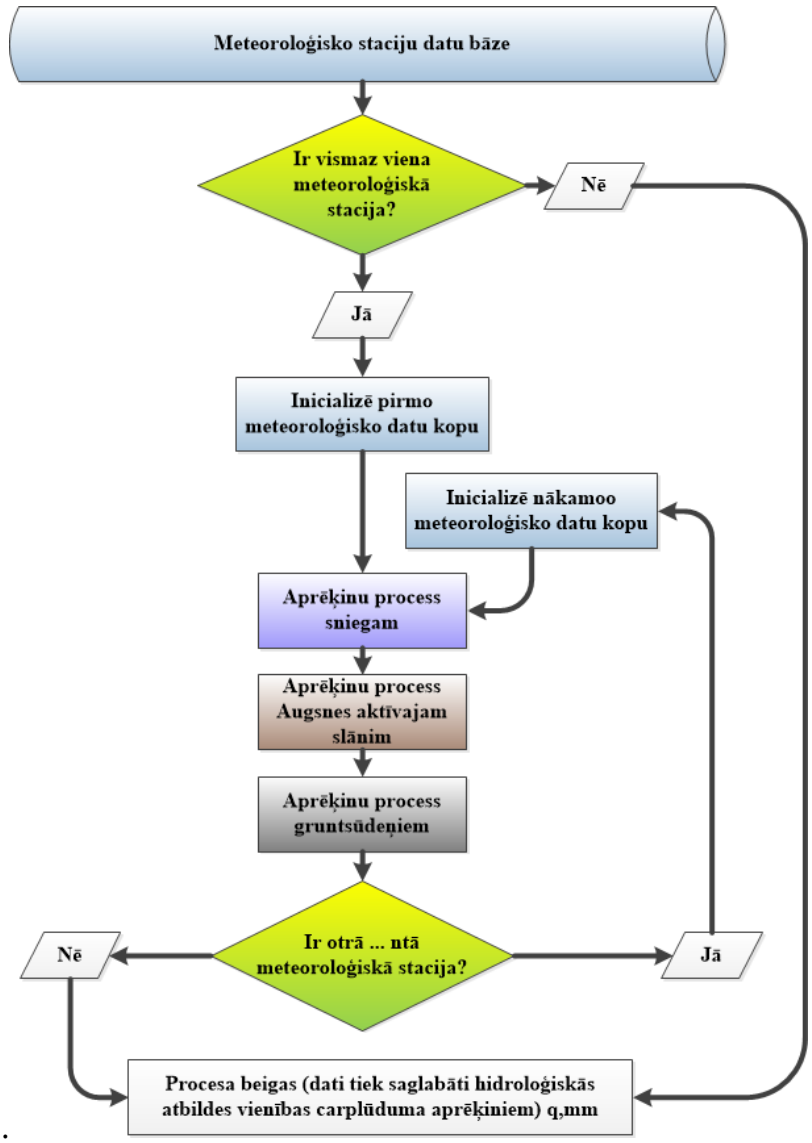
Augšējam slānim, kas nosaukts par augsnes aktīvo slāni, šajā modelī nav precīzi definētas apakšējās robežas, toties ir norāde, ka tajā izvietojas augu sakņu galvenā daļa. Veģetācijas periodā šī slāņa summāro iztvaikošanu nosaka galvenokārt augu transpirācija. Savukārt, gruntsūdens krājumi šajā hidroloģiskajā modelī tiek raksturoti ar brīvo poru tilpuma slāni starp zemes virsmu un gruntsūdens līmeni. Katras hidroloģiskās atbildes vienības *(hydrological response unit)* noteci raksturo ar šādām komponentēm: Q_1 – virszemes notece; Q_2 – augsnes notece; Q_3 – dziļā pazemes notece no slāņiem, kas drenējas apskatāmajā upes baseinā. Hidrogrāfiskajā tīklā šīs noteces komponentes apvienojas un transformējas izlīdzinātā upju notecē – Q. Konceptuālā hidroloģiskā modeļa METQ plūsmas diagramma ir dota 2.3.att. Šī koncepcija ir izmantojama neizpētītām upēm, kur ir zināms hidroloģisko atbildes vienību īpatsvars un tiek izmantoti noklusētie parametri katrai hidroloģiskās atbildes vienībai. Modelis paredz iespēju izmantot vairāku meteoroloģisko staciju datus, kur katrai stacijai iespējams definēt procentuālo īpatsvaru konkrētās ūdensteces sateces baseinā. Modelis aprēķina algoritmu atkārto katrai hidroloģiskajai atbildes vienībai un meteoroloģiskajai stacijai, uzkrājot noteces moduļa datus nākamajam aprēķina posmam. Promocijas darba vajadzībām modelēšanas platformā METQUL2012 tika iebūvēta urbānā hodroloģiskās atbildes vienība, kuras parametru kalibrācija tika veikta otrajā konceptuālā hidroloģiskā modeļa attīstības posmā. Nākamais

aprēķina posms saistīts ar caurplūduma aprēķinu ūdensteces gultnes vērumā un plūsmas sadalījumu sateces baseinā, ko nosaka ģeoloģiskie un ģeomorfoloģiskie apstākļi. Aprēķins tiek veikts katrai dienai saskaņā ar vienības hidrogrāfa koordinātām, kas apraksta virszemes noteces proporcionālo sadalījumu pa dienām.



2.3.att. **Konceptuālā hidroloģiskā modeļa METQ plūsmas diagramma**

Hidroloģiskās atbildes vienības aprēķina algoritms sastāv no trim aprēķinu blokiem: sniega veidošanās un kušanas aprēķina, aprēķina augsnes aktīvajam slānim un aprēķina gruntsūdeņiem. Katras hidroloģiskās atbildes vienības dati tiek saglabāti, lai tālāk izmantotu caurplūduma aprēķiniem ūdensteces gultnes vērumā (skat 2.4.att.).



2.4.att. **Konceptuālā modeļa METQ hidroloģiskās atbildes vienības aprēķina plūsmas diagramma**

Noslēdzošajā aprēķina posmā tiek aprēķināts caurplūdums katrai hidroloģiskajai atbildes vienībai proporcionāli meteoroloģisko staciju pārklājumam, un veikts caurplūduma korekcijas aprēķins, atbilstoši vienības hidrogrāfa koordinātēm, ja lejtecē ir ezers vai ūdenskrātuve, papildus tiek veikts plūsmas transformācijas aprēķins.

Daļbasiena kopējo noteci aprēķina pēc 1.formulas, kur uzlabotajā modeļa versijā tika pievienota urbānā hidroloģiskā atbildes vienība:

$$Q = \frac{(Q_{ALL} \cdot W_{ALL} + Q_{AHL} \cdot W_{AHL} + Q_F \cdot W_F + Q_B \cdot W_B + Q_L \cdot W_L + \boldsymbol{Q_U \cdot W_U})}{100} \quad , \qquad (1)$$

kur

Q – kopējā baseina notece, mm d^{-1};

Q_{ALL} – līdzenu lauksaimniecības zemju notece, mm d^{-1};

Q_{AHL} – lauksaimniecībā izmantojamo pauguraiņu notece, mm d^{-1};

Q_F – notece mežiem, mm d^{-1};

Q_B – notece purviem, mm d^{-1};

Q_L – notece ezeriem, mm d^{-1};

$\boldsymbol{Q_U}$ **– notece urbānajām teritorijām, mm** $\boldsymbol{d^{-1}}$;

W_{ALL} , W_{AHL} , W_F , W_B , W_L $\boldsymbol{W_U}$ – minēto elementārbaseinu veidu īpatsvars attiecīgajā daļbaseinā, kuru summa ir 100%.

2.1.2. Pētījuma vajadzībām izveidotā modelēšanas platforma METQUL2012

Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformu METQUL2012 veido sešas secīgas darba virsmas, kas ļauj veikt, ikdienas caurplūduma modelēšanu un modeļa parametru kalibrāciju un validāciju. Atverot modelēšanas platformu, darbu uzsāk izvēlnē METEO. Šajā izvēlnē, kā noklusētā darbība ir uzstādīta, caurplūduma modelēšana konkrētā gultnes vērumā, taču modelēšanas platforma METQUL2012 paredz iespēju pārslēgties uz gruntsūdens līmeņu modelēšanu. Šajā pētījumā tika izmantota caurplūdumu konkrētā gultnes vērumā modelēšanas izvēlne, tādēļ turpmākais izklāsts attieksies uz caurplūduma modelēšanu.

Izvēlnē METEO ir iespēja definēt caurplūduma modelēšanai izmantojamās meteoroloģisko datu kopas, modelī ir iebūvēta iespēja izmantot vienu vai vairākas meteostacijas, kuru svaru summai ir jābūt 1,0. Obligāti nepieciešams definēt sateces baseina platību gultnes aprēķina vērumā, un tiek piedāvāta iespēja saglabāt sateces baseina parametrus modelēšanas platformas METQUL2012 datu bāzē. Pēc noklusējuma tiek pieņemts, ka sateces baseina lejtecē nav ezers vai ūdenskrātuve, taču ja sateces baseina lejtecē ir ezers vai ūdenskrātuve ir iespējams definēt tā parametrus un modelis aprēķinās plūsmas transformāciju. Noslēgumā obligāti jāaktivizē poga SET METEO, kas modelim liek ielasīt datus atmiņā, lai turpmāk izmantotu modelēšanas procesā.

Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas METQUL2012 izvēlne CALIBRATION, lietotājam dod iespēju automātiski vai manuāli definēt hidroloģiskās atbildes vienību īpatsvaru apskatāmajā sateces baseinā *Subbasin*. Automātiski vai manuāli definēt vienības hidrogrāfa koordinātes *9 day Q hydro coordinates*, kā arī manuāli mainīt katras hidroloģiskās atbildes vienības parametru vērtības *Calibration,* var izmantot noklusētās vērtības (Ziverts, 2006). Tāpat visās iepriekšminētajās pozīcijās pastāv iespēja saglabāt definētās vērtības vai izmantot jau iepriekšdefinētas vērtības. Noslēgumā var izvēlēties modelēto caurplūdumu grafisko attēlojumu, un obligāti jāaktivizē poga RUN METQ. Modelis veic aprēķinu saskaņā ar iepriekšējā apakšnodaļā aprakstīto algoritmu un saglabā aprēķina rezultātus.

Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas METQUL2012 izvēlne ADD FILES ir izveidota, lai atvieglotu meteoroloģisko datu un novēroto caurplūdumu ievadi. Ir nepieciešams manuāli definēt meteoroloģisko vai caurplūduma datu rindas sākuma datumu un faila nosaukumu, kas tiks saglabāts modelēšanas platformas arhīvā. Papildu nosacījums ir nepārtraukta datu rinda bez iztrūkstošām datu rindām, un meteoroloģisko datu rindām ir jābūt vienāda garuma. Pēc visu iepriekšminēto darbības veikšanas obligāti jāaktivizē ADD poga. Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas METQUL2012 jaunievedums ir autokalibrācijas izvēlne AUTOCALIBRATION, kas ļauj veikt autokalibrāciju izmantojot septiņus dažādus autokalibrācijas algoritmus, (Neldera Mīda algoritms (*Nelder-Mead algoritm NEL*); Ģenētiskais algoritms (*Genetic algorithm GE*N); Levenberga Markuardta algoritms (*Levenberg-Marquardt algorithm LMA*); Kvazi-Ņūtona BFGS algoritms (*Quasi-Newton BFGS apgorithm*); Kvazi-Ņūtona DFP algoritms (*Quasi-Newton DFP apgorithm*); Fledčera konjuētā gradienta algoritms (*Conjugate gradient (FLETCHER) algorithm*); Polaka konjugētā gradienta algoritms (*Conjugate gradient (POLAK*) *alghorithm)*) (Broyden, 1969; W C Davidon, 1959; William C Davidon, 1991; R. Fletcher, 1970; R. Fletcher & Powell, 1963; Gilbert & Nocedal, 1992; Goldfarb, 1970; Inga Grinfelde & Lauva, 2012; Levenberg, 1944; Marquardt, 1963; Nelder & Mead, 1965; Nocedal, 1992; Polak & Ribière, 1969; Polyak, 1969; Powell, 1987; Shanno, 1970). Autokalibrāciju var veikt vienam vai vairākiem konkrētās hidroloģiskās atbildes vienības parametram. Papildu nosacījums ir meteoroloģisko datu kopai un novēroto caurplūdumu datu kopai jābūt vienāda garuma.

Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas METQUL2012 izvēlne DATA EXPORT ļauj lietotājam izvēlēties nepieciešamos datus un tos eksportē *excel* formātā. Lietotājam tiek dota iespēja izvēlēties eksportēt kopējo caurplūdumu un tā komponentes aprēķina gultnes vērumā, kā arī pastāv iespēja eksportēt katras hidroloģiskās atbildes vienības caurplūdumu un tā komponentes aprēķina gultnes vērumā.

Konceptuālā hidroloģiskā modeļa METQ modelēšanas platformas METQUL2012 izvēlne HYDROGRAPH grafiski attēlo modelētos lielumus un ļauj grafiski novērtēt modelēšanas rezultātus.

2.2. Pētījumā izmantie dati un statistikas metodes

Pētījumā izmantotās datu kopas, statistikas metodes un to izmantošanas mērķis ir apkopots 2.1. tabulā, kur izsekojamības nolūkos katrs modeļa pilnveides posms iezīmēts ar atbilstošu krāsu, kas sasaucas ar 1.3. un 2.1. attēlos parādītajiem pētījuma veikšanas posmiem.

2.1.tabula **Pētījumā izmanto datu un statistikas metožu kopsavilkums**

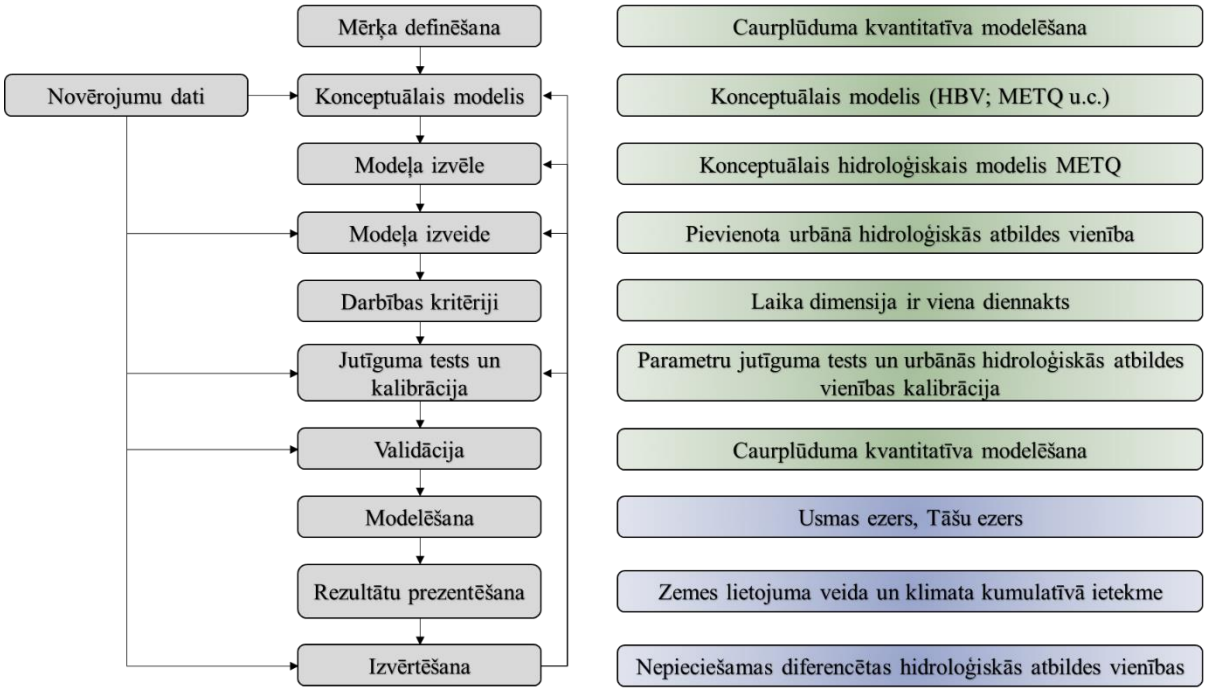
Publ. Nr.	Izmantotās datu kopas	Izmantotās statistikas metodes	Izmantošanas mērķis
I.	Vienziemīte (1993-2015) klimata dati Katram parametram modelētās vērtības	METQ modelis Hidrogrāfa grafiskā analīze R^2; NSE; PBIAS un RSR Hierarhiskā klāsteru analīze	Veikts METQ parametru jutīguma tests ar mērķi izdalīt paramatrus urbānās hidroloģiskās atbildes vienības kalibrācijai.
II.	Amerikas Savienoto Valstu Ģeoloģiskās aģentūras (USGS) 6 urbānie sateces baseini ar platību no 9.76 km^2 līdz 183.63 km^2	METQ modelis Hidrogrāfa grafiskā analīze R^2; NSE; PBIAS un RSR	Veikta METQ parametru kalibrācija urbānajai hidroloģiskajai atbildes vienībai
III.	Usmas ezera ūdens līmeņa dati no 1927-2014	Homogentitātes tests Aprakstošā statistika	Sagatavoti izejas dati METQ modeļa izmantošanai
IV.	12 klimata scenāriji Stendes stacijai Divi lineāri zemes lietojuma veida scenāriji	METQ modelis Aprakstošā statistika	Analizētas caurplūduma izmaiņas mēneša griezumā
V.	12 kimata scenāriji Stendes stacijai Divi lineāri zemes lietojuma veida scenāriji	METQ modelis Aprakstošā statistika Regresijas analīze	Analizētas izmaiņas caurplūduma ekstrēmajām vērtībām.
VI.	12 kimata scenāriji Ezera gultnes skanēšana izmantojot ADCP RiverRay Divi lineāri zemes lietojuma veida scenāriji	3D modelis METQ modelis Hidrauliskais modelis Aprakstošā statistika	Analizētas izmaiņas caurplūduma ekstrēmajām vērtībām.
VII.	N_2O mērījumu dati ar CRDS iekārtu Picarro G2508	Lineārā regresija	Sagatavota un aprobēta metodika datu ievākšanai N_2O no augsnēm modelēšanas vajadzībām
VIII.	CO_2, CH_4, N_2O un NH_3 mērījumu dati ar CRDS iekārtu Picarro G2508	Lineārā regresija	Sagatavota un aprobēta metodika datu ievākšanai CO_2, CH_4, N_2O un NH_3 no augsnēm modelēšanas vajadzībām
IX.	N_2O un N_2O izotopu mērījumu dati ar CRDS iekārtu Picarro G2508 un iekārtu G5131i	Aprakstošā statistika	Sagatavota un aprobēta metodika datu ievākšanai N_2O veidošanās posmu (nitrifikācija vai denitrifikācija) modelēšanas no augsnēm vajadzībām
X.	Literatūras studijas SEG emisiju aprēķina no augsnēm modelēšanai un METQ modeļa aprēķina algoritms	METQ modelis	Sagatavots risinājums SEG emisiju no augsnēm aprēķina moduļu integrācijai modelī METQ

3.REZULTĀTI UN DISKUSIJA

Šajā nodaļa ir apkopoti galvenie promocijas darba pētījuma rezultāti, kas nosacīti iedalīti divās apakšnodaļās, kur pirmajā apakšnodaļā sniegti konceptuālā hidroloģiskā modeļa METQ urbānās hidroloģiskās atbildes vienības integrācijas un modeļa aprobācijas pētījumu rezultāti. Otrajā apakšnodaļā īsi aprakstīti SEG emisiju no augsnēm modelēšanai nepieciešamo datu ievākšanas metodika un SEG emisiju no augsnēm aprēķinu moduļu konceptuālais risinājums, to integrācijai konceptuālajā hidroloģiskajā modelī METQ.

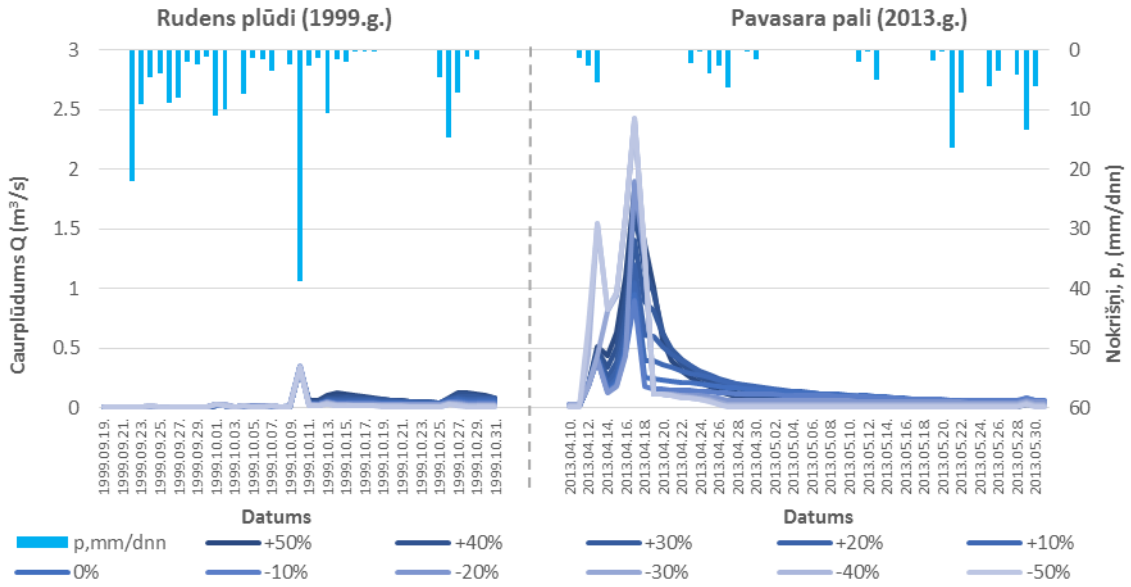
3.1. Urbānās hidroloģiskās atbildes vienības integrācija un modeļa aprobācija

Konceptuālā hidroloģiskā modeļa METQ pilnveides (I. un II. Publikācija) un izmantošana sarežģītu ūdenssaimniecības jautājumu risināšanā (III., IV., V., un VI.publikācija) tika izmantots modelēšanas darbu veikšanas ietvars, kas urbānās hidroloģiskās atbildes vienības integrācijas kontekstā tika iziets pilnā apmērā (skat 3.1. att.). Ubānā hidroloģiskā atbildes vienība modelī nodrošina caurplūduma kvantitatīvu modelēšanu un Latvijas apstākļos ieteicams ir izmantot konceptuālo hidroloģisko modeli METQ.



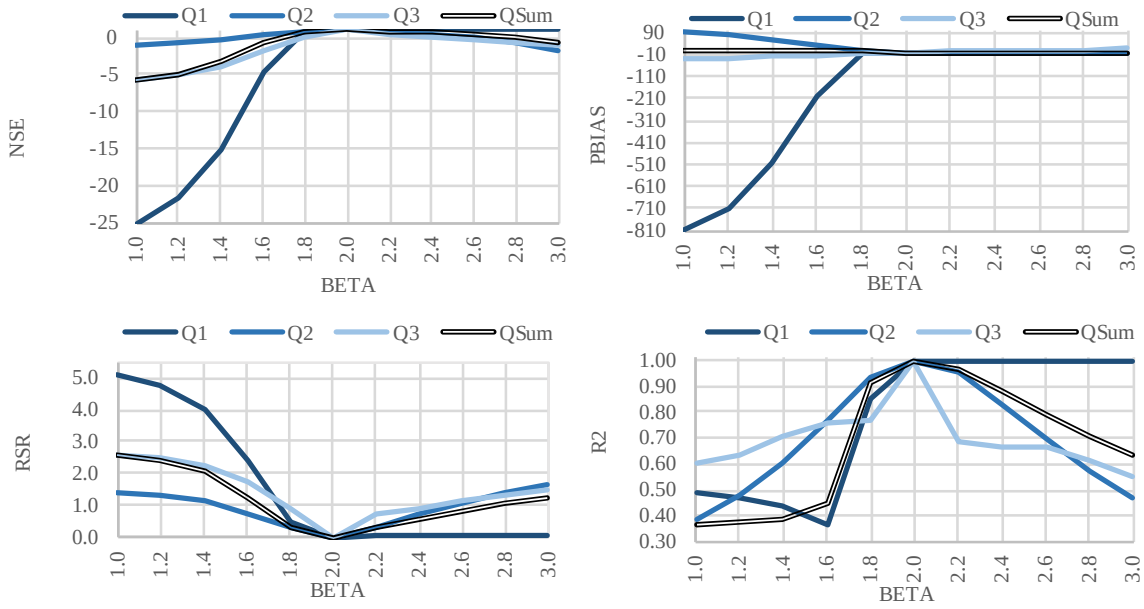
3.1.att. **Konceptuālā hidroloģiskā modeļa METQ urbānās hidroloģiskās atbildes vienības integrācija un izmantošana saskaņā ar modeļu attīstības posmiem**

Lai sagatavotos urbānās hidroloģiskās atbildes vienības kalibrācijai, tika veikts konceptuālā hidroloģiskā modeļa METQ parametru jutīguma tests 23 parametriem (I.Publikācija). Konceptuālā hidroloģiskā modeļa METQ parametra BETA jutīguma testa grafiskais piemērs ir sniegts 3.2.att. Noteces veidošanās parametra BETA vērtība parāda augstu jutību pret parametra vērtības izmaiņām īpaši pavasara palu periodā. Visas BETA parametra izmaiņas ir rūpīgi jānovērtē konceptuālā hidroloģiskā modeļa kalibrēšanas procesā.



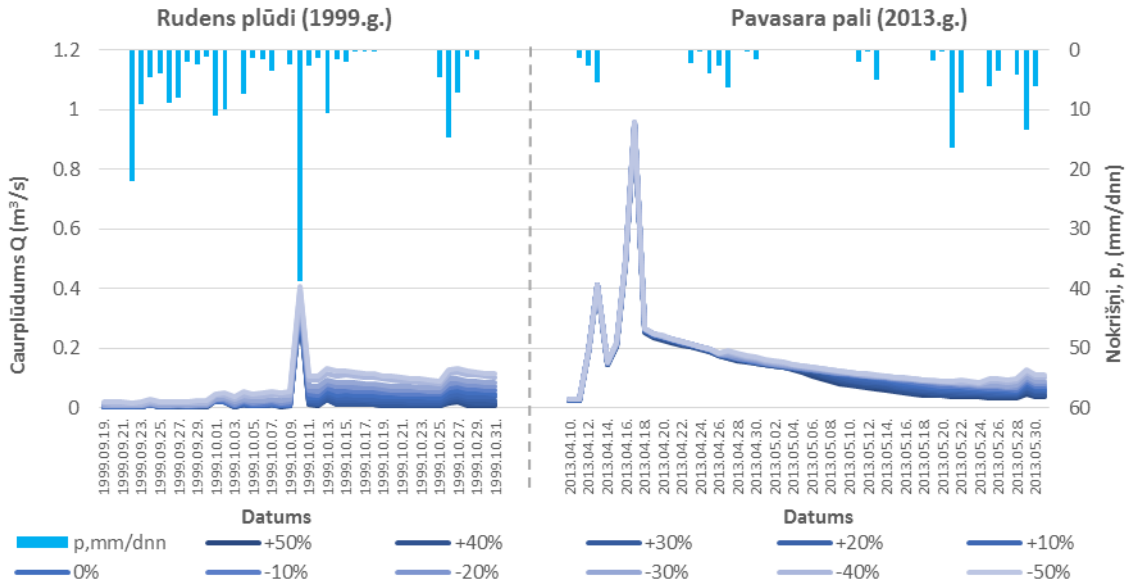
3.2.att. **Parametra BETA jutīguma testa grafiskā analīze**

Noteces komponenšu Q_1; Q_2; Q_3 un kopējā noteces Q_{sum} izmaiņu analīze, mainot BETA parametru amplitūdā ± 50%, ir parādīta 3.3.att. NSE, RSR, R^2 un PBIAS analīze parāda parametru BETA nozīmīgo ietekmi uz noteces komponenti Q_1.



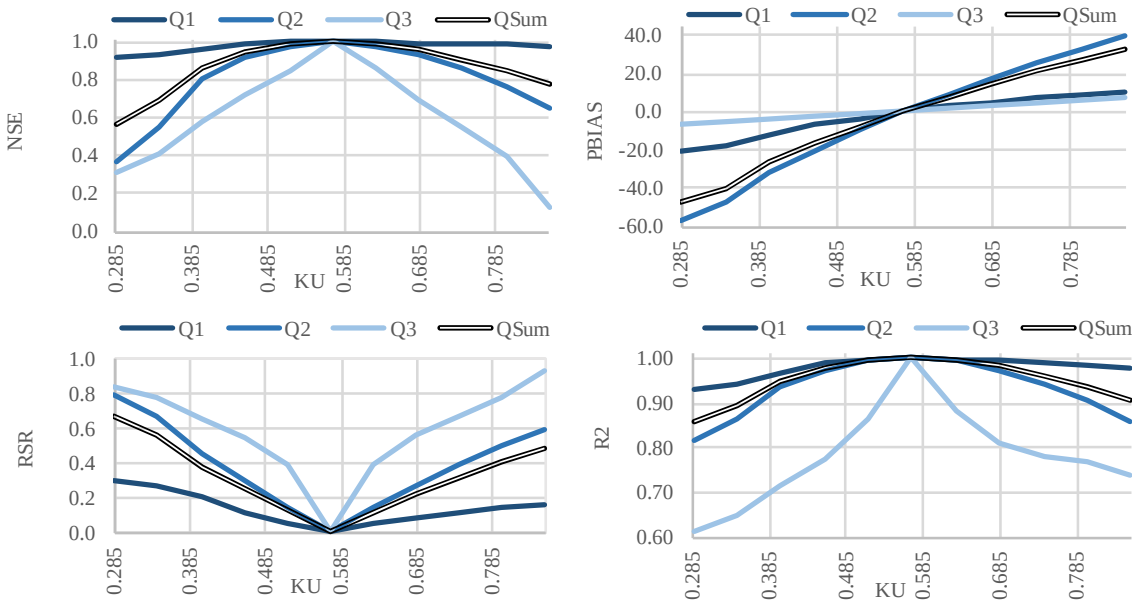
3.3.att. **Parametra BETA ietekmes uz konceptuālā hidroloģiskā modeļa METQ veiktspēju grafiskā analīze**

Parametra KU jutīguma testa rezultātu grafiskā analīze ir parādīta 3.4.att. Parametrs KU ir viens no aktīvā augsnes slāņa zonas parametriem, un tam ir izteikta ietekme uz ilgtermiņa noteci, savukārt nenozīmīga ietekme uz pavasaru paliem un vasaras rudens plūdiem.



3.4.att. **Parametra KU jutīguma testa grafiskā analīze**

Modelēto caurplūdumu komponenšu Q_1; Q_2; Q_3 un kopējo caurplūdumu Q_{sum} izmaiņu analīze, mainot parametru KU amplitūdā ± 50%, ir parādīta 3.5.att. Modeļa veiktspējas rādītāju NSE, RSR, R^2 un PBIAS analīze parāda parametru KU ietekmi uz noteces komponenti Q_3.



3.5.att. **Parametra KU ietekmes uz konceptuālā hidroloģiskā modeļa METQ veiktspēju grafiskā analīze**

Konceptuālā hidroloģiskā modeļa METQ parametri ALFA; CMELT; ROBK, BETA, DPREC, DZ, KU un ZCAP uzrāda paaugstinātu jutību, salīdzinot ar pārējiem parametriem. Konceptuālā hidroloģiskā modeļa METQUL2012 kalibrēšanas laikā ir nepieciešams analizēt un izvērtēt parametru izmaiņas ne tikai no jutīguma skatupunkta, bet arī no modeļa konceptualitātes prizmas, lai parametru izmaiņas neizjauktu modelī iestrādātās hidroloģisko procesu konceptuālās algoritmu kopas. Nepieciešams izvērtēt padziļināti konceptuālā hidroloģiskā modeļa METQ dažādu parametru atšķirīgo ietekmi uz dažādu noteces komponenšu modelēšanas rezultātiem. Turpmākā izpēte jākoncentrē uz konceptuālā

hidroloģiskā modeļa parametru jutīguma analīzi attiecībā uz katru noteces komponenti (Q_1; Q_2; Q_3).

Konceptuālā hidroloģiskā modeļa METQ parametru jutīguma testa rezultātu hierarhiskās klasteru analīzes rezultātos iegūto klasteru vidējās vērtības modeļa veiktspējas parametriem NSE; RSR, PBIAS. R^2 ir parādītas 3.1.tabulā. Parametru A2; A3; CFR; KS; PZ; RROB; RROB2; RROB2Z; T1; WHC; WMAX; ALFA; AMCOR; ROBK; RROBZ; CMELT; DPREC; KL; ZCAP; DZ un T2 vērtības maiņa par +50% konceptuālā hidroloģiskā modeļa METQ veiktspēju ietekmē ieteiktajās NSE; RSR, PBIAS. R^2 vērtību robežās. Tomēr parametru BETA un KU izmaiņas par +50% ievērojami ietekmē konceptuālā hidroloģiskā modeļa METQUL2012 veiktspējas rādītājus NSE; RSR, PBIAS R^2 (Moriasi et al. 2007).

3.1.tabula **Hierarhiskās klasteru analīzes rezultāti pēc R^2; PBIAS; RSR; NSE vērtībām attiecībā uz noteces (Q_{sum}) novirzi pie parametru izmaiņām par + 50%**

Klase	Objekti	Klases starpība	R^2	PBIAS	RSR	NSE	Parametri
1	11	0.065	**0.993**	**0.014**	**0.075**	**0.992**	A2; A3; CFR; KS; PZ; RROB; RROB2; RROB2Z; T1; WHC; WMAX
2	4	0.020	**0.966**	**0.409**	**0.207**	**0.957**	ALFA; AMCOR; ROBK; RROBZ
3	1	0.000	0.630	-4.440	1.262	-0.591	BETA
4	1	0.000	**0.828**	**1.075**	**0.431**	**0.814**	CMELT
5	3	0.251	**0.997**	**6.644**	**0.096**	**0.990**	DPREC; KL; ZCAP
6	1	0.000	**0.984**	**-8.498**	**0.159**	**0.975**	DZ
7	1	0.000	0.907	33.507	0.478	0.771	KU
8	1	0.000	**0.901**	**-2.972**	**0.327**	**0.893**	T2

Parametru A2; AMCOR; RROB; RROBZ; T2; A3; CFR; KL; KS; PZ; RROB2; RROB2Z; T1; WHC un WMAX vērtības maiņa par -50% konceptuālā hidroloģiskā modeļa METQUL2012 veiktspēju ietekmē ieteiktajās NSE; RSR, PBIAS. R^2 vērtību robežās (sk. 3.2.tabula). Tomēr astoņu parametru ALFA; CMELT; ROBK; BETA; DPREC; DZ; KU un ZCAP maiņa par -50% būtiski ietekmē konceptuālā hidroloģiskā modeļa METQ rezultātus un pārsniedz NSE; RSR, PBIAS, R^2 vērtību robežas (Moriasi et al. 2007).

3.2.tabula **Hierarhiskās klasteru analīzes rezultāti pēc R^2; PBIAS; RSR; NSE vērtībām rezultāti attiecībā uz noteces (Q_{sum}) novirzi pie parametru maiņas par – 50%**

Klase	Objekti	Klases starpība	R^2	PBIAS	RSR	NSE	Parametri
1	5	0.036	**0.936**	**0.901**	**0.266**	**0.928**	A2; AMCOR; RROB; RROBZ; T2
2	10	0.033	**0.992**	**-0.729**	**0.079**	**0.991**	A3; CFR; KL; KS; PZ; RROB2; RROB2Z; T1; WHC; WMAX
3	3	0.099	0.802	-2.443	0.525	0.717	ALFA; CMELT; ROBK
4	1	0.000	0.371	10.706	2.615	-5.841	BETA
5	1	0.000	0.995	-16.559	0.202	0.959	DPRKS
6	1	0.000	0.536	7.992	1.375	-0.890	DZ
7	1	0.000	0.858	-47.038	0.656	0.570	KU
8	1	0.000	0.989	-10.105	0.153	0.977	ZCAP

Trešais līdz astotais klasteris uzrāda vienas vai vairāku R^2; PBIAS; RSR; NSE vērtību neatbilstību noteiktajām robežām, kas liecina par parametru jutīgumu un būtiski ietekmi uz

modeļa veiktspēju. Savukārt otrajā un pirmajā klasterī ietilpstošie parametri pēc R^2; PBIAS; RSR; NSE vērtībām, katrs atsevišķi neuzrāda būtisku ietekmi uz modeļa veiktspēju.

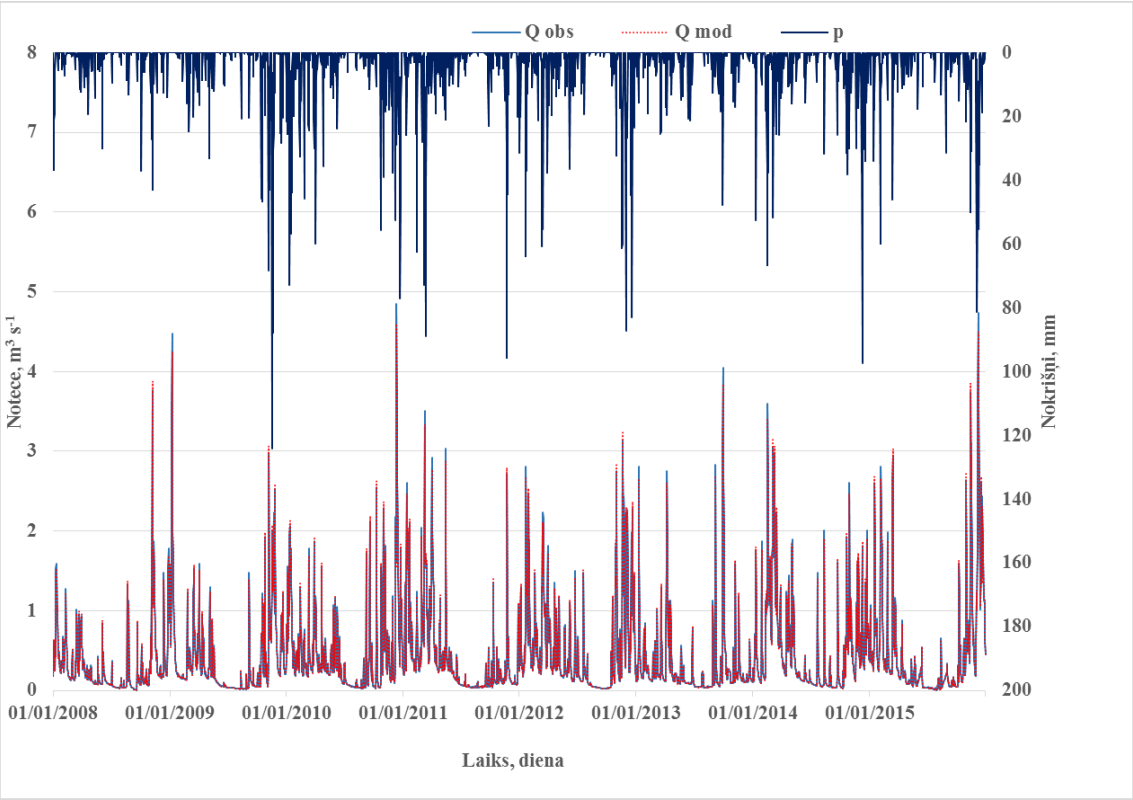
Urbānās hidroloģiskās atbildes vienības kalibrācija un validācija veikta 6 urbāniem sateces baseiniem (II.Publikācija). Kalibrācijas un validācijas rezultāti ir apkopoti 3.3.tabula. NSE visiem sateces baseiniem ir pieņemams (Moriasi et al., 2007) un mainās robežās no 0.69 līdz 0.96 kalibrēšanas periodam un no 0.67 līdz 0.91 validācijas periodam. R^2 ir pieņemams visiem sateces baseiniem visos periodos (Moriasi et al., 2007) un variē no 0.81 līdz 0.98 kalibrēšanas periodam un no 0.95 līdz 0.79 validācijas periodam.

3.3.tabula **Urbānās hidroloģiskās atbildes vienības kalibrācijas un validācijas rezultāti**

Sateces baseins	**Kalibrācijas periods**				**Validācijas periods**			
	NSE	**R^2**	**RSR**	**PBIAS**	**NSE**	**R^2**	**RSR**	**PBIAS**
NY_BO	0.69	0.81	0.69	-23.63	0.67	0.79	0.70	-24.87
NY_VA	0.78	0.91	0.47	11.67	0.79	0.91	0.44	10.18
WA_SP	0.82	0.93	0.31	-3.03	0.80	0.92	0.30	-3.48
WA_MI	0.96	0.98	0.21	-1.07	0.91	0.95	0.24	-2.11
MI_EC	0.76	0.87	0.43	14.86	0.73	0.84	0.49	16.36
MI_PA	0.72	0.84	0.40	17.01	0.75	0.87	0.42	15.28

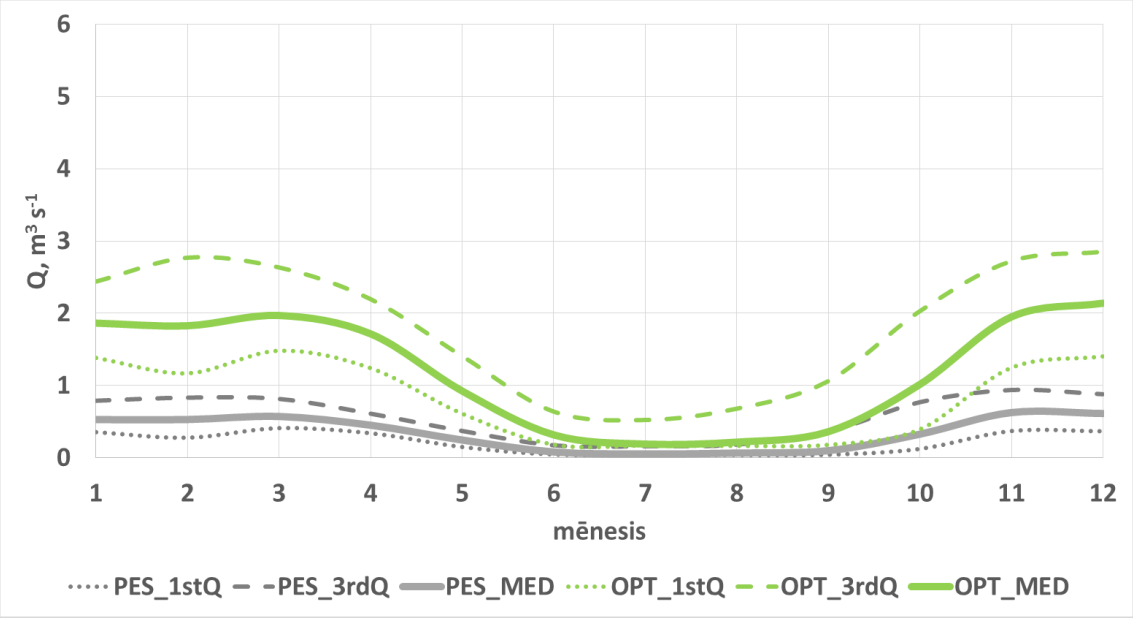
NY_BO uzrāda labākus modelēšanas rezultātus kalibrēšanas periodā. Tomēr MI_PA ir labāki rezultāti validācijas periodam nekā kalibrācijas periodam. Modeļa kalkulācijas precizitāti ietekmē vairāki faktori: nokrišņu datu precizitāte; caurplūdumu mērījumu precizitāte un upes gultnes apstākļi (Benedetti et al., 2012; L. Cuo, Lettenmaier, Alberti, & Richey, 2009; Meng, 2022). Konceptuālā hidroloģiskā modeļa METQ parametrus A2; A3; CMELT; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; DPREC; AMCOR; BETA ieteicams kalibrēt dabiskajos sateces baseinos (A. Ziverts & Jauja, 1999), un pārējie parametri ir nemainīgi. Veicot urbānās hidroloģiskās atbildes vienības parametru kalibrēšanu, tika pieņemts lēmums papildus kalibrēt parametrus (WMAX; ALPHA; ZCAP; KU; KL; T1; T2; KS; WHC; CFR; AMCOR). Pilsētās ir liela virsmas neviendabība un traucēta straumes veidošanās, kā arī atšķirīgs mikroklimats (Burszta-Adamiak, Biniak-Pieróg, Dąbek, & Sternik, 2023; Techapinyawat, Goulden-Brady, Garcia, & Zhang, 2023; Van de Ven, 1990). Modelēto un novēroto caurplūdumu grafiskais salīdzinājums ir parādīts 3.6.att. Modelētais un novērotais caurplūdums hidrogrāfā uzrāda labu atbilstību, tomēr ir vērojama maksimālo caurplūdumu modelēto rezultātu nesakritība ar novērotajiem.

Šī nenoteiktība ir saistīta ar mērījumu precizitāti un lietus intensitāti un izplatību sateces baseinā. Parametri WMAX, ALPHA, ZCAP, T1, T2, KS, DZ, PZ, DPREC, BETA uzrāda būtiskas atšķirības – vairāk nekā 20% starp sateces baseiniem un dažos gadījumos vairāk nekā 40%. Šī variācija ir saistīta ar zemes seguma neviendabīgumu, lietus ūdens savākšanas sistēmu vēsturisko attīstību un urbanizācijas blīvumu (Burszta-Adamiak et al., 2023; Techapinyawat et al., 2023; Van de Ven, 1990). Turpmākos pētījumos nepieciešams klasificēt pilsētu sateces baseinus pa segtajām teritorijām un izstrādāt vismaz trīs pilsētas hidroloģiskās atbildes vienību parametru kopas, kā arī integrēt aprēķina algoritmu konceptuālajā hidroloģiskajā modelī METQUL 2012.



3.6.att. **WA_MI sateces baseina novērotie nokrišņi un novērotie un modelētie caurplūdumi**

Klimata un zemes lietojuma veida scenāriju modelēšanas rezultāti liecina, ka ārkārtīgi lieli caurplūdumi ir saistīti ar lietus gadījumiem nekā sniega kušanu(III. IV. un V. Publikācija). Minimālie noteces periodi kļūst garāki un biežāki. 30 gadus mēneša vidējā vērtība 1.kvartile un 3.kvartile no 2070. gada līdz 2100. gadam klimatiskajiem scenārijiem ar palielinātām meža platībām (pesimistiskais (PES)) un palielinātām lauksaimniecības un urbānām teritorijām (optimistiskais (OPT)) zemes izmantošanas scenārijiem ir attēlota 3.7.att.



3.7.att. **Zemes lietošanas veida scenāriju un klimata scenārija ietekme uz mēneša vidējiem caurplūdumiem Usmas ezera sateces baseinā**

Pētījuma rezultāti liecina par būtisku zemes izmantošanas izmaiņu ietekmi uz Usma ezera hidroloģisko režīmu visos divpadsmit klimatiskajos scenārijos.

Usmas ezera modelēto aprēķina caurplūdumu vidējās aritmētiskās vērtības lielākajā daļā no analizētajiem klimatiskajiem scenārijiem ir prognozētas lielākas optimistiskā zemes lietojuma scenārija gadījumā, t.i., pieaugot lauksaimniecībā izmantojamo zemju platībām un palielinoties urbanizācijai. Usmas ezera modelētajiem vidējiem caurplūdumiem 30 gadu laika periodā (2070.-2100.g.) tendencei pieaugt ir 6 no 12 klimatiskajiem scenārijiem neatkarīgi no zemes lietojuma veida scenārija, taču 8. klimatiskā scenārija gadījumā prognozēts caurplūduma tendences pieaugums, izpildoties optimistiskā zemes lietojuma veida scenārijam un tendences samazinājums – izpildoties pesimistiskajam scenārijam Usmas ezera modelētajiem maksimālajiem caurplūdumiem 30 gadu laika periodā (2070.-2100.g.) tendencei pieaugt ir 7 no 12 klimatiskajiem scenārijiem neatkarīgi no zemes lietojuma veida scenārija, taču 1. klimatiskā scenārija gadījumā prognozēts caurplūduma tendences pieaugums, izpildoties optimistiskā zemes lietojuma veida scenārijam un tendences samazinājums – izpildoties pesimistiskajam scenārijam.

Usmas ezera modelētajiem minimālajiem caurplūdumiem 30 gadu laika periodā (2070.-2100.g.) tendencei pieaugt ir tikai 2 no 12 klimatiskajiem scenārijiem neatkarīgi no zemes lietojuma veida scenārija, un 2 no 12 klimatisko scenāriju gadījumiem prognozēts caurplūduma tendences pieaugums, izpildoties optimistiskā zemes lietojuma veida scenārijam un tendences samazinājums – izpildoties pesimistiskajam scenārijam;

Visos klimatiskajos scenārijos gada aukstajā periodā notece ir lielāka optimistiskā zemes izmantošanas scenārijā, kur urbanizēto platību īpatsvars palielinās, tas izskaidrojams ar ūdens necaurlaidīgo zonu palielināšanos un infiltrācijas samazināšanos. Pesimistiskie zemes izmantošanas scenāriji, palielinot meža platību Usma ezera sateces baseinā, var būtiski ietekmēt hidroloģisko režīmu visos divpadsmit klimatiskajos scenārijos, samazinot kopējo noteci, kas ir saistīta ar evapotranspirāciju meža teritorijās. Pesimistiskais zemes izmantošanas scenārijs visiem klimata scenārijiem, samazina noteci, un turpmākos pētījumus var vērst uzmanību uz hidroloģiskā režīma izmaiņu ietekmi uz mazo hidroelektrostaciju efektivitāti.

Tāšu ezera ūdens līmeņa svārstības saglabā sezonālu raksturu, kur ūdens līmeņa paaugstināšanās rudens-ziemas periodā, mijās ar ūdens līmeņa pazemājumu vasarā (VI. Publikacija). Visos scenārijos caurtekas/regulatora esošais pārgāznes platums 0.8m nespēj nodrošināt ūdens līmeņa režīmu, kas atbilstu Ālandes upes, kā valsts nozīmes ūdensnotekas funkcijām. Analizējot Tāšu ezera ūdens līmeņa svārstības gada griezumā nākotnes klimata scenāriju modelētās vērtības pie pārgāznes platuma 0.8m spēj nodrošināt gada ūdens līmeņa svārstību amplitūdu no 17.60 līdz 18.3 m LAS 2000.5, kas nav pietiekoši, lai nodrošinātu valsts nozīmes ūdensnotekas Ālandes upe funkcionalitāti. Analizējot Tāšu ezera ūdens līmeņa svārstības gada griezumā nākotnes klimata scenāriju modelētās vērtības pie pārgāznes platuma 2.0 m spēj nodrošināt gada ūdens līmeņa svārstību amplitūdu no 17.60 līdz 18.00 m LAS 2000.5, kas ir pietiekoši, lai nodrošinātu valsts nozīmes ūdensnotekas Ālandes upe funkcionalitāti.

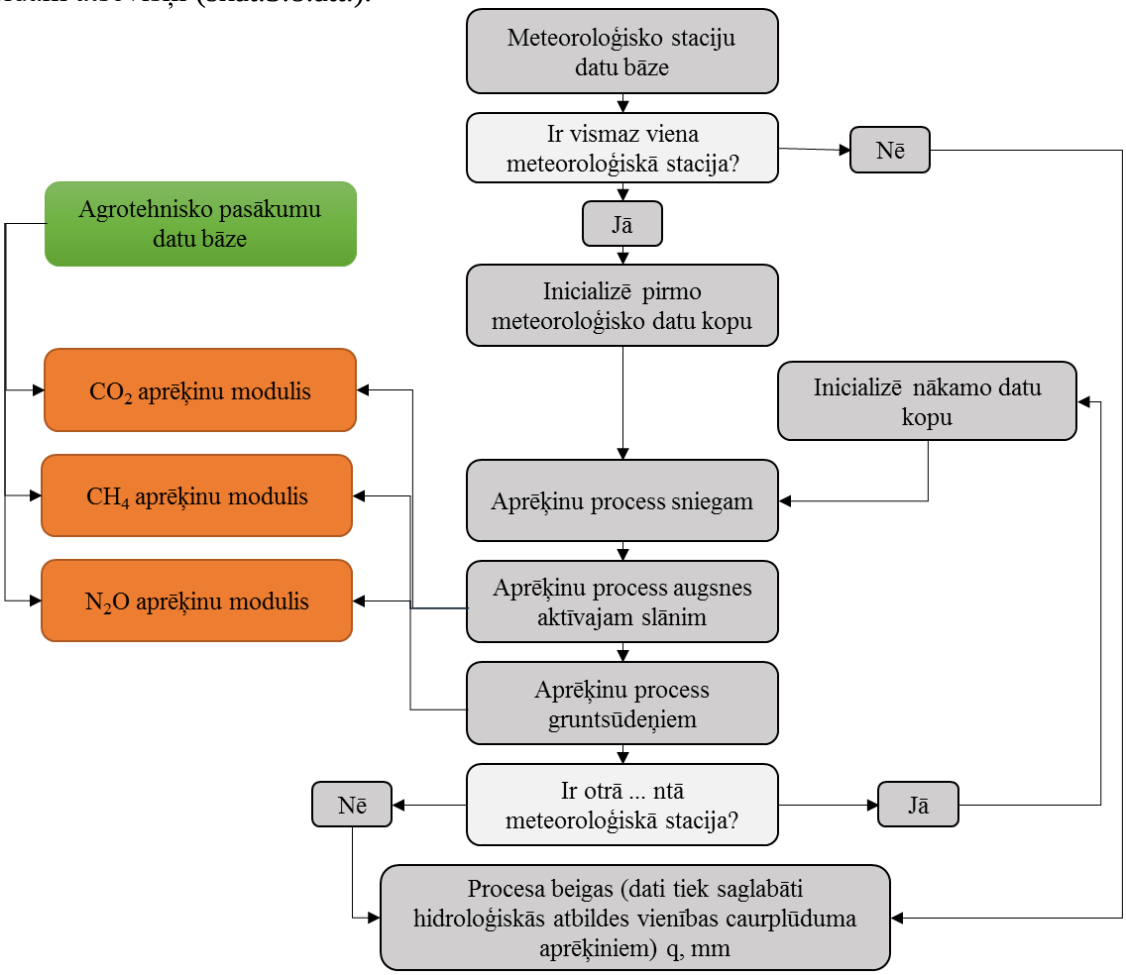
3.2. SEG emisiju no augsnēm modelēšanas iespējas

Kopš 2016.gada tiek veikti regulāru SEG emisiju mērījumi no augsnēm laboratorijas un lauka apstākļos. Kopš 2017. gada dati tiek ievākti pēc metodikas kas izstrādāta šī pētījuma ietvaros (VII. un VIII. Publikācija). Kopš 2018.gada ir uzsākta sistemātiska N_2O izotopu mērījumu datu ievākšana un uzkrāšana (IX. Publikācija)

Konceptuālā hidroloģiskā modeļa METQ uzbūve un SEG emisiju aprēķina algoritmu integrācijas iespējas tiek izvērtētas no konceptualitātes prizmas un identificēti četri galvenie posmi, kas nepieciešami SEG emisiju aprēķinu moduļa veiksmīgai integrācijai konceptuālajā hidroloģiskajā modelī METQ (X.Publikācija).

Pirmajā posmā nepieciešams izvērtēt SEG emisiju modelēšanai nepieciešamo datu kopu atlases iespējas no konceptuālā hidroloģiskā modeļa METQ starprezultātiem, kā arī papildus parametru un datu rindu nepieciešamību SEG emisiju modelēšanai. Otrajā posmā jāizvērtē konceptuālā hidroloģiskā modeļa METQ esošie algoritmi un jāizveido konceptuāls risinājums SEG emisiju moduļu integrācijai vai papildus algoritmu izveidei. Trešajā posmā katrai SEG gāzei tiek izveidots aprēķina algoritms kas izmanto konceptuālā hidroloģiskā modeļa METQ augsnes aktīvā slāņa aprēķinu starprezultātus un papildus parametrus kas saistīti SEG emisiju aprēķinam. Ceturtais solis ir ilgtermiņa pasākums, kur gāzu mērījumi lauka apstākļos tiek izmantoti izveidoto SEG emisiju aprēķinu moduļu kalibrācijā. Šajā pētījumā tiks aprakstīti pirmie divi soļi un aprakstīts moduļu integrācijas konceptuālais risinājums.

SEG aprēķina moduļi ir jāiedala divās grupās, pirmā moduļu grupa ir emisijas no augsnes, kur SEG aprēķina moduļus ir iespējams pieslēgt konceptuālā hidroloģiskā modeļa METQ aprēķina algoritmiem. SEG aprēķinu moduļi jāveido ogļskābajai gāzei, metānam un dislāpekļa oksīdam atsevišķi (skat.3.8.att.).



3.8.att. **Ogļskābās gāzes, metāna un dislāpekļa oksīda emisiju aprēķina moduļu integrācijas konceptuālajā modeli METQ**

Analizējot galvenos faktorus, kas veicina CO_2 emisijas no augsnes ir vairāki. Augsnes granulometriskajam sastāvam ir būtiska ietekme uz CO_2 emisijām, jo granulometriskais sastāvs tieši ietekmē augsnes porainību (Bouma & Bryla, 2000). Nokrišņi būtiski ietekmē augsnes elpošanu un kopā ar augsne granulometrisko sastāvu veido augsnes mitruma režīmu, kas tieši ietekmē rizosfēras aktivitāti un nosaka CO_2 emisiju apmērus (Borken & Matzner, 2009). Tāpat nokrišņiem iefiltrējoties augsnē un izspiežot no augsnes porām gaisu tiek izspiest CO_2 tādējādi veidojot CO_2 emisiju pīķi. Konceptuālā hidroloģiskā modeļa METQ aprēķinu algoritmu kopa

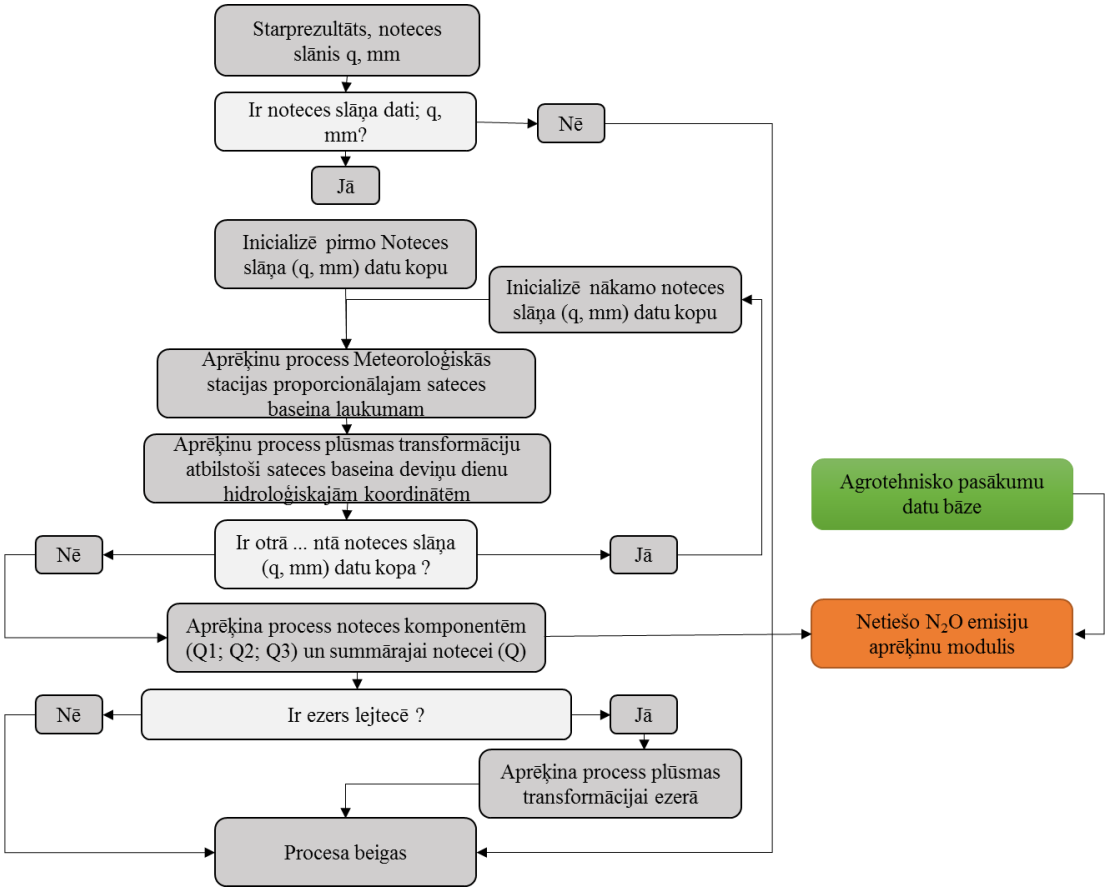
ir paredzēta aktīvā augsnes slāņa procesu aprēķiniem, kur veiksmīgi ir iespējams integrēt CO_2 aprēķinu moduli.

Metāna emisijas ir sarežģītāks process, kur svarīgākie faktori ir augsnes mitruma apstākļi un organiskās vielas daudzums un organiskās vielas sadalīšanās ātrums (Changsheng Li, Frolking, & Frolking, 1992b). Taču paralēli metāna producēšanai notiek metāna patēriņš augsnē, kas ir cieši saistīts ar skābekļa pieejamību augsnē (Changsheng Li, 2007). Iepriekšminētie faktori ļauj metāna aprēķina moduli integrēt konceptuālās hidroloģiskā modeļa METQ augsnes aktīvā slāņa un gruntsūdens aprēķina algoritmos.

Dislāpekļa oksīda emisiju aprēķinam no augsnes ir vissarežģītākais aprēķina algoritms, jo ir cieši saistīts ar nitrifikācijas un denitrifikācijas procesiem, kas savukārt ir atkarīgs no tādiem faktoriem kā augsnes temperatūras, augsnes mitruma un pH (Blagodatsky & Richter, 1998). konceptuālā hidroloģiskā modeļa METQ augsnes aktīvā slāņa aprēķina algoritms ļauj ģenerēt starprezultātus, kas nepieciešami nitrifikācijas un denitrifikācijas procesu konceptuāliem aprēķiniem.

Papildus esošajiem algoritmiem ir nepieciešams izveidot papildus aprēķinu moduli, kas izmantojot klimata datus, augsnes parametrus, un agrotehniskos apstākļus *farm management practice* spēj ģenerēt diennakts vidējo augsnes mitrumu un augsnes temperatūru. SEG emisiju aprēķina algoritmu veiksmīgai integrācijai ir ieteicams izmantot esošos konceptuālā hidroloģiskā modeļa METQ aprēķina algoritmus, kas ir detalizēti aprakstīti (Krams & Ziverts, 1993).

Savukārt otrā emisiju aprēķinu moduļu grupa ir netiešās N_2O emisijas un metāna emisijas no ūdensobjektiem, kur SEG aprēķina algoritmu ir iespējams pieslēgt konceptuālā hidroloģiskā modeļa METQ summārās noteces aprēķina algoritmam (skat.3.9.att.).



3.9.att. **Netiešo dislāpekļa oksīda emisiju aprēķina moduļu integrācijas konceptuālajā modeli METQ**

Analizējot pieejamo statistikas datu bāžu un zinātnisko pētījumu rezultātu informāciju, pašlaik iespējams izveidot N_2O aprēķina moduli. Tas izmantojot esošos lauksaimniecības noteču monitoringa datus, kas atspoguļo agrotehniskos apstākļus (*farm management practice)*, un konceptuālā hidroloģiskā modeļa METQ noteces komponenšu aprēķina algoritmu aprēķina netiešās N_2O emisijas.

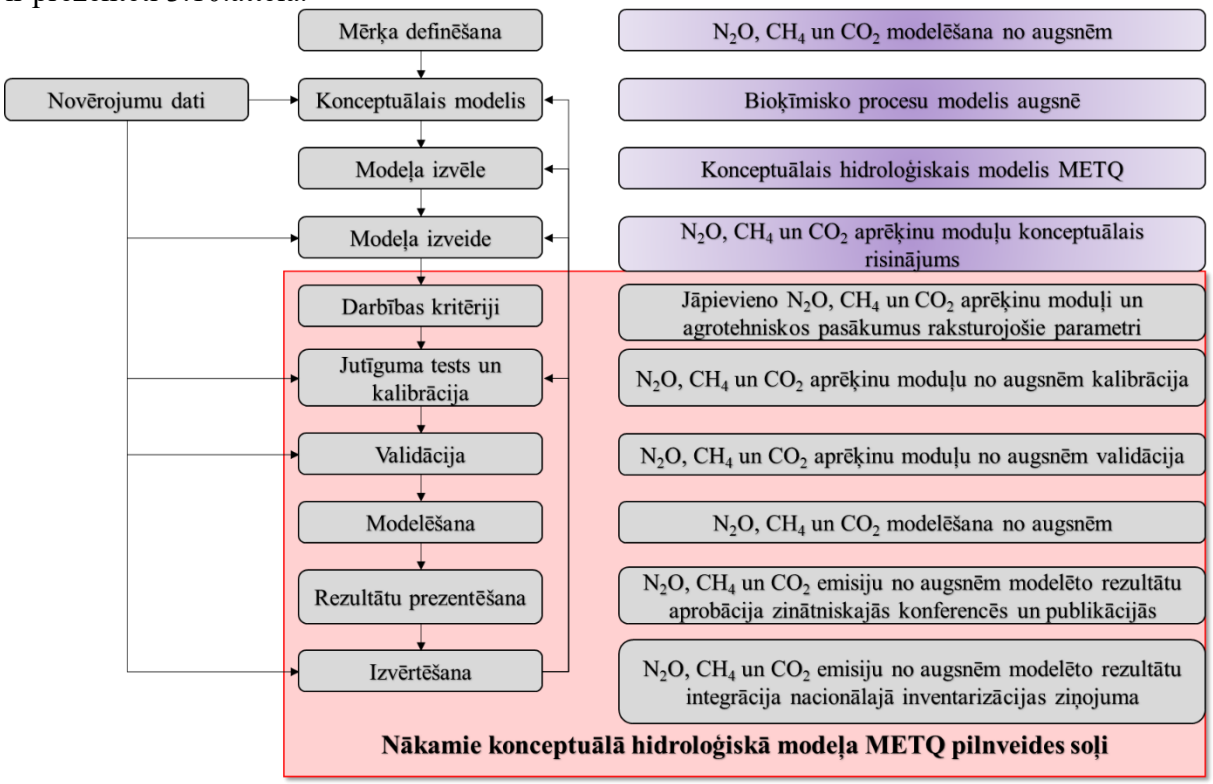
Konceptuālā hidroloģiskā modeļa METQ modelēšanas platforma ļauj izmantot modeļa aprēķinu starprezultātus, tādus kā, gruntsūdens līmenis dienas beigās, kapilārā pacelšanās, summārā iztvaikošana u.c., kas nepieciešami SEG emisiju aprēķina algoritmos.

Konceptuālā hidroloģiskā modeļa METQ algoritmi ir labi dokumentēti un ļauj integrēt SEG emisiju aprēķina moduļus ogļskābās gāzes, metāna un dislāpekļa oksīda emisiju aprēķinam no augsnes. Taču nepieciešams izveidot papildus parametru ievades iespējas, katram SEG emisiju no augsnes aprēķinu modulim.

SEG aprēķina integrācijai konceptuālajā hidroloģiskajā modelī METQ ir nepieciešams esošo modelēšanas platformu pārprogrammēt un izveidot atvērtu platformu jaunu aprēķinu moduļu pievienošanai. SEG modelēšanai no lauksaimniecības augsnēm, kur aprēķina pamatā ir nitrifikācijas un denitrifikācijas procesi augsnē, kā arī netiešā SEG modelēšana no ūdenstecēm, kur par pamatu tiek ņemtas slāpekļa noplūdes un nitrifikācijas un denitrifikācijas procesi ūdenī.

3.3. SEG emisiju moduļu integrācijas konceptuālajā hidroloģiskajā modelī METQ turpmākie pētījumu soļi

Konceptuālā hidroloģiskā modeļa METQ uzlabošanas stratēģiskie ieguvumi saistās ar Latvijas klimatisko un hidroģeoloģisko apstākļu ņemšanu vērā dažādu sarežģītu jautājumu risināšanā. SEG emisiju moduļu integrācijas konceptuālajā hidroloģiskajā modelī METQ šī pētījuma ietvaros apstājas pie datu sagatavošanas un koncepta izstrādes. Nākamie pētījumu soļi ir prezentēti 3.10.attēlā.



3.10.att. **SEG emisiju moduļu integrācijas konceptuālajā hidroloģiskajā modelī METQ turpmākie pētījumu soļi**

Pamatojoties, ka promocijas darba veiktajiem pētījumiem ir nepieciešams attīstīt modelēšanas platformu, kas ir starpdisciplinārs uzdevums. Modelēšanas platformu ieteicams veidot tā, lai pastāv iespēja pieslēgt papildus moduļus dažādu ar hidroloģisko ciklu saistītu jautājumu modelēšanai. Primāri nepieciešams izstrādāt atvērta tipa algoritmu, kur iespējams esošā modelēšanas algoritma starprezultātus izmantot jaunajos moduļos. Veidojot modelēšanas platformu, jāparedz iespēja izmantot jau esošos algoritmus jaunu starpvērtību radīšanai kā arī pieslēgt papildus izejas datu plūsmas.

Konceptuālā hidroloģiskā modeļa METQ pilnveide ir jāfokusē uz diviem galvenajiem virzieniem. Hidroloģisko atbildes vienību diferenciāciju un iespēju palielināt hidroloģisko atbildes vienību skaitu urbānajās, lauksaimniecības un mežsaimniecības teritorijās. Otrs virziens ir SEG emisiju moduļu izveide un attīstība, kas sniegtu iespējas precīzi prognozēt SEG emisijas no augsnēm.

4.SECINĀJUMI UN PRIEKŠLIKUMI

1. Hidroloģisko procesu modelēšanā aktīvi tiek izmantoti vairāki simti modeļi, kas ir iedalāmi divās galvenajās grupās konceptuāli un fizikālie. Konceptuālo modeļu izmantošana dod precīzākus rezultātus sateces baseiniem ar platību virs 5 km^2. SEG emisiju modelēšanā tiek izmantoti jaunizbūvēti modelēšanas rīki, taču veiksmīgi tiek izmantoti hidroloģiskie modeļi ar papildus algoritmu, kas ļauj modelēt gāzu emisijas un izceļas ar lielāku precizitāti dislāpekļa oksīda modelēšanā mērenajā klimata joslā, kur novērojama augsnes sasalšana ziemas periodā;
2. Konceptuālā hidroloģiskā modeļa METQ aprēķina algoritms ļauj integrēt neierobežotu daudzumu hidroloģisko atbildes vienību, kas paver iespējas ne tikai integrēt urbāno hidroloģisko atbildes vienību, bet arī nākamajos konceptuālā hidroloģiskā modeļa METQ attīstības posmos, izdalīt vairākas urbānās hidroloģiskās atbildes vienības, kas katra kalibrēta dažādam ūdensnecaurlaidīgo virsmu īpatsvaram un urbānās teritorijas hidromorfoloģiskajām īpašībām;
3. Konceptuālā hidroloģiskā modeļa METQ modelēšanas platforma ļauj saglabāt un aprēķina algoritmā izmantot modeļa aprēķinu starprezultātus, tādus kā, gruntsūdens līmenis dienas beigās, kapilārā pacelšanās, summārā iztvaikošana u.c., kas nepieciešami SEG emisiju aprēķina algoritmos;
4. Konceptuālā hidroloģiskā modeļa METQ modelēšana platforma METQUL2012 ir izveidota un validēta. Optimālākos kalibrācijas rezultātus uzrādija Neldera-Mīda algoritms, kas saskan ar citu autoru rezultātiem;
5. Konceptuālā hidroloģiskā modeļa METQ parametru jutīguma tests parāda, ka modeļa parametri ALFA; CMELT; ROBK; BETA; DPREC; DZ; KU un ZCAP ir jākalibrē īpaši rūpīgi, lai saglabātu aprēķina algoritma konceptuālo jēgu un tajā pašā laikā uzlabotu modeļa veiktspēju;
6. Konceptuālā hidroloģiskā modeļa METQ urbānā hidroloģiskā atbildes vienība ir izveidota un integrēta modelī. Urbānās hidroloģiskās atbildes vienības kalibrācijas un validācijas rezultāti 6 urbānajiem sateces baseiniem ir pietiekoši NSE > 0.5; R^2 > 0.75; RSR < 0.70 un PBIAS +/- 25%, lai modeļa parametrus varētu izmantot neizpētītu urbāno sateces baseinu modelēšanai;
7. SEG aprēķina integrācijai konceptuālajā hidroloģiskajā modelī METQ ir nepieciešams esošo modelēšanas platformu pārprogrammēt un izveidot atvērtu platformu jaunu aprēķinu moduļu pievienošanai. SEG modelēšanai no lauksaimniecības augsnēm, kur aprēķina pamatā ir nitrifikācijas un denitrifikācijas procesi augnē, kā arī netiešā SEG modelēšana no ūdenstecēm, kur par pamatu tiek ņemtas slāpekļa noplūdes un nitrifikācijas un denitrifikācijas procesi ūdenī;

8. Konceptuālo hidroloģisko modeli METQ var izmantot ūdens kvalitātes pētījumos, kas tiek veikti, zinātniekiem sadarbojoties, starpnozaru līmenī. Modelēšanas rezultāti parāda, ka klimata mainībai un zemes lietojuma veida maiņai ir nozīmīga summārā ietekme uz virszemes noteci un tās komponentēm.

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THE LOCAL PARAMETERS SENSITIVITY OF URBAN HYDROLOGICAL RESPONSE UNIT OF CONCEPTUAL HYDROLOGICAL MODEL METQ

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The urbanised areas have a significant impact on hydrological processes of the catchment. The average annual urbanisation temp in EU is 0.6%. The existing version of conceptual hydrological model METQ is developed for natural hydrological response units such as forests, swamps and agricultural land. The growing urbanisation level force to add to the model urban hydrological response unit. This study aims to analyse local parameter sensitivity of urban hydrological response unit of conceptual hydrological model METQ. The local sensitivity was made using Monte-Carlo simulations. To evaluate local sensitivity Nash–Sutcliffe efficiency index (NSE), determination coefficient R2, percent bias (PBIAS), ratios the root mean square error to the standard deviation of measured data (RSR) in addition to the graphical method were used.
The results show seven parameters to be calibrated the other 16 parameters have to stay as constant values for urban hydrological response unit.

Keywords: conceptual hydrological model METQ; parameter sensitivity; run-off component.

INTRODUCTION

The conceptual hydrological model METQ is developed to the model discharge of modelled catchment area according to climate data such as temperature, precipitation and humidity (Krams and Ziverts, 1993; Ziverts and Jauja, 1999) The additional hydrological response unit describing urban areas were integrated into the model (Grinfelde and Bakute 2017). The adaption of new hydrological response unit requires sensitivity analysis of all parameters to identify each parameter sensitivity and response to the model performance. There are developed several methods to evaluate model performance (Donigian et al., 1983; Gupta et al., 1999; Saleh et al., 2000; Santhi et al., 2001; Van Liew et al., 2007) however they are very specific and developed for particular project or specific.

In the previous studies of METQ, there was Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and coefficient of determination (R^2) used. The NSE is commonly used end (Sevat and Dezetter 1991) recognise NSE as the best objective function for reflecting the overall fit of modelled and measured hydrograph. However, Legates and McCabe, 1999 identify oversensitivity of extreme values because of squared differences. The R^2 is commonly used to evaluate model performance. However, risks are overestimating extreme values such as spring floods and underestimate proportional differences between measured and modelled data (Legates and McCabe, 1999).

To provide accuracy in hydrological modelling Moriasi et al. 2007 proposes to use several model performance evaluation approaches. For runoff, there are recommended acceptable NSE is more significant than 0.75, PBIAS is ± 10%, and the ratio of the root mean square error to the standard deviation of measured data (RSR) is smaller than 0.50, and they recommend in addition to using the graphical techniques (Moriasi et al. 2007). R^2 typically with values greater than 0.75 are considered acceptable (Santhi et al., 2001, Van Liew et al., 2003).

This study aims to evaluate the sensitivity of parameters of conceptual hydrological model METQ.

MATERIALS AND METHODS

The Vienziemite catchment with 5.92 km^2 of total area and climate data from 1st of January 1993 until 31st of December 2015 were used to make sensitivity analysis of model METQ parameters. Totally 23 parameters were tested during the study. The sensitivity analysis can be divided into three steps (see Figure 1). The first step of analysis was the generation of reference hydrograph with default parameter values defined by Ziverts and Jauja 1999. Monte Carlo simulations of the parameter in amplitude ± 50% of its value by keeping other parameters fixed.

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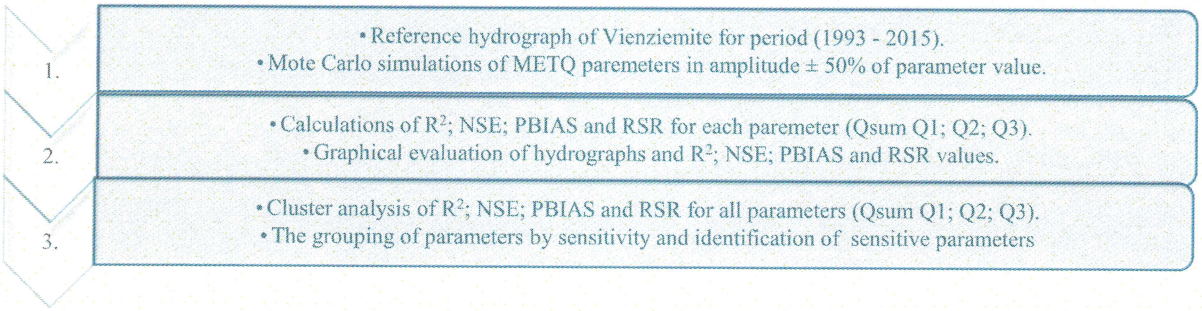


Figure 1. The steps of sensitivity analysis

The second step is to calculate model performance characteristic values of total run off (Qsum) and separately run-off components: surface run-off (Q1); upper layer subsurface run-off (Q2) and base layer run-off (Q3).

The NSE were calculated using following formula:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right]$$

where Qobs – measured runoff; Qsim – simulated runoff; Qmean – average measured runoff (Nash and Sutcliffe, 1970).

The RSR were calculated using following formula:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q^{mean})^2}\right]}$$

where Qobs – measured runoff; Qsim – simulated runoff; Qmean – average measured runoff.

The PBIAS were calculated using formula:

$$PBIAS = \left[\frac{\sqrt{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim}) * (100)}}{\sum_{i=1}^{n}(Q_i^{obs})}\right]$$

where Qobs – measured runoff; Qsim – simulated runoff (Gupta et al., 1999);

The R^2 were calculated using formula:

$$R^2 = \left(\frac{n(\sum_{i=1}^{n}(Q_i^{obs} * Q_i^{sim}) - \sum_{i=1}^{n}(Q_i^{obs}) * \sum_{i=1}^{n}(Q_i^{sim})}{\sqrt{[n(\sum_{i=1}^{n}(Q_i^{obs})^2 - (\sum_{i=1}^{n}(Q_i^{obs}))^2] - [n(\sum_{i=1}^{n}(Q_i^{sim})^2 - (\sum_{i=1}^{n}(Q_i^{sim}))^2]}}\right)^2$$

where Qobs – measured runoff; Qsim – simulated runoff (Anderson-Sprecher, 1994).

The graphical analysis of hydrograph was made using hydrograph of spring floods in 2013 and hydrograph of summer floods after long period of droughts in 1999. The third step is to use hierarchical agglomerate cluster analysis to classify parameters in groups by their similarities (Al-Odaini et al. 2012; Farmaki et al. 2012; Zhang et al. 2013). The classification of conceptual hydrological model METQ parameters can be illustrated using a dendrogram measuring the degree of homogeneity using the Ward method and Euclidean distance calculation (Lau et al 2009).

RESULTS

The Monte Carlo simulations were made for all 23 parameters (A2; A3; CFR; KS; PZ; RROB; RROB2; RROB2Z; T1; WHC; WMAX; ALFA; AMCOR; ROBK; RROBZ; BETA; CMELT; DPREC; KL; ZCAP; DZ; KU; T2) of conceptual hydrological model METQ. The example of Monte Carlo simulation of parameter BETA is presented in figure 2. The parameter BETA show high sensitivity to parameter value change. Any change of parameter BETA has to be carefully evaluated during conceptual hydrological model calibration process.

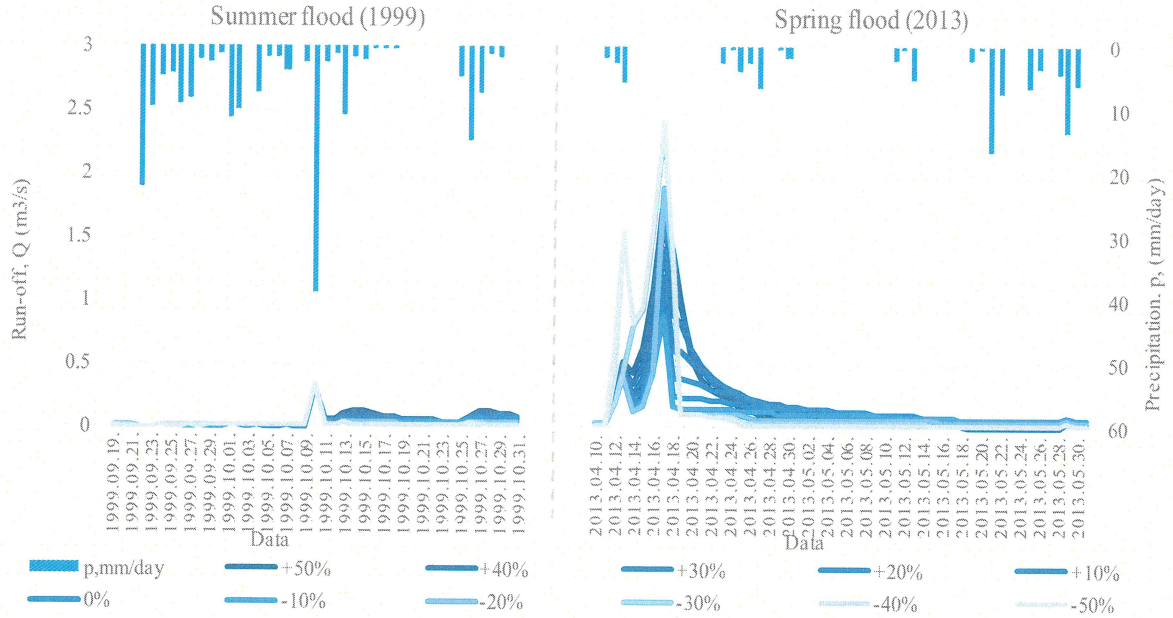


Figure 2 The graphical analysis of parameter BETA sensitivity

The graphical analysis of parameter KU sensitivity is presented in figure 3. The parameter KU is one of root zone parameters and show high impact on long term run-off.

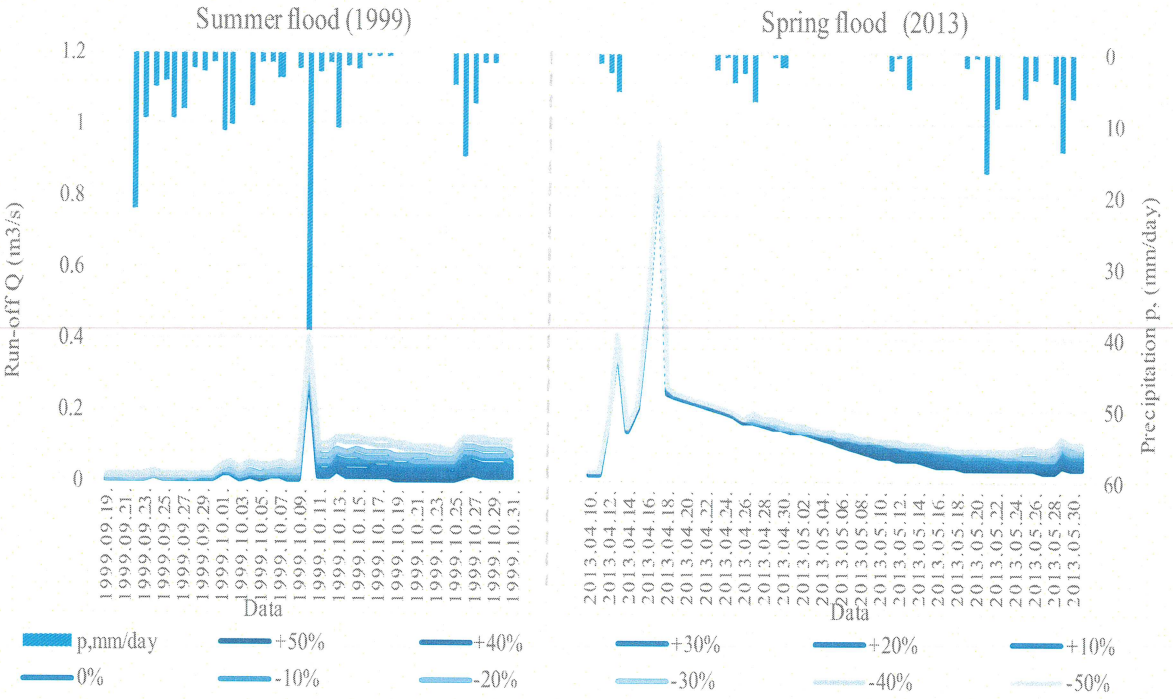


Figure 3 The graphical analysis of parameter KU sensitivity

The clusters of sensitivity analysis results of 23 parameters are presented in table 1. The change of parameters A2; A3; CFR; KS; PZ; RROB; RROB2; RROB2Z; T1; WHC; WMAX; ALFA; AMCOR; ROBK; RROBZ; CMELT; DPREC; KL; ZCAP; DZ and T2 value by +50% the conceptual hydrological model METQ performance is very good. However, the change of parameters BETA and KU by +50% impact the performance of the conceptual hydrological model METQ (Moriasi et al. 2007).

The change of parameters A2; AMCOR; RROB; RROBZ; T2; A3; CFR; KL; KS; PZ; RROB2; RROB2Z; T1; WHC and WMAX value by -50% the conceptual hydrological model METQ performance is very good (see Table 2). However, the change of parameters ALFA; CMELT; ROBK; BETA; DPREC; DZ; KU and ZCAP by -50% impact the performance of the conceptual hydrological model METQ (Moriasi et al. 2007).

Table 1 The results of cluster analysis of runoff (Qsum) deviation at parameter change by + 50%

Class	Objects	Within-class variance	R2	PBIAS	RSR	NSE	Parameters
1	11	0.065	**0.993**	**0.014**	**0.075**	**0.992**	A2; A3; CFR; KS; PZ; RROB; RROB2; RROB2Z; T1; WHC; WMAX
2	4	0.020	**0.966**	**0.409**	**0.207**	**0.957**	ALFA; AMCOR; ROBK; RROBZ
3	1	0.000	0.630	-4.440	1.262	-0.591	BETA
4	1	0.000	**0.828**	**1.075**	**0.431**	**0.814**	CMELT
5	3	0.251	**0.997**	**6.644**	**0.096**	**0.990**	DPREC; KL; ZCAP
6	1	0.000	**0.984**	**-8.498**	**0.159**	**0.975**	DZ
7	1	0.000	0.907	33.507	0.478	0.771	KU
8	1	0.000	**0.901**	**-2.972**	**0.327**	**0.893**	T2

Table 2 The results of cluster analysis of runoff (Qsum) deviation at parameter change by - 50% by (R2; PBIAS; RSR; NSE)

Class	Objects	Within-class variance	R2	PBIAS	RSR	NSE	Parameters
1	5	0.036	**0.936**	**0.901**	**0.266**	**0.928**	A2; AMCOR; RROB; RROBZ; T2
2	10	0.033	**0.992**	**-0.729**	**0.079**	**0.991**	A3; CFR; KL; KS; PZ; RROB2; RROB2Z; T1; WHC; WMAX
3	3	0.099	0.802	-2.443	0.525	0.717	ALFA; CMELT; ROBK
4	1	0.000	0.371	10.706	2.615	-5.841	BETA
5	1	0.000	0.995	-16.559	0.202	0.959	DPREC
6	1	0.000	0.536	7.992	1.375	-0.890	DZ
7	1	0.000	0.858	-47.038	0.656	0.570	KU
8	1	0.000	0.989	-10.105	0.153	0.977	ZCAP

The radar diagram of standardised cluster centroids of model performance indicators at parameter change by + 50% is presented in figure 4. The cluster 3 represented by BETA and cluster 7 represented by KU strongly differ from others.

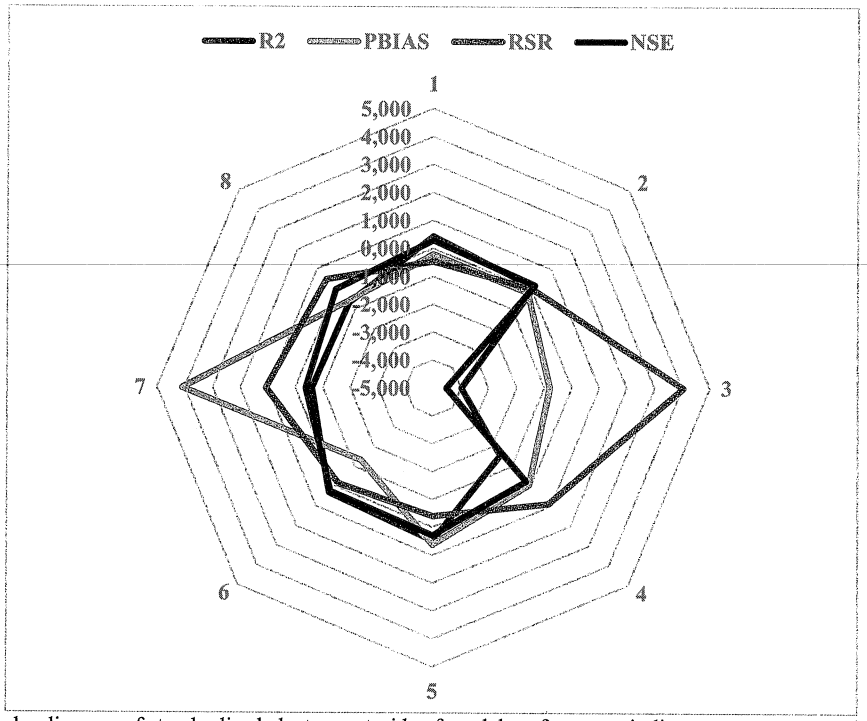


Figure 4. The radar diagram of standardised cluster centroids of model performance indicators at parameter change by + 50%

The radar diagram of standardised cluster centroids of model performance indicators at parameter change by - 50% is presented in figure 5. The cluster 3 represented by ALFA; CMELT; ROBK, the cluster 4 represented by BETA; the cluster 5 represented by DPREC, the cluster 6 represented by DZ, the cluster 7 represented by KU and the cluster 8 represented by ZCAP strongly differ from others.

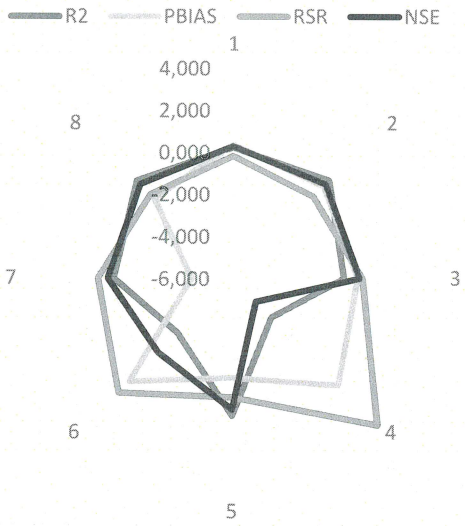


Figure 5. The radar diagram of standardised cluster centroids of model performance indicators at parameter change by - 50%

The analysis of run-off components Q1; Q2; Q3 and total run-off Qsum changes by changing parameter BETA in amplitude ±50 % is presented in figure 6. The analysis of NSE; RSR; R2 and PBIAS show parameter BETA impact on run off component Q1.

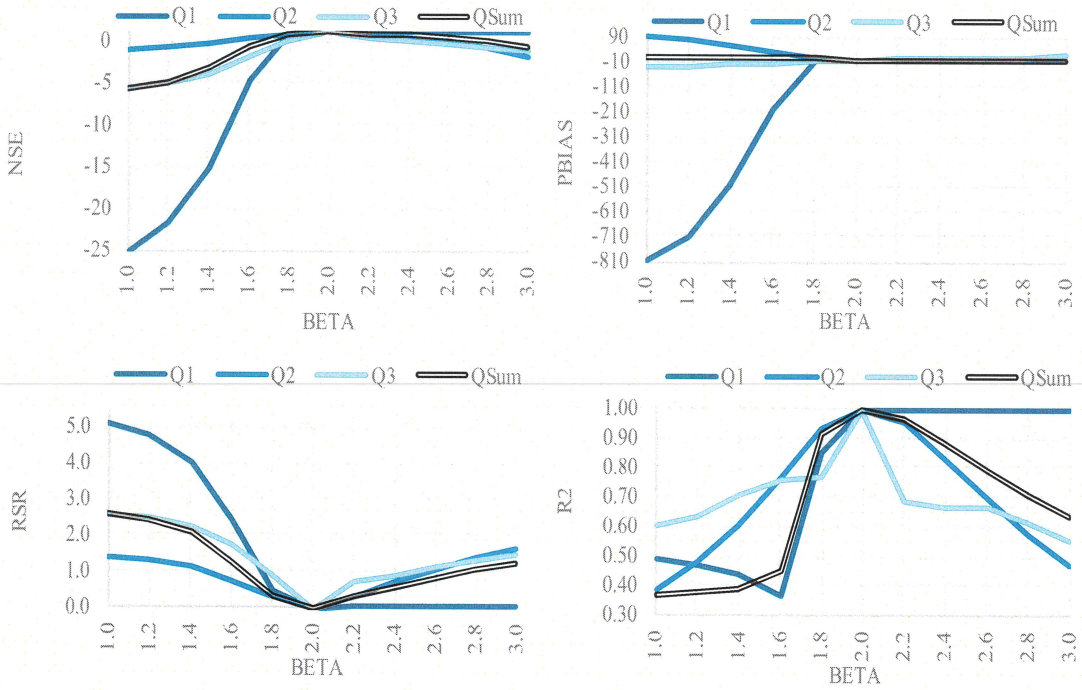


Figure 6. The graphical analysis of parameter BETA impact on conceptual hydrological model METQ performance

The analysis of run-off components Q1; Q2; Q3 and total run-off Qsum changes by changing parameter KU in amplitude ±50 % is presented in figure 7. The analysis of NSE; RSR; R2 and PBIAS show parameter KU impact on run off component Q3.

CONCLUSION

The conceptual hydrological model parameters ALFA; CMELT; ROBK, BETA, DPREC, DZ, KU and ZCAP are very sensitive. During calibration of conceptual hydrological model METQ there is need for evaluation of parameter changes.

The analysis shoved different impact of parameters on modelling results of different run-off components.

The future research has to be focused on sensitivity analysis of conceptual hydrological model parameters sensitivity for each run-off component.

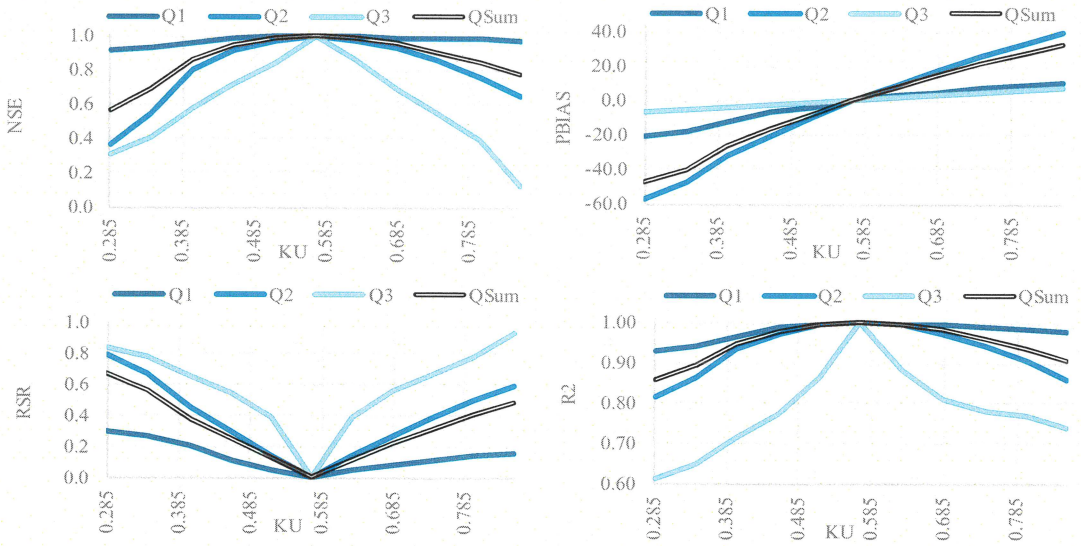


Figure 7. The graphical analysis of parameter KU impact on conceptual hydrological model METQ performance

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URBAN HYDROLOGICAL RESPONSE UNIT PARAMETER CALIBRATION AND VERIFICATION FOR CONCEPTUAL HYDROLOGICAL MODEL METQ

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Abstract. The growing urbanization level significantly impacts the hydrological regime of streams and rivers. Land use is changed and natural areas are transformed to living areas or industrial parks. The conceptual hydrological model METQ is developed by the Latvia University of Agriculture to calculate total run-off for different purposes. However, it was developed for rural areas and is missing the urban hydrological response unit. The aim of this research is to calibrate and verify the urban hydrological response unit parameters of the conceptual hydrological model METQ. In Latvia, there is no hydrometric station with urban catchment area and in Europe there was not possibility to get enough long run-off and meteorological data set. Free access run-off and meteorological data from the United States Geological Surveywere used in this research. The calibration was made using MonteCarlo simulations. To evaluate the calibration results Nash–Sutcliffe efficiency index (NSE), determination coefficient R^2, percent bias (PBIAS), ratios the root mean square error to the standard deviation of measured data (RSR) in addition to the graphical method were used. The calibration and validation results of the urban hydrological response unit parameters were satisfactory and achieved the recommended limits NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 % for all six catchments. There is variation of the parameter values between catchments, which is related with the urbanization level and hydrogeological conditions of the catchment. This paper gives recommendations for hydrological response unit parameter application for the conceptual hydrological model METQUL2012.

Keywords: urbanization, discharge, METQUL2012.

Introduction

More than half of the world population live on urban areas and according to the United Nations migration projections in 2030 more than 80 % of the population will live in urban areas [1]. Growing population and increasing urbanization rate force more and more to think about sustainable resource management, including water management [2; 3]. The change of land use and especially urbanization have significant impact on hydrological processes [4]. Urban areas, on the one hand, increase pollution pressure and deplete water resources, on the other hand, increase the amount and quality of water supply and sewerage infrastructure, as well as develop a flood protection system [5; 6]. Heavy rainfall in urban areas causes local flooding, which is becoming more and more intensive and repeats more and more often [7-10]. In flood events the most vulnerable social groups of societies suffer, as well as material losses during the flood events each year are several billions [11; 12]. The European Union flood risk mitigation measures are regulated by the Flood Directive (2007/60/EC), which entails an obligation to the Member States to organize a flood risk assessment and risk areas mapping [13]. At the scientific level, the understanding of the urban area hydrological regime is currently being designed and developed using monitoring data and modeling of the opportunities offered, but there is a need for a longer monitoring period at least two decades, during which to accumulate data of hydrological regimes in urban areas [14-17]. Modelling of urban catchment hydrological regime is difficult because of the fragmented environment with specific hydrological response, and so far, there is no clear understanding of the rain circulation cycles of the urban environment [18]. Bach et al.[19] highlighted the need to classify urban watershed integrated models and recommended to develop the model classification according to the degree of integration. However, there are ongoing discussions about the universal concept of the water cycle at watershed level and development of common methodology.

In Latvia, there was developed a conceptual hydrological model METQ [21; 22] with very good precision. Previous versions of models were developed for natural areas[22]. However, by growing urbanization of natural areas there is a need to integrate this hydrological response unit in hydrological models. The previous experience of integration of the hydrological response unit in the existing conceptual hydrological models shows good results [22-24]. Many researchers prefer manual calibration to increase the model performance [25-29]. The newest version of the METQ model is METQUL2012 where friendly interface and separated hydrological response units calculation modules are used [30].The aim of this research is to calibrate and validate the urban hydrological

response unit parameters of the conceptual hydrological model METQUL2012 and to give recommendations of the parameter integration in the model.

Materials and Methods

In Latvia, there are no data of discharge from the urban catchment areas. In the Northern part of Europe there was not a possibility to get enough long run-off and meteorological data set. In this research free access run-off and meteorological data from the United States Geological Survey (USGS) were used. Catchments with area from 9.76 till 183.63 km^2 from the cold climate zone where chosen. The location of the urban catchments is presented in Table 1. The smallest catchment is Valley Stream in New York City 9.76 km^2 and the largest catchment is Paint Creek in Detroit 183.63 km^2. The highest density of waterproof areas is in Valley Stream 95 % and Ecorse River 92 %.

Table 1

Characteristics of urban catchments

USGS Number	US State	Name	Latitude	Longitude	Density of waterproof areas, %	Drainage area, km^2	Shortening
01302020	NY	BRONX RIVER	40°51'44"	73°52'27"	74 %	99.45	NY_BO
01311500	NY	VALLEY STREAM	40°39'49"	73°42'16"	95 %	9.76	NY_VA
04168580	MI	ECORSE RIVER	42°16'10"	83°17'23"	92 %	25.90	MI_EC
04161540	MI	PAINT CREEK	42°41'18"	83°08'35"	56 %	183.63	MI_PA
12113346	WA	SPRINGBROOK CREEK	47°25'53"	122°13'35"	71 %	21.86	WA_SP
12113349	WA	MILL CREEK	47°25'49"	122°14'31"	86 %	14.58	WA_MI

Table 2

Climate of calibration and validation period of urban catchments

Station	Parameters	Calibration period				Validation period			
		2008	2009	2010	2011	2012	2013	2014	2015
NY_BO	Annual average temperature, °C	11.1	10.7	11.9	11.9	12.7	11.4	10.7	11.4
NY_VA		11.1	10.7	11.9	11.2	12.6	11.3	10.7	11.4
WA_SP		9.2	9.8	10.4	9.3	10.0	10.1	10.9	11.5
WA_MI		9.2	9.8	10.4	9.3	10.0	10.1	10.9	11.5
MI_EC		8.3	8.1	9.5	9.0	10.5	8.2	6.9	9.0
MI_PA		8.3	8.1	9.5	9.0	10.5	8.2	6.9	9.0
NY_BO	Annual sum of precipitation, mm	1382.2	1402.0	1068.3	1143.9	1104.3	1044.2	1224.7	899.3
NY_VA		1382.2	1402.0	1068.3	1143.9	1104.3	1044.2	1224.7	899.3
WA_SP		653.4	1228.6	1800.6	1327.1	1785.8	704.8	1435.5	1230.0
WA_MI		653.4	1228.6	1800,6	1327.1	1785.8	704.8	1435.5	1230.0
MI_EC		720.0	714.9	635.4	1085.0	527.3	1318.8	712.4	569.1
MI_PA		720.0	714.9	635.4	1085.0	527.3	1318.8	712.4	569.1
NY_BO	Annual minimal run-off, $m^3 \cdot s^{-1}$	0.566	0.510	0.340	0.481	0.340	0.280	0.397	0.340
NY_VA		0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.000
WA_SP		0.034	0.054	0.082	0.099	0.127	0.108	0.110	0.014
WA_MI		0.006	0.016	0.024	0.040	0.025	0.037	0.028	0.000
MI_EC		0.005	0.011	0.018	0.014	0.007	0.014	0.010	0.012
MI_PA		0.425	0.538	0.283	0.397	0.249	0.397	0.623	0.368
NY_BO	Annual maximal run-off, $m^3 \cdot s^{-1}$	21.637	23.562	31.718	62.587	13.650	26.054	30.302	18.068
NY_VA		1.529	1.218	2.322	3.257	0.595	1.359	2.322	0.736
WA_SP		3.030	3.285	4.191	2.605	2.209	3.993	1.926	3.257
WA_MI		3.767	4.475	4.843	3.512	3.144	4.050	3.597	4.729
MI_EC		5.296	4.588	7.335	6.542	3.342	3.852	7.477	3.653
MI_PA		16.709	12.433	7.307	11.328	7.392	15.859	10.563	7.816

The air temperature, precipitation and humidity data were used from the closest meteorological station in USGS data base.The air temperature, precipitation and humidity of calibration and validation periods are presented in Table 2. All six catchments represent cold climate with different continentality. The annual average air temperature is higher in New York City (NY_BO and NY_VA) and lower in Detroit (MI_EC and MI_PA). The annual precipitation varies from 527.3 in Detroit to 1785.8 (MI_EC and MI_PA) mm in Seattle (WA_SP and WA_MI).The calibration of the parameters of the urban hydrological response unit was made according to the flowchart presented in Figure 1.

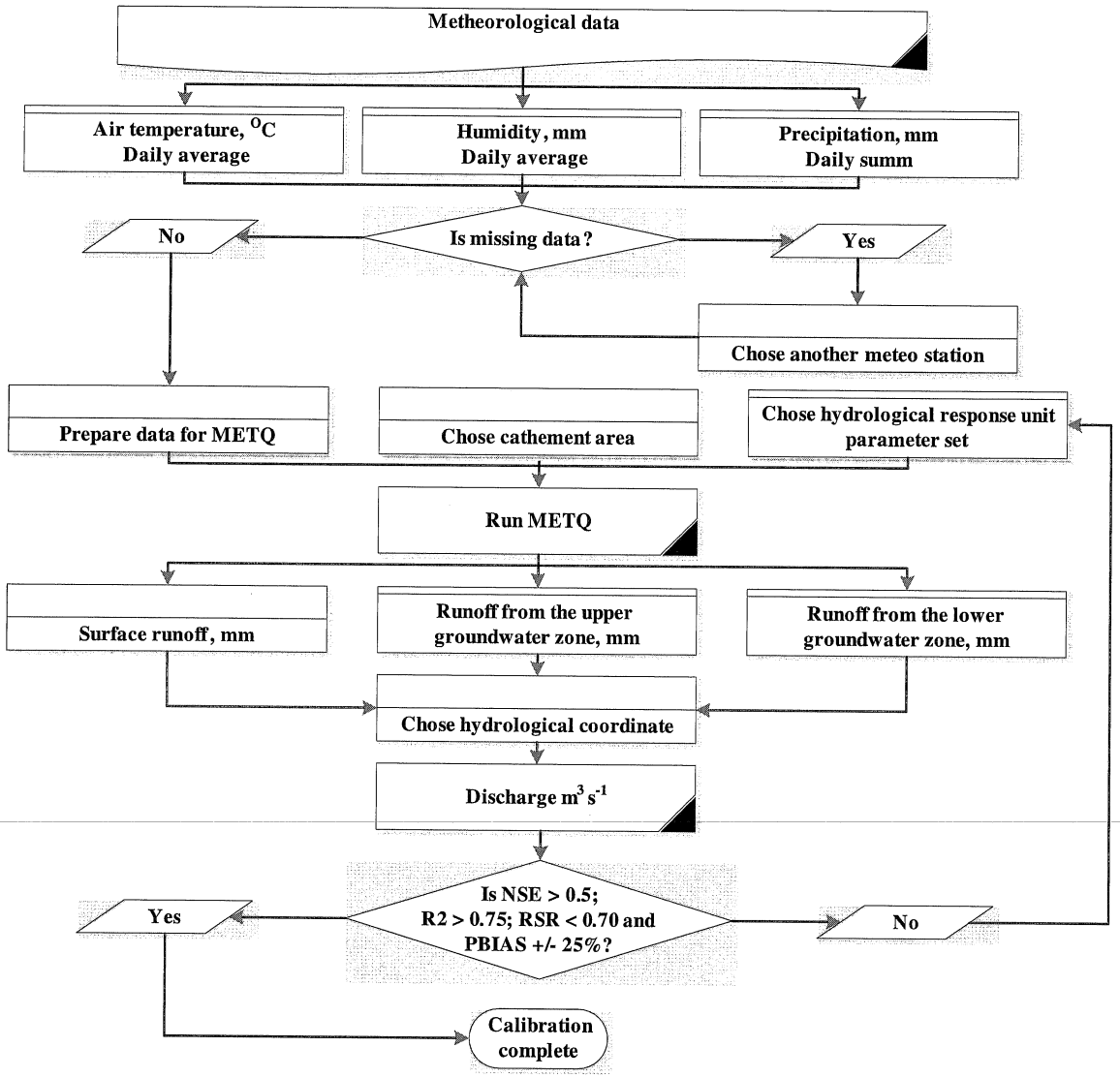


Fig. 1. **Flowchart of urban hydrological response unit calibration steps**

The conceptual hydrological model METQUL2012 calculates discharge of each hydrological response unit using the daily temperature, precipitation and humidity data. The calculation algorithm consists of 23parameters: WMAX; ALPHA; ZCAP; A2; A3; KU; KL; CMELT; T1; T2; KS; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; WHC; CFR; DPREC; AMCOR; BETA[20;21].The model METQUL2012 does not accept missing data, the meteorological data from the United States Geological Survey (USGS) were tested for the missing values. The Meteorological data set was uploaded in the model. All catchments are in urban areas, this means the catchment area is the urban hydrological response unit area. The hydrological response unit parameters were calibrated using MonteCarlo simulations and manual calibration of the parameters. To evaluate the calibration results the Nash–Sutcliffe efficiency index (NSE) [31], which is commonly used in hydrology, determination coefficient R^2[32], percent bias (PBIAS) [33], ratios the root mean square error to the standard

deviation of the measured data (RSR) [34] in addition to the graphical method were used. The recommended limits by Moriasi [35] is NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 %.

Results and Discussion

For all catchments, totally 30240 simulations of discharge were done. The best calibration results and verification results are presented in Table 3. The Nash–Sutcliffe efficiency index (NSE) is acceptable [35]and varies from 0.69 to 0.96 for the calibration period and from 0.67 to 0.91 for the validation period. The R^2 is acceptable for all catchments for all periods [35]and varies from 0.81 to 0.98 for the calibration period and from 0.79 to 0.95 for the validation period.

Table 3

Results of calibration of model METQUL2012

Catchment	Calibration period				Validation period			
	NSE	R2	RSR	PBIAS	NSE	R2	RSR	PBIAS
NY_BO	0.69	0.81	0.69	-23.63	0.67	0.79	0.70	-24.87
NY_VA	0.78	0.91	0.47	11.67	0.79	0.91	0.44	10.18
WA_SP	0.82	0.93	0.31	-3.03	0.80	0.92	0.30	-3.48
WA_MI	0.96	0.98	0.21	-1.07	0.91	0.95	0.24	-2.11
MI_EC	0.76	0.87	0.43	14.86	0.73	0.84	0.49	16.36
MI_PA	0.72	0.84	0.40	17.01	0.75	0.87	0.42	15.28

The NY_BO shows better modelling results at the calibration period, however, MI_PA shows to be better fit for the validation period than for the calibration period. Several factors influence the model fit: the precision of the precipitation data; the discharge measurement precision and the conditions of the riverbed.

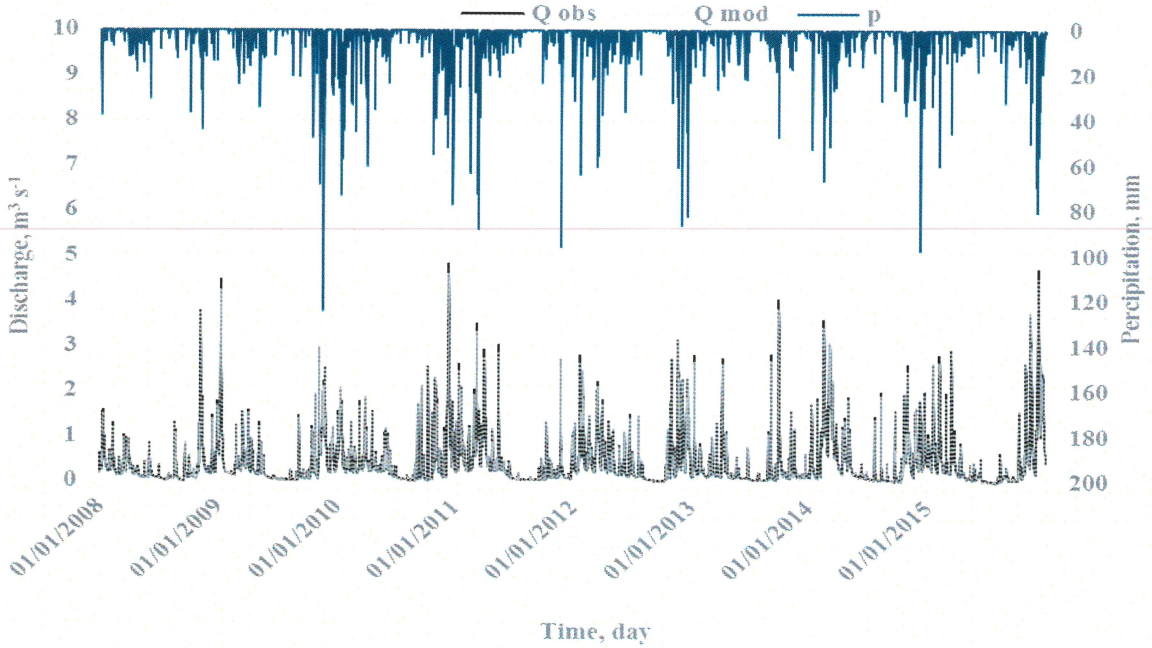


Fig. 2. **Modelled and observed discharge and percipitation of WA_MI cathement**

The conceptual hydrological model METQ parameters (A2; A3; CMELT; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; DPREC; AMCOR; BETA) can be calibrated for rural catchments [21] and other parameters are constant. During calibration of the urban hydrological response unit parameters there was made a decision to calibrate additional parameters (WMAX; ALPHA; ZCAP; KU; KL; T1; T2; KS; WHC; CFR; AMCOR). In urban areas, there is high heterogeneity of the surface and disturbed stream formation as well as different microclimate [36]. The best fit of the modelled and observed discharge is presented in Figure 2. The modelled and

observed discharges show good fit, however there are underestimation or overestimation of discharge. This uncertainty is related with measurement precision and rain event distribution in the catchment area.The parameters WMAX, ALPHA, ZCAP, T1, T2, KS, DZ, PZ, DPREC, BETA show significant variance - larger than 20 % between the catchments and in some cases more than 40 %. The variation is related with heterogeneity of the land cover, historical development of the storm water collection system and urbanization density [36]. There is a need to classify urban catchments by covered areas and develop at least three urban hydrological response unit parameter sets and integrate the calculation algorithm in the conceptual hydrological model METQUL 2012.

Conclusions

1. The calibration and validation results of the urban hydrological response unit parameters weresatisfactory and achieved the recommended limits NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 % for all six catchments.
2. There is variation of the parameter values between the catchments, which is related to the urbanization level and hydrogeological conditions of the catchment.
3. It is recommended to classify urban catchments by covered areas and develop at least three urban hydrological response unit parameter sets and integrate additional calculation algorithms in the conceptual hydrological model METQUL 2012.

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THE CHANGES OF LAKE HYDROLOGICAL CYCLE: A CASE STUDY OF LAKE USMA IN LATVIA

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ABSTRACT

Lake Usma is unique with hundred years' old nature reserve and Natura 2000 territories in one part of the lake and developing the tourism industry in other part of the lake. During last ninety years, the water level of Lake Usma increased for approximately one meter, which caused coast erosion, changed soil ground water level in large territories around it and it is regarded to be a major factor for lake ecosystem functioning. To find sustainable management solution of Lake Usma, there is a necessity to understand causes of hydrological cycle changes. The aim of this study is to evaluate an anthropogenic impact of Lake Usma hydrological regime.

In this research work to test the impact of anthropogenic factors, the lake water level data are divided into three separated periods: the first time period (1927 – 1960) before a significant anthropogenic impact, the second period (1961 – 1990) after amelioration and while constructed eel weir (1966) and the third period (2002 – 2003, 2011 – 2014) after hydroelectric station started its work. The first-period of monthly lake level data shows typical North Europe lake hydrological cycle, with the highest level at the end of April or at the beginning of May. Mean water level reaches about 20.70 m B.S. and minimum monthly water level – 20.20 m B.S. The second period shows the rise of water level. The highest water level observed at the beginning and the end of the year, because of high precipitation in this time. Mean monthly water level reaches about 21.10 m B.S. and minimum water level about 20.60 m B.S. In the third period there is observed the highest water level on March and in the summer the gap between maximum, mean, minimum and quartiles is limited, which shows very slight level amplitude. It indicates that hydrological cycle is changed. Mean water level is still about 21.10 m B.S., but minimum monthly water level reaches 20.80 m B.S. The result shows a significant impact of anthropogenic and natural factors.

Keywords: water level; hydrological cycle; anthropogenic impact

INTRODUCTION

The Lake Usma is the fourth largest lake in Latvia and locates in West part of Latvia 20.6 m above the sea level (Figure 1). The surface area of lake is 37.2 km^2 (with seven islands 41.4 km^2).



Figure 1. Location of the study area

There are ten inflowing rivers of Lake Usma and the the only outflow is the River Engure which flows into the Lake Puze. The total drainage area of the study site is 425 km^2. The climate is temperate, cool and humid. The mean temperature is -3.5 °C in January and +16.5 °C in July. The average amount of precipitation is 750 mm per year.

The drainage basin of Lake Usma is characterised by high percentage of forests - 50% cover of the entire basin.

Lake Usma is unique with hundred years' old nature reserve and Natura 2000 territories. The second oldest nature reserve in Europa and oldest in Latvia is located on Moricisland and Lielalksnītes island of Lake Usma. Moricsala nature reserve is founded in 1912. Viskūžu island is the largets island of the Lake Usma and laso in Latvia and its territory is under Nature 2000 [4].

The present situation of Lake Usma mainly is connected with water level rise during last forty years. First significant changes of water level of Lake Usma were observed in 1966 [5]. During this period eel migration net were build on the River Engure (Figure 2). Another cause of lake water level rise could be small hydropower stations which are build also on the River Engure in 2001 (Figure 2).

The aim of this study is to determine an anthropogenic impact of Lake Usma water level fluctuactions.

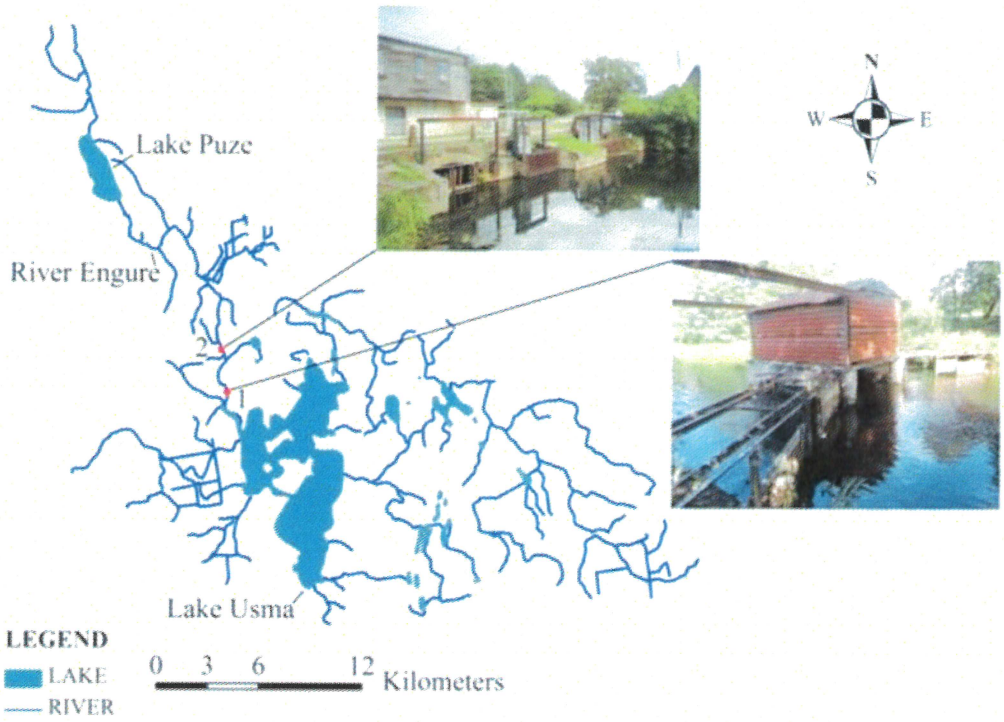


Figure 2. The drainage basin of the Lake Usma and location of small hydropower stations (2) and eel migration net (1) on the River Engure

Also the fluctuations of lake water level are affected by long – term changes of hydrological regime of lake [7], [10].
Over the past few years there are done several researches of anthropogenic impact on the lake water level [2], [3], [6], [9] and [11].

MATERIALS AND METHODS

In this study lake water level and precipitation data were analysed for period 1927 – 2014. Data were obtained from the Latvian Environment, Geology and Meteorology Centre.

Three periods were selected for the data series analysis: 1927 – 1960, 1961 – 1990, and 1991 – 2014. The Standard Normal homogenity test was used for homogeneous monthly data series of precipitation and lake water level [1].

For the trend analysis monthly mean, maximum and minimum time series were used. Trends in the time series of water level at Lake Usma hydrological station are analysed using Descriptive statistics [8].

RESULTS AND DISCUSSIONS

The daily data of Lake Usma water levels were analysed using simple statistics to identify water level fluctuation during year. The mean, minimal, maximal, 1st quartile and 3rd quartile of yearly water level fluctuations are presented in figure 3. The yearly mean of water level fluctuations is with positive trend. There are four maximums of water levels in Lake Usma. The first period is at the beginning of monitoring period from year 1926

till 1930. The second maximum is at year 1952 and it van be explained with beginning of land reclamation and installations of drainage systems in agricultural fields. The third extreme yearly maximums of water level are at 1980. It can be explained with very wet and cold climate conditions. The second extreme maximum of yearly water level is at 2002. It is none year after installation of hydropower station on Engure river. The yearly minimum of water level is over 20.60 m since year 1960.

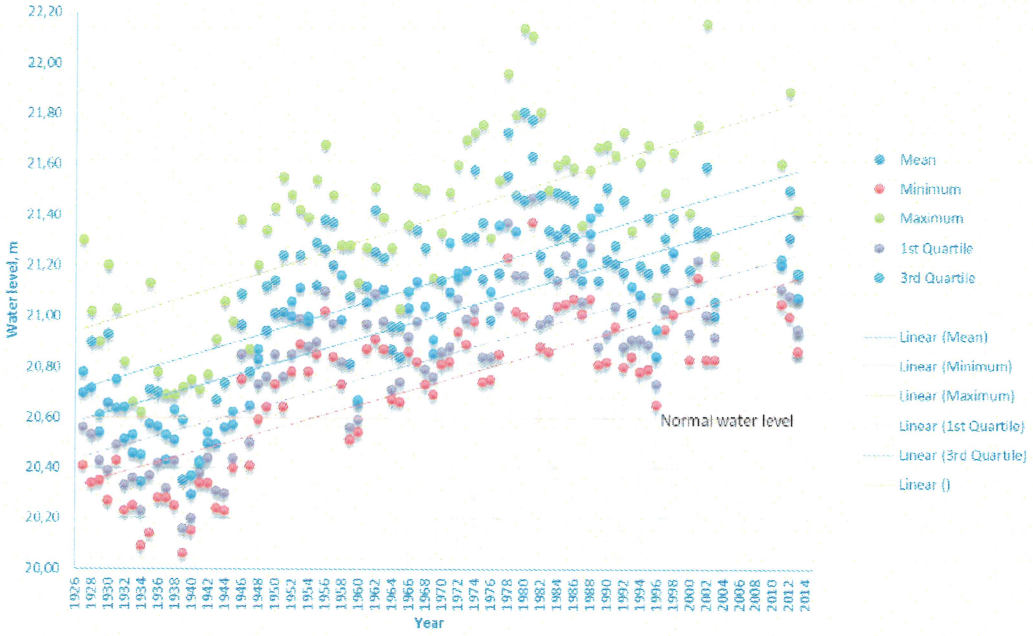


Figure 3. The yearly water level daily data analysis of Lake Usma yearly water level fluctuations

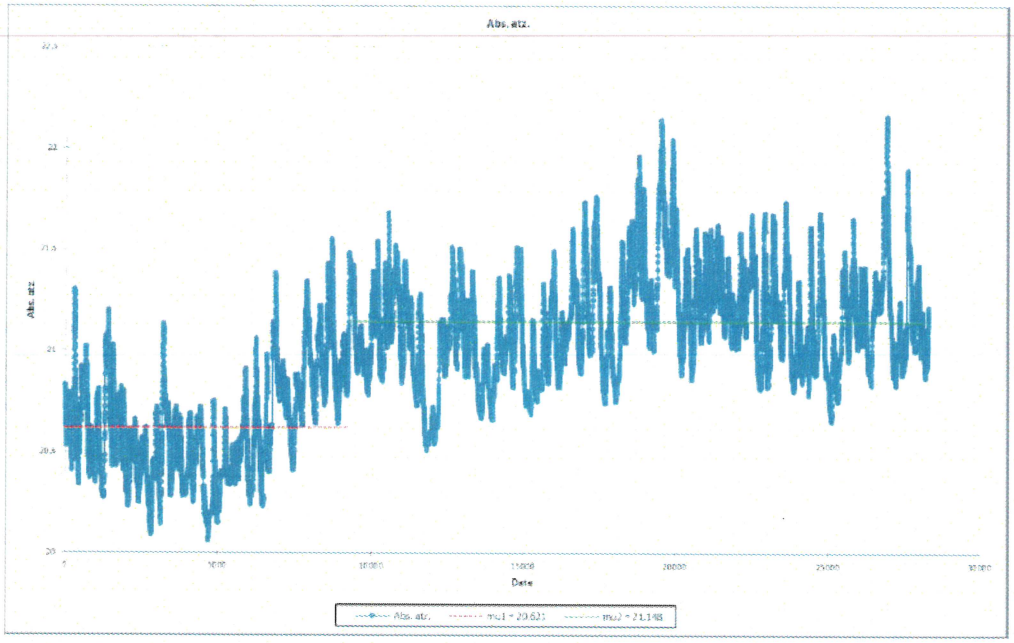


Figure 4. The heterogeneity test of daily water level fluctuation of Lake Usma

The water level fluctuations were analysed using homogeneity test. The results of homogeneity test show two periods and the change of periods are related with time when eel migration net was installed. The homogeneity test results show that eel migration net installation increased average water level by 50 cm (see Figure 4).

The daily water level data were spited in three periods to identify possible anthropogenic impact on Lake Usma water level fluctuations. The first period is from beginning of Lake Usma water level monitoring at 1927 till beginning of climate reference period at 1960. The second period is classical climate reference period from 1961 till 1990. The third period is since 1991 till 2014. Before reference period 1927 – 1960, reference period 1961 – 1990, climate change period 1991 – 2014 (see figure 5).

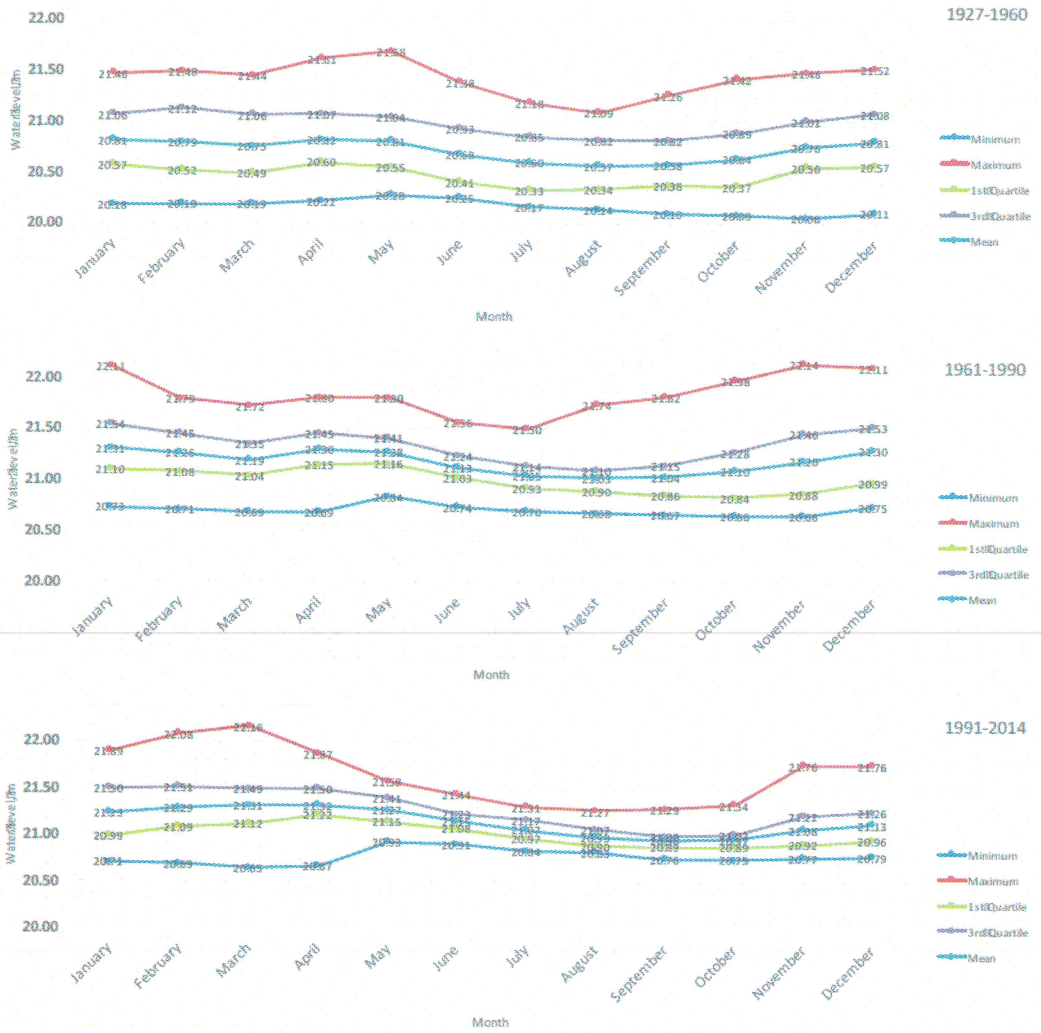


Figure 5. The monthly water level fluctuation of Lake Usma for three periods, before climate reference period 1927 – 1960, climate reference period 1961 – 1990, climate change period 1991 – 2014.

The first period from beginning of monitoring at 1927 till 1960 show spring and autumn maximums and summer and winter minimums. The highest water level of this period is

in spring at April and May and autumn at December and January. The minimal lake water levels fluctuate between 20.06 m in November and 20.28 m in May. The maximal lake water levels of first period is in May 21.68 m and in December 21.52. The amplitude of water level distribution is stable during all year approximately 0.5 m. The water level of Lake Usma is fluctuating according to climate conditions.

The analysis of water level of second period show significant changes. The minimal water level of second period fluctuate between 20.84 at May and 20.66 at October and November. The maximal water level of second period shifted from spring to winter November (22.14 m) December (22.11 m) and January (22.11 m). It can be related with impact of Baltic see and Climate changes when during wintertime is snow melt and there is very low evapotranspiration. The amplitude of water level distribution is not stable during the year. There is wide amplitude 0.6 m during November and December and during summer from May till August it is 0.3 m.

The analysis of water level of third period show more significant anthropogenic impact. The minimal water level of third period fluctuate between 20.93 at May and 20.65 at March. The maximal water level of third period is at March (22.16). The amplitude of water level distribution is in small amplitude from 0.11 m in September till 0.5m in January. During this period the anthropogenic impact is related with hydropower station installation. Where Lake Usma work as reservoir.

CONCLUSION

The analysis of water level of Lake Usma show significant changes since beginning of monitoring period. There is positive trend of minimal, maximal and average water levels. The water level of Lake Usma increased by 0.8 m during monitoring period.

The homogeneity test show two periods. The change of water level of Lake Usma is related with time when eel weir was installed. The homogeneity test results show that eel weir installation increased average water level by 0.5 m.

The analysis of three climatic periods show increase of anthropogenic impact on Lake Usma. The monthly minimal lake water levels fluctuate between 20.06 m in November and 20.28 m in May during first period. The minimal water level of second period fluctuate between 20.84 at May and 20.66 at October and November. The minimal water level of third period fluctuate between 20.93 at May and 20.65 at March. The significant rise of minimal water levels of Lake Usma is related with outgoing flow disturbance by eel weir and hydropower station.

The analysis of 1st quartile and 3rd quartile distance show increase of anthropogenic impact on Lake Usma. The amplitude of water level distribution of first period is stable during all year approximately 0.5 m. The water level of Lake Usma is fluctuating according to climate conditions. During second period there is wide amplitude 0.6 m during November and December and smaller during summer from May till August it is 0.3 m. This is evidence of eel weir impact on Lake Usma water level. The amplitude of water level distribution is in small amplitude from 0.11 m in September till 0.5m in January. During this period the anthropogenic impact is related with hydropower station installation. Where Lake Usma work as reservoir.

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THE IMPACT OF LANDSCAPE STRUCTURE OF CATCHMENT AREA ON LAKE HYDROLOGY

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ABSTRACT

One of the most investigated topics in hydrology, during last decades, is climate change impact on hydrological cycle. Changes in the use of land is additional factor influencing hydrological regime and watershed run-off. To understand urbanisation and climate change cumulative impact on watershed run-off, modelling of different climate change and land use scenarios would be essential. The aim of this study is to investigate how watershed run-off of the Usma Lake, located in Kurzeme region of Latvia, will respond to urbanisation and climate change using conceptual hydrological model METQ. To quantify watershed run-off changes, eighteen climate change scenarios (from very low to very high) and two linear urbanisation scenarios (low and high) analysed. Totally thirty-six climate-urban scenarios modelled, using conceptual hydrological model METQ. The results of climate-urban scenarios reviled, that extremely high watershed run-off events are more related with rain events than snow melting. The minimal watershed run-off periods become longer and with more often frequency. The urbanisation have significant impact on extreme watershed run-off values. The peaks of watershed run-off become more extreme and low watershed run-off (in some cases) are close to zero.

Keywords: Conceptual hydrological model METQ, climate change, urbanisation, cumulative effect

INTRODUCTION

The natural hydrological cycle is complex system with several components (Fig. 1) we can divide three most important components: precipitation, evapotranspiration and run-off. One of the most investigated topics in hydrology during last decades is climate change impact on hydrological cycle [1], [2]. The human activities and growing economies impact not only climate but also change land surface and transform natural areas to urban as well as overuse water resources and nowadays each component of hydrological cycle have anthropogenic impact (Fig. 2). Changes in the use of land is additional factor influencing hydrological regime and watershed run-off.

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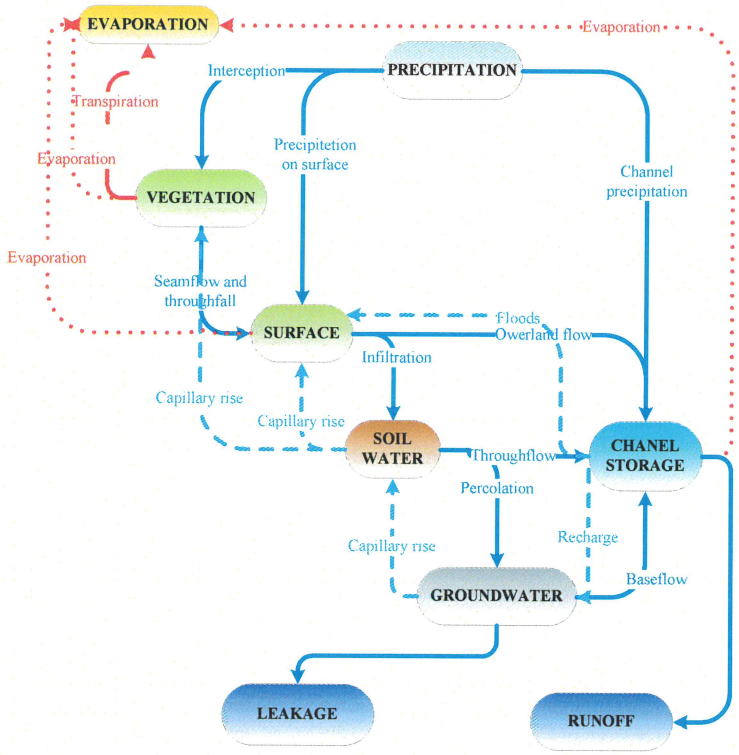


Figure 1. The natural hydrological system of the watershed [7]

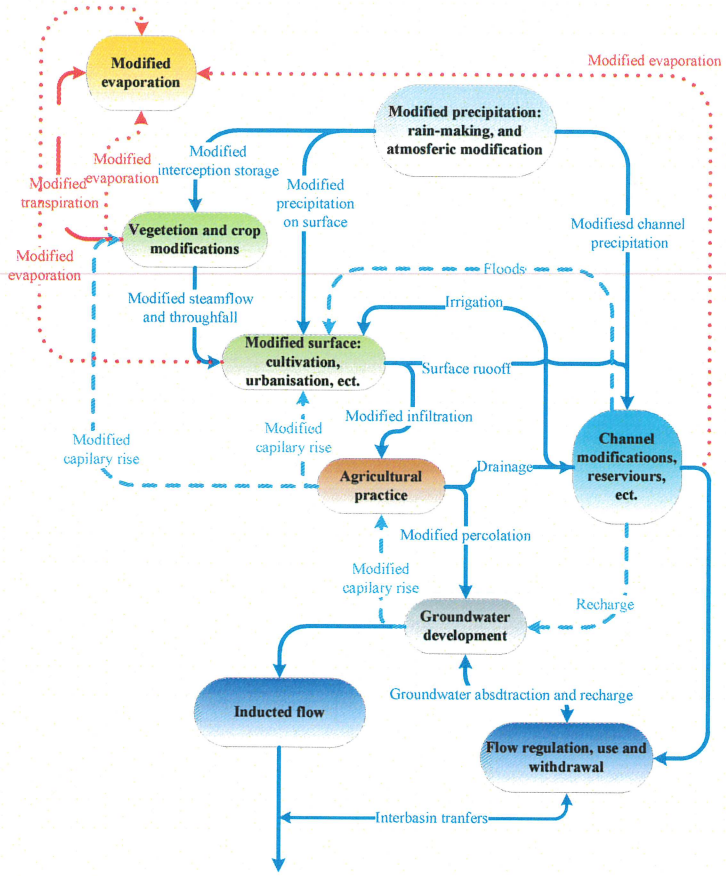


Figure 2. The anthropogenic hydrological system of the watershed [7]

To understand land use changes of lake drainage basin and climate change cumulative impact [3] on watershed the modelling of run-off of different climate change and land use scenarios would be essential [4], [5] [6]. The aim of this study is to investigate how watershed run-off of the Usma Lake, located in Kurzeme region of Latvia (Fig. 3), will respond to urbanisation and climate change using conceptual hydrological model METQ.



Figure 3. The location of the Usma Lake watershed

MATERIALS AND METHODS

To quantify watershed run-off changes, twelve climate change scenarios (from very low to very high) and two linear urbanisation scenarios (pessimistic and optimistic) analysed [8]. The conceptual framework of research is presented in Figure 4.

To develop linear land use models the GIS systems were used to evaluate land use structure in Usma Lake watershed. The spatial information analysis were made for three time periods. The first time period from year 1924 to year 1935 is characterized by economic development of Latvia Republic with relatively intensive agriculture. The second time period from year 1940 to year 1990 is characterised by consolidation of land and intensive development of land drainage systems. The third time period from year 1991 to year 2015 is characterized by forest cutting and abandonment of agricultural lands. The future land use projections of pessimistic scenario (PES) were modelled using existing trends where agricultural land transforms to forest land. The optimistic (OPT) scenario were developed using existing urbanization trend in Europe Union.

The conceptual hydrological model METQUL2012 calculates discharge of each hydrological response unit using daily meteorological data. In the calculation process are taken into account 23 parameters: WMAX; ALPHA; ZCAP; A2; A3; KU; KL;

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CMELT; T1; T2; KS; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; WHC; CFR; DPREC; AMCOR; BETA. Totally twenty-four climate-urban scenarios modelled, using conceptual hydrological model METQUL2012 [9], [10], [11].

The results of modelled daily run-off were analyzed for 30 years time period from year 2070 till year 2100. The daily run-off of 30 year period for each month were analysed using descriptive statistics and 1st Quartile, Median and 3rd Quartile of daily run-off was calculated for each month. The results for each climate scenario were displayed according to pessimistic (PES) and optimistic (OPT) land use scenarios.

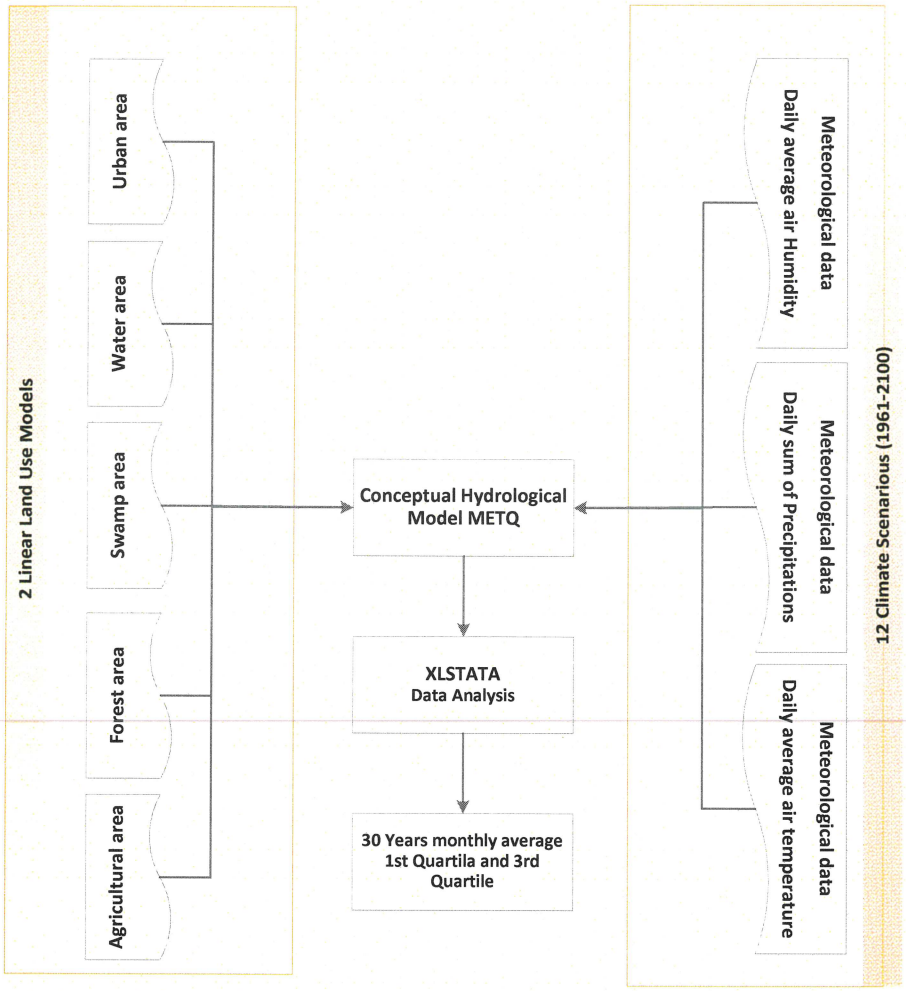


Figure 4. Conceptual framework of land use and climate change cumulative impact on drainage basin run-off assessment

RESULTS AND DISCUSSIONS

The results of GIS analysis for three time periods by actual area km^2 and proportion is presented in Table 1. The total forest land area is increased by 15.41 %, the agricultural land area is decreased by 12.83 %. The time period from year 1991 to year 2015 differ by increasing clearcutting forest areas and by decreased swamp areas as result of intensive land drainage system development during from year 1940 to year 1990. The

proportion of urban areas is decreasing and it is related with development of living areas in village centre and abandonment of rural small farm areas from year 1940 to year 1990.

Table 1. Land use in the catchment area of the Lake Usma

Types of land use	1924-1935 (years)		1940-1990 (years)		1991-2015 (years)	
	km²	%	km²	%	km²	%
Forests	226.59	56.98	274.21	68.95	265.09	66.66
Clear cuts of forests	7.35	1.85	3.28	0.82	30.12	7.57
Total forest area	233.94	58.82	277.49	69.78	295.21	74.23
Agriculture lands	94.90	23.86	61.32	15.42	43.87	11.03
Water bodies	6.29	1.58	6.47	1.63	6.85	1.72
Swamps	18.42	4.63	9.10	2.29	8.88	2.23
Urban areas	5.47	1.38	4.64	1.17	4.20	1.06

The spatial distribution of land use at Usma Lake watershed by time periods is presented in Fig. 6; Fig. 7; Fig. 8. The land use have significant impact on hydrological cycle and increasing forest area proportion change lake hydrological regime [12], [13].

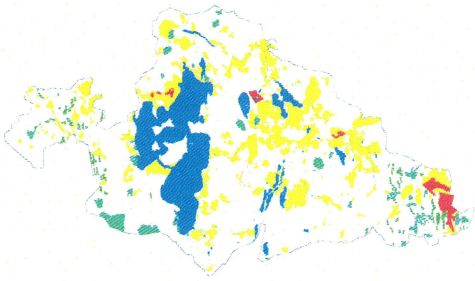


Figure 6. The Usma lake watershed land cover structure at time period (1940-1990)

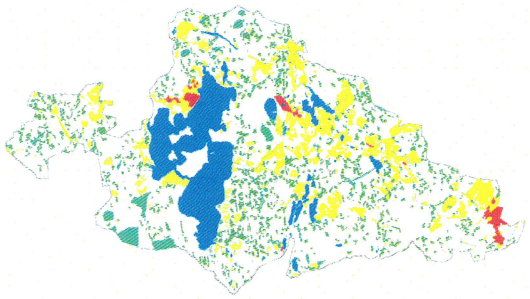


Figure 7. The Usma lake watershed land cover structure at time period (1991-2015)

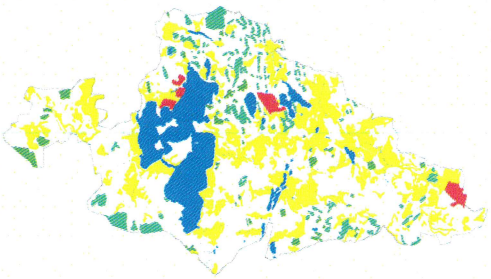


Figure 8. The Usma lake watershed land cover structure at time period (1924-1935)

Forests	
Water bodies	
Swamps	
Agricultural Lands	
Clear cuts of forests	
Populated areas	

Legend for the land cover maps

The results of climate-urban scenarios reviled that extremely high watershed run-off events are more related with rain events than snow melting. The minimal watershed run-

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off periods become longer and with more often frequency. The 30 years monthly average monthly 1st Quartile and monthly 3rd Quartile of time period from 2070 till 2100 climate scenarios with pessimistic and optimistic land use scenarios is presented in Figure 9. The urbanisation have significant impact on watershed run-off in all climate scenarios. The urbanisation increase monthly average runoff during winter and spring. The 3rd Quartile show strong evidence of run-off events during summer [10], [11].



Figure 9. The 30 years monthly average, monthly 1st Quartile and monthly 3rd Quartile of time period from 2070 till 2100 climate scenarios with pessimistic and optimistic land use scenarios.

CONCLUSION – <u>min 1000/1500 char</u>

The research results show significant land use change impact on Usma Lake hydrological regime in all twelve climate scenarios. In ten climate scenarios, the run-off 3rd Quartile of pessimistic scenarios and 1st Quartile of optimistic scenario do not overlay in December, January, February and March.

The urbanisation have significant impact on extreme watershed run-off values. The peaks of watershed run-off become more extreme and low watershed run-off (in some cases) are close to zero.

In all climate scenarios the run-off during cold period of the year is higher in optimistic land use scenario where proportion of urbanised area increase, this is explained by increased waterproof areas, decreasing of infiltration and lack of interception.

The pessimistic land use scenarios by increasing forest area in Usma Lake watershed can significantly impact Usma Lake hydrological regime in all twelve climate scenarios by decreasing total run-off which is related with evapotranspiration in forest areas.

The pessimistic land use scenario show in all climate scenarios decreasing run-off and future research can be focused on hydrological regime change impact on small hydropower efficiency.

ACKNOWLEDGEMENTS

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THE LAND USE AND CLIMATE CHANGE IMPACT ON LAKE USMA HYDROLOGICAL REGIME

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ABSTRACT

Changing climate variability and the type of land use are the main factors influencing the hydrological regime. The hydrological regime of the lake has a direct impact on biodiversity and has an impact on socio-economic processes in areas adjacent to the lake. The aim of the study is to predict and assess the impact of climate change and the change in the type of land use on the hydrological regime of Lake Usma. Two linear land-use change scenarios were used for modelling. Twelve climate scenarios were used to model climate variability. The modelling was carried out in two stages. First, METQ modelled the flows for sub-basins, each describing the type of land use using the conceptual hydrological model. The next step used land-use change scenarios to predict the flow rate for the period 2070-2100. The average, maximum and minimum flow-rate data rows for each scenario year were analysed to assess the expected changes in Lake Usma hydrological regime. The modelled average flow rates tend to grow in 7 out of 12 climate scenarios regardless of land use. The modelled maximum flow rates tend to rise in 10 out of 12 climate scenarios, regardless of land use. The modelled minimum flow rates have only 3 out of 12 climate scenarios, regardless of land use.

Keywords: climate, hydrological regime, land use, hydrological modelling

INTRODUCTION

In recent years, many researchers have studied the relationship between changes in land use and changes in the hydrological regime in the catchment areas [3]. Land use patterns and changes affect hydrological processes, resulting in changes in groundwater level depth, water infiltration rate in the bottom and evaporation, resulting in changes in surface runoff, water flow rate and flood risk [5], and the area climate [2]. The economic activity of humans has a significant impact on soil properties, which affect hydrological processes [2]. Studies have shown that changes in evaporation and surface runoff are directly influenced by the type of land use [2]. A better understanding of the hydrology of the catchment areas and the relationship between changing the type of land use and relative changes in total evaporation and the formation of surface drainage

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helps local authorities to take decisions on sustainable management of the catchment area [3].

The aim of the study is to predict and assess the impact of climate change and the change in the type of land use on the hydrological regime of Lake Usma.

MATERIALS AND METHODS

2.1. Description of Lake Usma

Lake Usma (57 ° 12 'Z. p. 22 ° 10' a.) is located in the lowlands of Kursa, in the river basin of Irb, 20.6 m v.j.l., and its mirror surface area is 37.2 km^2, the area of the catchment area 396 km^2 [1]. Lake Usmas is by volume the second largest lake in Latvia (210 million m^3) [1], and 100 million m^3 of water flows into the lake during the year, meaning that the exchange of water takes place every two years [4]. The hydrographic network of the catchment area of Lake Usma consists of ten small rivers – Mazupe, Godele, Vāržupīte, Melncelma, Meķupe, Sērža, Ostupe, Baņģeva, Struncene, and Kāņupe, while the runoff of the lake is composed of only one source – the Engure River, which in turn flows into Lake Puze, the runoff of which lies along the Rinda and Irbe rivers to the Baltic Sea [4]. The maximum depth of Lake Usma is 27 m, with an average depth of 5.4 m [1]. The lake's surrounding area comprises one of the largest forest areas in Latvia, i.e. more than half of the catchment area of Lake Usma is covered by forest areas, including the islands of the lake also surrounded by forest. In many places, the shores of the lake are intact, slightly altered. Around 20% of the catchment area of Lake Usma is occupied by farmland, less than 10% is occupied by swamps, under 10% by surface waters, and the same percentage is occupied by residential areas [4].

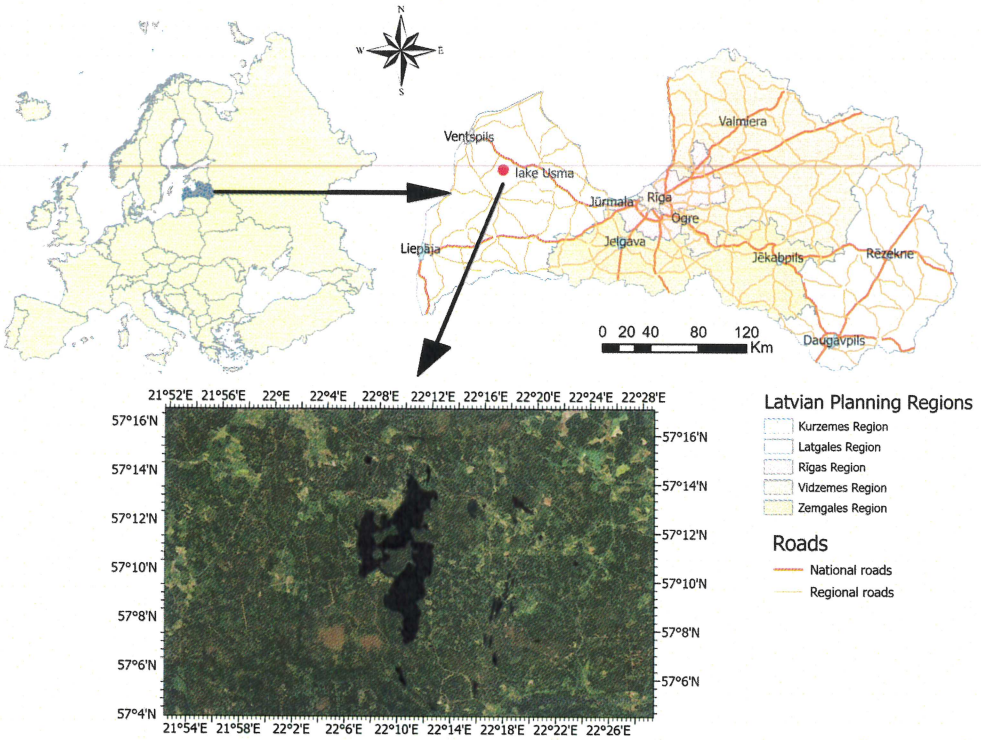


Figure 1. Location of the lake Usma

2.2. Hydrological and meteorological data

Hydrological data is derived from water level data measured by the surface water monitoring automatic station Usma. The trend observed in the reference period 1961-1990 for the changes in aggregate flow-rates values was adopted based on modelled aggregated flow rate data for the period 2070-2100.

Meteorological data shall be derived from the meteorological observation station Stende, which belongs to the Latvian Environment, Geology and Meteorology Centre (LVGMC) meteorological observation network, using meteorological data - air temperature, rainfall, etc. - during the reference period 1961-1990.

2.3. Modelled scenarios for land-use change and climate change

In the research work for the analysis of changes in the hydrological regime of Lake Usma, depending on human activity, changes in calculation rates over time (2070-2100) are modelled, with changes in land usage patterns over time one of the modelled 19 climate scenarios.

Depending on human activity, two future land-use scenarios in the catchment area of Lake Usma – optimistic and pessimistic – are modelled. It is assumed that, in the case of an optimistic scenario, the location of arable land and farmed land is increasing, as well as the average annual increase in urbanisation in Latvia, i.e. 0.01% per year. In contrast, in the case of the pessimistic scenario, an increase in the trend of forest areas modelled on the trend observed during the period 1990-2015 for the growth of forest areas in the catchment area of Lake Usma is modelled.

Modelled climate scenarios are taken from the database of the "Interbranch Scientist Group and Model System for Underground Waters Studies (PUMA)" project [6].

2.4. Statistical methods

Scientific research shall carry out a graphical analysis of quantitative data, a visible visual interpretation of the results obtained. Data processing uses the MS Excel computer program.

The data set available for the analysis of the results is modelled daily flow data from the lake from 2070 to 2100, where flow values are modelled for optimistic and pessimistic land-use scenarios, depending on the forecasts of the modelled climate scenarios. The values of the total flows were obtained using the mathematical model METQ2012.05.08. Annual calculation aggregate flows such as annual arithmetic average, maximum and minimum flows are analysed. For a representative graphical analysis of the data in the available set, 11 sample data are used to calculate the arithmetic mean values of average, maximum and minimum flow rates over decades.

In the research is used a regression analysis that determines how the resulting characteristic changes when the values of the actual feature change. The function describes the relationship between the factorial characteristic X and the resulting characteristic Y [4]:

$$y = b1x + b0, \quad (1)$$

where b1 – regression straight-line ratio,

b0 – non-member of the regression line

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The paper analyses the comparison of factor b 1 values for the trend (slope) of the decade's calculation flows between the optimistic and pessimistic land uses scenarios in each climate scenario. Regression lines are constructed for each graph, and function equations are compiled using the functions of the MS Excel computer program.

RESULT AND DISCUSSION

Changes in the modelled average flow rate mean values by decade, depending on the type of land use, are illustrated graphically in Figure 2 for each climate scenario.

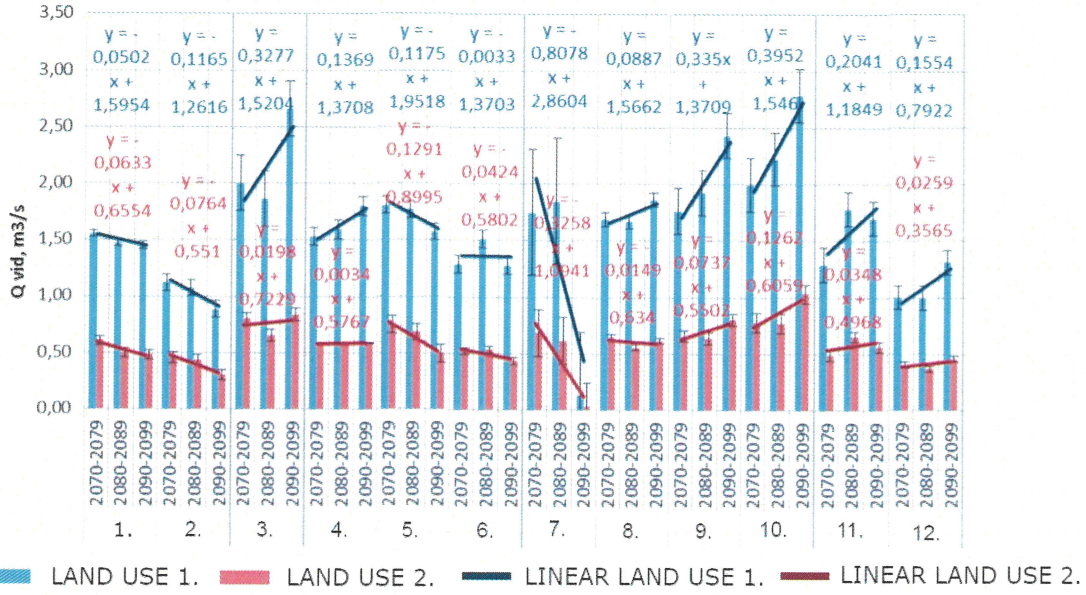


Figure 2. Changes in simulated mean flow-rate values

In the analysis of the trend of changes in average flow rate values and extreme climate scenario 7, the trend of negative flow rate increases is predicted in the case of an optimistic and pessimistic land-use scenario. A more considerable decrease in the flow-rate trend is expected for the optimistic land-use type scenario. The regression straight-line ratio b 1 pes = -0.8078, while for the pessimistic scenario b 1 opt = -0.3258. The average standard error of the sample for the sample of the optimistic scenario is Sxopt = ± 0.56; for the pessimistic scenario, Sxpes = ± 0.21.

Changes in the modelled arithmetic mean values of the maximum flow rate by decade, depending on the type of land use, are illustrated graphically in Figure 3 for each climate

scenario.

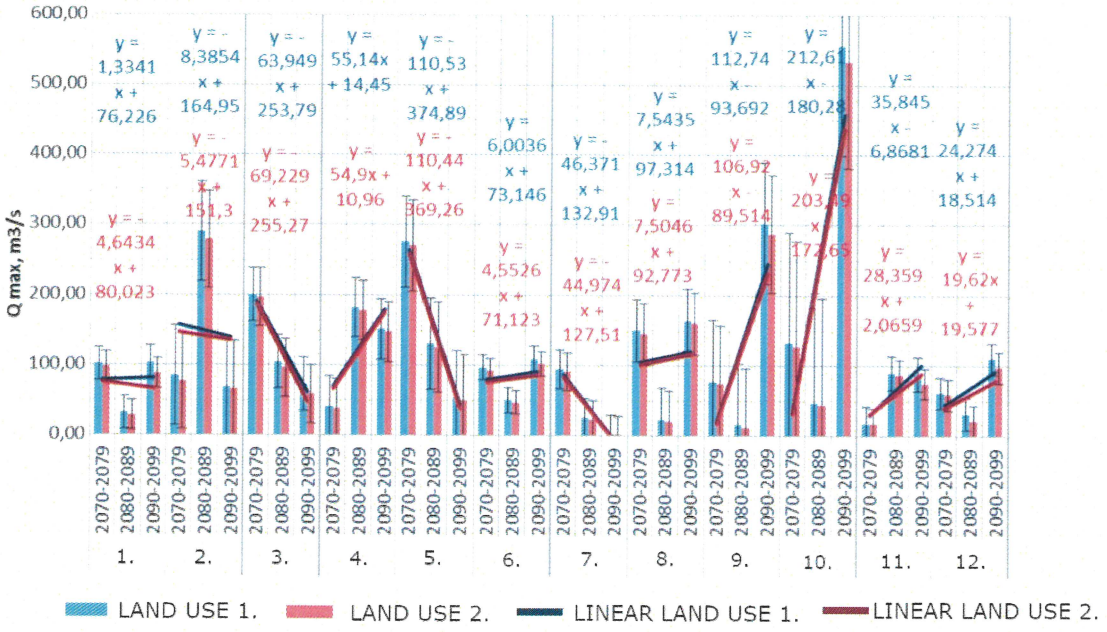


Figure 3. Changes in modelled maximum flow-rate values

In the analysis of the trend of changes in the maximum flow rate values and extreme climate scenario 10, the trend of positive rate increases is predicted in the case of an optimistic and pessimistic land-use scenario. A higher rate trend is expected for the optimistic land-use scenario, where the regression straight-line ratio b1opt = 212.6100, while for the pessimistic scenario b1pes = 203.4900. The average standard error of the sample for the sample of the optimistic scenario is Sxopt = ± 157.89; for the pessimistic scenario, Sxpes = ± 151.20.

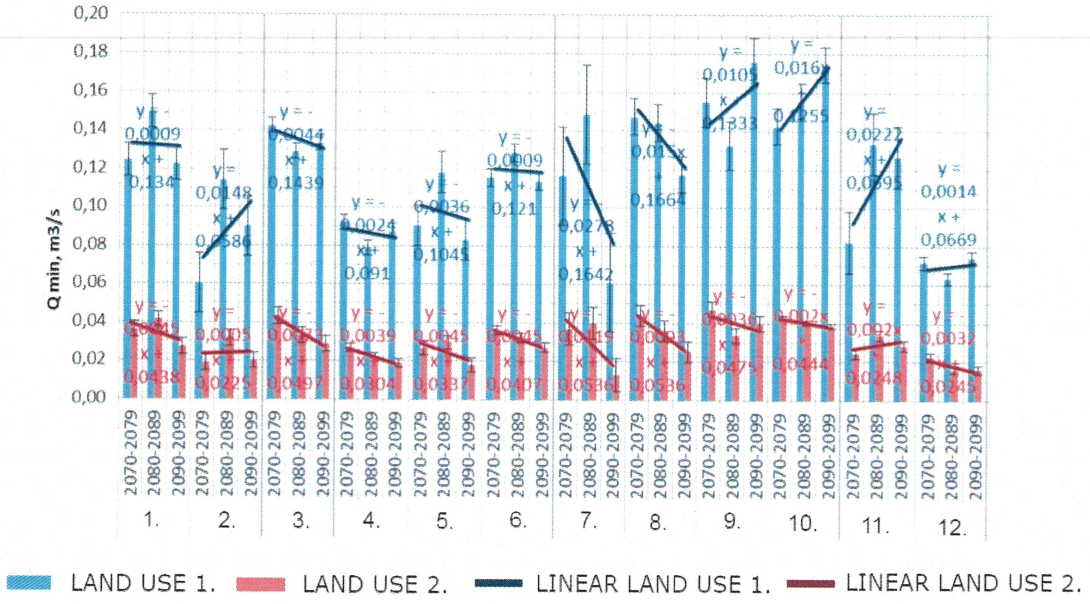


Figure 4. Changes in simulated minimum flow-rate values

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The changes of the simulated maximum flow average arithmetic values over decades depending on the type of land use for each climatic scenario are shown graphically in Figure 4.

Analysing the trend of changes in maximum flow values and extremes for the 7th climate scenario, a negative flow growth trend is predicted in the optimistic and pessimistic land-use scenario. A more significant decrease in the flow trend is expected for the optimistic land-use type scenario, where the regression line direction coefficient is b1opt = -0.0278, while for the pessimistic scenario - b1pes = -0.0119. The standard error of the sample is Sxopt = ± 0.0256 for the sample set of the optimistic scenario and Sxpes = ± 0.0085 for the pessimistic scenario.

CONCLUSION

1. The arithmetic mean values of the calculated flows of Lake Usma in most of the analysed climatic scenarios are predicted in the case of a higher optimistic land-use scenario, i.e. with an increase in agricultural land areas and an increase in urbanisation.

2. The modelled average flows of Lake Usma in the 30 years (2070-2100) tend to increase in 6 out of 12 climatic scenarios, regardless of the land-use scenario, but in the case of the 8th climate scenario, the flow trend is expected to increase due to the optimistic land-use scenario and a downward trend in the pessimistic scenario.

3. The maximum flows of Lake Usma modelled in the 30 years (2070-2100) tend to increase in 7 out of 12 climatic scenarios, regardless of the land-use scenario. Still, in the case of climate scenario 1, the flow trend is expected to increase due to the optimistic land-use scenario and a downward trend in the pessimistic scenario.

4. The modelled minimum flows for Lake Usma over the 30 years (2070-2100) tend to increase in only 2 out of 12 climatic scenarios, regardless of the land-use scenario, and in 2 out of 19 climatic systems, the flow trend is projected to increase due to optimistic land-use type of scenario and trend reduction - in the event of a pessimistic scenario;

5. Since the reference error values for modelled maximum, minimum (including average) flow rates (in the case of climate scenario 9) have an amplitude that does not indicate the statistical reliability of the analysis of actual results, further studies need to evaluate the analysis of results over shorter periods to determine the most appropriate sample data analysis, which is representative to the maximum and statistically general data.

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HYDROLOGICAL REGIME OPTIMIZATION MODEL FOR SUSTAINABLE MANAGEMENT OF LAKE: CASE STUDY OF TASU LAKE

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ABSTRACT

The increasing world population demand for bioeconomy products intensify the nitrogen cycle and encourage eutrophication in water bodies. Global climate change and land use transformation have a significant impact on the hydrological cycle. Integrated water management in the catchment area is a sustainable solution for catchment area development and balancing economic and environmental interests. The aim of this study is to develop an optimization model for sustainable lake management. The case study is done in eutrophic Tasu lake, located in the Southwest part of Latvia and is a part of the Alande river catchments basin. The optimization model for sustainable lake management was made in four steps. Firstly the lake bead was scanned by hydroacoustic stream meter RiverRay and data processed using WinRiver II data-processing software. Secondly, the verified data were used to develop a three-dimensional model of Tasu Lake. Thirdly, twelve climate scenarios and two land use transformation scenarios were used to model daily runoff for the period 1990-2099 using the conceptual hydrological model METQ. Finally, the three-dimensional model and modelled runoff data were used to optimize Tasu lake hydraulic parameters and develop optimal parameters for segmentation basin and constructed wetland. The results show the complexity and sensitivity of the lake hydraulic system and highlight the need for integrated catchment area management to balance economic and environmental interests.

Keywords: Integrated water management, hydrological regime, optimization model, sustainable nitrogen management

INTRODUCTION

Global climate change and land use transformation have a significant impact on the hydrological cycle [1]. Integrated water management in the catchment area is a sustainable solution for catchment area development and balancing economic and environmental interests [2]. Hydrological models of catchment areas are used to address environmental and water management issues, such as flood protection and security of hydro-technical structures [3], flood prediction [4], drought prediction [5], deterioration of the condition of the lakes [6], water resource management [7] and other issues[8].

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Tasu Lake is located in the administrative territory of Medze municipality in Grobina region. Lake, just like a river, is an open ecosystem, meaning that because of surface runoff, it is linked to large-scale territories. The waters of catchment area land extensive amounts of plant nutrients in lake water used by aquatic organisms - plants, animals, bacteria. The processes in the lake depend on the amounts of nutrients – dissolved substances in water, mainly phosphorus and nitrogen compounds. Tasu Lake is located in Rietumkursa upland Vartaja plain valley of Alande river. Tasu Lake is included in the Alande river basin from the river source to Eile spring, which flows in and out of the lake; however, Alande river and Tasu Lake are included in the Liepaja Lake catchment area and Venta river basin district. According to GIS data, the catchment area of Tasu Lake is 59.86 km^2. Forests cover 16.70%, and 10.97% are covered by bogs, and the open water surface area, including Tasu Lake itself, is 0.94 km^2.

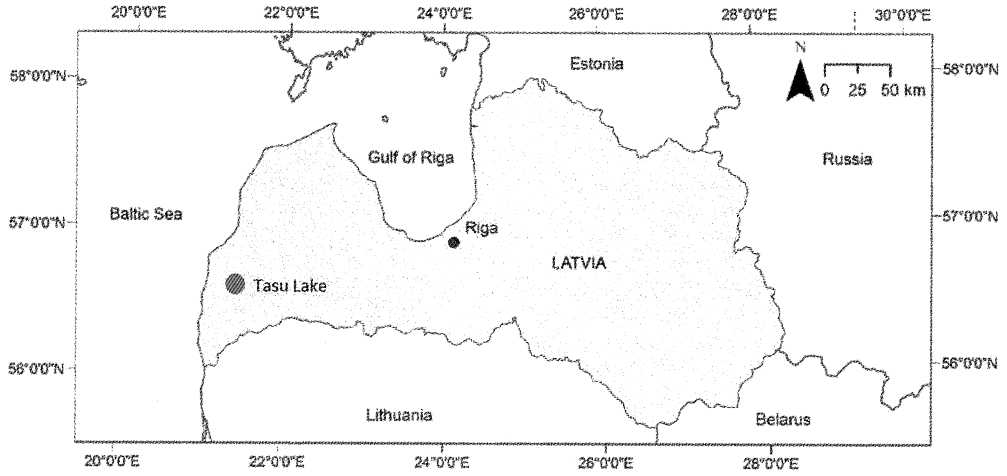


Figure 1. Tasu Lake Location

Lake is located into northwest-southeast-oriented (NW-SE) longish dry-land deepening – lakebed. Tasu Lake is eutrophic. In eutrophic lakes, dissolved oxygen levels are low, especially in layers closer to the bed. However, eutrophic lakes are rich in nutrients which also affects phytoplankton growth. At the bottom of the lake, a thick layer of sludge and sapropel has accumulated up to a depth of 6 meters. However, its shores are inclined or shallow; however, at the top and bottom of the lake, beaches are low, and coasts are covered with a well-developed groundcover layer. From a fishing point of view, the lake is rich in fish resources with *Scardinius erythropthalmus, Abramis brama, Perca fluviatilis, Carassius carassius, Esox lucius, Tinca tinca* and *Rutilus rutilus.* Tasu Lake has become a popular fishing place for local residents because of the wide variety of fish. A large area in the catchment area of Tasu Lake is occupied by agricultural land. Intensive agricultural activity in the lake's catchment area contributes to a rapid stockpiling of nutrients, resulting in algae growth in the central part of the lake and creating and accumulating sediments. Aquatic plants are growing in the coastal part of the lake, and a layer of sludge is being formed.

Such processes are also observed in Tasu Lake because coastal areas are heavily overgrown (Figure 2), and floating islands have developed (Figure 3), showing the development of eutrophication. Also, 6 metres deep layer of sludge has developed in Tasu Lake. The spillway water level in Tasu Lake is currently held at ~18.00 m (LAS 2000.5).

At this water level, extreme humidity conditions are created in approximately 259 ha area above the lake. The extreme humidity conditions in areas adjacent to the lake are shown by the dead trees and bushes on the coast of the lake. In the current situation, it is necessary to develop a hydrological model of Tasu Lake to assess the impact of the changes of hydrological regime of the catchment area on natural values in nature preserve "Tasu Lake".

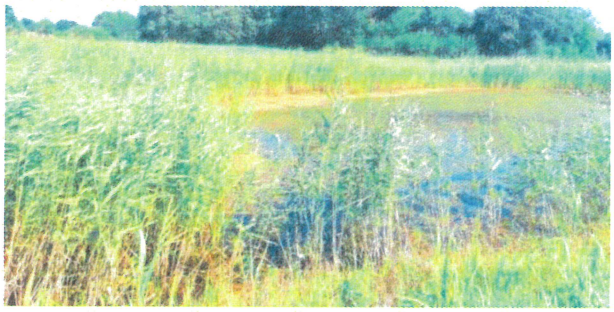


Figure 2. Overgrown coastal zone in Tasu Lake (taken on 25.07.2019.)



Figure 3. Floating islands formed by aquatic plants (taken on 25.07.2019)

The water level depends on incoming watercourses (Alande river, Zonu ditch, drainage ditches, surface runoff from agricultural lands, and artificial water level regulating with spillway.

The aim of this study is to develop an optimization model for sustainable lake management.

MATERIALS AND METHODS

The optimization model for sustainable lake management was made in four steps (see Figure 4). ***Firstly*** the lake bead was scanned by hydroacoustic stream meter RiverRay and data processed using WinRiver II data-processing software.



Figure 4. The conceptual framework of research

Measurements of water depth and sludge layer depth in Tasu Lake were done using Acoustic Doppler Current Profiler (ADCP) RiverRay (Figure 4)[9]. During the measuring of Tasu Lake, the passive–floating structure assembled device was moved manually using a cableway system. Transverse profiles were measured perpendicular to the flow direction, but longitudinal profiles in the direction of the water flow (Figure 5). The watercourse bed profile is created automatically and displayed in the data reading device [10]. Measurements were done using the data processing application WinRiver II. Visual display of data occurs during the measurement, allowing to control both the direction of movement and the quality of measures. A graphical representation of the collected data during the measuring of Tasu Lake is shown in Figure 6. Data matrix is obtained at each

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measurement that includes bed profile with the relative value of bed depth and the displacement of dissolved solid particles against the flowrate in each cell in the measurement grid. The reference point for every measurement is the water level, which is the measurement relative value "0".

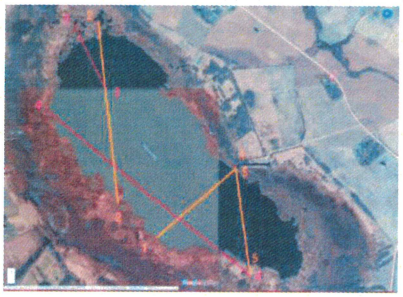


Figure 5. Scheme of Tasu Lake measurements

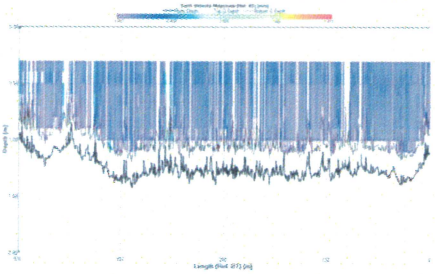


Figure 6. Tasu Lake transverse profile 234/00 (1st transverse profile)

Secondly, the verified data were used to develop a three-dimensional model of Tasu Lake. From the collected measurement data, 3D models of Tasu Lake (Figure 7), Tasu Lake lakebed (Figure 8) and Tasu Lake sludge layer (Figure 9) were created.

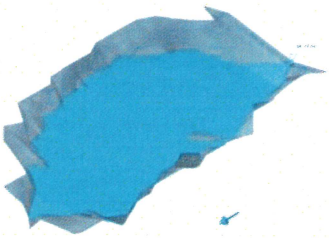


Figure 7. 3D model of Tasu Lake at water level 17.60 m (LAS 200.5)



Figure 8. 3D model of Tasu Lake lakebed



Figure 9. 3D model of Tasu Lake sludge layer

Thirdly, twelve climate scenarios and two land use transformation scenarios were used to model daily runoff for the period 1990-2099 using the conceptual hydrological model METQ [11]; [12]. The climate scenarios were used from previous studies [13].

Finally, the three-dimensional model and modelled runoff data were used to optimize Tasu lake hydraulic parameters and develop optimal parameters for segmentation basin and constructed wetland. When performing modelling and optimization calculations, the equation for the lake's used:

$$A(h)_{dhdt}=Q_{in}-Q_{out}(h)+Q_{gwin}-Q_{gwout}+(P-E)A(h) \qquad (1)$$

Where, *A - lake surface area, which depends directly on the water level in Lake (h); Q_{in} - flowing surface water; Q_{out} - the flowing surface water directly dependent on the water level (h) in Lake; h- lake water level; Q_{gwin} - ingoing groundwater flow; Q_{gwout} - extruding groundwater flow; P – precipitation; E - total evaporation.*

The main task in the hydraulic calculation of the overhead/regulator is to determine the amount of passage passing over the overhead. Looking at a rectangular surface with a thin wall and no narrowing. To determine the flow rate of the overhead, the above values are taken into account, and the hydraulic calculation of the overhead is carried out. Overhead flow rate calculated by the formula:

$$Q = mb\sqrt{2g}H^{\frac{3}{2}} = mb\sqrt{2g}H_0^{\frac{3}{2}} \quad (2)$$

Where *Q – overflow rate, m^3/s; g – free-fall acceleration, m/s^2; H –water level before overhead, m; b – overhead width, m; m – overflow rate factor.*

RESULTS AND DISCUSSION

The conceptual hydrological pattern METQ was used to make forecasts for the water level changes in the future scenario of the future water level of Lake Tasu to modelling the average daily flow rates of lake Tasu for future climate scenarios. In contrast, the flow rate data were used for modelling the water level of Lake Tasu at two different widths of the overhead, namely 0.8 and 2.0 m.

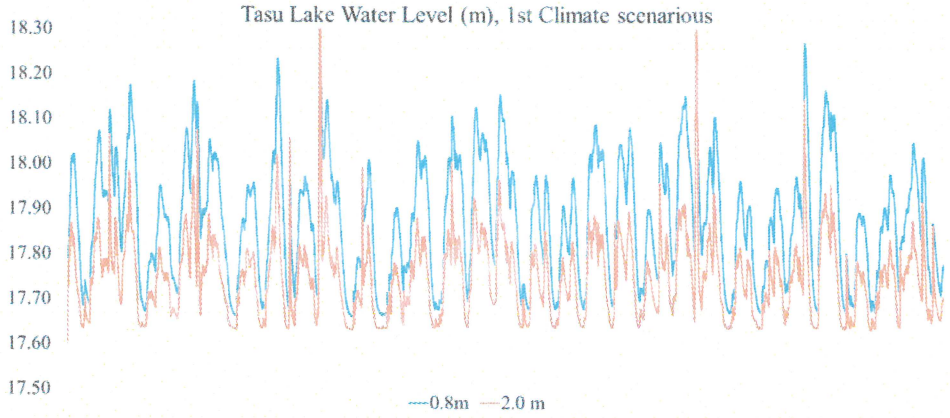


Figure 10. Changes in water levels of Lake Tasu at first climate scenario

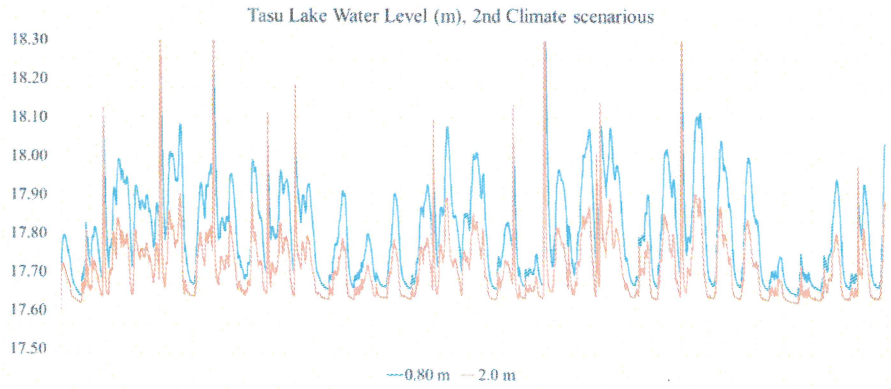


Figure 11. Changes in water levels of Lake Tasu at second climate scenario

As shown in Figures 10 and 11, fluctuations in the water levels of Lake Tasu remain seasonal, where increases in water levels during the autumn-winter period were interspersed with a decrease in water levels over the summer. As can be seen in all

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scenarios, the width of the pipeline/regulator is 0.8 m, unable to provide a water-level regime corresponding to the functions of the River Alande as a national watercraft.

In an analysis of the oscillations of the water level of Lake Tasu in the annual section, the modelled values of future climate scenarios at the overhead width of 0.8 m are capable of ensuring the range of variation of the yearly water level from 17.60 to 18.3 m LAS 2000.5 (see Figure 12), which is not sufficient to ensure the functionality of the State-important water waste river according to the Latvian construction standard regulatory requirements specified by LBN 224-15 "Liquidity Systems and Hydrotechnical Construction".

In the analysis of the oscillations of the water level of Lake Tasu in the annual section, it appears that the modelled values of future climate scenarios are capable of ensuring a yearly range of water levels from 17.60 to 18, 00 m LAS 2000.5 (see Figure 13), which is sufficient to ensure the functioning of the State-important river Alande according to the Latvian construction standard. Regulatory requirements specified by LBN 224-15 "Liquidity Systems and Hydrotechnical Construction".

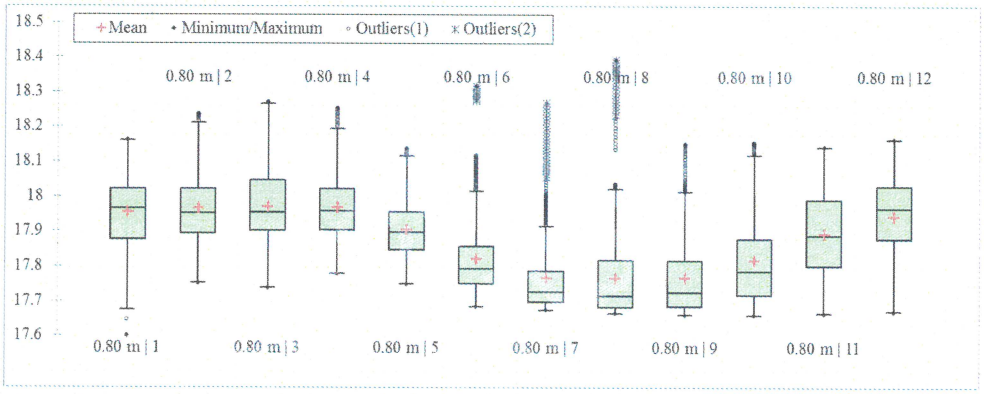


Figure 12. The amplitude of oscillation of water levels of Lake Tasu during the month at the width of the overhead of 0.8 m

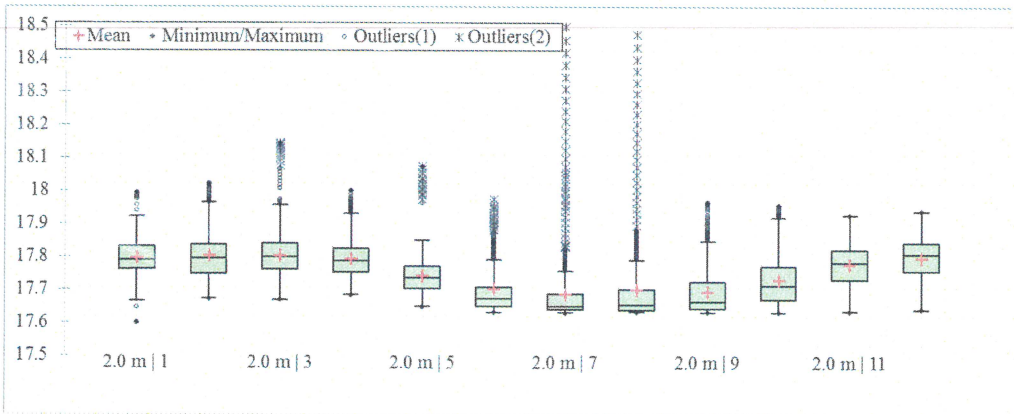


Figure 13. The amplitude of oscillation of water levels of Lake Tasu during the month at the width of the overhead of 2.0 m

CONCLUSION

The Tasu lake bead was scanned by hydroacoustic stream meter RiverRay and data processed using WinRiver II data-processing software. Measurements of water depth and sludge layer depth in Tasu Lake were done using Acoustic Doppler Current Profiler

(ADCP) RiverRay. This technology is time-saving and precise and can be used as an additional tool for lake investigation. The collected data were effectively used to develop a three-dimensional model of Tasu Lake. The RiverRay and 3D modelling can be used for waterbody investigation.

The water level of Lake Tasu at 17.6 m is determined by the LAS-2000.5 national water drain Aland River and the regulations for the operation of drainage systems in the catchment area of Lake Tasu, which are designed to prevent damage to the road surface of the national road V1192 "Apriķi – Cirava - Medze" and in accordance with the Regulations on the Latvian construction standard LBN 224-15 "Melioration systems and hydraulic structures", as well as ensure the optimal moisture regime of agricultural land.

Future research should be directed towards the automation of lake water-level optimization models, where RiverRay data is directly transformed into a 3D model. The scarring algorithm connects it to the conceptual hydrological model METQ. Such optimization practices would benefit decision-makers, and researchers would need to provide three main sets of parameters and data. Meteorological observation data, future climate scenario data, lake bed 3D data, and the parameters of the dimensions of the regulating structure of outflow are necessary.

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AUTOMATED CAVITY RING DOWN SPECTROSCOPY USAGE FOR NITROUS OXIDE EMISSION MEASUREMENTS FROM SOIL USING RECIRCULATION SYSTEM

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Abstract. The nitrous oxide accounted for the year 2015 gives 60 % of Latvia`s greenhouse gas emissions from the agricultural sector. Majority of nitrous oxide comes from mineral fertiliser application and manure management. Nitrous oxide emission from soils is strongly correlated with the soil moisture and temperature. Since nitrous oxide has very low concentrations in natural environment, there is a risk to overestimate or underestimate nitrous oxide emission. Automated cavity ring down spectroscopy for nitrous oxide emission measurements is a relatively new technology and there is a need for development of proper methodology. The aim of this study is to identify proper measurement time for nitrous oxide emission from soil by using automated cavity ring down spectroscopy with recirculation system. The automated cavity ring down spectroscopy, namely Picarro G2508, was connected in a closed recirculation system with the chamber of total volume 2 litres. Dray soil samples were weighted in containers and different amounts of water and ammonium nitrate were added. Totally 36 samples were used in the experiment. Each sample was measured 10 minutes and the nitrous oxide concentration was recorded for each second. For each sample measurements were repeated three times. The linear regression method was used to calculate the emission amount for different time periods from 30 seconds till 600 seconds. The results of the research show quite high variation of nitrous oxide emission from the soil samples. Data analysis showed that the minimal measurement time has to be at least 250 seconds.

Keywords: CRDS, Picarro G2508, chamber enclosure time.

Introduction

The measurements of nitrous oxide (N_2O) emissions have become an actual topic during the last 20 years[1]. N_2O emissions from soil are measured by using closed static chembers [2]. The cavity ring down spectroscopy (CRDS) has pre-eminent detection limit and high precision [3; 4]. However, the CRDS device Picarro G2508 is limited by one outlet [5]. The chamber enclosure time is limitation for the experiment design. The N_2O concentration in atmosphere is 0.325 ppm [6] and during the measurement N_2O fluctuated. The measurement error of N_2O is 0.005 ppm [5]. The fluctuaction of N_2O is related with concentrations of other gases as well as climatic factors. The previous research shows that appropriate chamber closure time for measurements with CRDS is from 200 till 400 seconds [3].

The aim of this study is to identify the GHG measurement time for cavity ring down spectroscopy Picarro G2508 by using the recyrculation system for soil flux experiments in laboratory conditions.

Materials and methods

The experiment was conducted in laboratry conditions with fixed air temperature, air presure and humidity. 36 soil samples with weight of 100g and moisture of 20 % were colected in plastic containers. The amonia nitrate dosings were 0 g, 1 g, 2 g, 3 g, 4 g and 5 g. The water dosings were 0 ml, 10 ml, 20 ml, 30 ml, 40 ml and 50 ml. Water and amonia nitrate in each sample were added before the measurement. The CRDS device Picarro G2508 was connected with the chamber by using zero leaching conectors and the zero leaching external vacuum pump Picarro [5]. Each soil sample with the container were inserted into the chamber. After closure of the chamber, the gas concentrations of N_2O were measured for 600 seconds. The gas concentration data of the 600 seconds period for each sample of each gas were used for further data analysis. The slope of concentration change is the main parameter for further calculations of GHG emmisions from soil. The linear regression (1) was used to calculate the slope of concentration fluctuactions for each data set.

$$C = S \cdot T + c, \quad (1)$$

where C – concentrations, ppm;
S – slope, ppm·s^{-1};
T – time, s;
c – intercept, ppm.

The slope (2) of linear regression and the coefficient of determination (3) were calculated for 1 minute (n = 60) time period by using a step of 1 second. 286 slopes and coefficients of determination were calculated for each sample. The same procedure were repeated for 4 minutes (n = 240) time period by using slope calculation for each sample. 160 slopes and coefficients of determination were calculated for 4 minutes time period.

$$S = \frac{n\sum(TC) - \sum T \sum C}{n\sum(T^2) - (\sum T)^2}, \quad (2)$$

where n – count of measurements;

Coefficient of determination (R^2) was calculated as follows:

$$R^2 = \left(\frac{n\sum(TC) - \sum T \sum C}{\sqrt{[n\sum(T^2) - (\sum T)^2][n\sum(C^2) - (\sum C)^2]}} \right)^2 \quad (3)$$

The slope (2) and coefficient of determination (3) values were used to calculate the slope (5) and relative changes of the determination coefficient per time unit (4):

$$\Delta R^2 = \frac{R_{i-1}^2 - R_i^2}{R_i^2} \cdot 100, \quad (4)$$

where ΔR^2 – relative change of determination coefficient, %;
i – current observation

$$\Delta S = \frac{S_{i-1} - S_i}{S_i} \cdot 100, \quad (5)$$

where ΔS – relative change of slope, %.

The calculated relative changes of slope and coefficient of determination in time unit were used for further analysis by using XLSTAT program package.

Results and discussion

The measurement session was done at 25 °C soil and air temperature and the air pressure 1032 bar. The N_2O concentrations of 36 soil samples were verifyed for slope and R^2 calculations.The descriptive statistics of the N_2O concentration data is presented in Table 1. The total number of the analysed N_2O concentration data is 14,405. There are no missing values. The mean concentrattion of N_2O is 0.348 ppm, the standart deviation is 0.014 ppm.

Table 1

Descriptive statistics of N_2O concentration data

Nr.	Statistic	N_2O, ppm
1.	Number of observations	14,405
2.	Number of missing values	0
3.	Minimum	0.215
4.	Maximum	0.407
5.	Range	0.192
6.	1st Quartile	0.339
7.	Median	0.347
8.	3rd Quartile	0.356
9.	Mean	0.348
10.	Variance (n-1)	0.000
11.	Standard deviation (n-1)	0.014

The relative change of slope was analysed on one second step base. The 36 relative slope change data points were analysed for each second. The mean of the relative change of slope is not stable and it is fluctuating between 20 % and -20 % (see Figure 1).

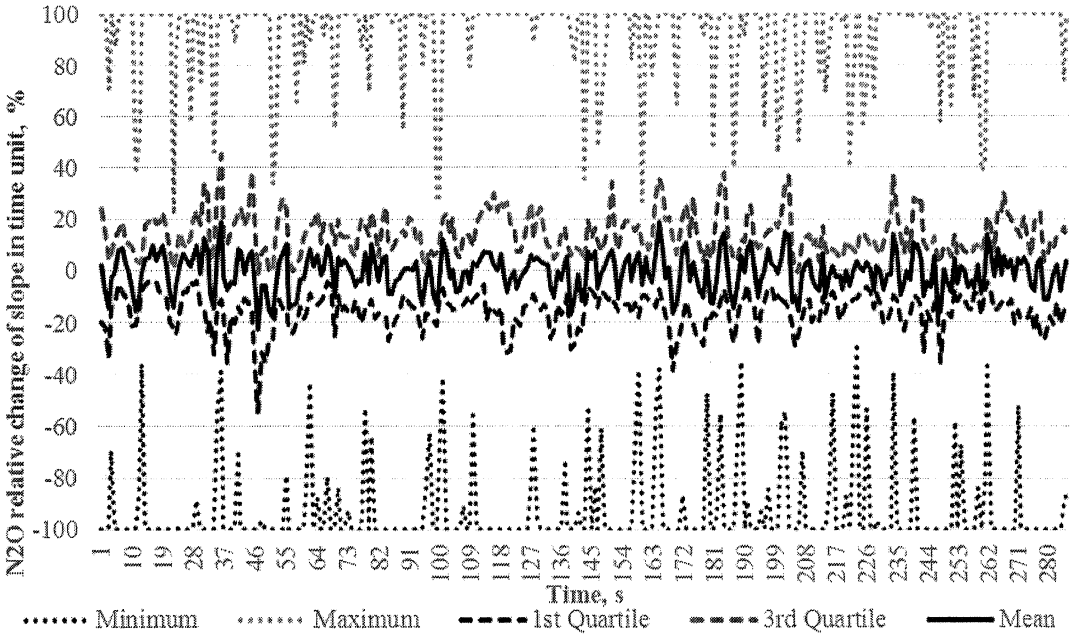


Fig. 1. **Relative change of slope for 1 minute slope calculation period**

The 1st quartile and 3rd quartile are close to mean, but the fluctuaction amplitude is between 40 % and -40 %. The minimal and maximal values are close to 100 % and -100 %. The relative change of slope was analysed for 4 minutes time period and it showed acceptable satbilistation of the slope change. The amplitude is between 20 % and -20 % (see Figure 2).

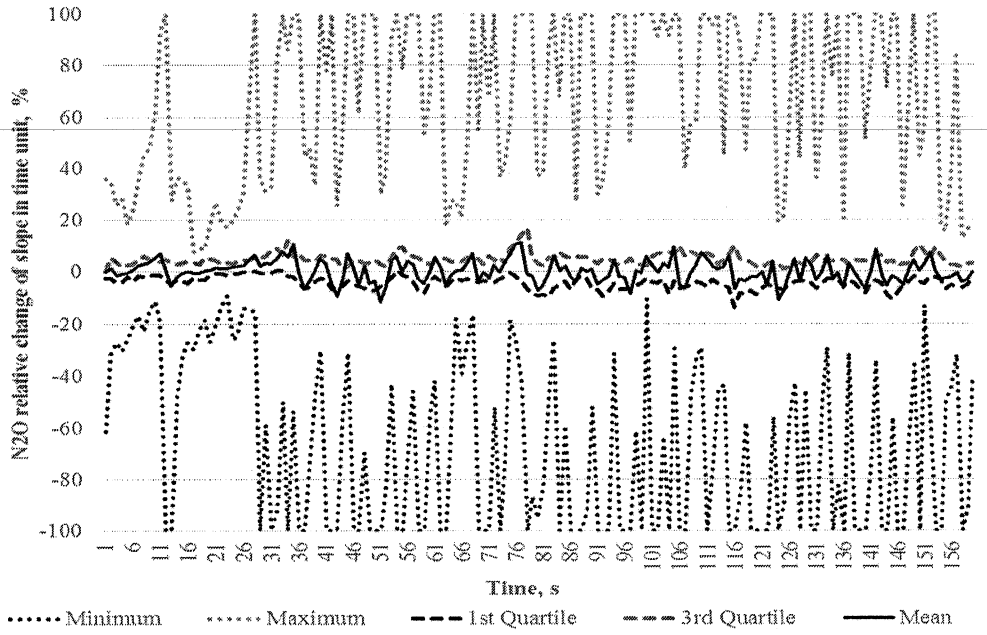


Fig. 2. **Relative change of slope for 4 minutes slope calculation period**

However, there are still high maximal and minimal values of the relative slope change. The relative change of the determination coefficient is analysed on one second step base. 36 relative changes of data point of the coefficient of determination were analysed for each second. The mean of

the relative change of the coefficient of determination is not stable and it is fluctuating between 30 % and -20 % (see Figure 3).

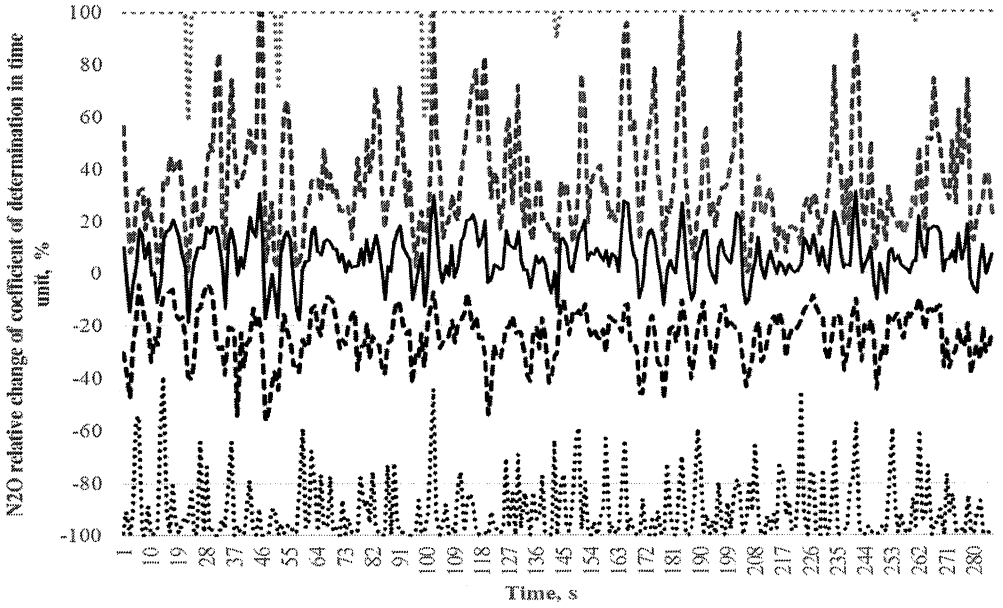


Fig. 3. **Relative change of coefficient of determination for 1 min slope calculation period**

The 1st quartile and 3rd quartile are close to mean, but the fluctuaction amplitude is between 100 % and -60 %. The minimal and maximal values are close to 100 % and -100 %. The relative change of the coefficient of determination was analysed for 4 minutes time period. It shows acceptable satbilistation of the change of the determination coefficient and it is in the amplitude from 5 % till -1 % (see Figure 4). However, there are still high maximal values of the relative slope change.

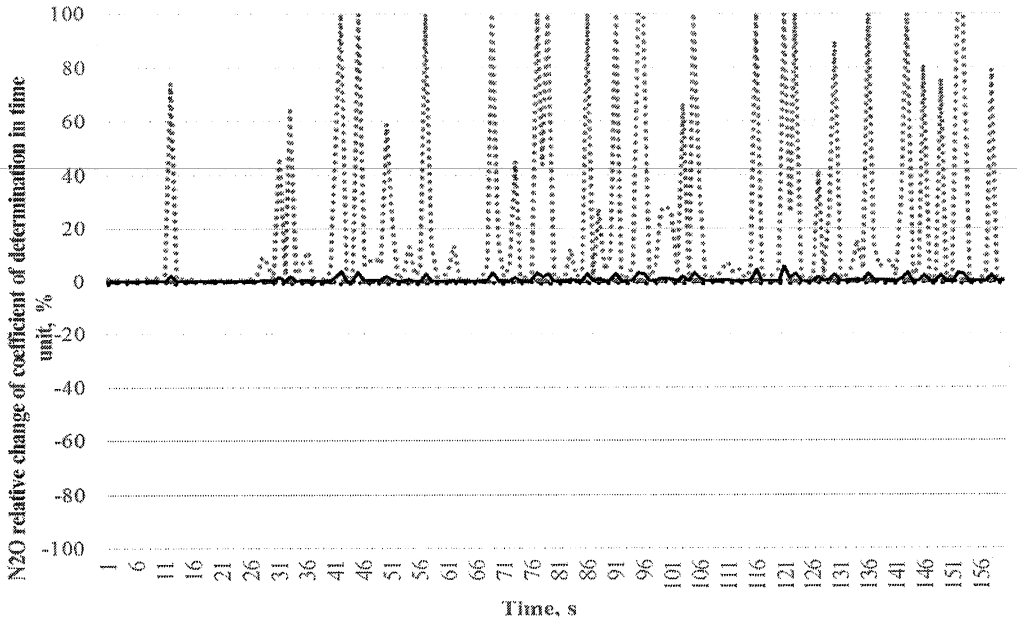


Fig. 4. **Relative change of coefficient of determination for 4 min slope calculation period**

The 1st quartile and 3rd quartile are close to mean, but the fluctuaction amplitude is between 100 % and -60 %. The minimal and maximal values are close to 100 % and -100 %. The relative change of the coefficient of determination was analysed for 4 minutes time period. It shows acceptable stabilistation of the change of the coefficient of determination and it is in the amplitude from 5 % till -1 % (see Figure 4). However, there are still high maximal values of the relative slope change. The

acceptable slope calculation start is from 10 till 20 seconds from the measurement start. The first 10 seconds of the measurement are optional to exclude for further calculations.

The acceptable measurement data are presented in Figure 5, where the graph on the left shows the measured concentration with minimal positive slope. However, the trend of concentrations is clearely positive. The graph in the middle presents the slope and R^2 relation with the slope calculation period 1 min. The graph on the right side presents the slope and R^2 relation with the slope calculation period 4 min. There is clear correlation between the slope and R^2. The highest slope values are with higher R^2.

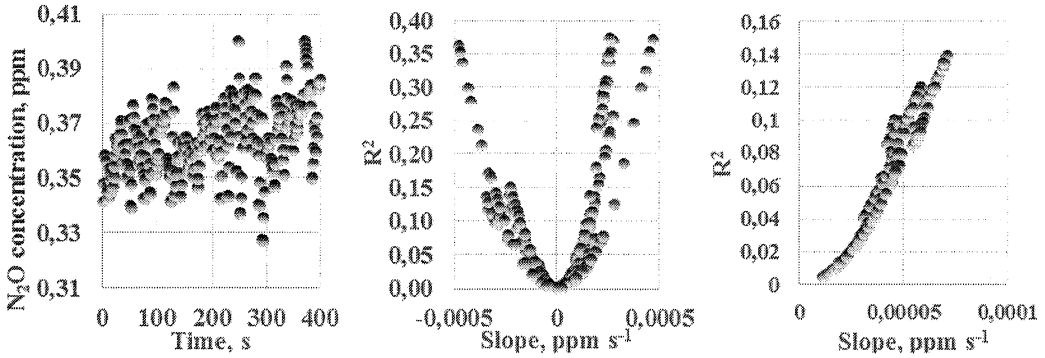


Fig. 5. **Acceptable example of measurement (left-measured concentartions; middle – R^2 and slope relation at 1minute calculation period; right – R^2 and slope correlation at 4 minute calculation period)**

The unacceptable measurement data are presented in Figure 6, where the graph on the left shows the measured concentration with unclear slope. The concentrations fluctuacte, but there is too wide fluctuaction amplitude. The graph in the middle presents the slope and R^2 relation with the slope calculation period 1 min. The relation is not symmetrical and it shows 3 outliers. The graph on the right side presents the slope and R^2 relation with the slope calculation period 4 min. There is clear correlation between the slope and R^2. However, the N_2O slope is negative or close to 0.

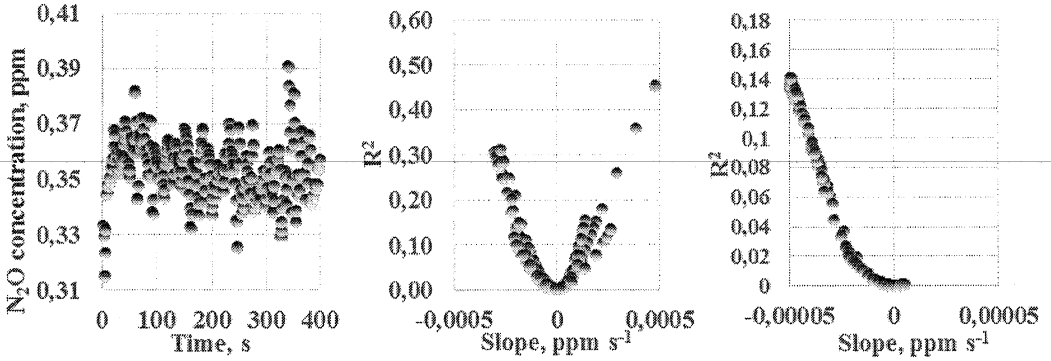


Fig. 6. **Unacceptable example of measurement (left-measured concentartions; middle – R^2 and slope correlation at 1minute calculation period; right – R^2 and slope correlation at 4 minutes calculation period)**

Conclusions

1. The CRDS device Picarro G2508 can be used for N_2O emission measurements at laboratory and field conditions. The recirculation system is sensitive to fluctuaction of N_2O concentrations as well as the concentration of other gases is an important factor.
2. The minimal measurement time is 4 minutes and 10 seconds for N_2O emissions. The previous timescale can be used for laboratory experiments with the air temperature and soil temperature range from 20 °C till 30 °C.
3. Each measurement data set has to be veifyed and evaluated before calculation and repeated measurements have to be optional.
4. The multiple slope calculation aproach can be used for slope calculations, where the slope of samples is calculated as average from several slopes.

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MEASUREMENT TIME ESTIMATION OF CO_2, CH_4, N_2O AND NH_3 IN CLOSED CHAMBERS AND RECIRCULATION SYSTEM WITH PICARRO G2508 ANALYSER

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ABSTRACT

The European Union has set a target to cut its greenhouse gas emission levels by 80% to 95% until 2050, if compared to 1990. Agricultural soil is an important carbon store and food provider in the world as well as greenhouse gas emission reducer via carbon sequestration. In order to assess the climate change mitigation effectiveness of the measures, it is necessary to obtain statistically significant data before and after the implementation.

The greenhouse gas measurements from soil are commonly determined using static chamber-based method in which the gas sample is collected at regular intervals and stored for later analysis by gas chromatography. Picarro G2508 performs measurements in field or laboratory directly from the chamber with the interval of one second. The aim of the study was to determine the optimal measurement time for greenhouse gas measurements in different soil types by using mobile ring-down spectrophotometer Picarro G2508. N_2O, CH_4, CO_2, NH_3 and measurement data from four chambers and laboratory experiments were used.

Field measurements were carried out using static chambers with the diameter of 23 cm and volume of 3 litres, which was connected to the Picarro G2508 via tube with an outer diameter of 0.125 inches. Recirculation system with the chamber volume of 2 litres was used to make the laboratory experiment. The linear regression was used to evaluate the measurement time and to compare the stability of emission coefficients.

The results showed that statistically significant optimum measurement time is 8-10 minutes on a field and 2-4 minutes in laboratory.

Keywords: soil, emission coefficient, agriculture, ring-down spectrophotometer

INTRODUCTION

In 1994, the United Nations Framework Convention on Climate Change was developed to prevent climate changes caused by human activities. The Kyoto Protocol, linked to the Convention, was adopted in 1997 to set internationally binding emission reduction

targets. Since then, 197 countries, called Parties, have ratified the Convention and have set emission reduction targets [1]. The annual emission inventories and national reports are being reported yearly by Parties using guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) [2]. Recently, 195 countries adopted the First Global Action Plan at the Paris Climate Conference to decrease the global average temperature by 2 °C when compared to the temperature in pre-industrial levels. The greenhouse gas (GHG) emission reduction target by 80% to 95% compared to 1990 levels by 2050 has been set by European Union [3]. In order to ensure air quality and human health, the European Union has set an objective to reduce ammonia (NH_3) emission by 27 % by 2020 [4].

Agricultural land covers 37% of the land surface of the earth [5]. Agriculture is responsible for 12% of the total greenhouse gas emissions worldwide [6], including 50% of global methane (CH_4) and 60% of global nitrous oxide (NO_2) emissions from agricultural soils [7].

GHGs in soils are produced by microbial activity, root respiration and chemical processes. Soil water content, soil temperature, nutrient availability, pH-value, as well as meteorological and climatological parameters and land use and land use change are the key drivers of GHG emissions from soils [8].

The greenhouse gas measurements from soil are commonly determined using static chamber-based method in which the chambers are sampled at 10, 20, 30 and 40 minutes after closure and samples are stored in headspace flasks for later analysis by gas chromatography [9].

The performance of CO_2, CH_4 and N_2O measurements with cavity ring-down spectroscopy and gas chromatography in laboratory and field experiments were compared [10]. The measurements showed the same temporal trend and treatment effects between cover crop and no cover crop treatments for CO_2 and N_2O. The cavity ring-down spectroscopy and gas chromatography can perform the same trend for CO_2 and N_2O measurements, but not for CH_4. In estimation of CH_4 the cavity ring-down spectroscopy performed better result than gas chromatography.

MATERIALS AND METHODS

Simultaneous CO_2, CH_4, N_2O and NH_3 measurements from soil were made by mobile ring-down spectrophotometer Picarro G2508. Detailed description of Picarro G2508 parameters are found in Fleck et al., (2013) [11].

To provide measurements in field conditions, chamber with diameter of 23 cm and volume of 3 litres was connected with Picarro G2508 via 9 m long teflon tube with an outer diameter of 0.125 inches. The base of chamber was made from metal and its edge is sharpened to provide easy installation into the soil. The transparent dome was placed on the top of the base. The compound between the dome and the tube was made using quick connector which was isolated by rubber seal (Figure 1). The measurements of air temperature and chamber temperature and chamber pressure were done and pressure using Diver DI 500, Eijkelkamp. The air temperature was measured on the dark side. To measure chamber temperature, Diver DI 500 was set in chamber before the imposition of the dome. The measurement of soil temperature was conducted in crop fields in soil

depth of 20 cm. The total number of measurements was 24 where each measurement time was 20 minutes.

The laboratory experiment was carried out using recirculation system with chamber volume of 2 litres (Figure 2). Recirculation system consists of chamber, 2 m long teflon tube with an outer diameter of 0.125 inches, 0.6 m long metal tube with an outer diameter of 0.24 inches and two quick connectors. Soil samples were collected from Zemgale Region, these samples were dried in a laboratory where the average temperature was 25 °C. The 100g of dray soil sample (moisture 20%) were filled in plastic container. The different amount of water and fertiliser were added to each sample. The amount of ammonia nitrate were 0 g, 1 g, 2 g, 3 g, 4 g and 5 g. The amount of water were 0 ml, 10 ml, 20 ml, 30 ml, 40 ml and 50 ml. Totally 36 samples with different water and fertiliser amount were created. Each soil sample were measured after adding water and fertilisers and one day after. The soil temperature and air temperature were 25 °C during all experiment time. The total number of measurements was 72 and the time of each measurement was 10 minutes.



Figure 1. Chamber for GHG measurements on field (author: J.Pilecka).



Figure 2. Chamber for GHG measurements in laboratory (author: K.Valujeva).

The data of CO_2, CH_4 NH_3 and N_2O concentration were used for further analysis to estimate the measurement time. The slope of concentration fluctuations was calculated by using linear regression equation (1) [12].

$$C = S * T + c \quad (1)$$

where C – concentration, ppm;

S – slope, ppm s^{-1};

T – time, s;

c – intercept, ppm.

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$$S = \frac{n\sum(TC) - \sum T \sum C}{n\sum(T^2) - (\sum T)^2} \quad (2)$$

where n – number of measurements, ppm.

The calculation of coefficient of determination is given by equation (3):

$$R^2 = \left(\frac{n\sum(TC) - \sum T \sum C}{\sqrt{[n\sum(T^2) - (\sum T)^2]\,[n\sum(C^2) - (\sum C)^2}}\right)^2 \quad (3)$$

The slope of CO_2, CH_4 NH_3 and N_2O concentration data were calculated for different measurement times. The first slope was calculated for 35 seconds of concentration data and each next calculation time were 5 seconds longer than previous (35; 40; … 1460). The coefficient of determination for each slope were calculated. The slope and coefficient of determination values of each gas were analysed using graphical method.

RESULTS AND DISCUSION

The results of slopes and coefficients of determination of field and laboratory measurements data of CO_2, CH_4, NH_3 and N_2O concentrations were analysed by using graphical method.

Field measurements

The each measurement of concentrations on field were 20 minutes long. In the graphical analysis we used data of 1,156 slope (emission) and coefficient of determination of each gas.

The results of emission and coefficient of determination of CO_2 show that emissions calculated from collected data during first 200 seconds are not stable and show overestimation or underestimation risk (see Figure 3). The coefficient of determination during 200 seconds also are not stable. The emissions calculated for period of 200 – 400 seconds shows stable emission rate and gives highest coefficient of determination rates ($R^2 < 0.98$). The recommended time period of CO_2 emission calculation is from 200 till 400 seconds.

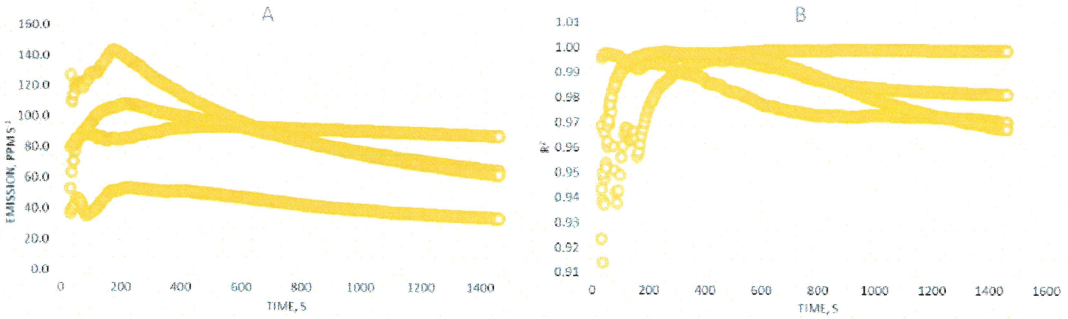


Figure 3. The estimation of measurement time for CO_2 on field by using linear regression depending on (A) emission and (B) coefficient of determination.

The emissions of CH_4 show stable emission coefficient after 150 seconds since the start of measurement. The coefficient of determination is close to 1.00 after 200 seconds (see

Figure 4). The emission coefficient for CH_4 can be calculated for any time period from 200 till 1480 seconds and it is stable.

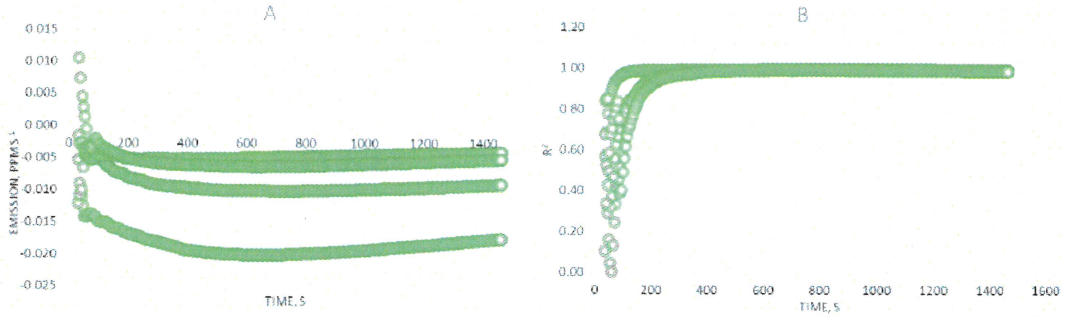


Figure 4. The estimation of measurement time for CH_4 on field by using linear regression depending on (A) emission and (B) coefficient of determination.

The emission coefficient of N_2O shows strong fluctuation at first 200 seconds but later it is constant for all measurement period (see Figure 5). However, coefficient of determination reach acceptable value after 800 seconds since the start of measurement. The long time period of stabilisation of coefficient of determination is related with amount of N_2O concentrations and measurement error. The emission is stable but N_2O concentration have stable fluctuation in small amplitude from 5 till 10 ppb and since N_2O concentration in air is from 345 till 355 ppb, this amplitude gives high uncertainty. There is trade-off between measurement time and coefficient of determination. The slope is stable at 200 second emission calculation time and we advise to use the measurement time of 200 seconds and do not try to get high coefficient of determination values.

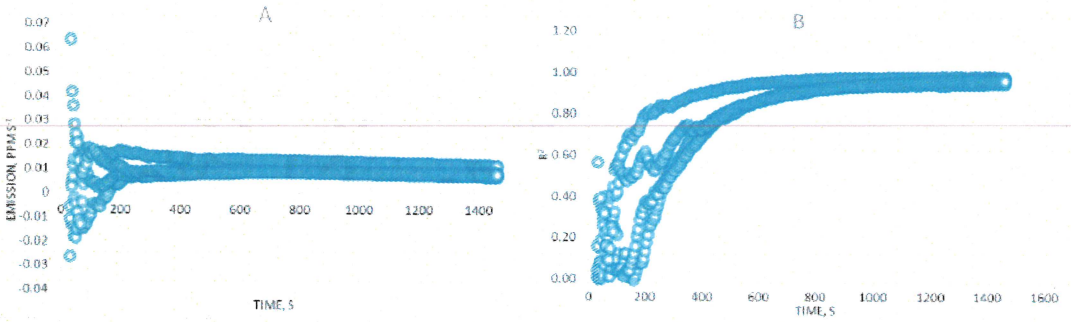


Figure 5. The estimation of measurement time for N_2O on field by using linear regression depending on (A) emission and (B) coefficient of determination.

The emission coefficient of NH_3 stabilises after 200 seconds and stay stable for all measurement period (see Figure 6). The coefficient of determination of NH_3 is not stable. The changes are related with NH_3 and water proportion in air sample. If there is high air humidity the NH_3 transforms to NH_4 and shows reduction of NH_3 in air sample.

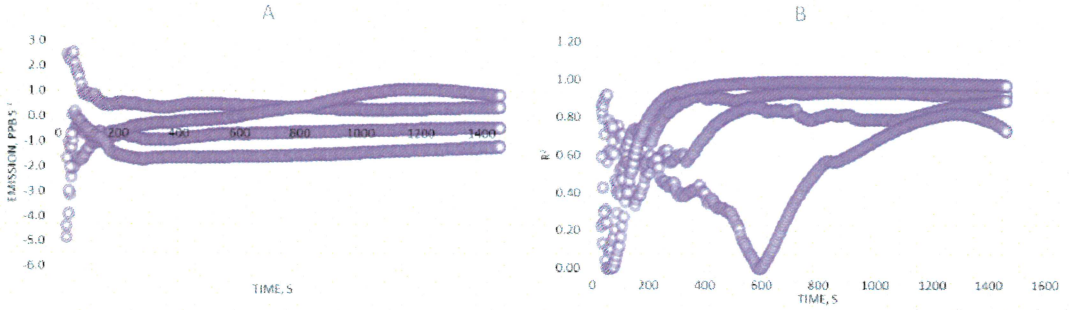


Figure 6. The estimation of measurement time for NH_3 on field by using linear regression depending on (A) emission and (B) coefficient of determination.

Laboratory measurements

The each measurement of concentrations in laboratory were 10 minutes long. In the graphical analysis, data of 292 slopes (emissions) and coefficients of determination for each gas were used.

The CO_2 emission coefficient is stable after 100 seconds since the start of measurement for low emissions and after 200 seconds for high emissions (see Figure 7). The coefficient of determination stabilises at 300 seconds.

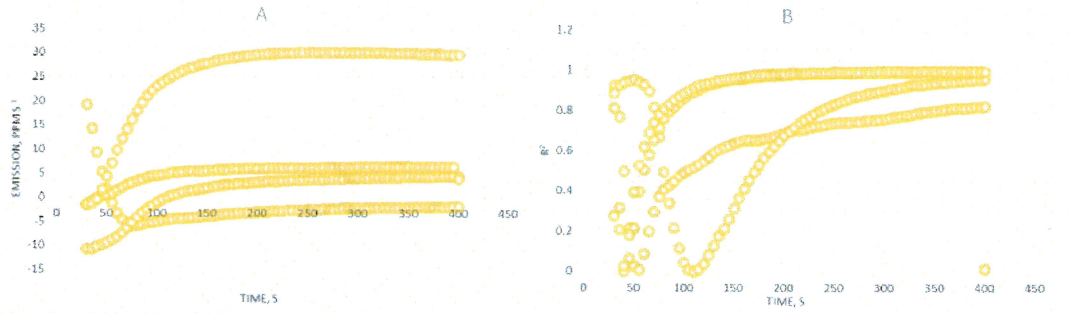


Figure 7. The estimation of measurement time for CO_2 in laboratory by using linear regression depending on (A) emission and (B) coefficient of determination.

The emission coefficients of CH_4 stabilises after 60 seconds since the start of measurement (see Figure 8), however, coefficient of determination fluctuates during all measurement time.

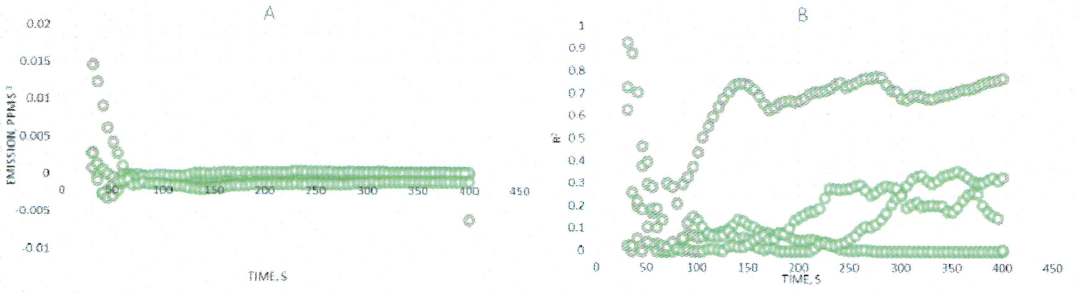


Figure 8. The estimation of measurement time for CH_4 in laboratory by using linear regression depending on (A) emission and (B) coefficient of determination.

The emission coefficient of N_2O also shows strong fluctuation at first 200 seconds but later it is constant for all measurement period (see Figure 9). However, coefficient of determination fluctuates during all measurement time.

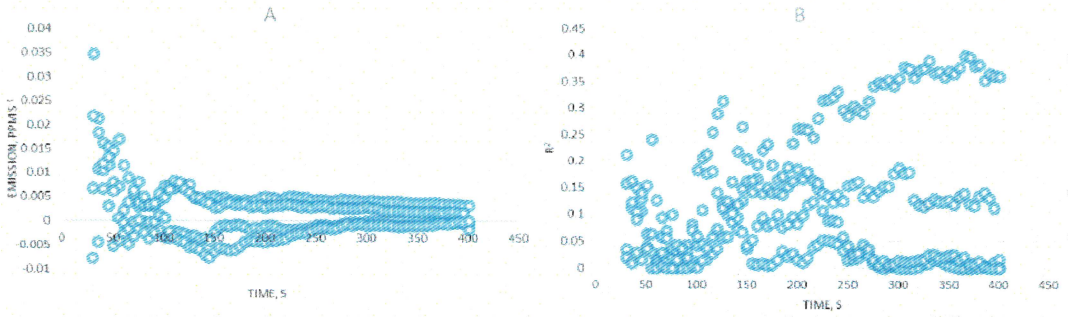


Figure 9. The estimation of measurement time for N_2O in laboratory by using linear regression depending on (A) emission and (B) coefficient of determination.

The emission coefficient of NH_3 is stabile after first 100 seconds and stay stable for all measurement period (see Figure 6). The coefficient of determination of NH_3 is not stable for all measurements due to water proportion in air sample.

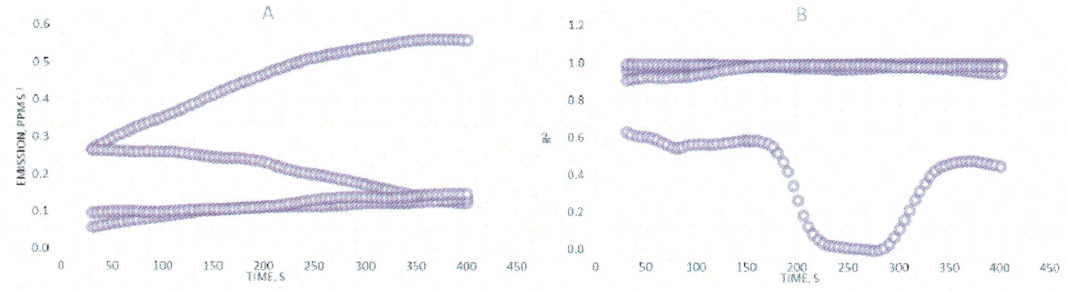


Figure 10. The estimation of measurement time for NH_4 in laboratory by using linear regression depending on (A) emission and (B) coefficient of determination.

CONCLUSION

The key drivers of GHG emissions from soils are soil moisture, soil temperature, nutrient availability, pH-value, as well as meteorological and climatological parameters and land use and land use change. Cavity ring-down spectroscopy is useful for simultaneous CO_2, CH_4, N_2O and NH_3 measurements in soil. In order to determine the measurement time of CO_2, CH_4, N_2O and NH_3 measurements, the linear regression equation is valid to use. To obtain statistically significant data, it is advisable to disregard the first 100 or 200 seconds of measurement depending on amount of the emission. The statistically significant optimum measurement time for CO_2, CH_4, NH_3 and N_2O measurements is from 8 till 10 minutes on a field including first unstable measurements. The optimum measurement time for GHG measurements in laboratory is from 2 till 4 minutes including first unstable measurements. There is a necessary for further research to determine the length of measurement time for different gradient of emission.

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COMPOSITION OF THE ISOTOPES OF NITROUS OXIDE IN THE CLAY SOIL AT DIFFERENT MOISTURE CONDITIONS

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ABSTRACT

Reducing emissions of nitrous oxides in the agricultural sector is one of the main challenges. Stable isotopes are one of the tools that record information on changes in greenhouse gas production, transportation and emissions. The relationship between the processes in soil and emissions entering the atmosphere. Stable isotopes, which are direct isotopes of nitrous oxide emissions from soil, are already recognised as a promising tool for tracking atmospheric nitrous oxide emissions from various studies. The purpose of this study is to clarify the isotope relationship of nitrous oxide in clay soil at different humidity conditions. Samples from 12 test fields were collected. Samples were weighed in 3 l buckets, each at a total of 1.8 kg. The moistening plan was developed for aerobic and anaerobic soil conditions. Samples were moistened with rainwater every three days, 150 ml and 300 ml, respectively. Measurements for nitrous oxide isotopes have been performed using the Picarro G5131-i equipment under laboratory conditions. During the development of the study, the information gathered and the results obtained give an idea of carrying out measurements of nitrous oxide isotopes under laboratory conditions and set new objectives for further studies. The nitrous oxide isotope ^{18}O is significant and allows tracked sources of soil nitrous oxide emissions and microbiological processes.

Keywords: Nitrification, denitrification, GHG mitigation measures

INTRODUCTION

Several essential processes, based on different elements, their interaction and influencing factors, are taking place in nature to build and sustain life. One of the following elements is nitrogen (N). Although nitrogen is the most abundant element in the atmosphere, and approximately 78% of the atmosphere consists directly of nitrogen gas (N_2), most living organisms cannot use nitrogen. Therefore, nitrogen fixation occurs through various processes, such as during the nitrogen life cycle, resulting in many complex organic compounds required for living organisms. In order to create the required nitrogen compounds, various nitrogen compounds enter the life cycle as by-

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products, both in the atmosphere and in the hydrosphere, which may have a negative impact on the environment and climate. One of the damaging climate-impacting compounds is N_2O gas, dinitrogen oxide. Dinitrogen oxide is one of the greenhouse gases.

The nitrogen cycle is an essential, integral process in nature. Since amino acids form an essential part of life-building and maintenance, nitrogen and its chemical compounds are integral nutrients and ingredients for all living organisms [1]. Nitrogen living organisms are used to form a number of complex organic compounds, such as amino acids, nucleic acids, chitin. As well as nitrogen associated with organic compounds, protein and enzymes are essential components. This means that nitrogen contributes to the main metabolic processes that are a source for growth and energy transfer [2]. Molecular nitrogen N_2 is the main gas that is the basis for the nitrogen cycle. Soil bacteria provide the majority of nitrogen life cycle steps [3]. The natural life cycle of nitrogen is a process that transforms N_2 into an essential part of the living organisms and returns N_2 to the atmosphere at the end of the cycle [4].

The aim of this study is to clarify the isotope relationship of nitrous oxide in clay soil at different humidity conditions.

MATERIALS AND METHODS

A total of 12 samples were collected in the test the soil of experimantal fields. Samples are weighed in 3 l buckets, each at a total of 1.8 kg, where wetting is designed for wet aerobic and humid anaerobic soil mode. Samples are moistened with rainwater every three days, 150 ml and 300 ml, respectively. The moistening was performed on 25/06/19, 01/07/19, 05/07/19 and 11/07/19. Information on soil weight changes following soil wetting, sample weight and calculated evaporation was also collected. N_2O isotopes have been measured using Picarro G5131-i in laboratory conditions (see Fig. 1)

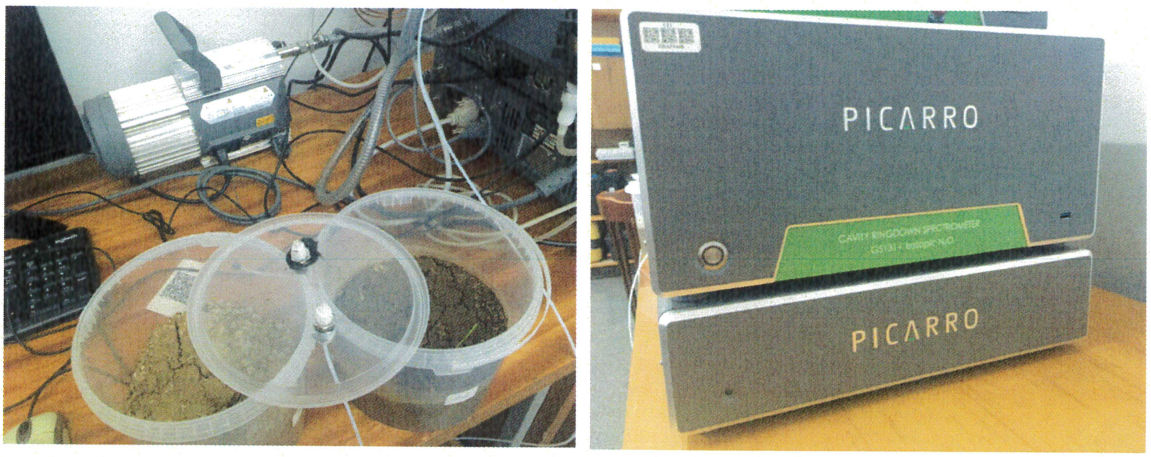


Figure 1. Gas concentration and isotope measurement equipment Piccaro G5131-I

Measurements have been selected for data processing, evaluating changes in N_2O measured concentration at the time of each soil sample. Measurements at which N_2O

concentrations have stabilised have been accepted as valid. Considering all N_2O concentrations, its values range from 330 to some of the measurements taken above 2000. Measurements of N_2O concentrations exceeding the average values of more than three reference errors were not considered. These extreme values are explained by inaccurate measurements for execution or equipment error. Data from the corresponding isotopes $\delta\ ^{15}N$, $\delta\ ^{15}N\alpha$, $\delta\ ^{15}N\beta$, $\delta\ ^{18}O$ have been selected based on N_2O concentrations (see Table 1).

Table 1

Results of isotope measurements (example)

Data	Sample	Camera	^{15}N, %	$^{15}N\alpha$,%	$^{15}N\beta$, %	^{18}O,%
06/07/2019	0-1	1	-0.32	5.93	-0.73	32.13
	0-1	2	1.76	5.87	-1.25	27.78
	0-1	3	6.69	6.34	-1.45	22.76

Based on the conditions and use of atoms of the N_2O molecule, the resulting and selected isotopes $^{15}N\alpha$ and $^{15}N\beta$ data have been used to calculate $\delta^{15}N^{SP}$ and $\delta^{15}N^{bulk}$. This calculation is carried out to allow more details to assess the relationship of isotopes with the microbiological processes on soil and compare the results of existing studies. Examples of calculation are shown in equations 1 and 2 using data from the sample of the measurement results.

$$\delta^{15}N^{SP} = {}^{15}N\alpha - {}^{15}N\beta \quad (1)$$

$$\delta^{15}N^{bulk} = \frac{{}^{15}N\alpha - {}^{15}N\beta}{2} \quad (2)$$

When collecting the data, they are divided into several parts: total results $\delta\ ^{15}N\alpha$, $\delta\ ^{15}N\beta$, statistical values for isotopes of $\delta\ ^{18}O$, data are broken down by soil samples for the isotopes concerned, as well as separately aggregated results for $\delta^{15}N^{SP}$ and $\delta^{15}N^{bulk}$ referring to the [1] study-designed variation between isotopes and calculated $\delta^{15}N^{SP}$ and $\delta^{15}N^{bulk}$. Statistical isotopes of $\delta\ ^{15}N\alpha$, $\delta^{15}N\beta$, $\delta\ ^{18}O$, give an idea of minimum, maximum and mean values.

RESULTS

The average values of $\delta\ ^{15}N\alpha$, $\delta\ ^{15}N\beta$, are 6.74 ‰ and -10. 07 ‰ and $\delta\ ^{18}O$ respectively, are 28.88 ‰. These data would be compiled to provide an insight into the reliability and relationship of the overall data. However, it is impossible to clarify and track the relationship between the isotope values between soil samples and the factors affecting them. Based on the available literature, it can be concluded that the values of δ

$^{15}N\alpha$, $\delta\ ^{15}N\beta$ and $\delta\ ^{18}O$ and the ratio of these measurements have been approximated to the results of previous studies. When compiling the calculated values in $\delta\ ^{15}N^{SP}$ graphics, both for all samples together and separately for humidity modes, a generally uniform distribution of the data is observed with some exceptions (see Figures 2., 3., 4.). The distribution of the values of $\delta^{15}N^{SP}$ shows a ratio of a pronounced extreme value to the other results shown in the graph with a discontinued line, in sample 0-1 in the sample, particularly the measurements made on the 08/07/19 date. For sample 0-1, this significant difference in value could be explained because it is a control sample collected in the natural part of the field.

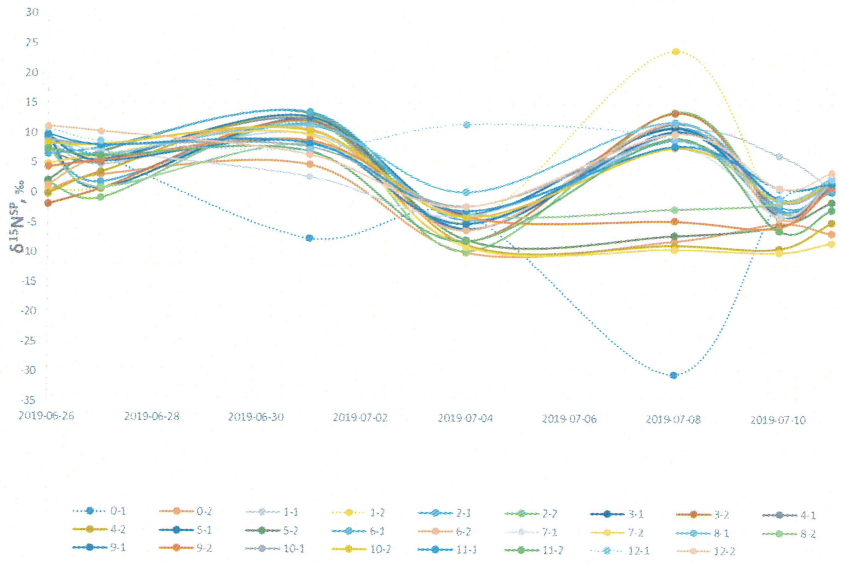


Figure 2. $\delta^{15}N^{SP}$ in soil samples by day of measurement

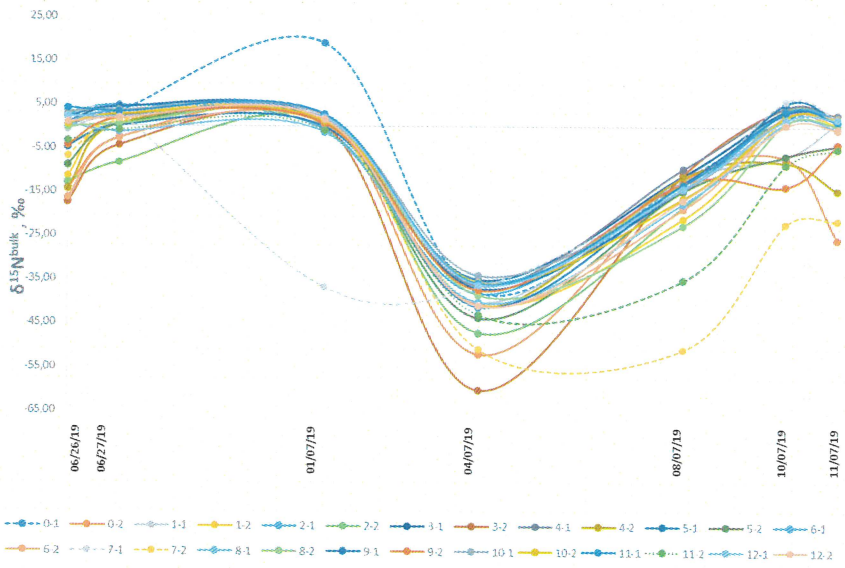


Figure 3. $\delta^{15}N^{SP}$ in soil samples by day of measurement

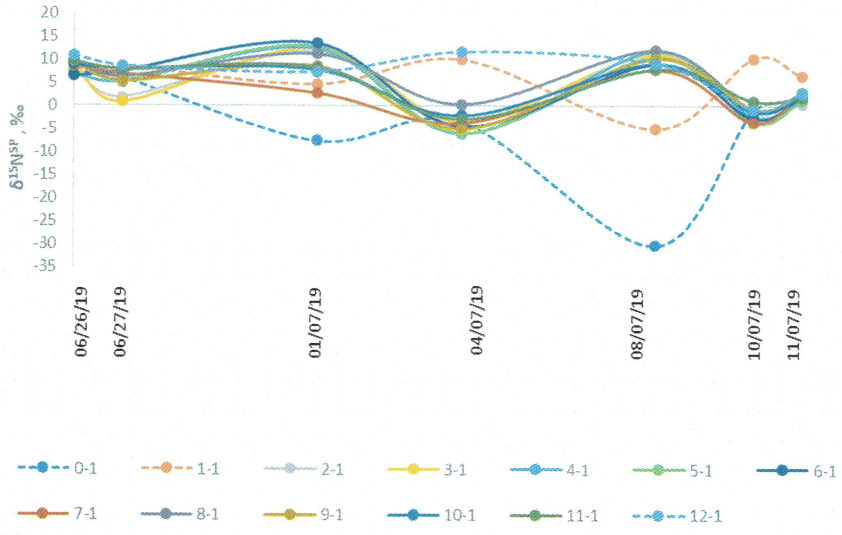


Figure 4. $\delta^{15}N^{SP}$ in soil samples by day of measurement

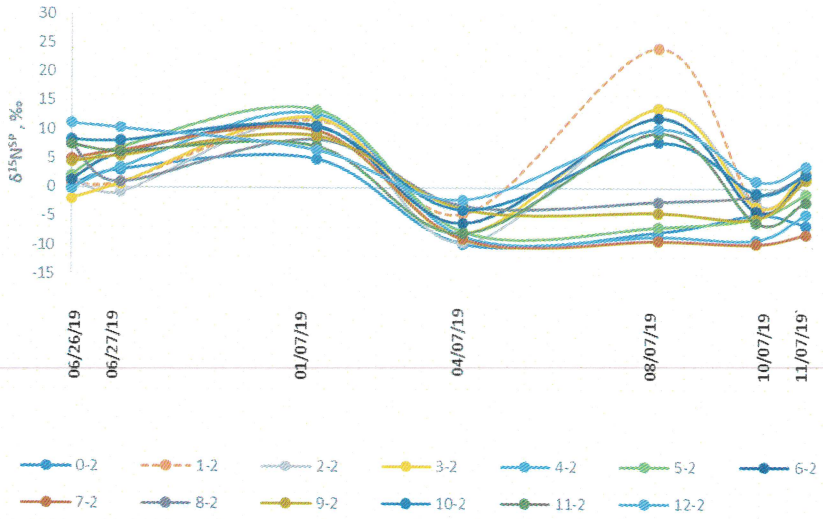


Figure 5. $\delta^{15}N^{bulk}$ in wet soil samples by day of measurement

When assessing these values, they can also be explained by the dates of soil wetting and the days when measurements have been made. The soil was moistened on 06/25/19, and measurements have been taken immediately in the coming days. In general, statistical data show that the calculated maximum and minimum values of $\delta^{15}N^{SP}$ are of high amplitude, which would be explained by the wetting and evaporation of the soil, as well as the dates of measurement, whether measured immediately after wetting or after a few days, respectively. As well as the average value of $\delta^{15}N^{SP}$, wet soil is less than normal humidity conditions.

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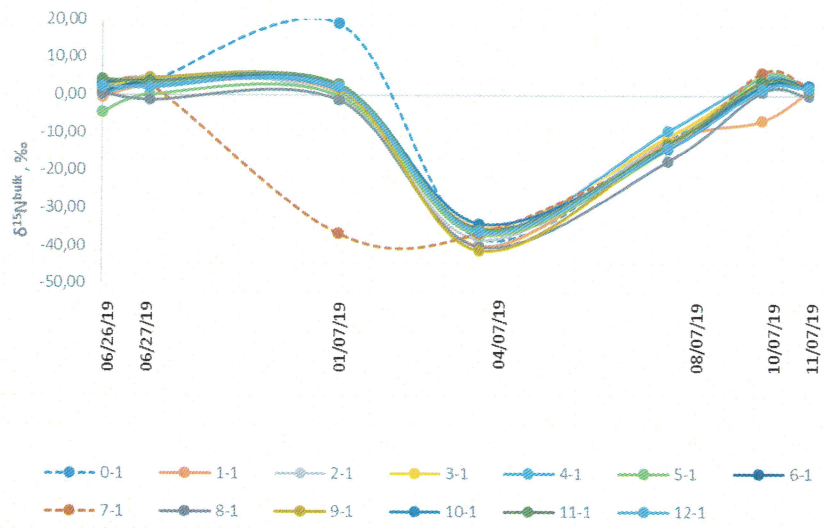


Figure 6. $\delta^{15}N^{bulk}$ in soil samples with normal humidity conditions by day of measurement

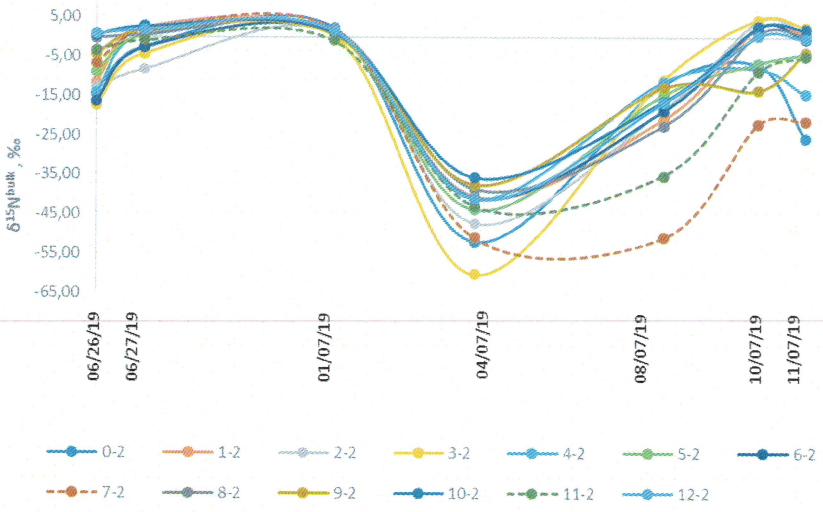


Figure 7. $\delta^{15}N^{bulk}$ in wet soil samples by day of measurement

The statistical values of $\delta^{15}N^{bulk}$ also indicate fluctuations in high calculated values. The mean value of total $\delta^{15}N^{bulk}$ is -8.82 ‰ , but there is a difference between soil samples at normal humidity and wet soil. As with the values of $\delta^{15}N^{SP}$, $\delta^{15}N^{bulk}$ shows extreme values in some soil samples relative to the other results. These extreme values are not observed in the same samples - $\delta^{15}N^{bulk}$ is 7-1, which is normal but 7-2 and 11-2 under wet soil conditions. However, as with $\delta^{15}N^{SP}$, these extreme values are observed on the 08/07/19 date (see Figure5., 6., 7.). The calculated data deviation and variation could also be explained by the availability of the substrate, which would refer more to the values of $\delta^{15}N^{bulk}$ since the values of [2] SP should nevertheless be independent of the substrate. In order to allow a more accurate assessment of nitrification and

denitrification in soil samples, it is necessary to analyse not only N_2O concentrations and isotope values but also valuable information from NO_3 and NH_4+ analysis.

CONCLUSION

Piccaro G5131-i can be used successfully to measure N_2O isotopes in soil under laboratory conditions, which provides an in-depth study of N_2O. Not all differences and relationships between the dispersal of the resulting N_2O isotope data can be directly linked to the physical properties of the soil. Differences between the germinative differences of micro-organisms and the effects of the population of micro-organisms cannot be excluded. This work highlights the fact that N_2O is a complex isotopic molecule, but the isotopes of this molecule and $\delta^{15}N^{bulk}$ and $\delta^{15}N^{SP}$ are valuable for tracking soil N_2O emissions and microbiological processes. According to previous studies and their results, the results of this study and the relationship between $\delta\ ^{18}O$ and $\delta^{15}N^{bulk}$ and between $\delta\ ^{18}O$ and $\delta^{15}N^{SP}$ have been observed with a similar correlation.

In order to obtain as accurate and reliable data as possible, the acquisition and verification of N_2O isotope data are essential, but it would also be necessary to perform an accurate calibration of the equipment. Unfortunately, until now, calibration standards and their use have been ambiguous and may not be consistent with individual studies, since the exact calibration of N_2O isotope equipment is one of the biggest problems faced by researchers around the world, so individual methods are frequently applied as well as the resulting isotope data are relevant to atmospheric isotope standards. It can be concluded from the data obtained and calculated that the soil humidity regime is one of the most critical factors influencing soil N_2O and N_2O isotopes corresponding to the aggregated literature. The data calculated by $\delta^{15}N^{bulk}$ and $\delta^{15}N^{SP}$ show steady results, with some exceptions and changes over time. However, it does not ultimately give a clear picture of the microbiological processes of the soil under the relevant circumstances.

During the development of the study, the information gathered and the results obtained give an idea of carrying out measurements of N_2O isotopes under laboratory conditions and set new objectives for further studies. Although this study does not highlight the dispersal of individual N_2O isotope ^{18}O data and the resulting data are not grouped by measurement day and respectively by soil humidity regime, the isotope ^{18}O is significant. It allows tracked sources of soil N_2O emissions and microbiological processes.

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THE CONCEPTUAL FRAMEWORK OF GHG MODULE INTEGRATION IN CONCEPTUAL HYDROLOGICAL MODEL METQ

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ABSTRACT

The mitigation of GHG emissions from anthropogenic ecosystems is one of a challenge for following decades. Successful GHG emission mitigation scenarios can be developed if there are tools to predict GHG emission trends according to climate, soil conditions, farm management practices, and other factors. One of the essential GHG emission sources is managed agricultural soils, and the most important factors are soil conditions, soil moisture, and temperature. The conceptual hydrological model METQ has been created under the leadership of scientists at Latvia University of Life Sciences and Technologies and validated for runoff modelling. The development of the conceptual hydrological model METQ by adding additional ecosystem modules is complex. However, the conceptual approach and developed algorithms allow using of this model for ecosystem modelling. The aim of the study is to establish a conceptual framework of GHG emission calculation module integration in the conceptual hydrological model METQ for the assessment and forecasting of the impact of climate change, land use, farming systems, and other factors on GHG emissions. The developed GHG emission calculation modules are designed in two groups. The first group is emissions from the soil, where the GHG emission calculation modules are connected to the soil active layer calculation algorithm of the conceptual hydrological model METQ. The second GHG emission calculation module is indirect N2O emissions from water bodies, where the GHG emission calculation algorithm is connected to the conceptual hydrological model METQ calculation algorithms. Integration of the GHG emission calculation into the conceptual hydrological model METQ requires the rewritten code of the existing modelling platform and the creation of an open platform for adding new calculation modules.

Keywords: GHG emissions, nitrous oxide, GHG mitigation, ecosystem modules, GHG modelling

INTRODUCTION

Mitigation greenhouse gas emissions and moving towards a carbon-neutral management model is one of the most significant challenges of this century, affecting all industries

and requiring the involvement of every inhabitant of the planet [1], [2]. Greenhouse gas emissions (GHG) from the agricultural sector represent 24% of total GHG emissions in Latvia, in the world meanwhile 19% [3]. The deep integration of the agricultural industry into natural processes requires additional knowledge and the ability to predict GHG emissions from soil change under different management scenarios in different soils and climatic conditions. This challenge can be solved by using modelling tools. The study of experience in GHG Emission Assessment Instruments development shows that the models have been developed for different purposes. In 2012, one of the first classifications of GHG calculators based on a model-use approach was established [4], [5] (Fig. 1).

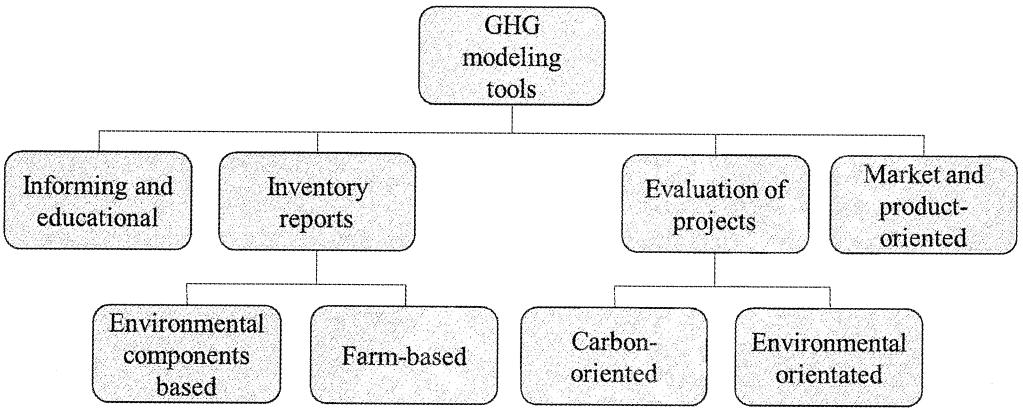


Figure 1. Classification of GHG modelling tools (created by author).

Soil GHG emissions mainly consist of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). CO_2 streams can be divided into three main stages: soil respiration, which includes respiration of roots, anaerobic and aerobic microorganisms [6] ecosystem respiration, which also provides respiration of the aboveground part of plants; net ecosystem exchange (NEE) is the balance of CO_2 used in photosynthesis and CO_2 released in respiration. Under anaerobic conditions, CH_4 is synthesized by methanogenesis, while CH_4 is consumed under aerobic conditions, where microorganisms use oxygen and CH_4 in metabolic processes [7]. N_2O and NO emissions are formed by nitrification (NH_4 + oxidation to NO_3 - with NO_2 -) and denitrification (NO_3 - reduction to N_2O and N_2). The denitrification process mainly forms N_2O under anaerobic conditions, where more than 50% of water-filled pore space (WFPS) is present [8].

Most GHG emission calculation tools are conceptual and based on conceptual hydrological models. The improvement of the conceptual model METQ is necessary to carry out multi-disciplinary research in the subfield of eco-hydrology, which studies the interaction between water and the ecosystem. And in environmental engineering, which solves diffuse pollution reduction and introduces technologies to reduce greenhouse gas emissions, soil water content and groundwater fluctuations play a crucial role in processes such as nitrous oxide emissions.

Conceptual hydrological model METQ is created under the guidance of scientists at Latvia University of Life Sciences and Technologies and validated for qualitative assessment of discharge and runoff [4], [9], [10].

The aim of the study is to establish a conceptual framework of GHG emission calculation module integration in the conceptual hydrological model METQ for the assessment and forecasting of the impact of climate change, land use, farming systems, and other factors on GHG emissions.

MATERIALS AND METHODS

The structure of the conceptual hydrological model METQ and the integration possibilities of GHG emission calculation algorithms are assessed from the prism concept. Four main steps required to successfully integrate the GHG emission calculation module in the conceptual hydrological model METQ are identified (Fig 2.).

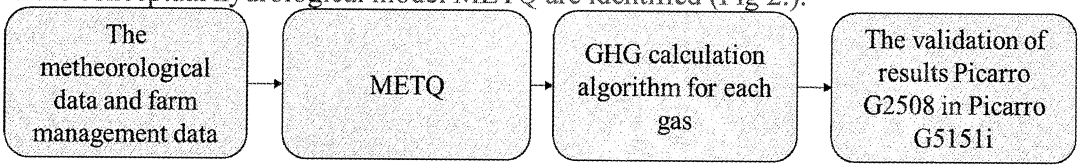


Figure 2. Feasibility of using the conceptual hydrological model METQ in modeling of GHG emissions (created by the author).

In the first phase, it is necessary to assess the selection of data sets required for the modelling of GHG emissions from the intermediate results of the conceptual hydrological model METQ and the need for additional parameters and series of data for the modelling of GHG emissions. In the second phase, the existing algorithms of the conceptual hydrological model METQ must be evaluated. A conceptual solution for integrating GHG emission modules or developing additional algorithms must be created. In the third phase, a calculation algorithm is generated for each GHG gas, which uses the intermediate results of the METQ soil active layer calculation of the conceptual hydrological model and additional parameters related to the calculation of GHG emissions. The fourth phase is a long-term activity, where field gas measurements are used to calibrate the developed GHG emission calculation modules.

In this study are described the first two phases and also the conceptual solution of module integration.

RESULTS AND DISCUSSION

GHG calculation modules must be divided into two groups. The first group of modules is emissions from soil, where GHG calculation modules can be connected to the METQ calculation algorithms of the conceptual hydrological model. The GHG calculation modules must be designed for carbon dioxide, methane, and nitrous oxide separately.

Analysing the main factors that contribute to CO_2 emissions from soil are several. Soil particle size distribution significantly affects CO_2 emissions, as particle size distribution directly affects soil porosity [11]. Precipitation significantly affects soil respiration and, together with the particle size distribution of the soil, forms the soil moisture regime, directly affecting the rhizosphere activity and measures CO_2 emissions [12]. Similarly, precipitation infiltrates into the soil and extrudes the air from the soil's pores; CO2 is pulled out, thereby creating a peak of CO_2 emissions.

A set of calculation algorithms for the conceptual hydrological model METQ is intended to calculate the processes of the active soil layer where the CO_2 calculation module can be successfully integrated.

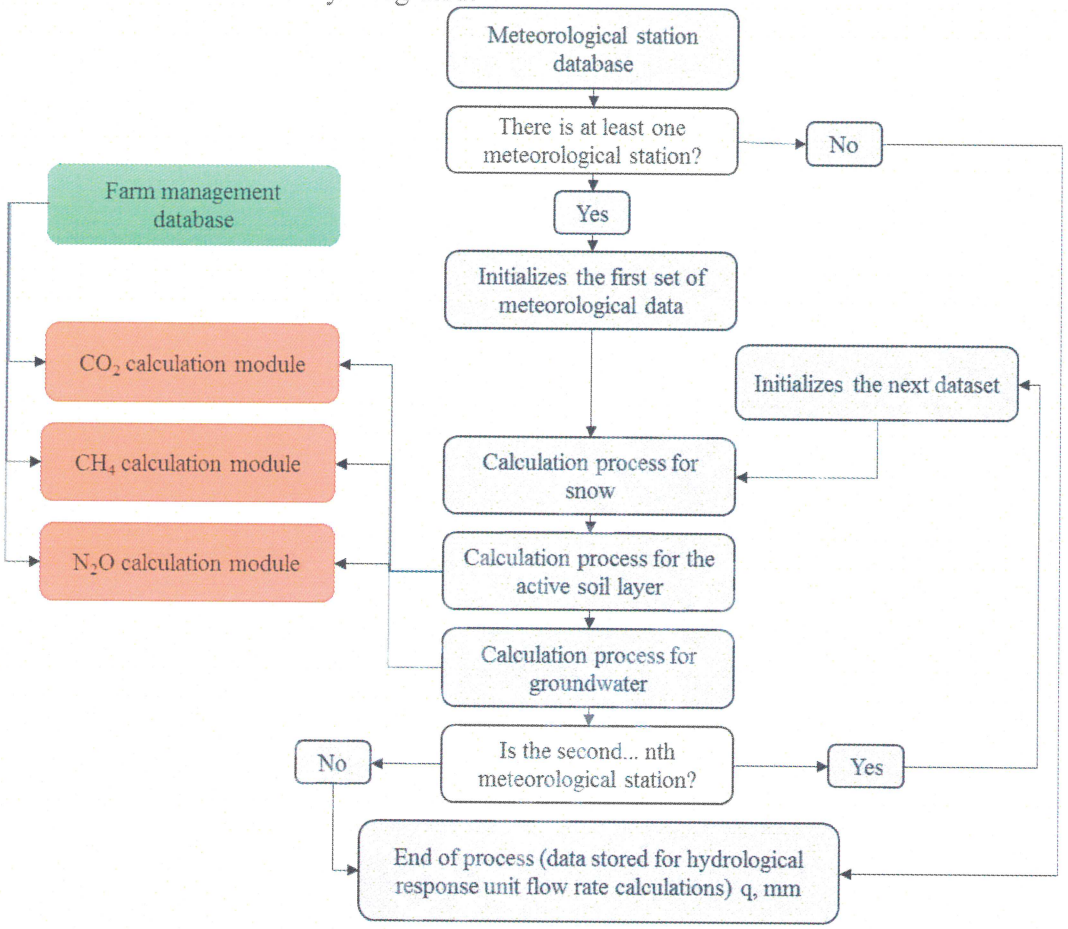


Figure 3. GHG calculation modules connection opportunities for conceptual hydrological model METQ.

Methane emissions are a more complex process, where the most important factors are soil moisture conditions and the amount of organic matter, and the decay rate of organic matter [13]. However, methane production is consumed in the soil simultaneously, closely linked to oxygen availability in the soil [14]. The above factors allow the methane calculation module to be integrated into the conceptual hydrological model METQ soil active layer and groundwater calculation algorithms.

The calculation of soil emissions of dinitrogen oxide is the most complex calculation algorithm because it is closely linked to nitrification and denitrification processes, which in turn depends on factors such as soil temperature, soil humidity, and pH [15]. The calculation algorithm for the active layer of METQ soil of the conceptual hydrological model allows you to generate intermediate results required for conceptual calculations of nitrification and denitrification processes.

In addition to existing algorithms, it is necessary to create an additional calculation module using climate data, soil parameters, and farm management practice is able to generate daily average soil moisture and soil temperature.

To successfully integrate the GHG emission calculation algorithms, it is recommended to use the existing METQ calculation algorithms of the conceptual hydrological model described in detail.

The second group of emission calculation modules is indirect N_2O emissions and methane emissions from water bodies. The GHG calculation algorithm can be connected to the METQ total runoff calculation algorithm of the conceptual hydrological model (Figure 4).

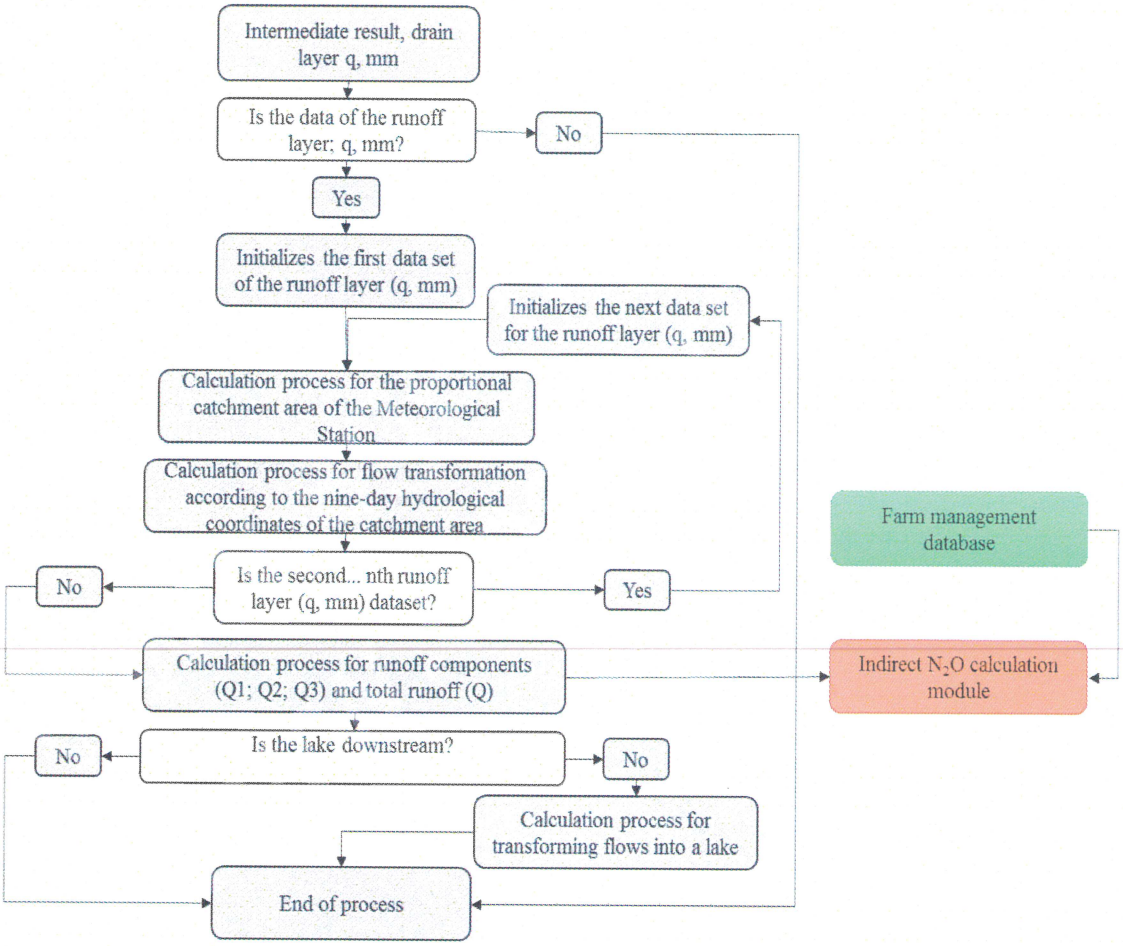


Figure 4. Indirect GHG calculation of connection opportunities for the conceptual hydrological model METQ.

In the analysis of the available statistical databases and the results of scientific studies, a calculation module for N_2O can currently be established. Using existing agricultural runoff monitoring data reflects farm management practice, and the conceptual hydrological model, METQ runoff component calculation algorithm, calculates indirect N_2O emissions.

CONCLUSION

The METQ modelling platform of the conceptual hydrological model allows the use of intermediate results of model calculations. Groundwater level at the end of the day, capillary raise, evapotranspiration are required in GHG emission calculation algorithms.

The METQ algorithms of the conceptual hydrological model are well documented and allow the integration of GHG emission calculation modules to calculate carbon dioxide, methane, and nitrous oxide emissions from soil. However, it is necessary to create additional parameter input options for each module of GHG emissions from soil calculation.

Integration of the GHG calculation into the conceptual hydrological model METQ requires modifying the existing modelling platform and creating an open platform for adding new calculation modules. GHG modelling from agricultural soils, where the calculation is based on nitrification and denitrification processes in the soil, and indirect GHG modelling from watercourses, where nitrogen leakage and nitrification and denitrification processes in water are used as a basis.

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