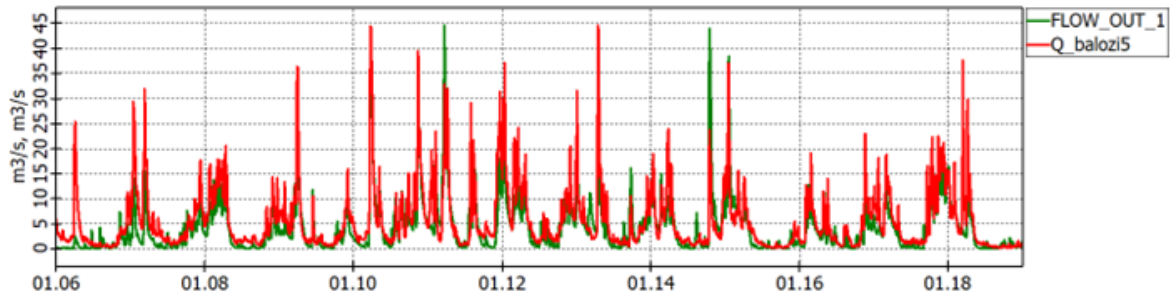
Eiropas Savienības LIFE programmas Integrētais projekts
"Latvijas upju baseinu apsaimniekošanas plānu ieviešana laba virszemes ūdens stāvokļa sasniegšanai"

MODELLING RESULTS FOR REFERENCE AND BASELINE SCENARIOS

DELIVERABLE R3



Prepared within the LIFE GoodWater IP Action C1: "Development of the water quality and quantity system for the territory of Latvia"

Rīga, 2022

Modelling results for Reference and Baseline scenarios

Uldis Bethers, Juris Seņņikovs, Pēteris Bethers, Andrejs Timuhins, SIA "Procesu analīzes un izpētes centrs"

Recommended citation: PAIC, 2022. Modelling results for Reference and Baseline scenarios. LIFE GoodWater IP, Rīga, 30p.

Document prepared in the frame of the integrated project "Implementation of River Basin Management Plans of Latvia towards good surface water status" (LIFE GOODWATER IP, LIFE18 IPE/LV/000014), project has received funding from the LIFE Programme of the European Union and the State Regional Development Agency.

The information reflects only the LIFE GoodWater IP project beneficiaries' view and the European Climate, Infrastructure and Environment Executive Agency is not responsible for any use that may be made of the information contained therein.

Document versioning sheet	
Document version number	**v 1.0**
Document planned elaboration date	**06.2021**
Document elaboration date	**06.2022**
Document actual version elaboration date	**06.2022**
Project activity/sub-activity number	**C1**

Summary

This document is a description of the electronic deliverable: Modelling results for Reference and Baseline scenarios. This document describes the organisation of the electronic deliverables. It also summarises the debugging of SWAT+ software elements, adding PAICSWAT software and dedicated original scripts for the postprocessing of the modelling results (Chapter 4).

Document is written in English, it contains 30 pages, 16 figures, 4 tables and 4 references.

Table of contents

Introduction

This document is a description of the electronic deliverable: modelling results for reference and baseline scenarios. The modelling results are obtained by the calibrated and validated modelling system for the water quantity and quality in the territory of Latvia delivered as Deliverable R2 in PAIC (2022). The modelling system is developed on the basis of the data base prepared within Deliverable R1, PAIC (2020).

The documentation of the modelling and its results for reference and baseline scenarios will be presented in the Deliverable R4 – "Documentation of development, calibration, validation and results of SWAT+ modelling system".

This document describes the organization of the elements of the modelling system as complemented for the modelling itself with debugging of SWAT+ software elements (Chapter 1), adding PAICSWAT software (Chapter 3) and dedicated original scripts (Chapter 4) for the postprocessing of the modelling results.

The organisation of the electronic deliverables is described in the Chapter 2.

1.SWAT+ debugging

The errors in SWAT+ elements and respective corrections are described in this Section.

1.1. Source code changes

The list of the SWAT+ errors and discrepancy with SWAT+ documentation[1] and SWAT+ executable (rev60.5.4) and corresponding SWAT+ source code was communicated to TAMUS team and by part corrected in rev60.5.4 of 13-Apr-2022:

- Documentation about recall input file format (we use it for pointsources) is not corresponding to what is in the SWAT+ source code and SWAT+ executable. Documentation states that first two columns of data for dayly, monthly and yearly timesteps are IYR and ISTEP, while in source code there are 6 columns (jday, mo, day_mo, iyr, ob_typ, ob_name) (see recall read.f90, line 150).

- Point source (recall) data format written by SWAT+ editor does not correspond to point source format used by SWAT+. It seems that it corresponds to the SWAT+ documentation, but not to source code.

- If pointsource is monthly, then only first calendar month of each year (January) is applied (read from file). There should be line istep = istep + 1 in monthly case (line 180 of recall_read.f90), otherwise all 12 monthly data will be assigned for January only (istep=1).

- It seems that if weather files start with the later date than simulation start, weather generator is used for the whole simulation period, instead of only for the missing dates.

- Seems that weather generator dewpoint values cannot anymore be entered as relative humidity, despite that documentation states "If all twelve months are less than one, the model assumes relative humidity is input". Comparing SWAT and SWAT+ source codes, it seems that relevant code part is missing in SWAT+.

- For some of the input files documentation states that "The title line is not processed by the model and may be left blank". It seems that it is not anymore the case (comparing to SWAT2012). For instance, if header or title lines in atmo.cli is blank then atmo.cli is read incorrectly. This is related to change to how the header lines are read from files. SWAT2012 used formatted input (e.g. read (127,5101) titldum, where line 5101 contained format) – that allowed to read the blank line also. Now in SWAT+ wildcard format is used (e.g. read (127,*,iostat=eof) titldum) – in that case if the line is blank

[1] inputs_swatplus_rev60_5.docx from https://swatplus.gitbook.io/docs/user/io

reading continues to the next non-blank line and real data could be misinterpreted as the comment.

- Names of files in pcp.cli, tmp.cli etc. and station names in atmospheric deposition atmodep.cli must be in sorted order (not stated anywhere in documentation!), otherwise potentially incorrect data will be assigned (searching procedure in search.f90 works only on sorted arrays (!), but on reading no sorting is performed!).

- If atmo.cli file is provided then even for the weather stations without assigned atmospheric deposition (set to null), some undocumented default values for wet deposition is used (c_NH4=1 mg/l, c_NO3=0.2 mg/l) (see type atmospheric_deposition of climate_module.f90).

The further changes listed below are made by PAIC in the reference SWAT+ source code and presented in github repository[2]:

1. Wrong output parameter unit. File *ru_day.tx*t
   https://github.com/andrejstmh/SWATplus/commit/4d8678d81f01cd79a1a7c74fb90c691ae9aa8b8d#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

2. Wrong output parameter unit. File *channel_sd_day.txt*
   https://github.com/andrejstmh/SWATplus/commit/cdf7c476bc205e16098fde4f558aa3983192a5f3#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

3. Output variables increase all the time (time step). File *soil_nutcarb_out.txt*
   https://github.com/andrejstmh/SWATplus/commit/c6c259351c2577d5bdbfee3fa5bc98b0f491ef57#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

4. Incorectly calculated channel depth. That leads to very small channel outflow. File *ch_watqual4.f90* (rchdep = 0.)
   https://github.com/andrejstmh/SWATplus/commit/764564e06fb0d8786a42789cdcb5b5d9fe7fddcc#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

5. Variables are misnamed (exchanged surq_gen <=> surq_cont)
   https://github.com/andrejstmh/SWATplus/commit/7a9c54eed89cbbfd5f8667ac8916ac4877320060#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

[2] https://github.com/andrejstmh/SWATplus/commits/main/source_codes

6. Surfaces runoff processes are not running in regular case. Mismatched (exchanged) wetland and regular cases.
https://github.com/andrejstmh/SWATplus/commit/d8a575c61e33339f1dd82c1e379880ac08c80ec9#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

7. Coefficients cn3_swf and perco are initialised to constant values if the tile drain is on
https://github.com/andrejstmh/SWATplus/commit/d588df775f37fa55a06da175d5b30d32ee0b07eb#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

8. Evapotranspiration model differs from SWAT (coeeficient esco) comparing SWAT theoretical documentation TWRI(2011)[3] Eq 2:2.3.17 with the source code rev.627/etact.f
https://github.com/andrejstmh/SWATplus/commit/e652f28d1665f32b06b63d664c681d4bf8af4fb3#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

9. Evapotranspiration model differs from SWAT. According to TWRI(2011) Eq 2:2.3.18 & source code rev.627/etact.f
https://github.com/andrejstmh/SWATplus/commit/f5401037f379defa733ee107d249287d37e6d19c#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

10. Aquifer nitrogen flow units and initial content are incorrect
https://github.com/andrejstmh/SWATplus/commit/21af44f544e4af0d2aca112228dff29d91dfdcf7#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

11. The computation of the travel time of the latteral flow is switched on
https://github.com/andrejstmh/SWATplus/commit/cf5e71eb7a838335e35b01e74ff4e57771a5e18d#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

12. The computation of the lateral subsurface flow from first soil layer is switched on
https://github.com/andrejstmh/SWATplus/commit/d2563c25ab187bbfbe677befc3db435807d6e47a#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

13. Redundant line with wrong code is removed
https://github.com/andrejstmh/SWATplus/commit/cd931978ea8544d064d399069a888

[3] https://swat.tamu.edu/media/99192/swat2009-theory.pdf

6cc7e407440#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

14. *dep_imp* variable is introduced (like in SWAT v.627). https://github.com/andrejstmh/SWATplus/commit/a494ec84e131c3c85d16a3213bf1aef893904e34#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

15. A possibility to control output of files *wetland_*.txt* separately from the *reservoir_*.txt* is introduced: https://github.com/andrejstmh/SWATplus/commit/dff27eed54cdbfd82bac88884c7f287df7c8c054#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

16. Module wetland_control.f90 containing uninitialized variables is bypassed https://github.com/andrejstmh/SWATplus/commit/2a60358aceb00005a0a046c0a4961c7538539485#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

17. Delay time for aquifers is introduced (like in SWAT v.627) https://github.com/andrejstmh/SWATplus/commit/de55a5e7d4e1e92aac5196ec3fcead92eeee6ee0#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

18. Evaporation module is changed (like in SWAT v.627) https://github.com/andrejstmh/SWATplus/commit/3b1e2bff30186326fbad9f98c7c156317f5b10ec#diff-8fed27fc4815cb7df6aa86a3e660491b04b6323635c44972575ab52fc6a6d372

19. Error in search procedure. Uninitialized variable "aqu_found" https://github.com/andrejstmh/SWATplus/commit/a64dd6aeca7c620caeac491b6499d1655ddab248

20. Corrected snow pack temperature https://github.com/andrejstmh/SWATplus/commit/6e248856a34351c3450bcee6bfc38b63f67beadf

21. Corrected output_losses_header1 https://github.com/andrejstmh/SWATplus/commit/062b171a219a900fc538abefe07933097e0c15fa

22. Half-life of NO3 implemented
https://github.com/andrejstmh/SWATplus/commit/8bea0a7c778f50df9824567e3126cbad79f77893

23. Update fresh residue plants and soil layers procedure
https://github.com/andrejstmh/SWATplus/commit/88c0b3b45718724fd75a92f45758715cd8b12ff9

24. Fresh residue tillage mixing added
https://github.com/andrejstmh/SWATplus/commit/028e92666381df3e130dc4454b95aed7c95e4c04

25. Mgt_kill operation: add above ground mass to soil fresh residue pool
https://github.com/andrejstmh/SWATplus/commit/8b8756b00ef574b38d25491643a81cb14fdcce1f
https://github.com/andrejstmh/SWATplus/commit/b177c68d0b0f7f88dc84cbf9f08bb12cb4a9193e

26. Fresh organic nutrients remineralization added
https://github.com/andrejstmh/SWATplus/commit/7cdf7b30a0a1dfcae45b9881db9768e11db91b7b
https://github.com/andrejstmh/SWATplus/commit/831cfd17466b27b95510ac2f60aaca42ed8049a3

27. Bugfix for tillage of fresh organic resuidue mixing
https://github.com/andrejstmh/SWATplus/commit/6d89f0b887f043c8638a765009feb363c6e6e8d5

28. Corrected soil nitrate denitrification formula
https://github.com/andrejstmh/SWATplus/commit/d367c61606555e4cfcf4093410caef757b6c3514

29. Organic fertilizer added to fresh organic pool (as in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/6db7844c520e7c8036d7ead14fef4ead57fc0823

30. Harvest index routines modified to correspond to SWAT2012
https://github.com/andrejstmh/SWATplus/commit/f873c980f69592fd8b0e44ca74384c15d2fad922

31. Corrected sediment yield calculations
https://github.com/andrejstmh/SWATplus/commit/64060bd9ea1ae88d04ca839b77918300514261e5

32. Distribution of plant nitrogen uptake like in SWAT2012
https://github.com/andrejstmh/SWATplus/commit/324111ac9ca82dac768ae193bc644b85495148fd

33. Leaf area index growth dependent on total stress like in SWAT2012
https://github.com/andrejstmh/SWATplus/commit/d1d4d26ec4b1ef4746589d5334cadaac599088f4

34. Possibility to input initial organic phosphurus and nitrogen in soil layer implemented (as in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/85bfa1e220cff7a72f7013849f862a08801b2632

35. Changed routine for the biomass growth (bioday)
https://github.com/andrejstmh/SWATplus/commit/b46ea5b770bdd8a764222a3ccbc3756048d365da

36. Implemented soil carbon initialization from file
https://github.com/andrejstmh/SWATplus/commit/9697215d7508345b67086a18f9e3ffef4db87885

37. Restored possibility to select soil phosphorus model as in SWAT2012
https://github.com/andrejstmh/SWATplus/commit/62d51dcec2b3fc2ab7a2d6e72bfba466a324e7ab

38. Fixed units of conversion factor in soil initialization routine
https://github.com/andrejstmh/SWATplus/commit/c737f7f73be45517ead1e0d28b5e1a28e403fa9b

39. Implemented soil organic phosphorus initialization
https://github.com/andrejstmh/SWATplus/commit/dfe657d3117125b6d448b6d1175994514a1e1ddc

40. Implemented phosphorus in surface runoff from residue (as in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/566d7567fbfff3a2ec9153c9af9ef756833a3c9c

41. Implemented initialization of soil mineral phosphorus un nitrogen from input file (as in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/9aa67e5e64418c19406620b306cfb72da8b260e7

https://github.com/andrejstmh/SWATplus/commit/7f26f6e9dda43bc5a71f00a497f2ec2ddce99cac

42. Formula for initial stable soil phosphorus pool should use carbon concentration not mass per area
https://github.com/andrejstmh/SWATplus/commit/f78905f02d36c9a33b999268b5ea5d53441dfca6

43. Code merged with swat official version 13apr2022-Version-60_5_4
https://github.com/andrejstmh/SWATplus/commit/f9cfe948775a3871dd9fa983f726e0fc2155f193

44. Simulation.out header fixed
https://github.com/andrejstmh/SWATplus/commit/2b9f3b90b40b1071f1f958e9a7e9384edfa6941b

45. PSP calculation should contain carbon concentration not mass per area
https://github.com/andrejstmh/SWATplus/commit/733b0a2d1ee1b3f896eec74a57cfb6bc47c3fcb7

46. Fix for concentration based mixing in tillage
https://github.com/andrejstmh/SWATplus/commit/e44dba159f2ddf06ac4cc010f1223815a51dbeb5

47. Coefficient nperco_lchtile enabled
https://github.com/andrejstmh/SWATplus/commit/9764d1842217c09a356772fb682cee966ece3a3d

48. Revert soil soluble phosphorus routines to previous SWAT+ version to correspond to SWAT2012
https://github.com/andrejstmh/SWATplus/commit/8b8ff55f980a5d4a400140485af3976aa1362d06

49. Bugfix in phosphorus sediment calculations
https://github.com/andrejstmh/SWATplus/commit/dbb3cae2fa72168cadd0484c8950545adbbf5a6a

50. Change LAI, add leaf mass to residue at dormancy for perennials
https://github.com/andrejstmh/SWATplus/commit/4ca991f5dfc015956c6430034b014eb7d48439fa

51. Implemented leaf senescence dependent on plant accumulated phu
https://github.com/andrejstmh/SWATplus/commit/5f6a9fd085b46f18be99ad096384b34678636501

52. Leaf drop should affect total plant mass – fixed
https://github.com/andrejstmh/SWATplus/commit/765d01eefb290e78a0b94446688517ae3a5e660e

53. Dormancy for forests implemented
https://github.com/andrejstmh/SWATplus/commit/96e5dfc9801168ac95bb636b54959da55cbd178c

54. Plant partitioning for forests, additional parameter included
https://github.com/andrejstmh/SWATplus/commit/dc4874937d95365ea11d9d606feeb97f4662135e

55. End of year management operations added (as in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/27ec883b0edbdd338688dd54822734b7d907fce9

56. Bugfix - no need to reset phuacc after harvest only operation
https://github.com/andrejstmh/SWATplus/commit/c73dfce5eeb51ac9ecd64f711c3bb7e7eee4eb7b

57. Nutrients outflowing from reservoir was not subtracted from reservoir - fixed
https://github.com/andrejstmh/SWATplus/commit/7ea920867cd7ea185434dc97ec22aa9de074896a

58. Implemented reservoir settling rate as in SWAT2012
https://github.com/andrejstmh/SWATplus/commit/448473165355da58056918f2ac84ddb01aac2cbd

59. Reservoir initialization bug fix
https://github.com/andrejstmh/SWATplus/commit/5f0d0c9f02cb3f8c73f094072618395a2bed32f3

60. Minimal flow from reservoir implemented
https://github.com/andrejstmh/SWATplus/commit/730267719a4c2d464ea5c98e269dda3530b352f9
https://github.com/andrejstmh/SWATplus/commit/25d93a1eba9754bbd09c10b1b820945dc4f99514

61. Repaired aquifer flow numerical scheme that was unstable (implemented order of operations as was in SWAT2012)
https://github.com/andrejstmh/SWATplus/commit/dfde88519d5ede6951e3e01e90df43509d48a759

62. Corrected uninitialized output variable in action "hru_fr_update"
https://github.com/andrejstmh/SWATplus/commit/9b75dd914539b7d061946399e25cf8accee87c02

63. Aquifer nutrient output dimension changed to kg/ha
https://github.com/andrejstmh/SWATplus/commit/bec9744e2e3639b3a17323f5711443e0c30fcee5

64. Corrected routing unit output
https://github.com/andrejstmh/SWATplus/commit/1a248048fd12b4ec0c298cd99509406ea0413ea8

65. Routing unit number added to routing unit output
https://github.com/andrejstmh/SWATplus/commit/339081f285aa0f7148cbd6019b2467ce2a482a3f

66. Enabled and bugfix source code for grassed waterways
https://github.com/andrejstmh/SWATplus/commit/3fc00b39edc86951e374f07a24fa02ab50cdbaa1

67. Bugfix in plant determination at scheduled management operation
https://github.com/andrejstmh/SWATplus/commit/db46d5a3ec55775db9221dbab37fac9c6dd8f0a0

1.2. Documentation

The subsection documents errors and missing parts of SWAT input/output documentation[4]. This may include differences between the documentation and the source code. The following problems are found in *outputs_swatplus_rev60_5.pdf*:

- Document does not contain information about *soil_nutcarb_out*.
- Wrong documented unit. File *aquifer_day.txt* (**seepno3** kg(N)/ha)
- Wrong documented unit. File *channel_sd_day*.txt (**flo_in**, **flo_out** m3/s)
- Document does not contain information about input parameter **latq_co**
- Inconsistent parameter name **cn3_swf**

1.3. SWAT+ Editor

Errors found in SWAT+ Editor

1. There is no way to setup daily and monthly output for *soil_nutcarb_out.txt* in the SWATPlus editor.
2. Wrong name of the parameter. HRU/ Hydrology Properties /Plant ET curve number coefficient.
3. There is no possibility to create setup without routing units.
4. Error in the save procedure (file *ari/fileio/hru.py* class *Hru_data_hru* variable f*ield*).

[4] https://swatplus.gitbook.io/docs/user/io

2.Structure of modelling results

The water quality modelling system is electronically delivered containing all the data and scripts needed for the creation of the system, see PAIC (2022). The water quality modelling system is generated automatically by executing the script *main.py* from folder *projectDir/Scripts.*

Main.py also runs the calculation of the modelling system and creates the results in *setupsDir* folders. The folder structure where the results can be found would be as follows:

LVSWAT2022(projectDir)/Watersheds(setupsDir)/RiverBasinName/WatershedName/ScenarioName/

For, example, the result folder for baseline scenario in Venta river basin district and the 1st Abava watershed will be

LVSWAT2022/Watersheds/Venta/Abava_1/Baseline/

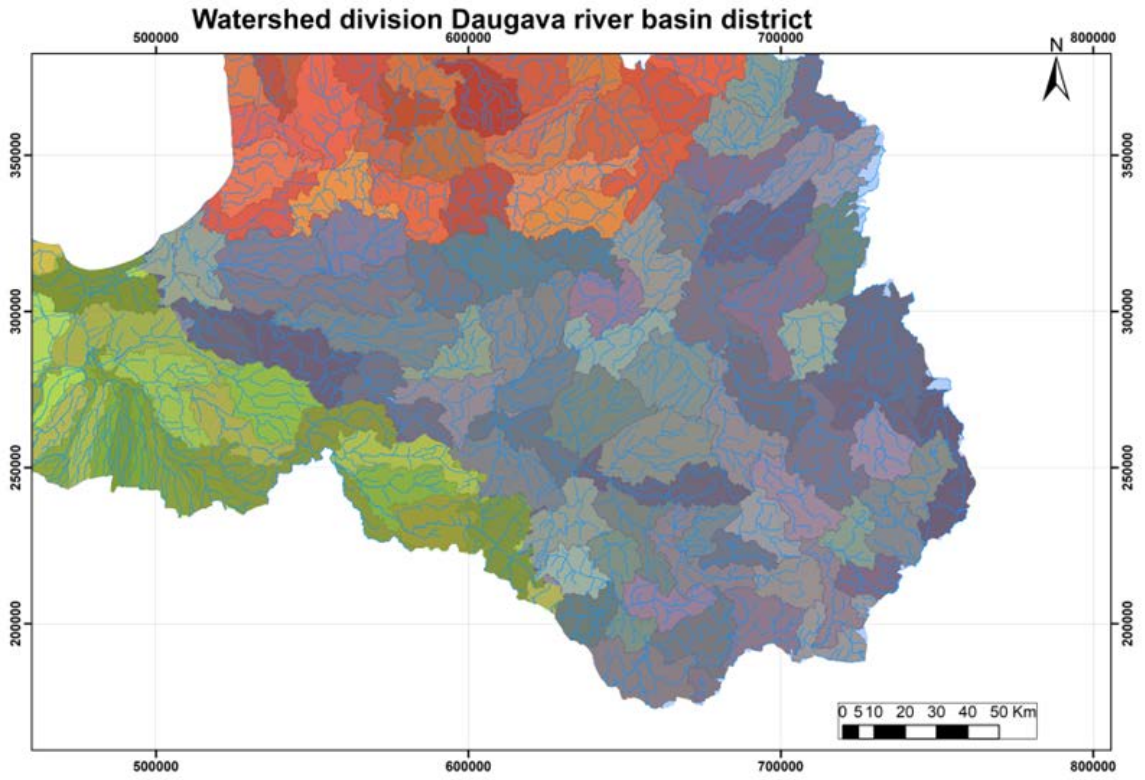


Figure 1: Watersheds of Daugava RBD.

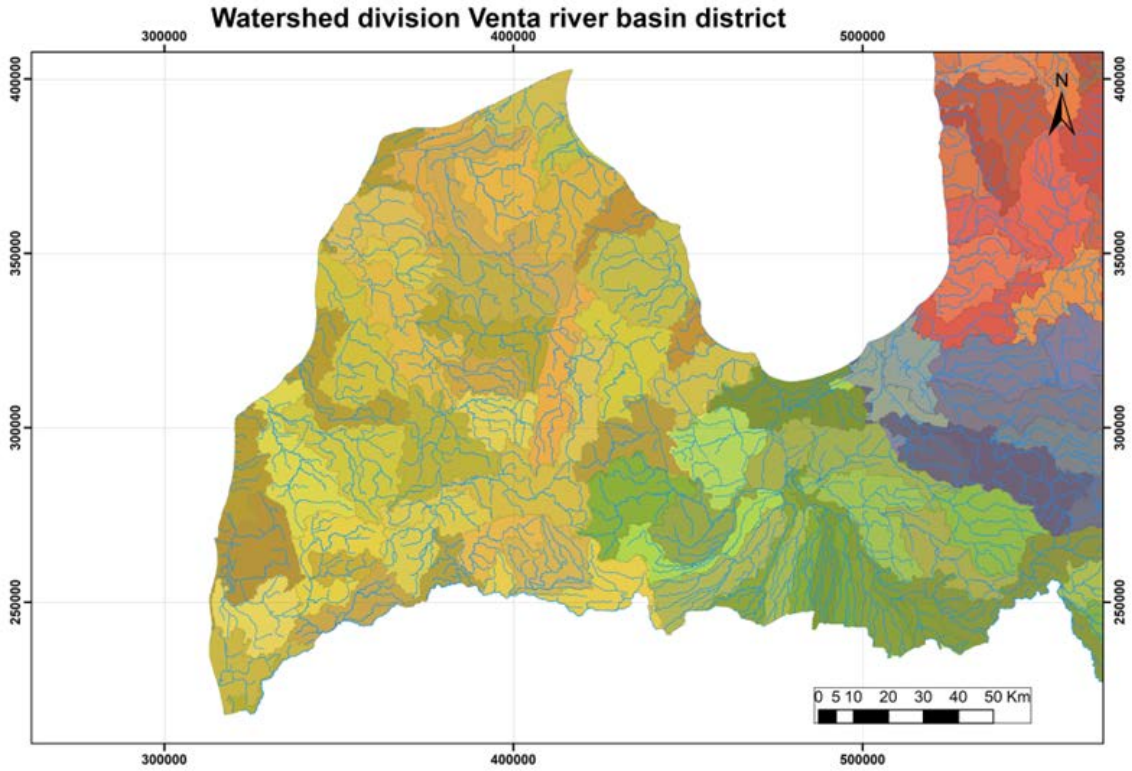


Figure 2: Watersheds of Venta RBD.

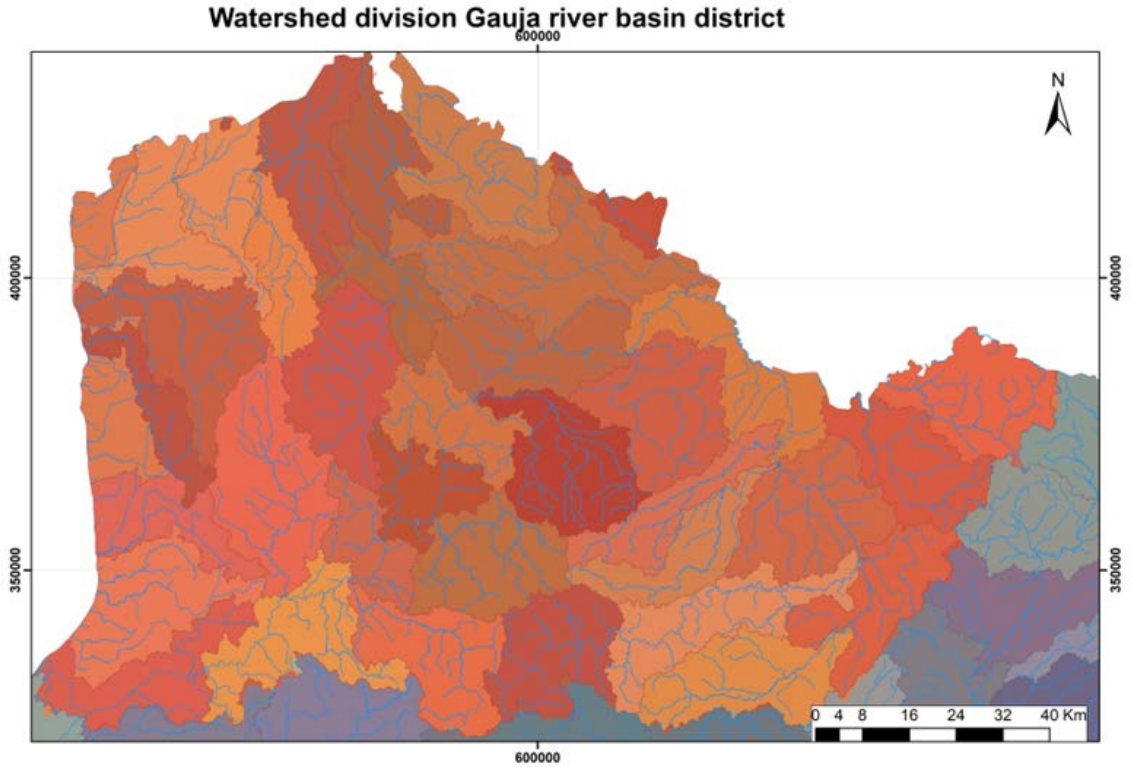


Figure 3: Watersheds of Gauja RBD.

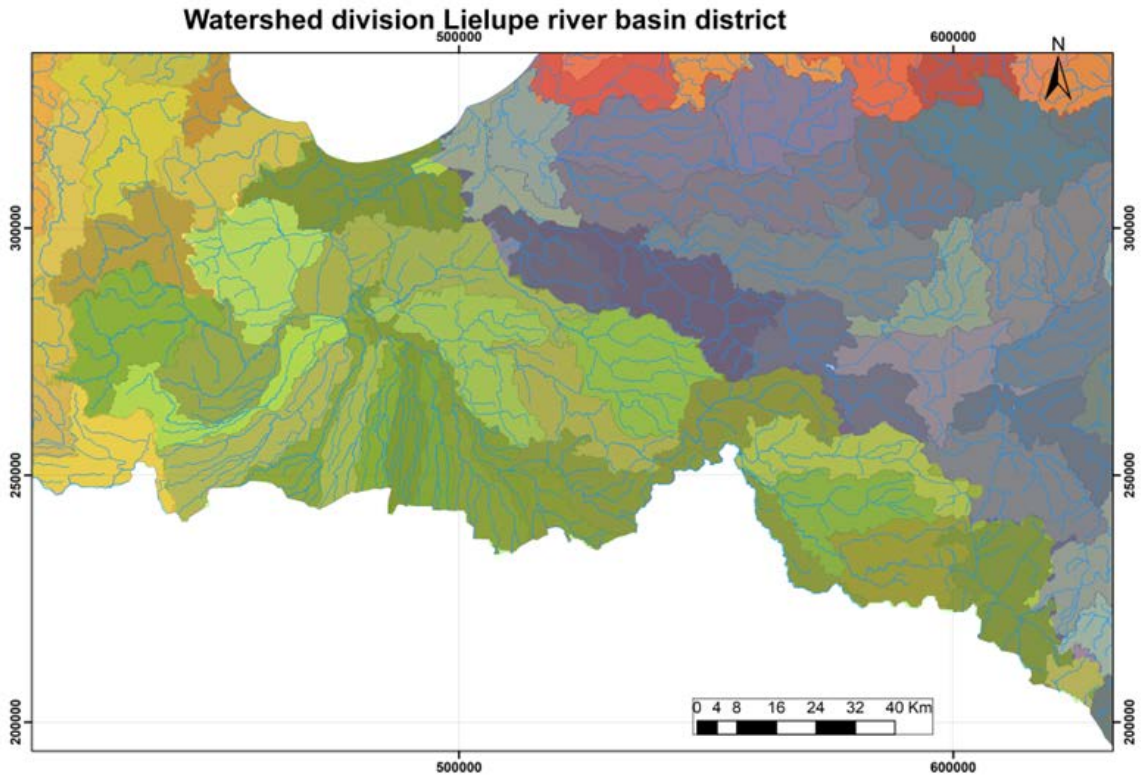


Figure 4: Watersheds of Lielupe RBD.

The SWAT+ model for the specific watershed can be found in this folder, together with its input and output files for the specific scenario. The output file extension .out indicates these files while most of the other files are text input files for the model to run.

Time period of calculation is 2006-2018 (with 2006 and 2007 used for warm-up of the model).

The model system for Latvia consists of 4 river basin districts which are divided into 169 watersheds, which are further divided into 3469 catchments. The division of 4 RBDs into watersheds is shown in Figures 1-4, while illustrations of further division of two watersheds in the catchments – in Figures 5-6.

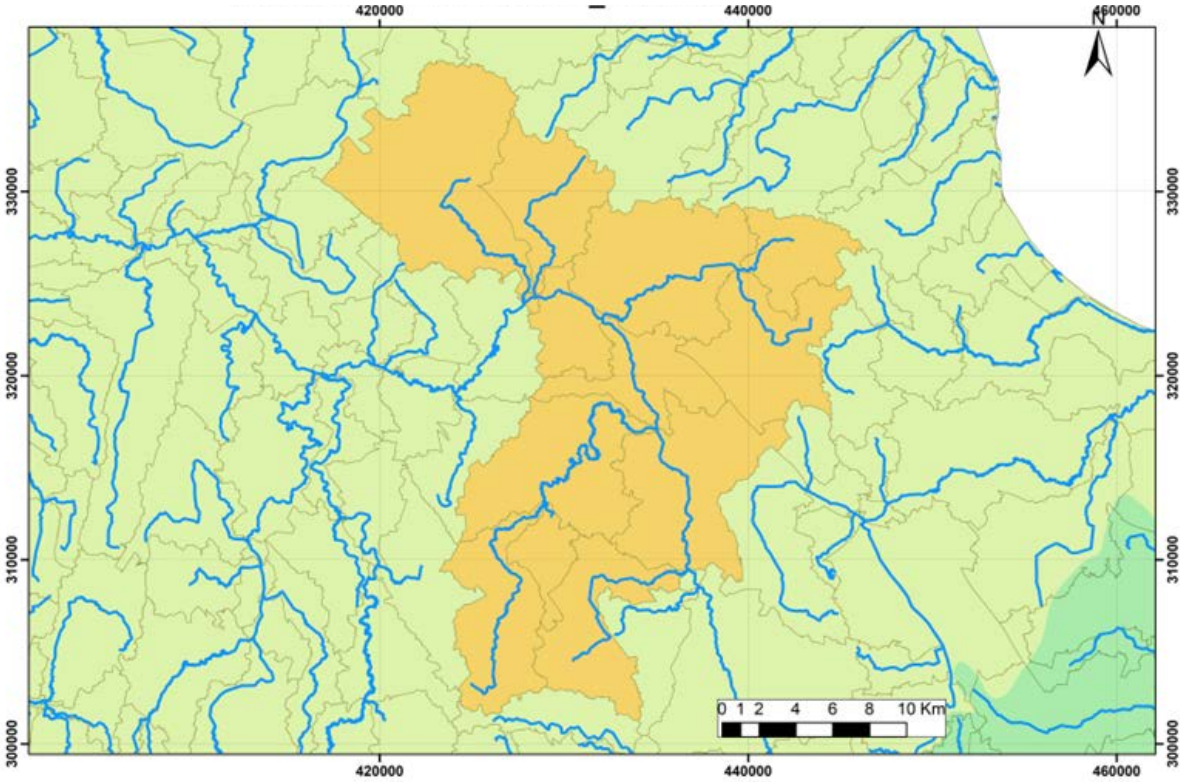


Figure 5: Catchments of Abava watershed.

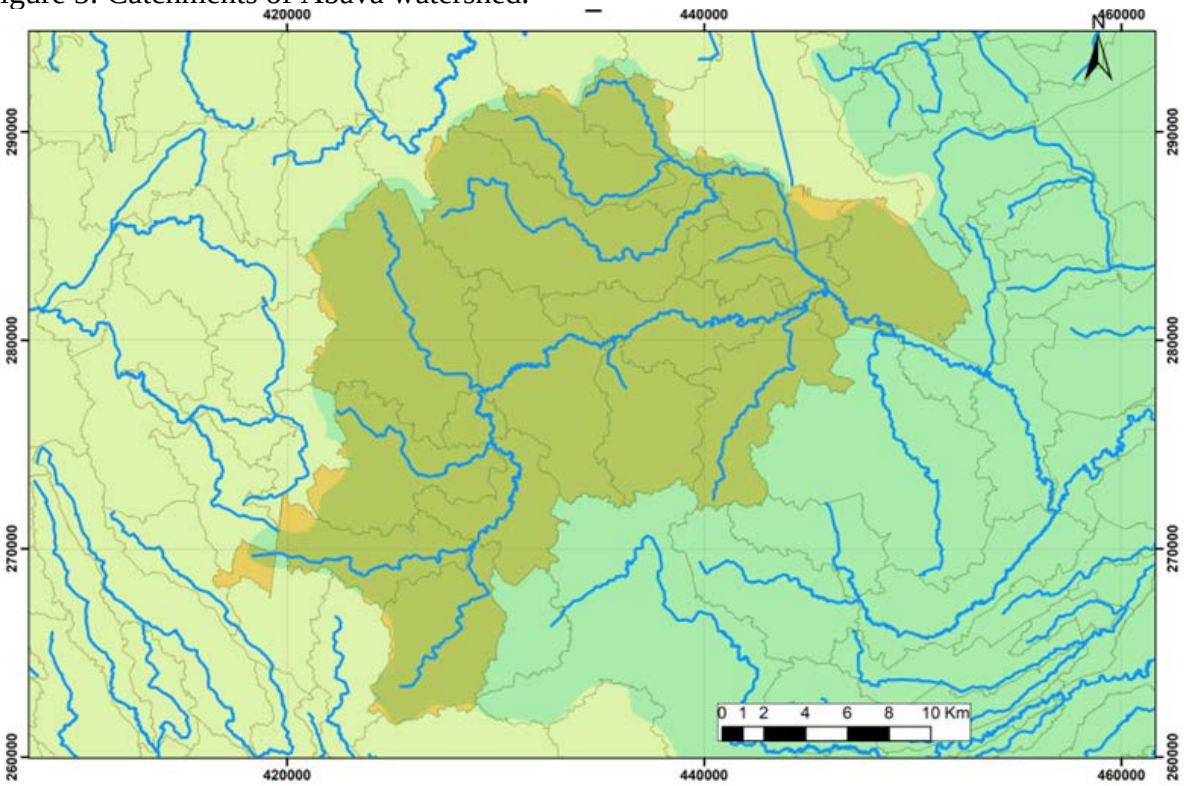


Figure 6: Catchments of Bērze watershed.

3.PAICSWAT

3.1. Description of PAICSWAT

The main tool for visualization and analysis of SWAT+ modeling results is PAICSWAT software by PAIC. Output results of modelling system could be visualized by PAICSWAT software (PAIC, 2012). The vizualisation works by converting output results calculated by SWAT+ to the SWAT2012 format which could be loaded into PAICSWAT. The preparation step includes running of *prepare_PAICSWAT.py* script located in the main scripts directory. It includes two subroutines:

1. *initPAICSWAT.prepare_PAICSWAT* – this subroutine regenerates *PAICSWAT.ini* configuration file. The location of the configuration file is provided in *settings.PAICSWAT_ROOT* configuration variable (by default it is located in *PAICSWAT* subdirectory of the project directory). In case if the *overwriteData* parameter is *True* then the catchment and river geometrical data in format required by PAICSWAT will be regenerated as well. Default location of PAICSWAT geometrical data is under subdirectory *PAICSWAT/Data* of the project directory.

```
initPAICSWAT.prepare_PAICSWAT(project,
PAICSWATDataDir=settings.PAICSWAT_ROOT + "/Data",
PAICSWAT_INI =settings.PAICSWAT_INI,
overwriteData = True)
```

2. *initPAICSWAT.FillPaicSWAT_forsetups* – this subroutine generates two SWAT2012 files that are required for the PAICSWAT to function – *file_paicswat.cio* and *fig.fig*. These files are copied to each of the watershed setups.

```
initPAICSWAT.FillPaicSWAT_forsetups(project,   watershednamelist =
watershednamelist)
```

Each change of thr calculation directory (provided in *settings.defaultCaseSubDir*) requires re-running of the preparation procedure.

Conversion of SWAT+ results to SWAT2012 format are achieved by the subroutine *convertOutputToPAICSWAT.convertAll*. The calculation loop in the main script (*main.py)* automatically call this conversion subroutine after calculation of each of the watersheds (for that particular watershed). It also can be called explicitly by script *convert_results.py* where selection of watersheds for conversion are implemented.

The executable of PAICSWAT software (*PAICSWAT.exe)* is provided under *PAICSWAT* subdirectory of the project directory. It could be run from there after preparation steps are accomplished. The *PAICSWAT* functionality compatible between SWAT+ and SWAT2012 includes:

- Selection of catchment and watershed on the PAICSWAT map.
- Loading of calculation setups (Menu *File->Load case).*
- Loading of compatible setup results (Menu F*ile->Load from directory*).
- Loading and visualisation of time-graphs in PAICSWAT data format (*.sta+.txt) (*e.g. observation and weather data).
- Visualisation of time-graphs of outputs at catchment level (reaches, subbasins, reservoirs (PAICSWAT tabs *Model->RCH, Model->SUB, Model->RES*)).
- Comparison of model outputs to observations (PAICSWAT tab *Calibration).*
- Statistics and correlations of abovementioned graphs (Buttons *Statistics, Correlations, Concentrations, Monthly value, Normalize by area).*

Incompatible functionality includes, but are not limited to:

- Visualisation of results on a HRU level.
- Displaying and modification of SWAT2012 input files.
- Running of calculation by SWAT2012.

3.2. Illustrations of modelling results

The modelling results for Bērze_2 watershed are illustrated with the use of PAICSWAT.

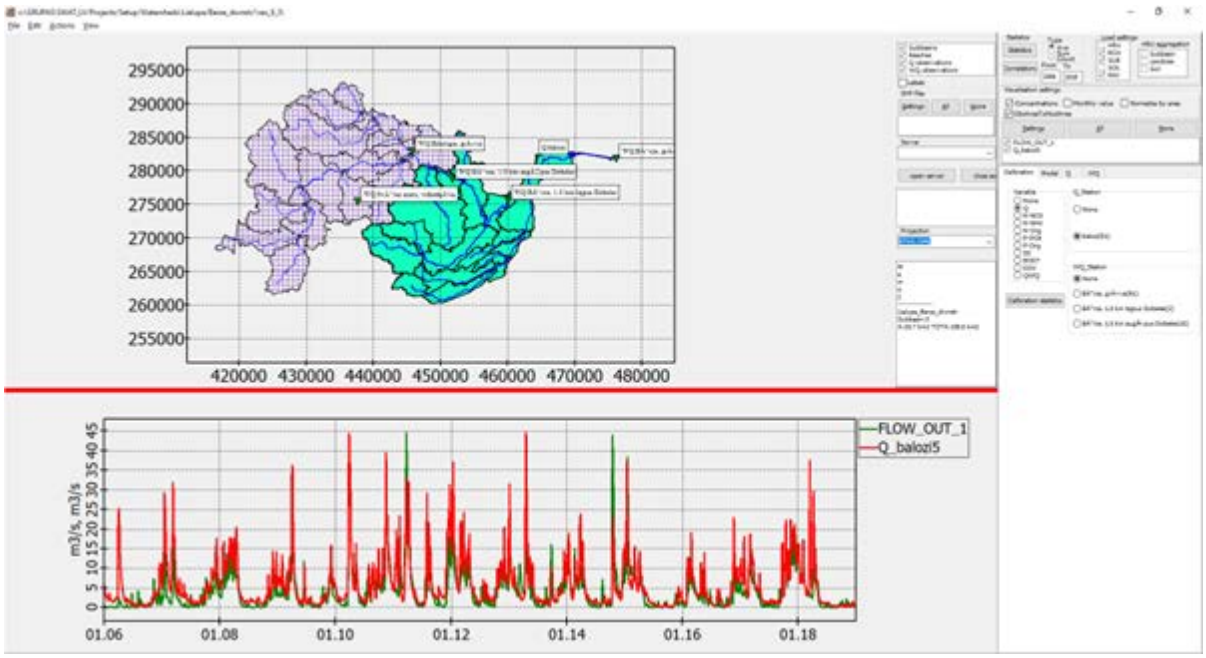


Figure 7: Screenshot of PAICSWAT.

The screenshot of PAICSWAT is shown in Figure 7. It consists of map of the watershed under consideration (Figure 8), time graph of observed and modelled parameters (Figure 9) and several control panels. Parameter selection and calibration panel is shown in Figure 10.

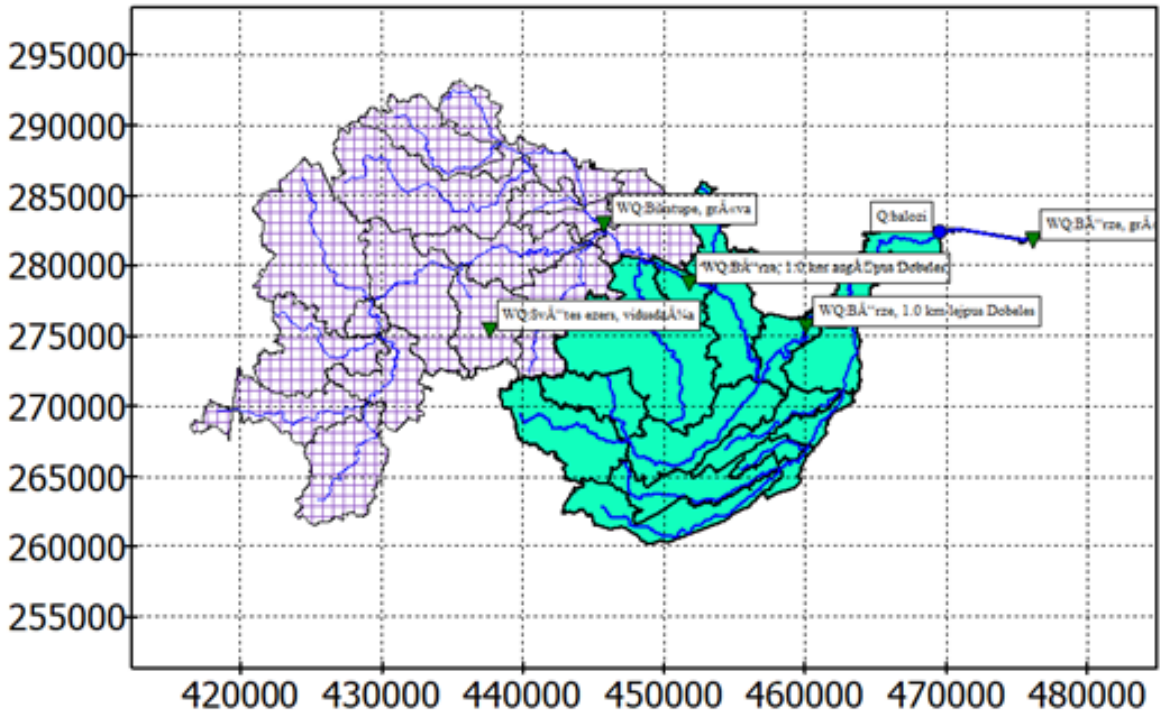


Figure 8: PAICSWAT: map of Bērze_2 watershed.

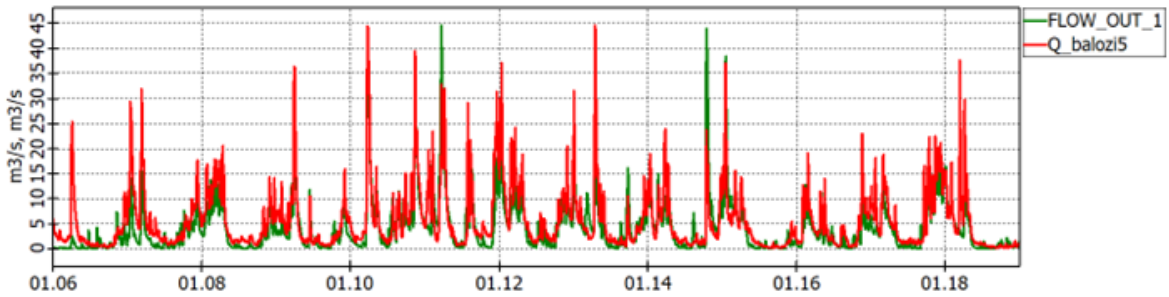


Figure 9: Obseerved vs modelled Discharge at Bērze-Baloži station.

PAICSWAT allows statistical analysis (Figure 12) and calculation of seasonal parameter values (Figure 11) from observed and modeled data series inselected (figure 13) stations.

Visualisation of water quality parameters and water balance components by PAICSWAT are given in Figures 14-16.

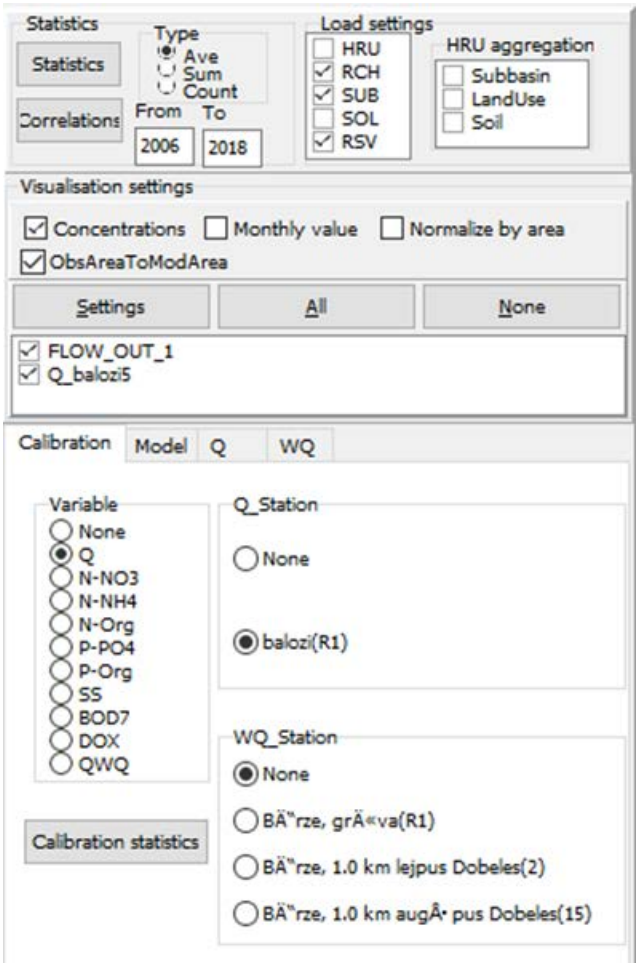


Figure 10: PAICSWAT selection and calibration panel.

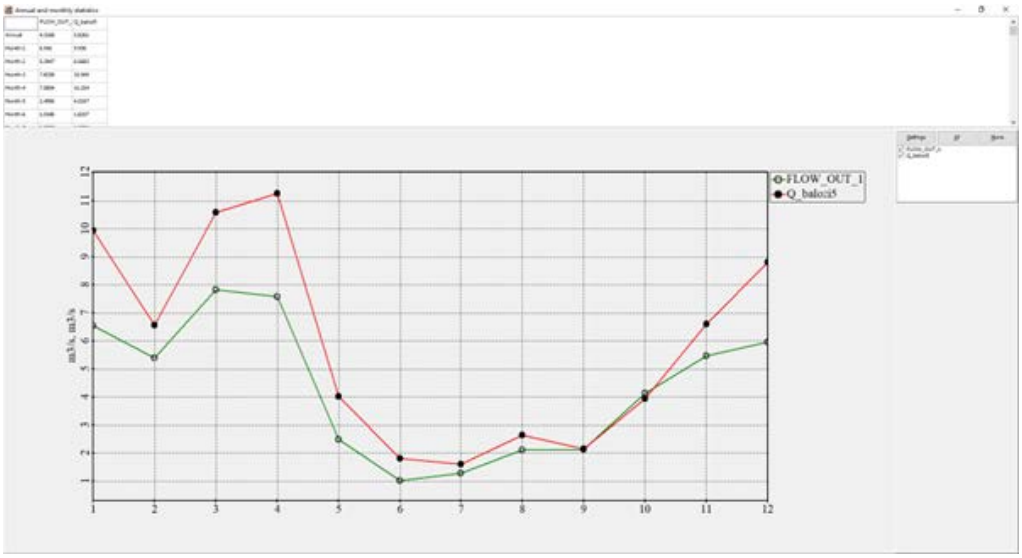


Figure 11: Yearly overview of discharge Bērze(Baloži) station Observed vs modeled, PAICSWAT statistics visualization screen.

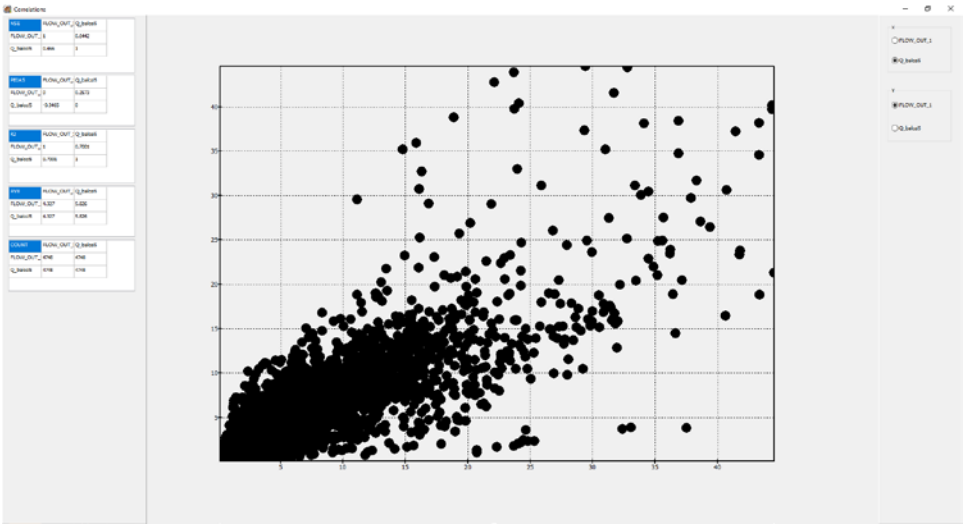


Figure 12: Statistical overview of discharge at Bērze (Baloži) station Observed vs modeled. PAICSWAT Correlations visualization screen.

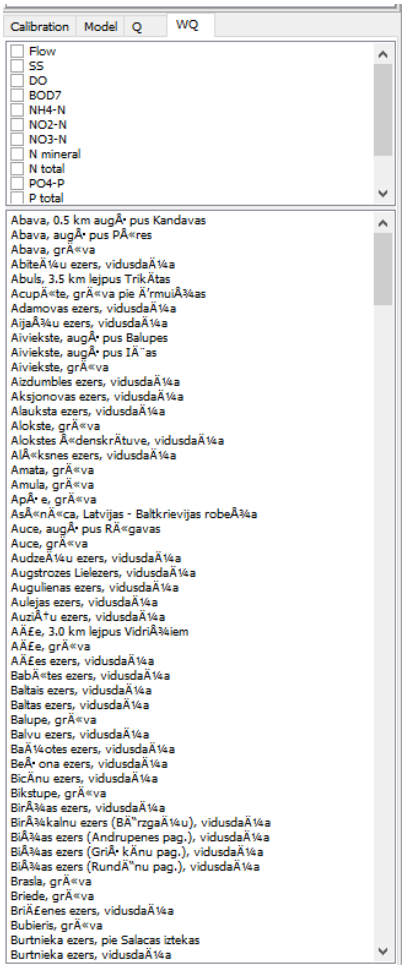


Figure 13: Water quality station selector in PAICSWAT for visualizing specific stations and parameter.

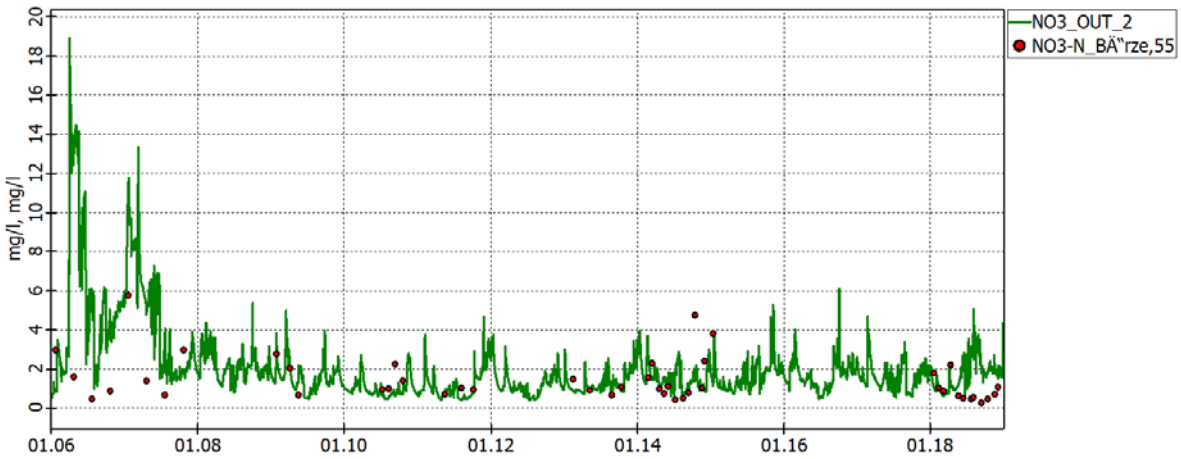


Figure 14: Mineral nitrogen (N-NO3) concentrations at measurement station Bērze- Bērze, 1km downstream Dobele.

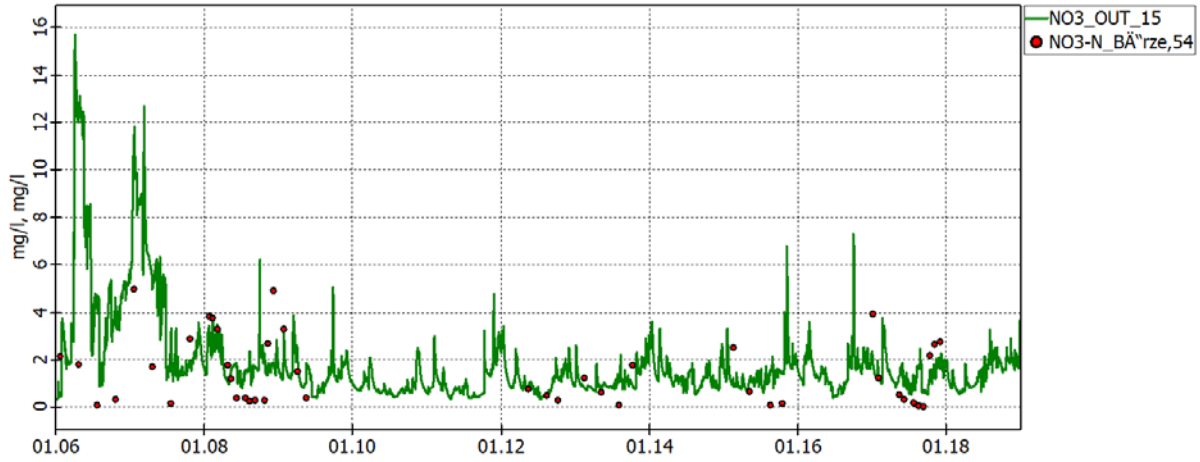


Figure 15: Mineral nitrogen (N-NO3) concentrations at measurement station Bērze- Bērze, 1km upstream Dobele.

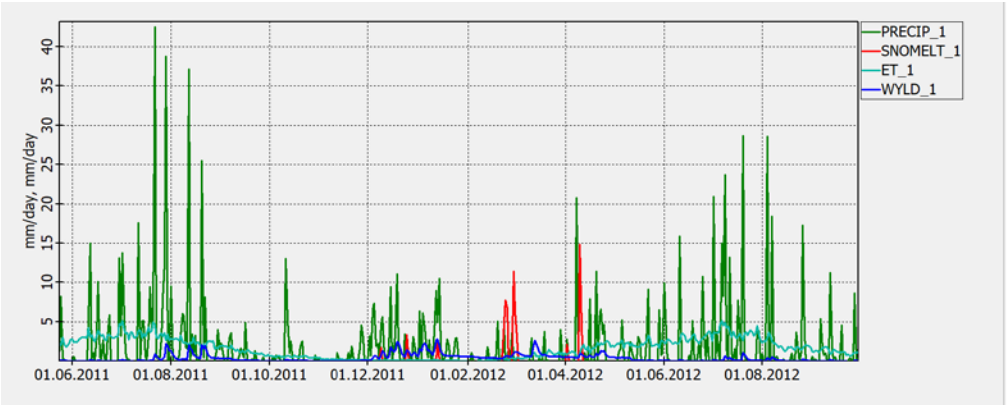


Figure 16: Time-series of water balance components in a Bērze_2 watershed.

4.Scripts for postprocessing of SWAT+ modelling results

4.1. Water and nutrient balance

Script for the calculation of a catchment level water balance from the calculation results is *waterbalance.py*. It is located in the main script directory of the project. It allows to calculated water-balance results in all LV territory or for selected watersheds (configurable by variable *watershednamelist*). The results are placed in the text file, the name of this file is user configurable (variable *wb_TXTFILE*). Internally, script uses subroutine *result_processing.prepare_sub_waterbalance* that returns the water balance table in *pandas Dataframe* format. The fields of the table are summarised in the Table 1.

Table 1. Fields of the water balance table.

Field	Description
catchmentid	Global Id of the catchment (corresponds to field *catchmentid* of *catchments* table under schema *catchments* of PostgreSQL database of project)
CNMIN_a	Average concentration of mineral nitrogen in a yield from the catchment, mg/l
CNTOT_a	Average concentration of total nitrogen in a yield from the catchment, mg/l
CPMIN_a	Average concentration of mineral phosphorus in a yield from the catchment, mg/l
CPTOT_a	Average concentration of total phosphorus in yield from the catchment, mg/l
ET	Average evapotraspiration in catchment, mm/day
GWNO3	Groundwater mineral nitrogen yield from the catchment, kg/ha/day
GW_Q	Groundwater water yield from the catchment, mm/day
LATNO3	Lateral mineral nitrogen yield from the catchment, kg/ha/day
LATQ	Lateral water yield from the catchment, mm/day
NMIN_YLD	Average mineral nitrogen yield from the catchment, kg/ha/day
NSURQ	Surface flow mineral nitrogen yield from the catchment, kg/ha/day
ORGN	Organic nitrogen yield from the catchment, kg/ha/day
ORGP	Organic phosphorus yield from the catchment, kg/ha/day
PET	Average potential evapotraspiration in catchment, mm/day
PMIN_YLD	Average mineral phosphorus yield from the catchment, kg/ha/day
PREC	Average precipitation in catchment, mm/day
SEDP	Average phosphorus yield in sediment from the catchment, kg/ha/day
SNOMELT	Average snowmelt in catchment, mm/day
SOLP	Average soluble phosphorus yield from the catchment, kg/ha/day
SURQ	Average surface water flow in catchment, mm/day
TILEQ	Average tile drain water flow in catchment, mm/day

Field	Description
TNO3	Average mineral nitrogen yield in tile flow from the catchment, kg/ha/day
TOTN_YLD	Toal nitrogen yield from the catchment, kg/ha/day
TOTP_YLD	Total phosphorus yield from the catchment, kg/ha/day
WYLD	Average water yield from the catchment, mm/day

Resulting text file can be loaded into QGIS as a text layer, joined on the field *catchmentid* to the *catchments* table under schema *catchments* of PostgreSQL database of the project to allow for visualisation of catchment water and nutrient balance components.

4.2. Calibration overview

Script for the calibration overview is *calibration_overview.py* located in the main *scripts* directory of the project. By running it the Nash-Suttcliff eficiency coefficients and bias of model results in comparison to observation results can be calculated. The resulting text file is determined by variable *statistics_TXTFILE* while list of watersheds could be provided in *watershednamelist* (in case of empty list – for the whole territory). Script allows for automatic distinction betwenn calibration and validation periods based on the variable *calibration_fraction* (0.0 – all period is validation, 1.0 – all period is calibration).

Before running the *calibration_overview* script, the script *prepare_calibration* should be run at least once. This script prepares connections between observation stations and model catchments in tables *qobs_catchments* and *wqobs_catchments* of scheme *calibration* of PostgreSQL database of the project (see configuration in *settings.Q_STATIONS_CATCHMENTS* and *settings.WQ_STATIONS_CATCHMENTS*).

The resulting text file contains columns listed in Table 2; possible "substances" are listed in Table 3.

Table 2: Columns of the calibration assessment text file.

Column	Description
STAID	Observation station identifier, corresponds to identifier in station files of observed data *Qobs.sta* and *Wqobs.sta*
STANAME	Observation station name
SUBSTANCE	Abbreviation of substance (see Table below)
CATCHMENTID	Global Id of the catchment (corresponds to field *catchmentid* of *catchments* table under schema *catchments* of PostgreSQL database of project)
IS_RESERVOIR	*True* if the output of catchment is from reservoir, *False* otherwise
DATACOUNT	Count of data points for comparison
CALIB_PER	Time period of calibration

Column	Description
CALIB_COUNT	Count of data points for comparison in calibration period
CALIB_NSE	NSE of daily time series for a substance in calibration period
CALIB_PBIAS	PBIAS of daily time series for a substance in calibration period
VALID_PER	Time period of validation
VALID_COUNT	Count of data points for comparison in validation period
VALID_NSE	NSE of daily time series for a substance in validation period
VALID_PBIAS	PBIAS of daily time series for a substance in validation period
CALIB_MON_PBIAS	PBIAS of monthly averages for a substance in calibration period
CALIB_MONR2	R2 of monthly averages for a substance in calibration period
VALID_MON_PBIAS	PBIAS of monthly averages for a substance in validation period
VALID_MONR2	R2 of monthly averages for a substance in validation period

Table 3: List of available parameters ("substances") in the calibration assessment text file.

Parameter	Description
Q	Discharge, m3/s
NO3	Concentration of nitrate nitrogen, mg/l
NORG	Concentration of organic nitrogen, mg/l
NTOT	Concentration of total nitrogen, mg/l
PO4	Concentration of phosphate phosphorus, mg/l
PORG	Concentration of organic phosphorus, mg/l
PTOT	Concentration of total phosphorus, mg/l
QNO3	Mass flow of nitrate nitrogen, g/s
QNTOT	Mass flow of total nitrogen, g/s
QPO4	Mass flow of phosphate phosphorus, g/s
QPTOT	Mass flow of total phosphorus, g/s

The output text file can be loaded into QGIS as a text layer, joined on the field *STAID* to either the *qobs_catchments* table (for substance *Q*) or the *wqobs_catchments* table (for any other substance) under schema *calibration* of PostgreSQL database of the project for the visualisation of calibration metrics in stations.

4.3. Overview of concentration in reaches

Script for the reach concentration overview is *reachConcentrations.py* located in the main *scripts* directory of the project. By running it the mean concentrations and loads of substances in rivers and reservoirs per catchment can be calculated. The resulting text file is determined by variable *output_TXTFILE* while the list of watersheds could be provided in *watershednamelist* (in case of an empty list – for the whole territory of LV). The resulting text file contains columns listed in Table 4; possible "substances" are listed in Table 3.

Table 4: Columns of the reach concentration text file.

Column	**Description**
CATCHMENTID	Global Id of the catchment (corresponds to field *catchmentid* of *catchments* table under schema *catchments* of PostgreSQL database of project)
SUBSTANCE	Abbreviation of substance (see Table above)
rch	Substance's concentration in the catchment's river
rsv	Substance's concentration in the catchment's reservoir
tot	Substance's concentration in the catchment

The output text file can be used for for the visualisation of the concentration in the reaches of watersheds. It should be loaded into QGIS as a text layer, joined on the field CATCHMENTID to either the *catchments* table of QGIS project or the *catchments* table under schema *catchments* of PostgreSQL database of the project.

References

PAIC, 2012. PAIC-SWAT: System for management of complex SWAT models. User manual. SIA „Procesu analīzes un izpētes centrs", Rīga, 2012.

PAIC, 2020. DATA BASE FOR MODEL IMPLEMENTATION. LIFE GoodWater IP deliverable R1, Rīga, 31p.

PAIC, 2022. CALIBRATED AND VALIDATED MODELLING SYSTEM. LIFE GoodWater IP deliverable R2, Rīga, 47p.

TWRI, 2011. Soil and water assessmemt tool theoretical documentation. Version 2009. Technical report #406. Texas Water Resources Institute, Sep-2011