Interreg Estonia-Latvia project No. Est-Lat155
“Joint actions for more efficient management of common groundwater resources (WaterAct)”

JOINT REPORT

on WP1 “Capacity building through exchange of knowledge and best management practices”
activities T1.1-T1.4

2022

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ABBREVIATIONS

CIRCABC – Communication and Information Resource Centre for Administrations, Businesses and Citizens

CIS – Common Implementation Strategy

DWPA – Drinking Water Protected Area

EC – European Commission

EQS – environmental quality standard

EU – European Union

GAAE – groundwater associated aquatic ecosystem

GDE – groundwater dependent ecosystem

GDTE – groundwater dependent terrestrial ecosystem

GQS – groundwater quality standard

GWB – groundwater body

GWD – Groundwater Directive

iRB – International River Basin

iRBD – International River Basin District

iRBMP – International River Basin Management Plan

LV – limit value

MP – monitoring point

MS – Member State

NBL – natural background level

RBD – River Basin District

RBMP – River Basin Management Plan

SWB – surface water body

TGWB – transboundary groundwater body

TV – threshold value

WFD – Water Framework Directive

WISE – Water Information System of Europe

WP – Work Package

INTRODUCTION

Within the framework of the Interreg Estonia-Latvia 2014-2020 program project "Joint actions for more efficient management of common groundwater resources (WaterAct)" cooperation took place between the Estonian and Latvian organizations involved in the preparation of River Basin Management Plans (RBMP) to improve the efficiency of joint groundwater resources management in the transboundary area. Joint transboundary management of the Gauja/Koiva and Salaca/Salatsi river basins is necessary for both countries to implement the requirements of the EU water policy, most directly - the WFD. Harmonized approach for the assessment of the status of GWBs in the Latvian-Estonian transboundary area within the WaterAct project was established, thus ensuring the protection of the main drinking water resource in Latvian and Estonia - groundwater.

For the implementation of the WFD, MS shall establish TGWBs, and to ensure consistent protection of groundwater resources, the MS sharing those GWBs should coordinate their monitoring, the setting of TVs, and the identification of relevant hazardous substances. Some guidelines have been developed for the TGWBs identification and management, however, detailed specific methodologies are not available. Also, each MS has different geological and hydrogeological conditions, as well as different approaches for the assessment and management of their groundwater resources.

The aim of activity T1.1 "Exchange of good practices and development of harmonized principles for groundwater assessment" was to develop harmonized principles for further joint assessment of common groundwater resources in transboundary Gauja/Koiva and Salaca/Salatsi river basins. During this activity, groundwater assessment methodologies and approaches used by project partners at national level (addressing such principles as GWB delineation methodologies, NBLs and TVs delineation methodologies, strategies of conceptual model development, schemes of GWB status assessment and other) were collected, translated and exchanged (Chapter 1 "Experience exchange within consortium on groundwater resources management and assessment in Estonia and Latvia") based on which joint principles on how to manage common groundwater resources in transboundary Gauja/Koiva and Salaca/Salatsi river basins were chosen and agreed, creating joint harmonized approaches (Chapter 3 "Development of joint principles on common groundwater resources management and assessment is cross-border Gauja/Koiva and Salaca/Salatsi river basins"), addressing topics which could be solved during the WaterAct project, taking into account data availability and quality in both countries, as well as available human resources and project timeline.

The aim of activity T1.2 "Analysis of the requirements of European water policy and best implementation practices" was to address the main gaps identified during activity T1.1 "Exchange of good practices and development of harmonized principles for groundwater assessment". During this activity extensive literature studies were carried out to gain an in depth understanding of the requirements of European water policies with an emphasis on common groundwater assessment according the WFD and the GWD. Guidelines and available best practices from other countries (as well as areas where implementation approaches were not defined or flexible) were analyzed (Chapter 2 "Studies of EU level guidelines and best practices from other countries on common groundwater resources management and assessment"). As a result, recommendations for further steps were developed, which were taken into account creating joint harmonized approaches for groundwater resources assessment (Chapter 3 "Development of joint principles on common groundwater resources management and assessment is cross-border Gauja/Koiva and Salaca/Salatsi river basins").

The aim of activities T1.4 "Experience exchange and trainings at EGU General Assembly 2021" and T1.3 "Capacity building at Nordic Hydrological Conference 2022" was to acquire latest groundwater management practices in Europe and get feedback from the best experts in field if implementation of EU water policies, as well as to introduce the WaterAct project to stakeholders and to share and accumulate new knowledge between different institutions. After both events, the summaries on acquired knowledge during both events were developed and circulated around all project partners to transfer the gained knowledge. The summaries of acquired information during activity T1.4 "Experience exchange and trainings at EGU General Assembly 2021" is available in Annex 14, but for activity T1.3 "Capacity building at Nordic Hydrological Conference 2022" – an Annex 15.

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1. Experience exchange on groundwater resources management and assessment in Estonia and Latvia

To develop harmonized principles for joint assessment of common groundwater resources in transboundary Gauja/Koiva and Salaca/Salatsi river basins, the first step was identification and exchange of groundwater assessment and other methodologies and approaches used by project partners at the national level. Available experiences and good practices were gathered and translated into English, as well as exchanged among the project partners during joint seminars, demonstrating step-by-step guidelines on how the processes were carried out and what data and tools were used.

This chapter collects all experiences and practices exchanged between project partners. The chapter is divided into multiple subchapters which in detail depicts each experience/practice in both project partner countries (if such information was available). Practices, which were chosen for further adaptation and harmonization (based on results reached from studies of EU level guidelines and practices from other countries in Chapter 2 "Studies of EU level guidelines and best practices from other countries on common groundwater resources management and assessment") to fit the specific needs of groundwater management in transboundary areas, are supplemented with annexes which in detail compares approaches in both countries and provides solutions for harmonization (if such solutions were reached) which serve as a basis of harmonized and/or agreed principles of groundwater resources management and assessment in cross-border Gauja/Koiva and Salaca/Salatsi river basins, depicted in Chapter 3 "Development of joint principles on common groundwater resources management and assessment is cross-border Gauja/Koiva and Salaca/Salatsi river basins".

This chapter does not include information on groundwater monitoring principles and strategies in Estonia and Latvia as this topic is the main focus of WP2 activity T2.3 "Development of strategy for transboundary groundwater monitoring in Gauja/Koiva and Salaca/Salatsi river basins". More information on this topic is available in the joint report of WP2 "Assessment of common groundwater resources in Gauja/Koiva and Salaca/Salatsi river basins" (Borozdins et al., 2022).

1.1. Groundwater body delineation

The WFD does not provide detailed, uniform, and binding guidelines on how to delineate GWBs in the MS – the development of appropriate methodologies is the responsibility of each MS and remains a major challenge. General guidelines are available that are recommendatory (EC, 2003; EC, 2004), but without the inclusion of additional conditions, these guidelines are unsuitable for Estonian and Latvian hydrogeological conditions (with multilayer geological structure). The possibilities to adopt methodologies and good practices from the other MS are limited due to the drastic differences in hydrogeological conditions (between and even within the MS), the different levels of detail of the available information, and the knowledge base.

A GWB is defined as a certain amount of groundwater in an aquifer or aquifers (EC, 2000), which is strictly defined within horizontal and vertical distribution boundaries. Within the boundaries of a GWB, there must be a minimum inflow of water from adjacent GWBs and low-variable chemical composition of water to calculate the water balance for each body and determine the NBLs of the water chemical composition. The link between two adjacent GWBs must be kept to a minimum so that it cannot be disregarded in the calculation of the water balance, i.e. there must be different catchment areas, or the link must be capable of being accurately assessed or quantified. In areas where cracked rocks predominate and/or karst processes have been observed, the characterization of the quantitative status of water can be particularly difficult. In such cases, the boundaries of specific rock formations or processes may be taken as the boundaries of GWBs, as far as possible to provide a reasonable description of such isolated bodies. A GWB may consist of one or more aquifers, and heterogeneity in water composition, levels, lithology, and geological characteristics is allowed within a GWB. However, GWB must be allocated in such a way that it is possible to prepare a reasonable description of the quantitative and qualitative status of this body. Based on all the above, regular and site-specific monitoring should be carried out in each GWB to identify any negative trends promptly (EC, 2003).

GWB cannot be considered as a classical hydrogeological unit – it is rather a unit for management and reporting for the River Basin Management Plans and groundwater status assessments – chemical and quantitative. When delineating GWBs, these general principles should be considered: (1) geological and hydrogeological boundaries, (2) groundwater quantity (porosity and amount of groundwater available), (3) groundwater chemistry (homogenous composition); (4) groundwater flow (direction) and watershed boundaries and (5) pressures and impacts to groundwater (EC, 2003; EC, 2004).

1.1.1.Groundwater body delineation in Estonia

In Estonia, the aquifers were first listed as GWBs in a project by the Estonian Environment Agency "Support to the implementation of the EUROWATERNET in the Baltic Countries". The work was done by Perens et al. (2001a) and Perens et al. (2001b) from the Geological Survey of Estonia commissioned by the Ministry of the Environment. With the reports, 30 possible GWBs were listed in the territory of Estonia. From these, 15 were selected to the first legislation in 2004 involving GWBs. Over the period 2004-2020, the list of the GWBs (that have been named in the legislation) has changed between 15 to 39 GWBs.

A detailed description of GWB delineation in Estonia can be found in a report published by the Geological Survey of Estonia (Perens et al., 2012). In 2018 and 2019, the Geological Survey of Estonia synthesized information collected on Estonian GWBs and updated their conceptual models according to the new dataset. A report "Characterization of the borders of the GWBs, evaluation of pressures and compilation of hydrogeological conceptual models" was compiled by Marandi et al. (2019).

As the geological setting of Estonia is characterized by the wide lateral distribution of different bedrock formations and similar hydrogeologic conditions in aquifers in different parts of the country, GWBs comprising bedrock aquifers have quite a wide lateral extent (FIGURE 1.1.1.1).

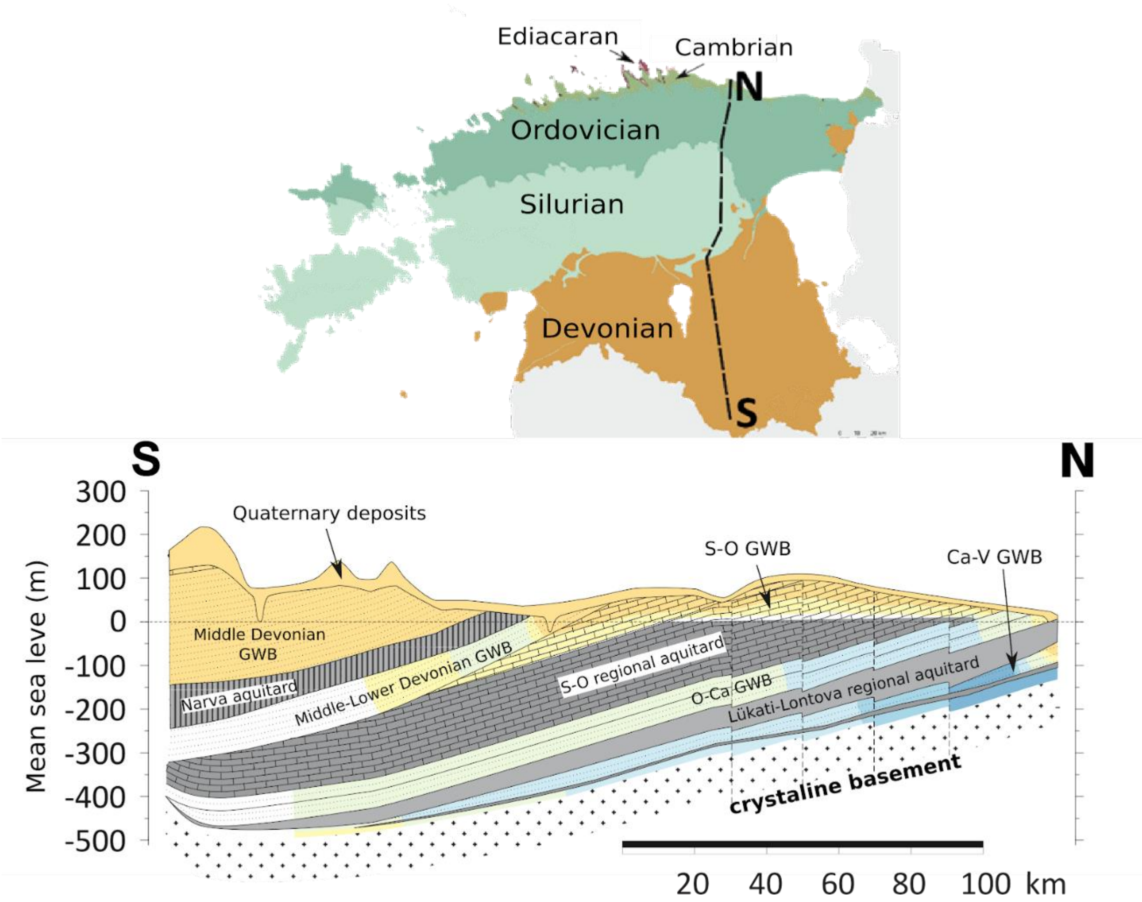


FIGURE 1.1.1.1 **Estonian geological map and hydrogeological cross-section showing the aquifers and aquitards** (modified after Pärn, 2018)

Existing geological and hydrogeological maps have been used from where the hydrogeological stratification (vertical extent) and lateral extent of the aquifers was taken into account. GWBs were delineated spatially, by compiling cross-sections for every GWB. This means that the thicknesses, upper and lower borders for every GWB were determined. Also, the hydrogeological model of Estonia (Vallner, 2002) was used to determine groundwater flow directions of the aquifer systems. In most cases, the aquifers forming GWBs are separated by aquitards. In the absence of an aquitard between different GWBs, the boundary was defined by different lithological compositions and the resulting water type differences or only the variance in water type.

Data from *Kataster* database about geology, hydrogeological parameters and water quality analyses (data from all registered wells in Estonia, now maintained by Estonian Environmental Agency), Environmental Agency databases on groundwater monitoring, water companies and wells with water usage permits abstraction and quality data were used to delineate GWBs in Estonia.

Aerial distribution of GWBs is based on three main RBD boundaries: West-Estonian River Basin, East-Estonian River Basin, and Koiva River Basin. First bedrock aquifers are additionally subdivided based on eight sub-basin districts and Pandivere nitrate vulnerable zone – a sensitive area with high groundwater pollution potential (formed in the Pandivere upland with extensive agricultural land use). Also, groundwater connection with SWBs and GDTEs were taken into account as they are listed with each GWB (Perens et al., 2012; Marandi et al., 2019). As Southern border for the deeper part of the aquifers (Cambrian-Vendian GWBs No.1, No.2 and No.3; Ordovician-Cambrian GWBs No.4 and No.5b), Cl^- concentration higher than 350 mg/l was set as a conditional limit.

Among many smaller changes to the existing network of Estonian GWBs, Marandi et al. (2019) suggested two general changes to the initial GWB delineation developed by Perens et al. (2012). The first concerns the Ordovician-Cambrian GWB No.5 in the East-Estonian RBD. It was recommended that this GWB should be split into two separate GWBs due to different anthropogenic pressures affecting different areas. Potential effects of current oil shale and future possible phosphorite mining in North-Eastern Estonia and groundwater abstraction in South-Eastern Estonia.

The second general change to the GWB delineation is broader and concerns the Quaternary aquifers in Estonia. In the delineation developed by Perens et al. (2012), 13 small Quaternary GWBs were delineated based on the areas where groundwater from the Quaternary aquifers form an important source of water supply. Other Quaternary aquifers were not considered as part of the GWB. However, Quaternary aquifers all over the country can affect the formation of groundwater quality, the infiltration rates, and the transmission of anthropogenic pollution from the land surface to the subsurface. Marandi et al. (2019) suggested joining all Quaternary aquifers with the underlying bedrock. The delineation of all Quaternary aquifers with a potential for groundwater abstraction or having an important influence on the GDEs would have led to a large number of GWBs, which would not have been administratively manageable.

This approach is justifiable because in most cases the Quaternary aquifers form a unified hydrogeological system with underlying bedrock aquifers and have the same anthropogenic pressures affecting them. It also greatly facilitates the calculation of groundwater budgets for different GWBs. Four Quaternary aquifers which have more regional importance to the water supply systems or which are located on islands and do not have underlying bedrock GWBs were kept as separate GWBs in the new delineation. In the future, new independent Quaternary GWBs can be delineated when water abstraction from an aquifer increases or when it is shown that they exert an important influence on the GDEs in the area. However, before such a new GWBs can be delineated, a comprehensive monitoring network has to be put in place in the area in question, so that the quantitative and chemical status of the GWB can be properly assessed (Marandi et al., 2019).

As a result, 31 GWBs were identified in Estonia in 2020 by reports made in 2012 and 2019. The current delineated boundaries of GWBs in Estonia are represented in FIGURE 1.1.1.2.

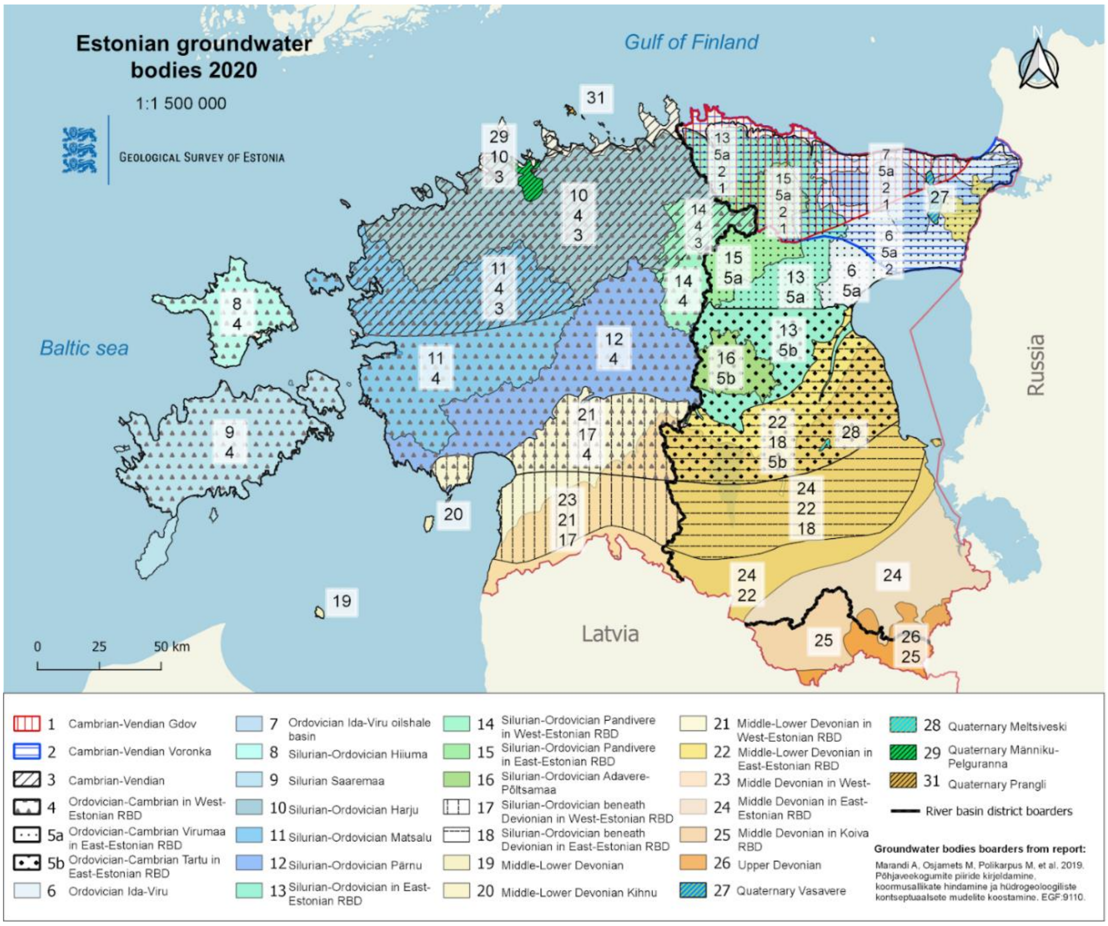


FIGURE 1.1.1.2 **GWBs in Estonia** (modified after Perens et al., 2012 and Marandi et al., 2019)

1.1.2. Groundwater body delineation in Latvia

The first GWBs in Latvia were delineated in 2004, within the framework of the Latvian-Danish joint project (DANCEE, 2004). The delineation of GWBs was performed according to the following principles (DANCEE, 2004a):

- the boundaries of the GWBs were mainly based on the hydrogeological conditions restricting the flow of groundwater: regional aquitards in the vertical section and watersheds in the horizontal section. Watersheds for the identified GWBs largely replicated the boundaries of RBDs, facilitating integrated surface and groundwater management;
- the density of the groundwater monitoring network was taken into account, as well as the capacity of the institutions managing and controlling it. It was decided that the recommended number of GWBs should not exceed a few tens and that the dimensions of the GWBs should be as similar as possible. As a result, small GWBs were not identified, taking into account all identified watersheds and cage layers.

Many piezometric level maps were prepared to identify watersheds and determine the horizontal boundaries of GWBs. Piezometric level maps were prepared without the help of a regional hydrogeological model and without taking into account the groundwater and surface water linkage, only by interpolating the static level data measured in the wells. Also, in 2004, the data entered into the national database WELLS was not yet completed. The DANCEE, 2004a project indicated that the proposed classification of GWBs is recommendatory and that the watersheds and the boundaries of GWBs, respectively, should be verified after the completion of the national database WELLS and the preparation of a regional hydrogeological model.

In the freshwater distribution interval, two dominant aquitards were identified, which were respectively taken into account when performing the vertical delineation of GWBs (DANCEE, 2004a):

1) regional aquitard - the thick and poorly permeable sedimentary layer of the Middle Devonian Narva formation, which isolates the active (freshwater) from the passive (saltwater) water exchange zone;
2) Upper Devonian Pļaviņas-Amula (D3pl-aml) formation of low permeability sedimentary layer that isolates the Famennian aquifer complex from deeper aquifers (D2ar-D3am) in the southwestern part of Latvia.

As a result, a total of three GWBs (F1, F2, and F3) were delineated in the southwestern part of Latvia. These GWBs included all aquifers from the land surface to the Pļaviņas-Amula (D3pl-aml) aquitard (excluding it). The low permeability sediments of Pļaviņas-Amula (D3pl-aml) and the part of the Aruküla-Amata (D2ar-D3am) aquifer complexes lying beneath them were separated as GWB A. In the rest of the territory of Latvia, a total of 10 GWBs were delineated (D1, D2, D3, D4, D5, D6, D7, D8, D9, and D10), including all aquifers from the ground surface to the Narva regional aquitard. The only exception was the Quaternary sand GWB Q, which was not included in the dormant GWB D4, due to the special importance in water supply - the largest groundwater well fields of the city of Rīga are located there. In North Vidzeme, a deep Pärnu-Ķemeri aquifer GWB P has been identified, which lies under the Narva regional aquitard and, unlike the rest of the territory of Latvia, contains good quality freshwater used for water supply. In total, 16 GWBs were delineated (DANCEE, 2004a).

In 2018, Latvia started the GWB review process (Retiķe, 2017). According to the WFD, the GWB delineation process should be iterative and ongoing considering a new knowledge base and new monitoring data.

The first step (FIGURE 1.1.2.1, Step 1) in the GWB review process was the initial identification of aquifers and their vertical boundaries according to the existing national knowledge – national hydrogeological stratification set in national legislation and freshwater distribution maps (Levins et al., 1998). This step is a common first step in the GWB delineation process in most MS because all national monitoring networks are built considering the national knowledge base. Ignorance of existing groundwater management principles would result in the need for installation of many new wells and monitoring stations which would be economically unreasonable and loss of long-term data series. As well, basic hydrogeological conditions do not change over time and are still valid (Retiķe, 2017).

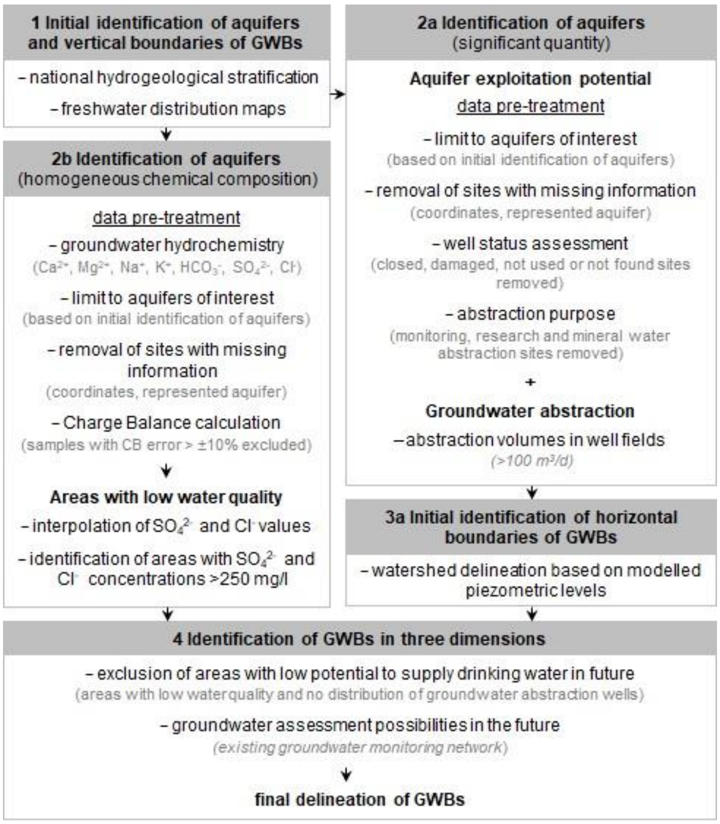


FIGURE 1.1.2.1 **Schematic flowchart illustrating main steps and data pre-treatment procedures for GWB delineation in Latvia** (Retiķe, 2017)

The second step (FIGURE 1.1.2.1, Step 2a) included identification of aquifers in terms of the WFD - only aquifers providing significant quantities of water should be considered as aquifers. For that reason, two main assessments were carried out. Firstly, the groundwater well fields were mapped to identify the areas where aquifers currently provide more than 100 m^3/day of water and supply the largest cities and villages. Secondly, the wells which currently supply or can provide more than 10 m^3/day of water were also mapped. As in Latvia at that time it was not possible to use such data due to database development, a stricter approach was chosen to select wells that might be used for more than 10 m^3/day in the future (Retiķe, 2017).

Then (FIGURE 1.1.2.1, Step 2b) aquifers were identified according to freshwater distribution. According to the WFD, only freshwater or water which are used for drinking water supply after the traditional treatment processes (e.g. iron removal with aeration) should be considered as aquifer and be a part of GWB. In this step, the areas which contain low water quality, are not used for water supply and if there are better groundwater quality aquifers above them, were not considered as aquifers and were excluded from GWBs. In some cases, low-quality water areas were kept as a part of the GWB as there were no better water resources available in the territory at the depth which is economically reasonable to install water supply wells (Retiķe, 2017).

In the third step (FIGURE 1.1.2.1, Step 3a) watersheds were modeled using 3D hydrogeological modeling results (Virbulis et al., 2013). In such a way horizontal hydrogeological conditions were taken into account. It could be observed that the initial GWB delineation carried out in 2008 provided more or less similar results (at least for the upper aquifers). As there was a limited amount of data in 2008 and the process was mostly manual, then more differences were observed in deeper aquifers as was expected (Retiķe, 2017).

Finally, GWBs in three dimensions were delineated based on all previous steps and considering the existing State Monitoring Network. This was an essential step as delineation of GWBs should not be carried out only statistically and scientifically, but should take into account national opportunities for further monitoring and assessment of the quantitative and chemical status of GWBs. For that reason, some of the watersheds were merged into larger GWBs based only on groundwater monitoring network distribution. In the future, when more funding is available for the installation of new monitoring sites, the GWBs could be split (Retiķe, 2017).

As a result, 22 GWBs were identified, the boundaries of which are represented in FIGURE 1.1.2.2.

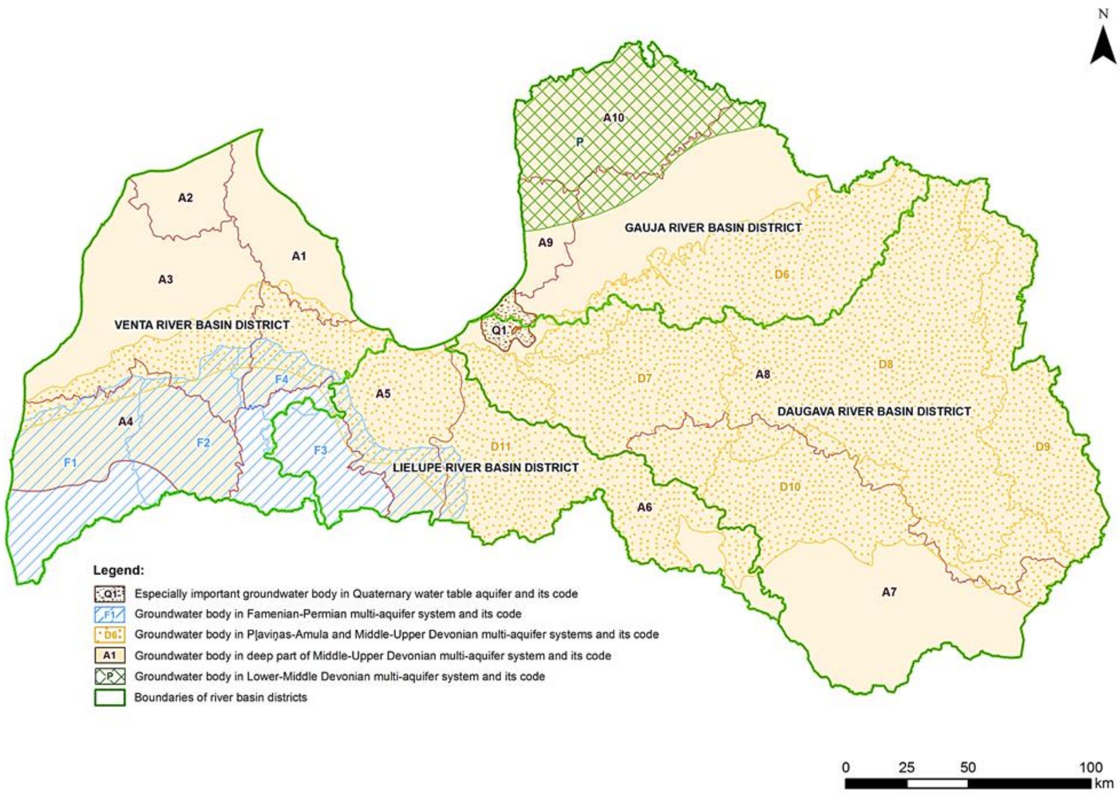


FIGURE 1.1.2.2 **GWBs in Latvia** (modified after Retiķe, 2017)

1.1.2.1. Groundwater body at risk delineation in Latvia

To ensure groundwater management and planning of appropriate measures in areas where historical problems have already been identified and good groundwater chemical and/or quantitative status cannot be achieved following the requirements of the WFD, in the period from 2018 to 2019, in existing GWBs, three GWBs at risk were identified and delineated as separate groundwater management units: Q2 (artificial groundwater recharge and seawater intrusion area), F5 (seawater intrusion area) and A11 (historical sulfuric acid tar pollution area). The methodology of identification and delineation in principle was equal to the identification of a "normal" GWB, taking into account, in addition, the risk factors of each specific area. Within the WaterAct project, none of the previously identified GWBs at risk in Latvia were recognized as being transboundary with Estonia.

Groundwater body at risk Q2

The main cause of the risk status of GWB Q2 is artificial groundwater recharge with surface waters, which are characterized by periodically increased mineralization and sodium-chloride water type. Elevated chloride content is formed by the periodic inflow of water from the Gulf of Riga into the Lake Mazais Baltezers through the interconnected surface water system (River Daugava - Lake Ķīšezers - Lake Jugla - Lake Lielais Baltezers - Lake Mazais Baltezers) waters of which are used as a source of artificial groundwater recharge. Due to elevated chloride concentration, the resulting situation can be characterized also as artificial seawater intrusion (LVĢMC, 2019).

Based on the requirements of the WFD, this artificial recharge and seawater intrusion affected zone must be managed separately:

1) GWB Q1, in which the affected area is located, is significantly larger and it is not foreseeable that the affected area could reach 20% of the whole territory of GWB Q1; accordingly, the status of GWB Q1 was artificially improved and at the same time it was not possible to plan stricter monitoring and management requirements for the affected area;
2) the affected area previously was delineated by the boundary generally corresponding to the artificial recharge affected zone, but boundaries should be updated including wells in which signs of surface water and groundwater interaction are identified.

In 2019, within the framework of a project financed by the Latvian Environmental Protection Fund, the affected area was delineated as a separate GWB at risk Q2, updating previously determined horizontal and vertical boundaries of the affected area (LVĢMC, 2019).

The previous boundaries in the vertical scale included the aerobic aquifer of the Quaternary sediments and the area of the GWB at risk was defined as territory of groundwater well fields Baltezers and Baltezers II reaching Lake Mazais Baltezers. Since the affected area is a unique area to which it is not possible to directly apply the management and groundwater allocation methods used in the other MS, it was decided to maintain the existing boundary of the affected area by clarifying and extending it (LVĢMC, 2019).

After analysis of the collected data, it was concluded that the boundaries at the vertical scale of the affected area should be maintained unchanged, including all Quaternary aquifer (in which periodically elevated chloride concentrations are identified at various depths) up to Gauja (D_3*gj*) formation which upper part clay and siltstones sediments are separating Quaternary aquifer from Gauja (D_3*gj*) aquifer. A horizontal scale the strict regime protection zone of groundwater well fields Baltezers, Baltezers I, and Baltezers II was used as the basis for determining the boundaries of the affected area, but boundaries were extended: around surface water infiltration basins and active groundwater abstraction wells safeguard zone within a radius of 100 meters were established. The new boundaries also include three active groundwater abstraction wells that show elevated chloride concentrations and a buffer zone within a radius of 100 meters was established for these wells. The boundaries also were updated following the current Lake Lielais Baltezers and Lake Mazais Baltezers shorelines, but SWBs themselves were not included as they function as groundwater discharge points, and SWBs are monitored within the national surface water monitoring network monitoring program (LVĢMC, 2019; FIGURE 1.1.2.1.1).

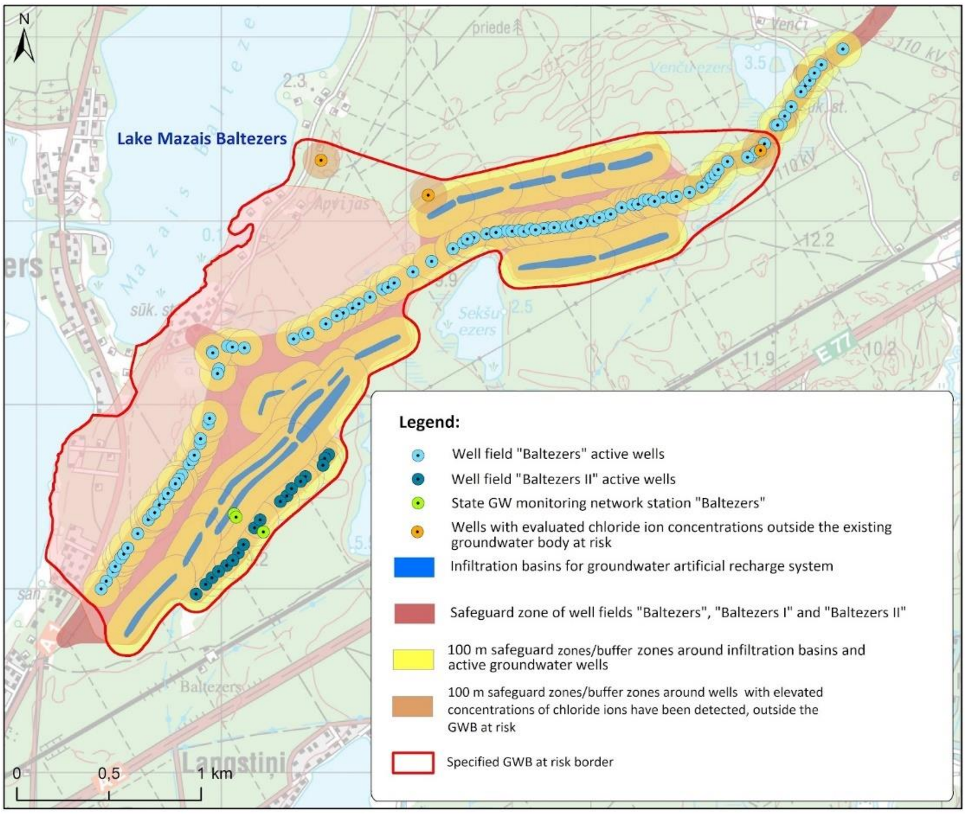


FIGURE 1.1.2.1.1. **The boundaries of delineated GWB at risk Q2** (modified after LVĢMC, 2019)

Groundwater body at risk F5

The intensive use of groundwater in the city of Liepāja for water supply was started at the beginning of the 19th century due to the lack of safe sources of surface drinking water near the city. By 1940, more than 200 new wells had been installed in the vicinity of Liepāja city, mainly in the Upper Devonian Mūri-Žagare (D_3*mr-žg*) and Lower Carbonian (C_1) aquifers. Along with the rapid development of the city, the volume of water extraction also started to increase significantly. In the 1930s, negative changes in water quality were detected in the city's water extraction wells, which were reflected mainly in high chloride concentrations. As a result of intensive and concentrated water abstraction, the affection zone could be observed in an area of about 15 km^2. When regular observations of the water regime (monitoring) were started in 1961, an already established underground water depression cone was found, which in the western part of the cone had affected the Baltic Sea water area, causing the intrusion of the seawater into the Mūri-Žagare aquifer complex (Retiķe, 2018).

Based on the requirements of the WFD, this seawater intrusion affected zone must be managed separately:

1) GWB F1, in which the affected area is located, is significantly larger and it is not foreseeable that the affected area could reach 20% of the whole territory of GWB F1; accordingly, the status of GWB F1 was artificially improved and at the same time it was not possible to plan stricter monitoring and management requirements for the affected area;
2) the boundary of the seawater intrusion affected area was not strictly defined, which makes it difficult to manage the affected area and to analyze the extent to which the intrusion has decreased due to lack of a reference point.

In the vertical dimension, historically identified boundaries include Ketleri, Žagare, and Mūri aquifers. In 2018, it was proposed to maintain the vertical boundaries and to include in GWB at risk previously mentioned aquifers. Further, based on the data of four wells No.2647, No.8850, No.8851, and No.8849 on the pier in Lake Liepāja, located almost in a vertical line, the penetration gradients of seawater intrusion were obtained. Correspondingly, the concentrations of chlorides obtained in one time period (years) were taken into account. From this, the gradients were calculated by subtracting the chloride concentrations from the wells and dividing them by the distance from one well to the other. As a result, coefficients were obtained, which characterize how many milligrams per liter the concentration of chlorides ions per meter decreases. Next, the worst-case scenario or the lowest trend of chlorides reduction, which is 0.65 mg/l per meter, was chosen, because the decrease of chloride ion content between wells is not linear (Retiķe, 2018).

Based on all available data set on chlorides in wells in the respective aquifers (Mūri-Žagare and Ketleri) and the calculated gradient, the buffer zones were calculated, the extreme limit of which describes the content of chlorides below or close to the limit of detection of the analytical method (FIGURE 1.1.2.1.2; buffer zones are shown with light blue circles). A previous study (Bikše et al., 2016) was also taken into account, which interpreted the 250 mg/l limits of chlorides in the worst-case scenario in 2001 and calculated an additional buffer zone similar to that around wells (FIGURE 1.1.2.1.2). The final boundary of GWB at risk F5 was defined mainly based on the worst-case scenario in the wells, as well as taking into account the location of groundwater well field Otaņķi - it was included in the border to monitor the main centralized well field of the city of Liepāja, as wells were included in the southern part, which also belongs to SIA "Liepājas ūdens" and show slightly increased concentrations of chlorinated ions (Retiķe, 2018).

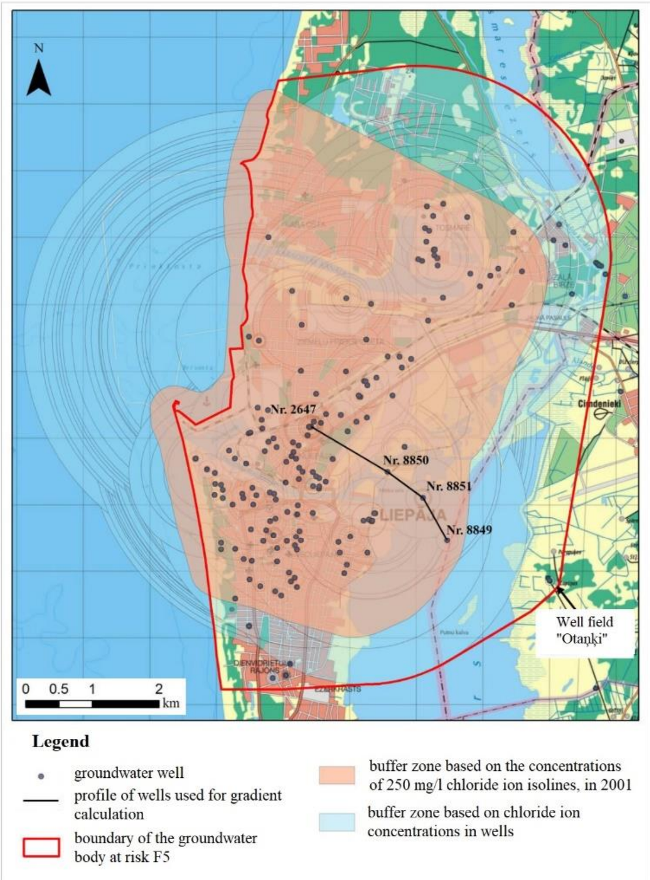


FIGURE 1.1.2.1.2 **The boundaries delineation approach of the GWB at risk F5**
(modified after Retiķe, 2018)

Groundwater body at risk A11

The main cause of the risk status of GWB A11 is historical pollution from Inčukalns sulfuric acid tar ponds. Between 1956 and the beginning of the 70s, on average, approximately 16 thousand tons of waste per year was exported to the northern part of the sand career, and from 1981 to the southern part. The southern landfill spans an area of approximately 1.6 ha, with an area of approximately 64 thousand m^3 in the sulfuric acid tar. The northern landfill comprises an area of approximately 1,5 ha, with a mixture of approximately 9,0 thousand m^3 sand and sulfuric acid tar. This waste was a waste of the former Riga oil processing and lubricating oil industry – the sulfur acid tar, which forms by purging medical and perfumery oils with sulfuric acid. The main ingredients in the sulfuric acid tar are oils, asphalt, sulfuric acid, and sulfuric acid (pH ~1,5; sulfur content ~4% by weight) (Karuša and Demidko, 2018).

The landfill was closed in 1986. Over time, pollution in both areas of the ponds has reached a depth of 70-90 m, which flows further north towards river Gauja, and therefore the areal extent of pollution is expanding at a rate of 25-35 m/year, reducing the resources of high-quality groundwaters that could be used for the water supply of Rīga and Inčukalns parishes, as well as endangering the river. The area of the acid tar ponds in Inčukalns is, in importance, the first to be remedied (Karuša and Demidko, 2018).

The boundary of GWB at risk A11 was delineated based on the following principles and steps (Karuša and Demidko, 2018):

1) identification of area affected by the surroundings of the Inčukalns sulfuric acid tar ponds on a horizontal scale, based on the results of the previous hydrogeological modeling;
2) identification of buffer zone around the area of contamination as part of the hydrogeological modeling, taking into account the modeling step;
3) identification of area impacted by the surroundings of the Inčukalns sulfuric acid tar ponds on a vertical scale, taking into account the migration forecasts of pollution.

The models used have been developed in the GROUNDWATER VISTA environment, which uses the MODFLOW, MODPATH, and MT3D (predicting models for pollutant movement and mass transport) software. SURFER software is used to prepare graphical materials for modeling results (Karuša and Demidko, 2018).

The results of hydrogeological modeling were used and compiled to identify the areas affected by the existing surface area of Inčukalns sulfuric acid tar ponds on a horizontal scale. The modeling results reflect the migration of the surfactant substances in the Upper Gauja (D_3gj_2) aquifer towards the river Gauja from the northern and southern sulfuric acid tar ponds. Several scenarios have been modeled for the distribution of SAS plume concentrations in the aquifer for 2015, 2055, and 2095 for two options (with and without SAS degradation) (Karuša and Demidko, 2018).

The final boundary of the GWB at risk A11 was defined mainly based on the "worst-case" scenario, as well as taking into account the location of the State Monitoring Network station Inčukalns wells No.1495, No.1494, and No.1493 and the location of the monitoring station in the north-east part of the GWB at risk A11 to be able to perform pollution control of the development of pollution. The two affected areas (northern and southern ponds) were merged into a single GWB, as shown in FIGURE 1.1.2.1.3.

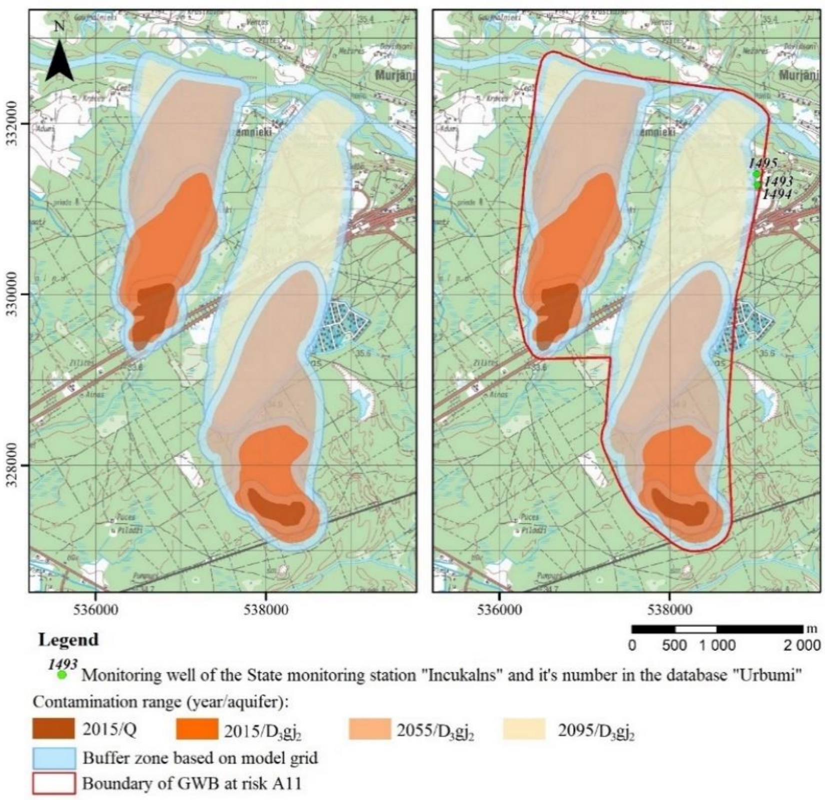


FIGURE 1.1.2.1.3 **The boundaries delineation approach of the GWB at risk A11**
(modified after Karuša and Demidko, 2018)

1.1.2.2. Latvian-Lithuanian transboundary groundwater body delineation

Groundwater is not limited by national borders, which means that joint action and management plans are needed to improve and maintain groundwater quality in transboundary areas. The development of a transboundary groundwater management plan initially requires hydrogeological information and data on the situation of groundwater in the transboundary area.

Groundwater resources management guidelines are outlined in the GWD and it states various requirements for groundwater management, for example MS shall ensure that for GWBs shared by two or more MS and GWBs within which groundwater flows across a MS's boundary, the establishment of TVs is subject to coordination between the MS, following Article 3(4) of Directive 2000/60/EC.

Identification of Latvian-Lithuanian transboundary groundwater bodies

To meet these requirements at the Latvian-Lithuanian border, the B-Solutions project (LGS-LEGMC, 2019) was implemented in 2019 between the Lithuanian Geological Survey and Latvian Environment, Geology and Meteorology Center on transboundary groundwater management cooperation, addressing various issues related to groundwater management, including TGWB delineation.

During the B-Solutions project, a total of 14 TGWBs were identified - respectively, 7 GWBs in Latvia and 7 GWBs in Lithuania (FIGURE 1.1.2.2.1). As delineation of GWBs is a matter of each MS and accompanied by many political decisions and national level planning principles, the boundaries of GWBs have not been changed. Changing GWB boundaries would negatively affect national groundwater monitoring networks and reporting to the EC in 2022 (LGS-LEGMC, 2019).

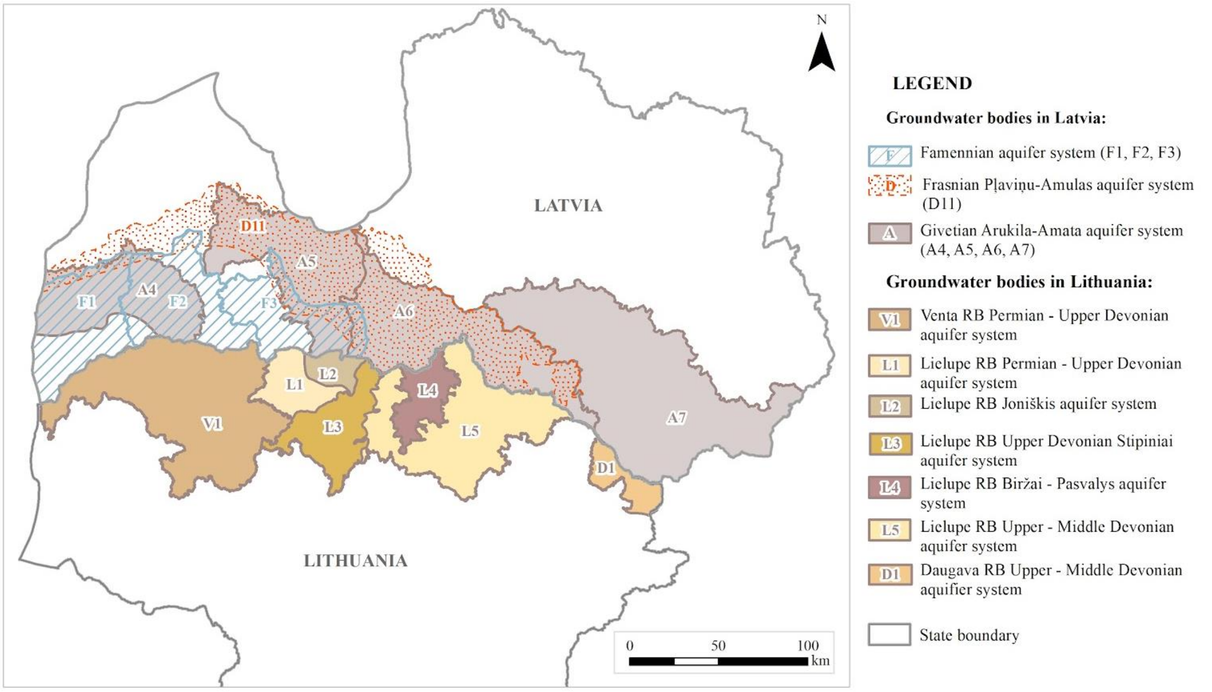


FIGURE 1.1.2.2.1 **Identified TGWBs in Latvia and Lithuania** (modified after LGS-LEGMC, 2019)

As GWB status reporting in River Basin Management Plans is strongly linked with large RBDs, the characteristics of agreed and joint TGWBs were separated according to three common RBDs: Venta, Lielupe, and Daugava (TABLE 1.1.2.2.1).

TABLE 1.1.2.2.1

Agreed TGWBs in Latvia and Lithuania (B-Solutions, 2019)

RBD	GWBs in Latvia	GWBs in Lithuania	Aquifer system
Venta	F1 and F2	V1	Permian - Upper Devonian (Famennian)
Lielupe	F3	L1 and upper part of L2	Permian - Upper Devonian (Famennian)
	D11	Deeper part of L3, the upper part of L4 and L5	Upper Devonian (Frasnian) (Pļaviņas-Amula)
	A5 and A6	Deeper part of L2, L4 and L5	Upper-Middle Devonian (Aruküla-Amata)
Daugava	A7	D1	Upper-Middle Devonian (Aruküla-Amata)

Preliminary status assessment of Latvian-Lithuanian transboundary groundwater bodies

The status assessment of TGWBs was carried out by assessing the volumes of water abstraction in both countries, groundwater vulnerability, and groundwater quality (LGS-LEGMC, 2019).

Groundwater abstraction in the Latvian-Lithuanian TGWBs has been assessed following each country's approach. The assessment of Lithuanian water abstraction volumes was performed by compiling water abstraction data (2017-2018) from groundwater well fields (abstraction rate > 100 m^3/day), as well as for decentralized wells where water abstraction is in the range of 10-100 m^3/day. In Latvia, groundwater abstraction was assessed by compiling information on abstraction volumes in groundwater well fields (abstraction rate > 100 m3/day) (LGS-LEGMC, 2019).

High vulnerability areas in Lithuania were indicated only in active karst zones in the Lielupe RBD. In Latvia, high vulnerability areas were more commonly indicated, also in Venta, Lielupe and Daugava RBDs. However, this might be due to different techniques on how to assess the vulnerability in general and the quality of available Quaternary cover data. Available shallow quaternary vulnerability maps for Latvia represent only the natural shallow groundwater vulnerability but do not take into account pressures (such as land use). Thus, it is recommended in the future to overlook the previously prepared map by considering also at least agricultural pressures (densities of livestock, manure, and fertilization application amounts) (LGS-LEGMC, 2019).

For TGWBs quality assessment, a joint database was created which gathered transboundary monitoring results in Latvia and Lithuania (2016-2017). As groundwater in both countries is the most important drinking water source, LVs taken from drinking water standards were used as TVs (LGS-LEGMC, 2019).

The joint methodology for practical application of quality assessment was agreed which included the following steps (LGS-LEGMC, 2019):

1) identification of parameters of main concern (sulfates, nitrates, ammonium);
2) the TVs were chosen as 75% of national drinking water standards (except pH);
3) average concentration for all MPs were calculated for period 2016-2017;
4) finally, the values were represented on maps to identify their relevance to GWBs and transboundary nature.

During this project, 5 groups of TGWBs have been identified and agreed to be further managed as joint GWBs. Grouped GWBs were described according to an agreed template which will serve as a basis for future development of groundwater section in transboundary River basin management plans. A joint database combining national groundwater monitoring results in transboundary areas was created for the years 2016-2018 which will serve as a template for further data exchange processes. As a conclusion during the draft assessment, all TGWBs were classified in good chemical status; however, a more detailed assessment is necessary to add confidence levels to the results, thus joint future cooperation in the field of groundwater assessment in the transboundary area is strongly encouraged (LGS-LEGMC, 2019).

1.2. Pressure assessment

Article 5 of the WFD requires the MS to identify the significant pressures likely to cause GWBs to be in less than good status. It also requires the MS to assess the impacts on GWBs to support the determination of status. The WFD requires the identification of significant pressures from point and/or diffuse sources.

Significant means that the pressure can contribute to an impact as a result of which the WFD objectives would not be met (e.g. good status of a GWB).

1.2.1. Pressure assessment in Estonia

The classification and prioritization of pressures related to the GWB in Estonia was based on WFD Reporting Guidance 2016 (*WFD Reporting Guidance 2016. Annex 1a: List of Pressure Types*). In the analysis of point and/or diffuse sources of pollution, the first step was to identify all potential sources and to analyze their occurrence density and location in a GWB (e.g., location to recharge/discharge areas). The identification of significant pressures is difficult because it often requires case studies that consider the type of the pressure source and the characteristics of the GWB (EC, 2003b).

The identification of significant pressure was based on WFD Reporting Guidance 2016, which provides a list of various pressures and main driver types, as well as the list of the Estonian GWBs, which are at risk or in poor status. These two lists were used for selecting a significant point and diffuse pressure sources. Each pressure source type was related to actual GIS data.

At first, the pre-estimation of pressure types was made. The pressure types that do not occur or are very rare in Estonia, or have no impact on GWBs and are considered insignificant were identified (Marandi et al., 2019):

- *1.8 – Point – Aquaculture Fisheries and aquaculture;*
- *2.9 – Diffuse – Aquaculture Fisheries and aquaculture;*
- *3.4 – Abstraction or flow diversion – Cooling water Industry, Energy - non-hydropower;*
- *3.5 – Abstraction or flow diversion – Hydropower Energy - hydropower;*
- *2.7 – Diffuse - Atmospheric deposition.*

Assessing the significance of the remaining pressure types was not as easy. It was possible to make a choice based on the available data and the connection of the pressure sources to groundwater resources before proceeding with a more detailed GIS analysis (Marandi et al., 2019).

1.2.1.1. Identification of point pressure sources

To assess the significance of each point pressure source, the available data were collected and its quality was assessed for further use (Marandi et al., 2019):

- ***Urban wastewater (1.1)*** and ***Storm overflows (1.2)*** – previous studies in Estonia have shown that most of the wastewater treatment plants in Estonia were reconstructed quite recently and do not have an important impact on GWBs; GIS data on wastewater treatment plants and its outflows is available, but digital data about the actual pressure types are missing. Both pressure types (1.1 and 1.2) were not used in the following GIS analysis;
- ***IED plants and industrial point sources from plants included in the E-PRTR (1.3)*** – GIS data is available, but with no relation to the pressure type; it was not possible to assess how a plant can affect the status of GWB, therefore the data were not used in the GIS analysis;
- ***Non-IED plants (any industrial point sources not included in the E-PRTR) (1.4)*** – Estonian Environmental Board maintains the Information System of the Environmental Permits which collects such kind of data, but efficiently processible digital data is not available; both point source types were discarded due to problems with data;
- ***Contaminated sites or abandoned industrial sites (1.5 and 2.5)*** – GIS data on contaminated and abandoned sites are available and both pressure types were considered in the GIS analysis;
- Waste disposal sites (1.6) – environmental requirements are met in landfills and they do not have significant impact on GWBs, and those sites that do not meet the requirements are already recorded in the database of contaminated and abandoned sites; the pressure type was not used in the GIS analysis;
- ***Mine waters (1.7)*** – mine waters are considered to be a significant pressure; GIS data was available and was used in the following analysis.

1.2.1.2. Identification of diffuse pressure sources

In order to assess the significance of each diffuse pressure source, the available data were collected and its quality was assessed for further use (Marandi et al., 2019):

- ***Urban run-off (2.1)*** – is not considered to be a significant pressure on GWBs; GIS data was not used in the following analysis;
- ***Agriculture (2.2)*** – is considered to be a significant pressure on GWBs; a map of agricultural land is available (provided by The Agricultural Registers and Information Board) and was used in the following analysis;
- ***Forestry (2.3)*** – assessed to be an unimportant pressure (fertilizers are not allowed to be used in forestry); pressure type was not used in the analysis;
- ***Transport (2.4)*** – generally an unimportant pressure type for most GWBs, but previous studies have shown that in Estonia for small Quaternary GWBs located in the vicinity of cities of Tartu and Tallinn transport is an important pressure source; in GIS analysis spatial data on streets were used – for every street line a 30 meters-wide buffer zone was calculated which can potentially affect the related GWB;
- ***Discharges not connected to sewerage networks (2.5)*** – might be an important pressure source; spatial data are available on areas where sewage networks exist. These areas were compared with Estonian Base map data, and areas of building and yard were selected where sewage networks do not exist;
- ***Mining (2.8)*** – important pressure in North-Eastern Estonia; spatial data for mining areas were used in GIS analysis;
- ***Groundwater abstraction (3)*** – important pressure type, but it was not included in the GIS analysis (was assessed separately with a hydrodynamical model – the total amount of groundwater abstraction was compared with natural water balance, which was calculated for each GWB);
- ***Groundwater recharges (6.1)*** – in the case of Estonia, pressure type includes sites where the land improvement ditches are led directly to the karst areas; it was assessed as potential point pressure sources and was included in the GIS analysis.

As a result of the preliminary analysis, significant point and diffuse pressure types were leakages from contaminated sites or abandoned industrial sites (1.5,2.5), mine waters and mining (2.8), agriculture (2.2), transport (2.4), discharges not connected to sewage network (2.4), groundwater abstraction (3) and recharges (6.1) (Marandi et al., 2019).

1.2.1.3. Spatial analysis of identified pressure sources

Spatial analysis were used to assess their potential impact on GWBs, which was based on two assumptions (Marandi et al., 2019):

- all pressure types will affect only the uppermost GWB, except groundwater abstraction;
- the point pressure source impact area is related only to the sub-catchment area where the pressure source is situated.

Concerning ***point pressure sources***, spatial GIS analysis included (Marandi et al., 2019):

- calculation of the areas of geometric intersection between the uppermost GWB and each overlapping sub-catchment area;
- performance of the spatial query to find the relation between points and areas;
- calculation of percentage of selected areas in the GWB;
- repetition of the analysis for each point pressure type separately.

Concerning ***diffuse pressure sources***, spatial GIS analysis included (Marandi et al., 2019):

- calculation of percentage of diffuse pressure areas on the **uppermost** GWB;
- repetition of the analysis for each diffuse pressure type separately.

As the result of the GIS analysis the percentage of the GWB area that may be affected by a particular pressure type was obtained. Based on GIS analysis, the impact of pressure sources for a GWB was categorized qualitatively in the three classes (Marandi et al., 2019):

- ***major impact*** – pressure type affects more than 50% of GWB area;
- ***minor impact*** – pressure type affects 25-50% of GWB area;
- ***no impact*** – pressure type affects less than 25% of GWB area.

Both point and diffuse pressure source was considered to have a major impact if the sum of point pressure-related sub-catchment areas or diffuse pressure areas covered more than 50% of the GWB area. If the coverage of sub-basins or diffuse pressure source areas was in the range of 25-50% of the GWB area, the pressure source was considered to have a minor impact. If the coverage was less than 25% of the GWB area, the pressure source was considered to have no impact (Marandi et al., 2019).

1.2.2. Pressure assessment in Latvia

The pressure assessment methodology development and pressure assessment itself in Latvia was performed in 2020/2021 for preparation of the 3rd River Basin Management Plans (LVĢMC, 2021). Pressure assessment was performed in three main categories: point pressure assessment, diffuse pressure assessment and groundwater abstraction pressure assessment. Pressure assessment does not include an assessment of GWBs at risk as they have already been delineated on the basis of specific pressures (see Chapter 1.1.2.1). Exception is groundwater abstraction pressure – in this case GWBs at risk due to their small territorial size were included in the hydrogeologically linked GWB. The process of pressure assessment is not automated – in each pressure category and assessment stage the activities were performed manually and in the final stages the assessment was heavily based on the expert judgment (LVĢMC, 2021).

1.2.2.1. Point pressure assessment

In order to identify and assess point pressure sources on GWBs, data from the Register of Contaminated and Potentially Contaminated Sites[1], data on shallow groundwater pollution by oil products at gas stations and oil terminals from the Unified Environmental Information System[2], data on Category A polluting activity permits issued in accordance with Cabinet Regulation No.1082 of November 30, 2010 "Procedure by which polluting activities of Category A, B and C shall be declared and permits for the performance of Category A and B polluting activities shall be issued"[3] (hereinafter - Cabinet Regulation No.1082), as well as the data of the Agricultural Data Center on the total number of livestock expressed in animal units[4] (LVĢMC, 2021). The assessment of the significance of point pressures was performed with the 3-stage procedure, which is schematically shown in FIGURE 1.2.2.1.1.

In order to prepare the list of significantly polluted sites (Stage 1), data from the above sources were collected. The list was prepared in accordance with the precautionary principle and also includes potential point sources of pollution that may cause significant pressure on groundwater. The list of significantly polluted sites include (LVĢMC, 2021):

1) Category 1 polluted sites (the level of pollution and the impact of it is high - the LVs of EQS are exceeded 10 times and more) from the Register of Contaminated and Potentially Contaminated Sites;
2) all sites for which, according to Cabinet Regulation No.1082 of 30 November 2010, Category A polluting activity permit has been issued (required for stationary technological equipment in which one or more polluting activities are performed);
3) all gas stations and oil terminals from Unified Environmental Information System managed by LEGMC, where significant pollution with oil products has been detected in the period from 2015 to 2019 and a high concentration of pollutants - the sum of petroleum hydrocarbons and monoaromatic hydrocarbons (BTEX)[5] or a floating layer of oil products has been detected;
4) all agricultural holdings where, according to the Agricultural Data Center, the total number of livestock exceeds 1000 units.

[1] Register of Contaminated and Potentially Contaminated Sites. Available: https://www.meteo.lv/lapas/vide/piesarnoto-un-potenciali-piesarnoto-vietu-registrs/piesarnoto-un-potenciali-piesarnoto-vietu-registrs?id=1527&nid=373
[2] Unified Environmental Information System. Available: https://www.meteo.lv/autorizacija/?josso_back_to=http://parissrv.lvgmc.lv/signon
[3] Cabinet Regulation No.1082 of 30 November 2010 "Procedure by Which Polluting Activities of Category A, B and C Shall Be Declared and Permits for the Performance of Category A and B Polluting Activities Shall Be Issued". Available: http://likumi.lv/ta/en/en/id/222147
[4] Agricultural Data Center, Number of livestock units, 2018
[5] Concentrations of pollutants exceed the LVs specified in Annex 10 to Cabinet Regulation No.118 of March 12, 2002 "Regulations regarding the Quality of Surface and Groundwater". Taking into account the fact that the above-mentioned regulations (as amended on October 3, 2015) no longer include target values and LVs for monoaromatic hydrocarbons (BTEX), but this parameter is the most frequently determined parameter when monitoring shallow groundwater at gas stations and oil terminals, a LV of 175 µg/l was adopted as the BTEX target for individual monoaromatic hydrocarbons (benzene, ethylbenzene, toluene and xylenes).

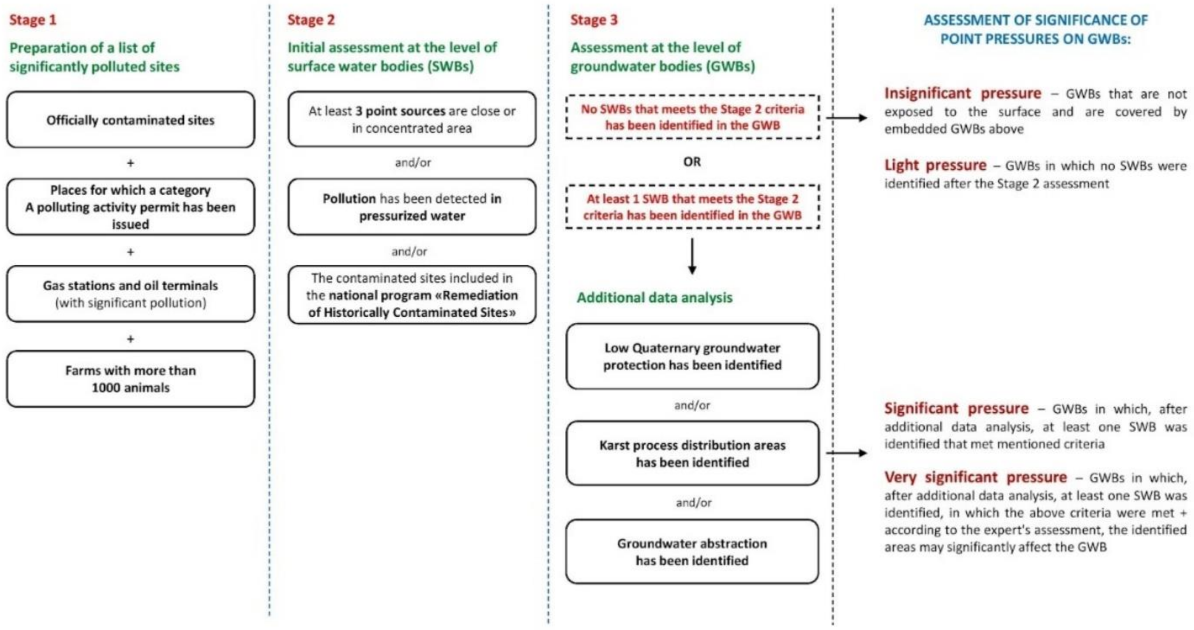


FIGURE 1.2.2.1.1 **Approach to assessing the significance of point source pollution pressures** (modified after LVĢMC, 2021)

In order to perform the initial assessment of the significance of point pressure sources (Stage 2), the information was collected by RBDs and SWBs, identifying those SWBs where at least 3 significantly polluted sites are located in close proximity or in a concentrated area. Then, on the basis of the GIS information, the extent of the dispersion of these sites on the scale of SWBs was assessed (if the sites were scattered throughout the SWB area, the impact was not considered significant). Parameters such as type, extent, potential impact on surface and/or groundwaters were also assessed for each site based on available information as an expert judgment (LVĢMC, 2021).

Significant impact were noted in those SWBs where pollutants have entered the pressurized waters, or in the SWB territory there is at least one point source of pollution included in the National Program for the Rehabilitation of Historically Contaminated Sites (hereinafter - historically contaminated site), at least 3 point pollution sites are located in a close or concentrated area, or in the vicinity of rivers, which, in the opinion of a surface water expert, have a significant impact on water quality and/or human health (according to the information prepared in the 3rd period RBDMPs) (LVĢMC, 2021).

The assessment of the significance of point pollution pressures at the level of GWBs (Stage 3) was performed based on the results obtained in the Stage 2 assessment and the hydrogeological conditions. Accordingly, the point pressure was considered to be insignificant at the GWB level if it is not exposed on the surface and is completely covered by other GWBs and aquifers. Light pressure was noted in those GWBs that are partially or completely exposed on the surface, but in which SWBs that would meet the set criteria were not identified during the implementation of Stage 2 (LVĢMC, 2021).

In turn, in those GWBs where SWBs meeting the criteria of Stage 2 were identified, an additional assessment was performed.

Firstly, the extent to which the identified SWBs have an impact on the GWBs was assessed based on GIS information. Taking into account the precautionary principle, point pressure was considered to be significant at the level of GWB if at least one point pressure site was located in SWBs' area (LVĢMC, 2021):

1) with a low degree of protection (high vulnerability) of Quaternary groundwater (corresponds to the categories of unprotected, weakly and moderately protected Quaternary groundwater; as well as areas where Devonian sediments are exposed on the surface-confined aquifers are also correspondingly vulnerable);
2) with karst processes distribution (pollution from groundwater may reach confined aquifers);
3) with groundwater intake (regardless of the depth of the exploited aquifer and the volume of groundwater obtained).

Secondly, based on the available information, very significant pressure was noted in those GWBs where, according to the expert judgment, point pressures cause or are likely to cause a significant impact on groundwater quality and/or human health. The assessment took into account the local hydrogeological conditions of each GWB (degree of groundwater vulnerability, distribution of flows, etc.), the volumes of groundwater abstraction, and the depth of input of pollutants (LVĢMC, 2021).

1.2.2.2. Diffuse pressure assessment

To assess the significance of diffuse pressure on GWBs, land use data (according to Corine Land Cover), livestock data, SWBs diffuse pressure assessment data, and distribution of nitrate vulnerable zones were used. The assessment was carried out in a 4-stage procedure (LVĢMC, 2021).

Using Corine Land Cover data[6], the specific area of agricultural land class in each GWB was calculated and expressed as a percentage (agricultural land class area concerning the total GWB area) (Stage 1). Using obtained information, the significance criterion was calculated by summing the occupied area within all GWBs (expressed as a percentage) and calculating its average value and standard deviation, additionally subtracting/adding the standard deviation to the average value. The significance criterion was calculated only for those parts of GWBs that are exposed to the ground surface and were assumed to be directly exposed to surface pollution (LVĢMC, 2021).

The significance criterion was divided into four classes (LVĢMC, 2021):

- ***insignificant*** (does not cause pressure on GWB);
- ***light*** (minimum pressure on GWB);
- ***significant*** (causes pressure on GWB);
- ***very significant*** (causes significant pressure on GWB).

he data of the Agricultural Data Center on the total number of livestock expressed in animal units[7] (a conditional animal that produces 100 kilograms of nitrogen with manure in one year) were also used to assess the diffuse pressure (Stage 2). The allowable number of animal units (DVp) (following the Annex 1 of the Cabinet Regulation No.834 of December 23, 2014 “Requirements Regarding the Protection of Water, Soil and Air from Pollution Caused by Agricultural Activity” (hereinafter - Cabinet Regulation No.834)) was calculated in each GWB using the formula:

$$L = \frac{\sum DV}{DVp},$$ where:

L - area of agricultural land required for manure application (ha);
∑DV - total number of livestock of the agricultural holding, expressed in animal units;
DVp - the permissible number of livestock units per hectare of agricultural land.

Accordingly, the indicator *L - area of agricultural land required for manure application (ha)*, was calculated in each GWB around each livestock farm by determining an individual 5 km buffer zone (optimal distance from the farm for manure application) and ultimately from these buffer zones by calculating the total area of agricultural land in each GWB. Based on the available data from the Agricultural Data Center, the total number of livestock in livestock units (∑DV) was also calculated for each GWB. As a result, the permissible number of livestock units (DVp) per GWB was calculated (LVĢMC, 2021).

Following Sub-paragraph 3.3.2 of Cabinet Regulation No.834, the permissible number of livestock units (DVp) per hectare of agricultural land in Latvia is 1.7 livestock units. ***Very significant pressure*** was applied to GWB if the permissible number of livestock units (DVp) per hectare of the utilized agricultural area was exceeded. If the number of livestock units in the GWB was not exceeded, the pressure was considered ***insignificant*** (LVĢMC, 2021).

To assess SWB diffuse pressure (Stage 3), the following data were summarized: SWBs with significant and very significant pressure from arable and livestock land and SWBs with poor and very poor-quality status to identify diffuse pressure (according to the information prepared for the 3rd period RBDMPs). All SWBs with poor and very poor quality resulting from agricultural diffuse pressure were identified. In SWBs with poor and very poor-quality status, those with distributed agricultural pressures with a significant or very significant

[6] The Copernicus Programme, 2018. Corine Land Cover. Available: https://land.copernicus.eu/pan-european/corine-land-cover/clc2018
[7] Agricultural Data Center, Number of livestock units, 2018

impact were taken into account. All poor and very poor quality SWBs affected by other distributed loads, such as forestry and households not connected to the central sewerage system, were also identified. For the previously identified pressures in SWBs, the specific area concerning the GWB area, expressed as a percentage, was calculated (LVĢMC, 2021).

For the determination of SWB diffuse pressure, a significance criterion limit of more than 20% of the GWB area was adopted (EC, 2004). Very significant pressure on GWB was attributed to the case where more than 20% of SWBs with poor or very poor-quality status affected by agricultural distributed pressures (as well as pressures from other processes) were identified within the GWB concerning the total area of GWB. If the 20% limit was not exceeded, the pressure was considered insignificant (LVĢMC, 2021).

The nitrate vulnerable zone was also taken into account for the assessment of diffuse pressure (Stage 4). If the area of the nitrate vulnerable zone occupied more than 20% of GWB, then the pressure was considered to be very significant, while in the area of the nitrate vulnerable zone that did not exceed 20% of GWB, the load was considered insignificant (LVĢMC, 2021).

Finally, the diffuse pressure on GWB was considered significant if at least one of the indicators (agricultural land (Stage 1), number of livestock expressed in livestock units (Stage 2), SWBs with poor and very poor-quality status affected by agricultural diffuse pressure (as well as other process pressures) (Stage 3) and nitrate vulnerable zone (Stage 4)) exceeds the LV of the significance criterion (significant or very significant pressure). In conclusion, the worst-case scenario was taken into account in the assessment of the diffuse pressure (LVĢMC, 2021).

1.2.2.3. Groundwater abstraction pressure assessment

To determine in which GWBs the pressure caused by water abstraction is significant and may harm the groundwater quantitative status, the data from the State Statistical Report Forms *No.2-Water. Reports on the Use of Water Resources* were analyzed. The assessment of the significance of the impact was carried out in a 5-stage procedure (LVĢMC, 2021).

The data of the State Statistical Report Forms *No.2-Water. Reports on the Use of Water Resources* in the period from 2015 to 2019 were used for the assessment, first performing the validation of the obtained data (Stage 1). The annual average groundwater abstraction volume (m^3/d) was calculated for each groundwater abstraction site (individual groundwater abstraction wells and groundwater well fields) (LVĢMC, 2021).

As the number of groundwater abstraction sites is not evenly distributed in each of the GWB's (inhomogeneous distribution) and cannot provide a spatial assessment of abstraction pressure at the level of GWBs, the information obtained in Stage 1 was interpolated by smaller administrative-territorial units (parishes, cities) (Stage 2). The data required to assess the significance of the pressures were classified into four groups (LVĢMC, 2021):

a) areas without groundwater abstraction;
b) areas with groundwater abstraction up to 100 m^3/d;
c) areas with groundwater abstraction from 100 m3/d to 1000 m^3/d;
d) areas with groundwater abstraction above 1000 m^3/d.

To avoid potential errors in the previous stages, it was examined whether the groundwater abstraction point belonging to a specific administrative-territorial unit falls within a specific GWB or is located outside its territory (Stage 3). In cases when administrative-territorial division units belonged to several GWBs at the same time, the manual connection of groundwater abstraction volumes with the corresponding GWBs was performed (LVĢMC, 2021).

The specific water abstraction indicator was introduced to more objectively assess the volume of water abstraction at the level of GWBs and to characterize significant groundwater abstraction pressure (Stage 4). It was calculated by dividing the amount of water abstraction in a particular GWB by the total area of the respective GWB. A specific water abstraction indicator was determined for each GWB. From these indicators, the average specific water abstraction indicator was expressed - 1.43 (LVĢMC, 2021).

The significance of the groundwater abstraction pressure in each GWB (Stage 5) was assessed taking into account what percentage of the territory of each GWB is occupied by each of the four groups classified in Stage 2 and the specific abstraction indicator. Four significance categories were adopted (TABLE 1.2.2.3.1).

TABLE 1.2.2.3.1

Significance distribution of water abstraction pressure (LVĢMC, 2021)

Significance category	Annual average groundwater abstraction (m^3/d)
Insignificant	0
Light	< 100
Significant	100 - 1000
Very significant	> 1000

If the number of administrative units with categories significant or very significant abstraction within a GWB do not exceed 20% of the total number of administrative units, then the groundwater abstraction pressure in the GWB was determined to be ***insignificant***. If more than 20% of the area at GWB level was occupied by areas (at the level of administrative units) with significant (100-1000 m^3/d) and very significant (> 1000 m^3/d) groundwater abstraction category obtained in Step 2, an additional criterion was considered - whether the specific water abstraction indicator (1.43) is exceeded at the GWB level. If this indicator was exceeded, then the pressure was considered ***very significant*** at the level of the whole GWB (LVĢMC, 2021).

1.3. Natural background and threshold values delineation

The GWD (2006/118/EC), following Article 17 (1) and (2) of the WFD (2000/60/EC), lays down specific measures to prevent and control groundwater pollution. These measures shall include (a) criteria for assessing good groundwater chemical status; and (b) criteria for identifying and reversing significant and sustained upward trends and for determining the starting point for trend reversals. This Directive also complements the WFD provisions aimed at preventing or reducing the input of pollutants into groundwater and seeks to prevent the deterioration of all GWBs.

Article 3 of the GWD describes the criteria for assessing the chemical status of GWBs, including the GQSs for nitrates and pesticides listed in Annex I to the Directive and the TVs set by each MS following the procedure set out in Annex II. The MS shall set LVs for pollutants, groups of pollutants, or indicators of pollution identified in their territory as being capable of being characterized as GWBs or groups of sites as risk groups or groups, taking into account at least the list in Part B of Annex II.

Under the GWD, LVs may be set at the national level, at the level of a RBD, or in a part of an iRBD lying within the territory of a MS, or at the level of a GWB or a group thereof. MS shall ensure that the setting of TVs for GWBs common to two or more MS and for GWBs where groundwater crosses a national border is established in cooperation between the MS concerned, following Article 3 (4) of the WFD. Where the GWB or a group of GWBs extends beyond the territory of the EC, the MS concerned shall endeavor to set TVs in cooperation with the relevant non-member countries following Article 3 (5) of the WFD.

If the risk of not achieving good groundwater status is not identified in the GWB during the initial characterization, further characterization and setting of TVs are not mandatory.

1.3.1. Natural background and threshold values delineation in Estonia

TVs and NBLs for Estonian GWBs were first proposed in 2013 (Infragate, 2013) and were updated by the Geological Survey of Estonia in 2019 (Marandi et al., 2019). The delineated TVs have been implemented at a national level (Minister of Environment Regulation No.48/2019).

In Estonian legislation two types of values are distinguished: *GQSs* and *TVs* (Ibid.; Marandi et al., 2019). *GQS* are EQS expressed as the concentration of a particular pollutant, group of pollutants, or indicator of pollution in groundwater, which should not be exceeded to protect human health and the environment. The GQSs in Estonia apply at a national level and in all GWBs. These standards are applied for nitrate and active substances in pesticides (including their relevant metabolites, degradation, and reaction products; Minister of Environment Regulation No.48/2019).

A TV is a GQS set by EU MS for the pollutants, groups of pollutants, and indicators of pollution which, within the territory of a MS, have been identified as contributing to the characterization of bodies or groups of bodies of groundwater as being at risk. The TVs in Estonia have been proposed at a GWB level.

NBL is a concentration of a substance or the value of an indicator in a GWB that corresponds to no, or only very minor, anthropogenic. It should be differentiated from ***a baseline level***, which is an average value measured at least during the reference years 2007 and 2008 or during the first period for which a representative period of monitoring data is available. In that sense, the work by Marandi et al. (2019) dealt with establishing and updating NBLs for Estonian GWBs.

The methodology for delineating the NBLs and TVs was based on previously established values (Infragate, 2013) and the simplified version of the BRIDGE methodology (Müller et al., 2006, Hinsby et al., 2008). Two types of criteria were taken into account in determining the TVs for the Estonian GWBs (EC, 2009; Infragate, 2013):

- ***environmental criteria***:
  1) TVs that aim to protect GAAEs and GDTEs;
  2) TVs which help to designate abstraction related saltwater intrusion into a GWB.
- ***usage criteria***:
  1) TVs that aim to protect drinking water in DWPAs;
  2) TVs to protect other legitimate uses of groundwater (e.g. crops irrigation, industry).

When establishing the TVs one must first establish *the receptor* which the status of groundwater can influence (e.g. drinking water, groundwater dependent ecosystems). When the receptor has been chosen, it is necessary to establish substances and indicators (e.g. drinking water quality standards, TVs used to assess the status of GDEs) used to determine whether the receptor is influenced by groundwater quality.

When such substances and indicators have been identified, their *NBLs* have to be designated as naturally occurring high concentrations for certain substances, and indicators are not considered pollution (EC, 2009). These high concentrations may originate from water-rock interaction, biological processes (e.g. redox reactions), inflow from adjacent aquifers and are not related to anthropogenic alterations. Finally, to establish the TVs the designated NBLs are compared to *the criteria values*. *The criteria value* is the concentration of a pollutant, which is designated not taking into account any natural background concentrations, but if exceeded may lead to a failure of the good status criterion concerned (EC, 2009). The most commonly used criteria values are the GQS.

When comparing the criteria values with the established NBLs, two outcomes are possible for any substance or an indicator (EC, 2009):

1) ***NBL*** < ***criteria value***: In that case, the MS will define the TV according to national strategies and a risk assessment (enabling a TV to be established above the BL providing it can be justified);
2) ***NBL*** > ***criteria value***: In this case, the TV should be equal to the NBL.

Marandi et al. (2019) followed the general strategy outlined above when updating the TVs for the Estonian GWBs. The basis of the analysis was the TVs and NBLs established in the previous analysis (Infragate, 2013) and TVs established at the time by the Minister of Environment Regulation. Drinking water, GDEs, and saltwater intrusion were considered the most important receptors. When calculating the NBLs for the GWBs, chemical data from the period 2004-2017 was chosen as the baseline. To establish TVs for groundwater macro components (e.g. Cl^-, SO_4^{2-}; but also NO_3^-), data from earlier periods were also considered.

The NBLs were derived as the 90th percentiles of this preselected dataset, using the following pre-selection criteria (Hinsby et al., 2008):

1) only samples where seven groundwater macro components (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}) were analyzed were considered, as they enabled the calculation of an ion balance for the sample;
2) samples with incorrect ion balance (exceeding 10%), unknown depth and unknown aquifer type were excluded;
3) time series at each MP were converted to average values (to assure that long time series do not bias results and that all sampling sites contribute equally to the NBL derivation).

As criteria values, GQS, TVs established for groundwater dependent ecosystems, and quality standards for dangerous substances were considered. The proposal to change the previous TV was given, when:

- the previous TV did not take into account the active pressures acting on a GWB (e.g. the TV should be omitted when no active pollution sites where a given substance may originate is present in a GWB);

- previous TVs did not take into account the NBLs in a GWB;
- the previous TVs did not take into account the potential influence of groundwater quality on GDEs.

The updated NBLs and TVs proposed for Estonian GWBs by Marandi et al. (2019) are given in Annex 1. Most of the suggestions for TVs were adopted in Estonian legislation but a few points deserve some further clarification. Firstly, for two GWBs (Cambrian-Vendian Gdov, Ordovician-Cambrian Tartu, and Middle-Lower Devonian Kihnu) a chloride TV significantly higher than the drinking water limit of 250 mg/l was established. The main reason for this was the much higher chloride NBLs observed in these GWBs (i.e. background levels > criteria value). This means that due to natural conditions it may be impossible to abstract water within the drinking water limit from those GWBs at least within their current boundaries.

Secondly, the most radical suggestion concerning the TVs was to establish TVs for total nitrogen (N_{tot}) and total phosphorus (P_{tot}) for GWBs where important GWDEs are situated (Terasmaa et al., 2015). This suggestion was not adopted in legislation. The rationale behind this suggestion was to protect the receptor with the lowest criteria value, which in this case was not drinking water but GWDEs. This would also enable a better assessment of the influence of groundwater quality on the chemical status of GWDEs. Currently, N_{tot} and P_{tot} are used as indicators to assess the chemical status of SWBs (i.e. lakes and rivers), but these parameters are not measured in groundwater from where only nitrate nitrogen ($N\text{-}NO_3^-$), nitrite nitrogen ($N\text{-}NO_2^-$), and ammonium nitrogen ($N\text{-}NH_4^+$) are measured and treated separately. From phosphorus-species, currently, only phosphate phosphorus ($P\text{-}PO_4^{3-}$) is measured for groundwater status assessment. Thus, it is very hard to compare the groundwater quality and surface water quality in the same areas. The values of N_{tot} and P_{tot} given in Annex 1 correspond to the boundaries between good and poor status for different types of rivers and lakes. For GDTEs, no chemical TVs have been adopted in Estonia.

Marandi et al. (2019) acknowledged that the TVs given for N_{tot} and P_{tot} are much lower than the previous TVs and values that can be encountered frequently in Estonian groundwater. The adoption of these values in legislation would lead to many administrative problems as probably a high number of GWBs would be assessed to be in poor status in the future. It would also need considerable effort and further studies to come up with land management practices that would enable such strict criteria to be reached for these nutrients. However, the authors still strongly advised that as a first step the analysis of N_{tot} and P_{tot} should be added to the list of substances studied for GWB chemical status assessment. A pilot project is currently underway in the framework of the LIFE IP CleanEst project, where N_{tot} and P_{tot} are studied simultaneously from groundwater and surface water in pilot catchments located in the Lääne-Viru county, northern Estonia.

Finally, as stated above, the strategy adopted by Marandi et al. (2019) for establishing NBLs and TVs for Estonian groundwater was a simplified version of the BRIDGE methodology. In the future, when more data is available, the number of pre-selection criteria for the dataset used to determine these values can be expanded. These include (Hinsby et al., 2008):

- data from MPs with median nitrate concentrations above 10 mg/l can be considered to be polluted and thus be excluded from the dataset. Thus, only samples with nitrate concentrations less than or equal to 10 mg/l are used as a proxy for groundwater with a natural composition;
- if the dataset contains anaerobic samples (here defined as $O_2 < 1$ mg/l) or denitrification occurs, the dataset would need to be evaluated separately for the aerobic and anaerobic samples. That would be especially important if the concentration of the investigated parameters is controlled by the redox environment (e.g. NO_3^-, Fe_{tot}, SO_4^{2-}). For example, in anaerobic groundwater nitrate does not work as a pollution indicator since nitrate could have been reduced.

It is also interesting to mention that other methodologies besides BRIDGE have been used in other parts of the world to determine NBLs/TVs for groundwater. An example is an approach borrowed from the field of mineral exploration used by Panno et al. (2002) to establish NBLs for groundwater in Illinois' Sinkhole Plain in the USA. This method can be briefly described as follows. A dataset for a studied GWB or groundwater catchment is collected and analyzed for a given indicator or an ion. The data is then plotted on a cumulative probability plot, which groups the data into various populations. The inflection points along the plots indicate the threshold between two or more populations. In this context, the background is defined by the inflection point with the concentration above which higher concentrations can be interpreted as an anomaly that is indicative of the presence or influence of an anthropogenic alteration (i.e. much like the presence of a mineral deposit).

1.3.2. Natural background and threshold values delineation in Latvia

NBLs and TVs for Latvian GWBs were developed by the University of Latvia during a project "The development of background and threshold levels for Latvian groundwater bodies'' in 2019 (Retiķe un Bikše, 2019). The project involved literature studies, the development of methodologies for the delineation of background and threshold levels for Latvian GWBs as well as the application of the methodologies to calculate NBLs and TVs. As a result, NBLs and TVs for the number of compounds were determined for Latvian GWBs, but only some of them were used during GWB status assessment as status assessment strongly depends on previously identified anthropogenic pressures (LVĢMC, 2021).

The developed methodologies are largely based on the BRIDGE methodology (Müller et al., 2006) and other EU member countries following the EU WFD and the GWD. The methodology is adapted to the Latvian situation according to available data.

For delineation of ***NBLs***, two main groundwater quality data sources were used, including national groundwater monitoring data and data from groundwater abstraction sites. The national groundwater monitoring dataset consisted of many observations in each monitoring well and each sample had a long list of analyzed parameters. In the case of Latvia, groundwater monitoring stations are constructed in a way that up to 10 wells can be placed within a single station therefore spatial coverage was not sufficient although 374 unique monitoring wells were present in this dataset. To broaden the dataset, it was supplemented with monitoring data from groundwater abstraction sites. This dataset consisted of 36 000 observations from over 21 000 groundwater abstraction wells and had much better spatial distribution than national monitoring wells. However, the data quality was a problem as the list of analyzed parameters was often very short and many abstraction wells had only a single measurement, therefore data consistency could not be assessed (Retiķe un Bikše, 2019).

The methodology for NBL detection consisted of multiple successive steps that can be structured in three parts. During the first part – development of a dataset consisting of discrete observations – multiple sub-steps were performed including data harmonization during which previously mentioned data sources (national groundwater monitoring data and data from groundwater abstraction sites) were joined together in a similar structure; from both datasets, only observations from 1994 and newer were selected to avoid samples that have been taken with bailer-like equipment (Levins et.al., 1995; Levina and Levins, 1994). Parameters having a value below the detection limit were replaced by a value that is half of the detection limit (except for dataset from groundwater abstraction sites where such information was not available). The preparation of the harmonized database also included the exclusion of anthropogenically impacted samples which included samples with detectable pesticide levels or synthetic compounds and samples having Na^{+}+Cl^{-} concentration higher than 1000 mg/l. Finally, only samples having full major ion chemistry (i.e. having Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SO_4^{2-}) were selected to be able to perform ion balance calculations and samples with incorrect ion balance (exceeding 10%) were excluded (Retiķe un Bikše, 2019).

During the second part aggregated datasets for each sampling site were developed. Further data transformation was done by aggregating data by each sampling point and each parameter of interest by finding the median value (the median value was preferred over the average value to minimize the impact of outliers). Sampling sites having median nitrate levels higher than 10 mg/l were considered to be anthropogenically impacted and were excluded from the data set. Further, sampling sites were classified according to the redox environment; taking into account the incompleteness of data set (majority of samples lacked dissolved O_2 and Mn measurements), a simplified approach was used (Retiķe un Bikše, 2019):

- if iron content < 0.2 mg/l, then the sample was considered oxic;
- if iron content ≥ 0.2 mg/l, then the sample is considered anoxic.

Although this approach has its drawbacks and is not very precise, it still can be used to detect NBLs for iron and nitrates according to redox state. Finally, sampling points were assigned to GWBs by joining them spatially (through geospatial files) and also vertically by assigning GWB according to an aquifer that the well screen interval represents (some wells did have several representative aquifers due to long screen intervals and in rare cases, these wells represented two GWBs instead of one). Special care was taken dealing with wells representing Quaternary aquifers, because the majority of Quaternary aquifers are combined with GWBs together with confined aquifers, therefore careful spatial join was implemented (Retiķe un Bikše, 2019).

Using the prepared harmonized and aggregated dataset, NBL was determined as 90th percentile from the selected data set for each substance: if the number of observations for a substance was relatively large (e.g. major ions), then NBL was determined within each GWB but if the number of observations for a substance was insufficient (e.g. less than 20-40% of all data set), then single NBL was determined for all GWBs. NBL for redox-sensitive substances was determined according to redox environment: if the substance was elevated in anoxic (anaerobic) conditions (e.g. Fe_{tot}, Mn), the NBL was determined within each GWB for anaerobic conditions, but a single NBL for all GWBs was determined for aerobic part of the observations; if the substance was elevated in oxic (aerobic) conditions (e.g. NO_3^-), then NBL was determined within each GWB for the aerobic part of the observations, but a single NBL was determined for anaerobic part of the observations. Unfortunately, it was not possible to apply this step due to too small several oxic observations (less than 300 for the whole territory of Latvia), therefore one single NO_3^- NBL was determined for all GWBs as an alternative until more oxic observations will be gathered in the data set (at least ~20 oxic observations must be present in most of GWBs) (Retiķe un Bikše, 2019).

NBLs that were determined for a substance for each GWB were combined in more general groups to reduce the number of different NBLs, to promote more rounded NBL numbers, and to ease further groundwater management process. Firstly, percentiles of 90th and 95th were calculated for the substance under consideration for each GWB. Starting with GWB having the highest 90th percentile, a (relatively) rounded value was chosen close to the 90th percentile (this value was the NBL for the first group of GWBs). If the determined NBL in the previous step fell within the 90th and 95th percentile of any other GWB, then this GWB was included in the same NBL group with the same NBL (determined in the previous step); if the rest of the GWB's fell outside of the developed NBL group, then GWB with the next highest 90th percentile was selected to repeat previous steps until all GWBs were grouped into NBL groups (Retiķe un Bikše, 2019). An example of grouping Latvian GWBs into NBL groups for Cl^- is shown in FIGURE 1.3.2.1.

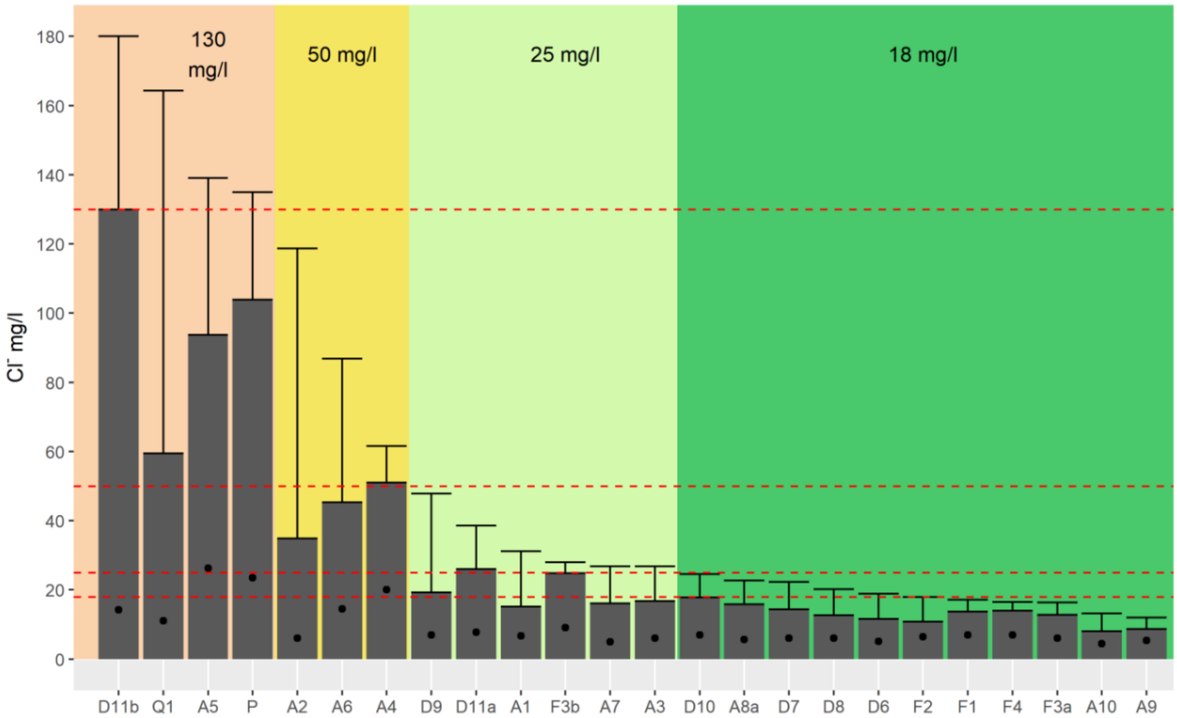


FIGURE 1.3.2.1 **Grouping of Latvian GWBs into chloride NBL groups according to Latvian background delineation methodology** (The X-axis represents Latvian GWBs. The upper edge of the gray column represents the 90th percentile for the GWB, while the thin horizontal line (whisker) represents the 95th percentile. The dotted red line represents the highest 90th percentile in each NBL group and each distinguished group is represented with a different background color) (Bikše un Retiķe, 2019)

The delineation of ***TVs*** for Latvian GWBs was based upon general principles developed by the EC (EC, 2009). These principles impose that to delineate a threshold value, two components are necessary: NBL (for each substance for each GWB) and reference value (for each substance).

NBL delineation methodology as described previously, but reference value was determined according to the purpose of each GWB (i.e. protection subject). Latvian GWBs are delineated to protect drinking water resources, therefore drinking water protection measures were used as reference values that are laid out in Regulation No.671 issued by the Minister Cabinet of the Republic of Latvia "Mandatory Harmlessness and Quality Requirements for Drinking Water, and the Procedures for Monitoring and Control Thereof".

Two most common approaches for threshold detection were selected according to the experience of other European countries:

1) if the reference value was higher than the NBL, the TV was calculated as the mid-point between NBL and reference value;
2) if the reference value was lower than the NBL, the TV was equal to NBL.

TVs were also set for groups of GWBs, established within the framework of the development of NBLs based on the NBL values of the combined groups. Also in the combined groups, all TVs for Mn and Fe_{tot}, as well as individual LVs for Cl^-, SO_4^{2-} and NH_4^+ ions were set as the corresponding NBL due to high NBLs exceeding the reference values (Retiķe un Bikše, 2019).

The NBLs and TVs (grouped by GWBs) proposed for Latvian GWBs are given in Annex 2.

1.3.2.1. Natural background and threshold values delineation for groundwater bodies at risk

NBLs and TVs for the delineated GWBs at risk (see Chapter 1.1.2.1) were established within the framework of separate studies in the period from 2018 to 2019.

Groundwater body at risk Q2

First NBLs and TVs for GWB at risk Q2 for the first time were established during a study conducted in 2007 (SIA "Vides projekti", 2007). NBLs for chloride ions, ammonium nitrogen, the sum of trichloroethylene and tetrachloroethylene (TCE+PCE), BTEX, trichloromethane, 1,2-dichloroethane, arsenic, cadmium, and lead were taken into account in setting the TVs. The TVs were set according to the following principles:

- for chloride ions, ammonium nitrogen, trichloroethylene and tetrachloroethylene (TCE+PCE), trichloromethane, 1,2-dichloromethane, arsenic, cadmium, and lead, the TV was determined according to the methodology recommended by BRIDGE (Müller et al., 2006) using the formula:

$$TV = \frac{(NBL + Reference\ value)}{2}$$

- for nitrate-nitrogen(N-NO_3^-), the drinking water EQS was adopted as a TV (following Cabinet Regulation No.671 of November 14, 2017 "Mandatory Harmlessness and Quality Requirements for Drinking Water, and the Procedures for Monitoring and Control Thereof");
- BTEX TV was established as NBL.

It should be noted that, according to BRIDGE methodology (Müller et al., 2006), NBLs for synthetic pollutants, such as trichloroethylene and tetrachloroethylene (TCE+PCE) and BTEX, which do not occur naturally, should be equal to "0", but in this study (SIA "Vides projekti", 2007) they were accepted as "below the limit of detection of the analytical method". Although this does not significantly affect the result, this is not correct, as the limits of detection of an analytical method may change over time and may vary from laboratory to laboratory (LVĢMC, 2019).

Taking into account that (1) in 2019 an in-depth study of GWB at risk Q2 was performed, as a result of which the vertical boundaries of it were revised (see Chapter 1.1.2.1) and (2) the long-term monitoring data set on groundwater and surface water quality was analyzed, it was decided to review the validity of the existing TVs (LVĢMC, 2019).

Given the fact that in 2007 (SIA "Vides projekti", 2007) the precautionary principle had been chosen and determined possible or preliminary indicators following the requirements of the GWD at that time and available data sources, in 2019 (LVĢMC, 2019) it was necessary to use up-to-date monitoring data and to verify whether the presence of parameters included in the previously developed list is discovered in groundwater. An analysis of the data for the period from 2000 to 2018 and comparison to aggregated data with the predefined TVs concluded that the list of ten indicators should be significantly reduced, as the only exceedance of the current TVs was for chloride ions and only as a higher concentration, not the average or median concentration. Parameters such as trichloroethylene and tetrachloroethylene (TCE+PCE), BTEX, and 1,2-dichloroethane were not detected at all (their concentrations were below the limit of detection of the chosen analytical method throughout the observation period), but trichloromethane was detected only once. Concentrations of nitrate nitrogen, ammonium nitrogen, as well as heavy metals As Cd and Pb were low, and at no time did they approach the established GQS and TVs. As a result, it was recommended that the TV be retained only for chloride ions, which directly allows the assessment of the chemical status of GWB at risk Q2 and the evolution of surface water interaction (LVĢMC, 2019).

GWB at risk Q2 hydro geologically is located in the area of GWB Q1 with the determined NBL of chloride ions of 130 mg/l (Retiķe un Bikše, 2019). When calculating the background value of chloride ions as 90th percentile for the respective GWB at risk Q2 area, the NBL for chloride ions was determined as 152 mg/l. Given the fact that the groundwater artificial recharge in the GWB at risk Q2 area will continue and the groundwater well fields "Baltezers" and "Baltezers II" will continue to provide a significant part of the centralized water supply to the city of Riga, it is not justifiable to set a NBL that would unambiguously determine GWB at risk Q2 to be in poor chemical status. It is undeniable that the natural quality of groundwater has been affected and it will not be possible to reach its original status in the period under review without a complete change in the way water is abstracted. Therefore, it was recommended to set the TV for chlorides as a determined NBL of GWB at risk Q2 itself and to monitor for future chemical deterioration by taking the current chemical status of it as a reference point - the TV for chlorides was set at 152 mg/l (see Annex 3).

Groundwater body at risk F5

NBLs and TVs for GWB at risk F5 were established during a study conducted by Retiķe un Bikše (2018). Longtime data from monitoring and abstraction wells were gathered about major ion chemistry (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}) and nitrates (NO_3^{-}) and limited to (1) the area of GWB at risk F5 which is the area affected by seawater intrusion and (2) to aquifers of interest - Upper Devonian Mūri-Žagare (D_3*mr-žg*). Data preprocessing included: (1) removal of historical samples which reported Na^+ and K^+ as a sum (Na^++K^+) (an additional criterion); (2) removal of samples with ionic balances error greater than ± 10% as suggested by Müller et al. (2006) and (3) where such information was available samples with nitrates content exceeding 4 mg/l were removed as potentially affected by human activities. A much stricter criterion than suggested 10 mg/l by Müller et al. (2006) was chosen based on the most recent study about the geochemical composition of groundwater in Latvia (Retiķe et al., 2016).

The NBL for chloride ions was calculated in two steps to minimize the error of visual identification of the inflection point. Firstly, freshwater samples were separated from seawater-affected samples - the value of the inflection point on groundwater samples was detected by applying probability plots (Panno et al., 2006). According to BRIDGE methodology (Müller et al., 2006) samples with NaCl > 1000 mg/l should be removed. Much stricter criteria were used, and the value of the inflection point for chloride was set at 18 mg/l. Results were compared with values obtained by Retiķe et al. (2016). Next, the NBL for chloride ions was determined as 90th percentile of all freshwater samples below the inflection point value according to BRIDGE methodology (Müller et al., 2006). This step was accomplished for two reasons: (1) the validation results from the previous study suggested that 18 mg/l for chloride might be too high (Retiķe et al., 2016) and (2) visual observation of the inflection point is subjective and may hold some uncertainty. Similarly, NBLs were set for sulfate and sodium ions (Retiķe un Bikše, 2018).

TVs for chloride, sulfate, and sodium ions were calculated according to BRIDGE methodology (Müller et al.,2006) which suggests deriving TVs based on the ratio between the estimated NBLs and relevant reference values. In this case NBLs < relevant reference values, therefore the following formula was used (Retiķe un Bikše, 2018):

$$TV = \frac{(NBL + Reference\ value)}{2}$$

Drinking water standard from Latvian legislation (Cabinet Regulation No.671 of November 14, 2017 "Mandatory Harmlessness and Quality Requirements for Drinking Water, and the Procedures for Monitoring and Control Thereof") was chosen as a relevant reference value, respectively 250 mg/l for chloride and sulfate ions, and 200 mg/l for sodium ions (Retiķe un Bikše, 2018).

Final NBLs for chloride ions were set as 13.2 mg/l, for sulphate ions - 42.5 mg/l and for sodium ions - 22.3 mg/l. Calculated TVs for chloride, sulphate and sodium ions were respectively 131.6 mg/l, 146.3 mg/l and 111.2 mg/l (see Annex 3).

Groundwater body at risk A11

NBLs and TVs for GWB at risk A11 for the first time were established during a study conducted in 2016 (Semjonovs, 2016). The boundaries of GWB at risk at that time were considered and the area in which hydrogeochemical studies and modeling of pollutants were performed in the calculation of TVs. Detailed information on groundwater dynamics, regime, recharge and discharge zones, migration parameters (sorption, diffusion, destruction) obtained in previous research and design works was used (Semjonovs, 2016).

In 2019 (LVĢMC, 2019), it was decided to review the background limits and TVs for GWB at risk A11 set in the study of Semjonovs (2016) taking into account the following reasons:

- in recent years, additional data on the chemical composition of shallow and confined groundwaters in the study area has been collected;
- in 2017, the boundaries of GWBs of Latvia were reviewed (see Chapter 1.1.2);
- in 2018, the boundaries of GWB at risk A11 were reviewed (see Chapter 1.1.2.1);
- in 2019, a study on NBLs and TVs determination in all newly delineated GWBs in Latvia was carried out (see Chapter 1.3.2), as well as changes in the background and LV determination methodologies at the European level.

The task of the new study in 2019 (LVĢMC, 2019) was not to search for and include new parameters in the list of GWB at risk A11 TVs but to review existing parameters and, if necessary, change or remove them from the list. It should be noted that the inclusion of new parameters, although possible, is not crucial in the current situation when the most important task of groundwater protection is the identification of pollution and control of its migration in groundwater. Following the completion of remediation work and environmental stabilization, the possibility of adding new pollution indicators to the list may be considered (LVĢMC, 2019).

In Semjonovs (2016) study, NBLs were calculated as 90% of the assurance, which is following the generally accepted BRIDGE methodology. The approach of using a very local data set near tar ponds and the small size of the data set is debatable. It can be concluded from the study that the NBLs of COD, sulfate ions, synthetic surfactants, and electrical conductivity are also expressed as TVs, which are not inherently incorrect but are very strict and unenforceable quality criteria for such a polluted GWB. Also, such an approach, although used in other EU MS, is not among the most popular (Retiķe un Bikše, 2019). It should be noted that for GWBs at risk in Latvia, such strict criteria were not used and the TVs were determined according to the methodology recommended by BRIDGE (Müller et al., 2006).

Within the framework of the research, Semjonovs (2016) determined the background limits and TVs for synthetic parameters as the detection limit of the analytical method. It should be noted that according to the methodology recommended by Müller et al. (2006), for synthetic pollutants, such as TCE+PCE or BTEX, which do not occur in nature, the NBL should be "0", but in the relevant study, they were assumed to be below the limit of detection of the analytical method. Although that does not significantly affect the result, it is not correct, as the limits of detection of the analytical methods may vary from laboratory to laboratory (LVĢMC, 2019).

In view of all the above, it was decided to make the following adjustments to the NBLs and TVs of GWB at risk A11 (LVĢMC, 2019):

- **NBLs**:
  - for the synthetic parameters (TCE+PCE, BTEX, trichloromethane, 1,2-dichloroethane and synthetic surfactants) to accept a value of "0" as a NBL according to the BRIDGE methodology (Müller et al., 2006) and the approaches of other EU MS;
  - for As, Cd and Pb to accept as NBLs the corresponding NBLs of the catchment area of GWB at risk, which is GWB A8 (Retiķe un Bikše, 2019), without distinguishing between aerobic and anaerobic waters, respectively;

- for sulphate ions to maintain the locally determined NBL (Semjonovs, 2016), which will ensure stricter monitoring of groundwater quality;
- for COD and electrical conductivity to maintain the locally determined NBLs (Semjonovs, 2016), as these are currently the best available NBLs data for the study area and will ensure stricter monitoring of groundwater quality.

- **TVs**:
  - for synthetic parameters (TCE+PCE, BTEX, trichloromethane, 1,2-dichloroethane and synthetic surfactants) the TV should be calculated according to the BRIDGE methodology (Müller et al., 2006) (1) using the reference values set in Cabinet Regulation No.118 of March 12, 2002 "Regulations Regarding the Quality of Surface Waters and Groundwaters" (TCE+PCE - 0.01 mg/l, BTEX - 10 µg/l, trichloromethane - 2.5 µg/l, synthetic surfactants – 200 µg/l) and the maximum permissible norm of Cabinet Regulation No.671 of November 14, 2017 "Mandatory Harmlessness and Quality Requirements for Drinking Water, and the Procedures for Monitoring and Control Thereof" (1,2-dichloroethane – 3 µg/l);
  - to maintain the locally determined COD TV (Semjonovs, 2016), as this is currently the best available TV data for the study area and will ensure stricter monitoring of groundwater quality, as well as close to the COD target value in Annex 10 of Cabinet Regulation No.118 of March 12, 2002 "Regulations Regarding the Quality of Surface Waters and Groundwaters" (40 µg/l) to assess the status of groundwater;
  - to calculate the TV for sulphate ions and electrical conductivity according to the BRIDGE methodology (Müller et al., 2006) using the reference value set in Cabinet Regulation No.118 of March 12, 2002 "Regulations Regarding the Quality of Surface Waters and Groundwaters" (for sulphate ions – 250 mg/l, electrical conductivity – 2500 mS/cm);
  - for As, Cd and Pb as TVs to adopt the corresponding TVs of the catchment area of the GWB at risk, which is GWB A8 (Retiķe un Bikše, 2019), without separating aerobic and anaerobic waters, respectively.

Within the framework of the new study (LVĢMC, 2019), the NBLs and TVs were initially specified within the existing list as described above, but in the second step, the validation of the inclusion of the recommended parameters in the list was performed based on the latest monitoring results. Following the GWD, TVs should be set for all substances that characterize GWBs as being at risk. Accordingly, if a parameter is not identified during the monitoring, it can be removed from the list, but if a parameter is identified during the monitoring (or based on some other new practical or theoretical knowledge) is not yet included in the list, it can be included in it. The aim of this specific study was not to find new pollutants and include them in the list but to confirm the list of existing ones. The study analyzed the results of research monitoring carried out in 2019, as well as the monitoring data set provided by the State Environmental Service, which was collected within the framework of remediation, works for the study area (2015-2019) (LVĢMC, 2019).

From the performed analysis it was possible to conclude that the indicators (LVĢMC, 2019):

- COD, sulfate ions, synthetic surfactants, electrical conductivity, TCE+PCE, BTEX, As, Cd, and Pb should be retained in the list of risk indicators for GWB at risk A11; although not all of these indicators have been exceeded, such as electrical conductivity, As, Cd and Pb, these indicators are easy to identify, relatively inexpensive and provide additional information for a more detailed interpretation of the status of GWB at risk A11, or the amount of data still available is insufficient;
- trichloromethane and 1,2-dichloroethane may be removed from the list of pollutants;
- for electrical conductivity, set the TV the same as the NBL, as the proposed new TV does not allow to follow the evolution of pollution correctly (compared to other TVs). In order not to affect the monitoring options of GWB at risk A11, the electrical conductivity values for the Quaternary aquifer are currently too strict, but they should be reviewed in the future in the light of careful local analysis (electrical conductivity is not correct to determine at regional level) to avoid an absurd situation where only due to increased groundwater mineralization GWB is in poor status.

The revised NBLs and TVs for GWB at risk A11 are given in Annex 3.

1.4. Groundwater associated aquatic ecosystem identification and assessment in Estonia

In Estonia a preliminary methodology for the identification and assessment of aquatic ecosystems associated with GWBs was developed in 2015 (Terasmaa et al., 2015). The methodology for identification differs significantly for standing and flowing water bodies. There is some variation in the methodology for assessing the potential negative effect of GWBs on standing and flowing water bodies as well. Only existing databases and studies were used, no new data was collected (Terasmaa et al., 2015).

1.4.1. Identification of significant groundwater bodies associated with standing water bodies

Most lakes in Estonia can be considered as associated with groundwater. Exceptions include bog and coastal lakes and lakes with considerable surface water throughflow. Therefore, the main task to be solved was to select the criteria for distinguishing significant and nonsignificant groundwater associated standing water bodies and to relate them to the contributing GWB (Terasmaa et al., 2015).

Three groups of lakes were considered as significant (Terasmaa et al., 2015):

- *Lakes in the Book of Primeval Nature*. It is a national database of inanimate natural features that was compiled in the 1980s and 1990s. According to its statute, only lakes associated with groundwater, including karst lakes, were included in it. Therefore all the lakes in that database were considered to be significant GAAEs. Though, often there is no indication in the database, whether the lake is feeding on the Quaternary aquifer or the bedrock aquifer beneath it. Therefore it was difficult to decide (without any fieldwork) whether to associate lakes situated in areas with a thicker overburden, but no Quaternary GWB, with the bedrock GWB or consider them not associated with any GWB at all. In questionable cases, the likeliness of being associated with bedrock GWBs was evaluated using the geological profiles and groundwater heads of nearby wells and boreholes in the Environmental Registry. If the lakes were situated on a Quaternary GWB, then they were automatically considered being associated with it.
- *Water bodies (according to the WFD)*. These lakes are those whose status is reported to the EU and are significant for that reason. Several water-body-lakes overlapped with the ones in the Book of Primeval Nature. For the others, the potential association with bedrock GWBs was estimated based on expert decisions according to groundwater head around the lakes. If the groundwater head of the uppermost bedrock GWB was deeper than the bottom of the lake, then the lake was considered not to be associated with the GWB. Lakes situated on a Quaternary aquifer were treated similarly to the lakes in the Book of Primeval Nature. Lakes with dark and soft water (water type IV according to Estonian classification) and coastal lakes (water type VIII) were automatically considered not associated with groundwater.
- *Lakes are listed as habitats according to the Habitats Directive*. The association with GWBs of lakes that were designated to belong to a habitat type according to Annex I of the Habitats Directive, and were not included in the previous two groups of lakes, was evaluated only if they were situated on Quaternary GWBs or formed lake districts under protection. Otherwise, the number of significant lakes would have grown too large. All these lakes situated on Quaternary GWBs were considered associated with the Quaternary GWB. Only lakes belonging to the habitat type 3160 - Natural dystrophic lakes and ponds, were excluded. In the case of protected lake districts that were not situated on Quaternary GWBs, the potential dependence on bedrock GWBs was evaluated as for the lakes in the previous groups.

The association with GWBs was performed based on the assumption that the lakes are associated with the uppermost GWB or not associated at all. All lakes on Quaternary GWBs were considered associated with these GWBs because the interaction of lakes with the sediments surrounding them is most likely. For lakes associated with a Quaternary GWB, the potential association with the bedrock GWB beneath it was evaluated as well (Terasmaa et al., 2015).

Karst lakes were included in the list of significant groundwater-body associated lakes according to the Book of Primeval Nature only. No karst lake has been listed as a water body according to the WFD. There are karst lakes in Estonia that have been assigned the habitat type 3180 – Turloughs, according to Annex I of the Habitats Directive, though. But the number of such objects is very small, they are geographically unevenly distributed and do not represent the actual number and distribution of karst lakes in Estonia. Therefore it was decided that this dataset is not considered in the identification process of significant GAAEs (Terasmaa et al., 2015).

1.4.2. Identification of significant groundwater bodies associated with flowing water bodies

The association of flowing water bodies with groundwater is best identifiable in the presence of springs. Springs feeding flowing water bodies are visually easier to identify, than springs feeding standing water bodies, therefore their presence is the best usable indicator of association with groundwater in the former case if no other data is available. It must be considered, though, that, as in lakes, groundwater may seep into rivers and streams also through the bottom in a diffuse way and that is not detectable using only the data on spring locations (Terasmaa et al., 2015).

It was decided that the full list of flowing water bodies that will be evaluated in terms of association with groundwater (i.e. significant rivers and streams) will contain all flowing water bodies delineated according to the WFD. At the time of performing the analysis, there were 644 WFD flowing water bodies in Estonia. It must be noted that one hydrologic flowing water body usually contains several WFD flowing water bodies. The association with GWBs was evaluated for each of the WFD flowing water bodies, excluding the ones with dark water (water type A). There were some exceptions in the rule in the cases where it was evident according to expert knowledge that the water type had been assigned erroneously (Terasmaa et al., 2015).

The association was determined using spatial analysis: dependence on groundwater was assumed if there were springs present in a 1 km radius of the water bodies. Some water bodies were excluded afterward, where, according to expert opinion, groundwater contribution from the spring(s) was insignificant. The resultant water bodies were associated with the topmost GWB beneath the water body (Terasmaa et al., 2015).

There is historical information on the share of groundwater in annual discharge at selected locations for the largest rivers in Estonia, but the data is more than 50 years old. Therefore that could not be taken as the criteria for the selection. According to Hinsby et al. (2015), critical dependence on groundwater means that groundwater should be the dominant source of water (> 50%) in a stream or river. Therefore the Estonian selection is most probably overestimated, as the presence of springs does not guarantee that the origin of most of the water in the water body is groundwater (Terasmaa et al., 2015).

1.4.3. Assessment of quantitative and qualitative effects of GWBs on GAAEs

According to the WFD, criteria have to be set for GAAEs to evaluate the effect of GWB on the ecosystem. To maintain favorable ecological status, GAAEs need to maintain groundwater discharge. If a GAAE is in an unfavorable ecological status and is caused by the pressures on GWBs, then it affects the status of the whole GWB (Terasmaa et al., 2015).

GWB can have a negative *quantitative* and/or *qualitative effect* on the GAAE (Terasmaa et al., 2015):

- *quantitative effect*: human influence has lowered groundwater levels so that the GWB does not provide enough water to sustain the GAAE in its natural state;
- *qualitative effect*: human influence has affected the GWB in such a way that its chemical composition causes the deterioration of the ecological value of the GAAE.

For *standing water bodies* the best criteria for assessing whether there could be a negative *quantitative effect* of the associated GWB to the SWB are (Terasmaa et al., 2015):

1) the annual average water level of the lake compared to some fixed water level. In some European countries the minimal ecologically acceptable water levels for standing water bodies have been set (Craig & Daly, 2010; The River Basin..., 2010) and their annual average water levels can be compared to these. If the ecologically acceptable minimal water levels have not been set, then the long-term average water level of the standing water body or a natural average water level, determined from various historical data, can be used.
2) the annual average water level of the GWB upstream (or occasionally also downstream) of the GAAE, compared to the long-term average. A sufficient period to consider water level data long-term is six years according to the principles used in the EU. If the data series is not as long, then it is reasonable to use shorter time series.

For *flowing water bodies* the best criteria for assessing whether there could be a negative *quantitative effect* of the GWB to the SWB are (Terasmaa et al., 2015):

1) The annual average discharge of the river/stream compared to some fixed discharge. The most convenient piece of data to use would be environmental flows or e-flows. If these have not been determined, then long-term average discharge data can be used.
2) The annual average water level of the GWB upstream (or occasionally also downstream) of the GAAE or the annual average discharge of the largest springs feeding the SWB, compared to the long-term average. The most direct way of evaluating potential changes in the hydrodynamics of the GWB would be using spring discharge data, but if that is not available, then the groundwater levels will suffice. As for standing water bodies, the reasonable period to consider water level data long-term is six years according to the principles used in the EU.

Criteria for assessing the potential negative qualitative effect of the associated GWB are the same for standing and flowing water bodies (Terasmaa et al., 2015):

1) the ecological and chemical status of the SWB. The substances and thresholds for determining the favorable or unfavorable status of SWBs have been set in Estonia by a regulation of the minister of the environment. These include total nitrogen, total phosphorus, and several harmful chemical substances.
2) the level of the substances used for assessing the status of the SWB in the associated GWB, measured from groundwater well upstream of the GAAE or from the largest springs in case of flowing water bodies. The dilution factor applied for the thresholds in the GWB could be set as 0,5, if the specific groundwater contribution to the assessed SWB is unknown. It is a relatively mild dilution factor, which assumes that groundwater does not contribute more than 50% of the water in the GAAE.

It is not possible to develop a simplistic and universal evaluation scheme that gives a high-reliability answer without the acquisition of additional data. Therefore, the developed assessment schemes enable to pinpoint the ecosystems for which the effect of GWB cannot be ruled out as the cause for the unfavorable status. In these cases, more thorough studies have to be performed to determine the actual effect of the GWB, the size of the effect, and suitable mitigation measures (Terasmaa et al., 2015).

The assessment scheme for the potential ***quantitative effect* of** a GWB on ***standing water GAAEs*** consists of the following steps (FIGURE 1.4.3.1):

1) GAAEs depending on the evaluated GWB have to be determined;
2) The annual average water level of the GAAE has to be compared to the minimal ecologically acceptable water level or, if that is unavailable, natural average water level, determined from various historical data.; if the annual average water level is lower than the threshold level, then the GAAE moves to the next step.
3) The water level of water bodies could drop below the average level also because of changes in the climatic conditions or surface water regime - the prerequisite for the changes caused by groundwater is that there is sufficiently intensive groundwater abstraction sufficiently close to the water body; as the size of depression cone depends on the properties of the aquifer, intensity and time since commencing the pumping and depth of the wells, it is impossible to give a universal radius of threat. For the evaluation scheme, the following solution is proposed: if in a 10 km radius of the GDTE at least 1000 m3/d of groundwater is abstracted, then the effect of abstraction on the water level drop in the ecosystem cannot be ruled out. The limits are rather conservative to assure that no potential cause of the negative effect is ruled out in this step.
4) The next step is to assess if the annual average groundwater level in the aquifer feeding the GAAE is lower than its long-term average (6 years) water level; a groundwater level drop in the recharge area of the GAAE will likely cause a drop in the amount of water reaching the ecosystem. On the other hand, a drop in the groundwater level downstream of the GAAE could cause an increase in the amount of water seeping out from the ecosystem. In both cases, a drop in the ecosystem's water level will probably follow.
5) If the assessment shows that the water levels in the ecosystem and in the groundwater aquifer that the ecosystem depends on are lower than they should be, and groundwater abstraction is taking place in the vicinity, then the groundwater level drop may be caused by the abstraction. To

prove or deny it, a thorough field-work based investigation should be carried out, to determine the functional connections between the GAAE and the GWB, and to clarify whether the water level drop in the SWB is caused by groundwater abstraction and a decrease of the water level in the GWB.

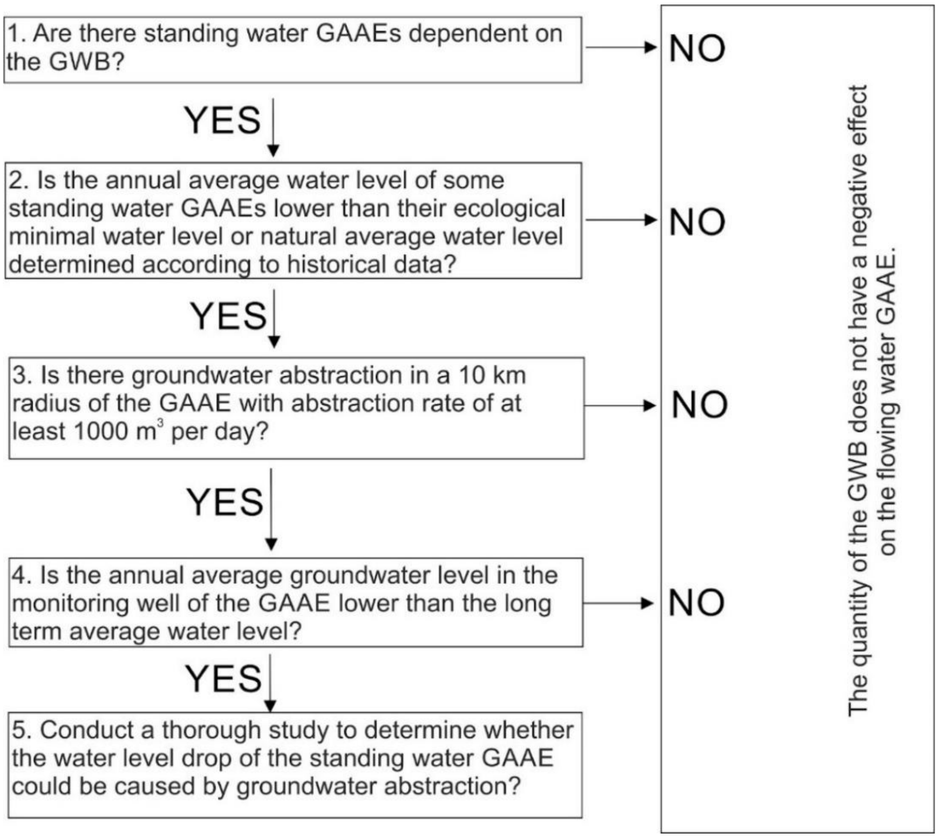


FIGURE 1.4.3.1 **Assessment scheme for the quantitative effect of a GWB on GAAEs (standing water bodies)** (Terasmaa et al., 2015)

The assessment scheme of a potential negative ***quantitative effect*** of associated GWB to ***flowing water GAAEs*** differs slightly from the assessment scheme for standing water GAAEs in steps 2 and 4 (FIGURE 1.4.3.2):

- for flowing water GAAEs the indicator for potential negative effect is the annual average discharge, which has to be compared to the environmental flow levels or if that is unavailable, long-term (6 years) average discharge; if the annual average discharge is lower than the threshold level, then the GAAE moves to the next step.
- Instead of evaluating whether the groundwater level in the GAAE monitoring well is lower than its long-term (6 years) average, the annual average spring discharge could be compared to long-term (6 years) average spring discharge, if that data is available. Changes in spring discharge indicate changes in the hydrodynamics of the feeding aquifer concerning the associated SWB more directly than the groundwater level.

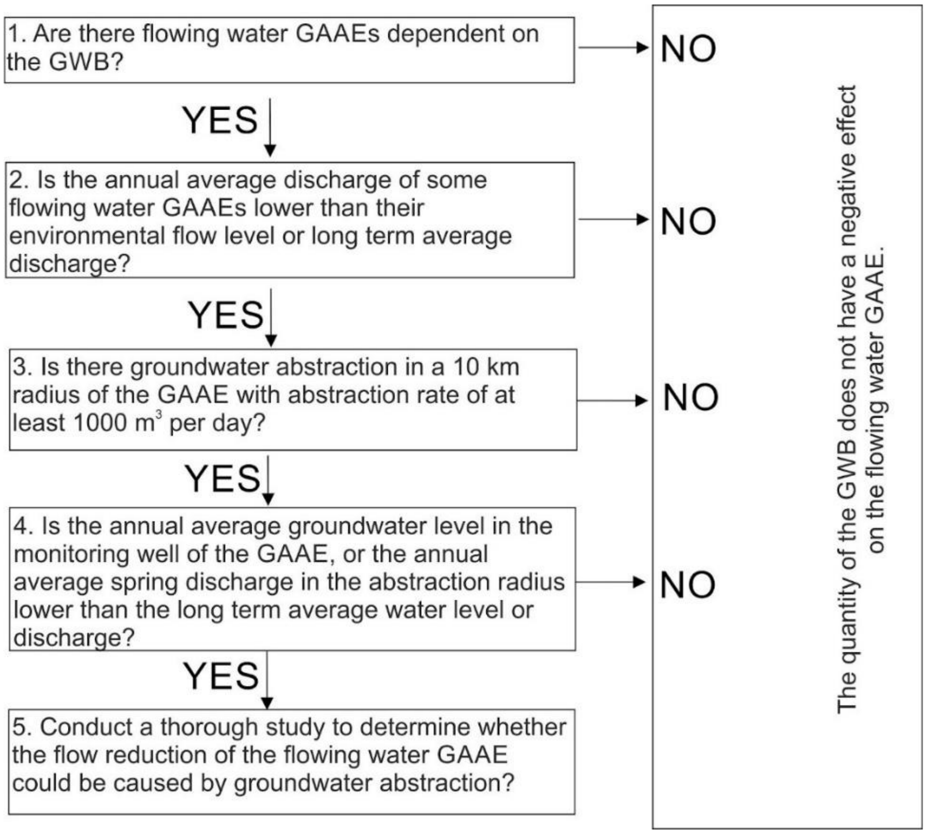


FIGURE 1.4.3.2 **Assessment scheme for the quantitative effect of a GWB on GAAEs (flowing water bodies)** (Terasmaa et al., 2015)

The assessment scheme for the potential ***qualitative effect*** of a GWB on ***GAAEs*** consists of the following steps (FIGURE 1.4.3.3):

1) GAAEs depending on the evaluated GWB have to be determined.
2) If the ecological or chemical status of the SWB is at least good, then the associated GWB cannot have harmed it. Therefore only these SWBs whose status is worse than good move to the next step.
3) In this step, these SWBs can be excluded whose ecological status is unfavorable, but the concentrations of the chemical indicators that may be potentially affected by groundwater (Ntot, Ptot, some other harmful chemical substance) correspond to good or very good status. In this case, the unfavorable status of the SWB is caused by factors irrelative to the groundwater quality.
4) If the unfavorable status of a SWB is at least partially caused by the elevated levels of Ntot and Ptot or some harmful chemical substance, it is necessary to evaluate if the status may be affected by point-source pollutants. If there are known point-source pollutants discharging into the SWB then the negative effect of groundwater may be ruled out until the elimination of the point-source pollutant. In reality, both point-source and diffuse pollution (incl. groundwater) often affect a SWB simultaneously, but in order to simplify the assessment, it is assumed in the scheme that the negative effect of point-source pollutants is more significant, as they are easier to pinpoint and verify.
5) If the groundwater quality could not be ruled out as the cause for the unfavorable status of the SWB in the previous steps, then the groundwater quality itself has to be evaluated. Adequate results can be obtained only if the surface water quality indicators are measured from the groundwater as well. In this case, a direct comparison can be made. Groundwater samples have to be taken from the wells of the associated GWB and associated aquifer situated in the recharge area of the SWB. In the case of flowing water GAAEs, it is preferable to take the samples directly from the largest springs feeding the water body, as spring water describes the quality of groundwater, actually reaching the river or stream most precisely. The negative qualitative effect of the associated GWB may be ruled out if the concentration of the unwanted substance in

groundwater is not higher than double the threshold for that SWB. The latter nuance takes into account the likely possibility that the evaluated GWB is not the sole source of water in the SWB. If the actual average share of groundwater in the annual water budget of the SWB is known, then that dilution factor may be modified accordingly.

6) For GAAEs to which the impact of groundwater cannot be ruled out as the cause for the unfavorable status, a thorough field-work based investigation should be carried out, to determine the functional connections between the GAAE and the GWB, and to clarify whether the unfavorable status is caused by groundwater quality and to offer potential measures for mitigation.

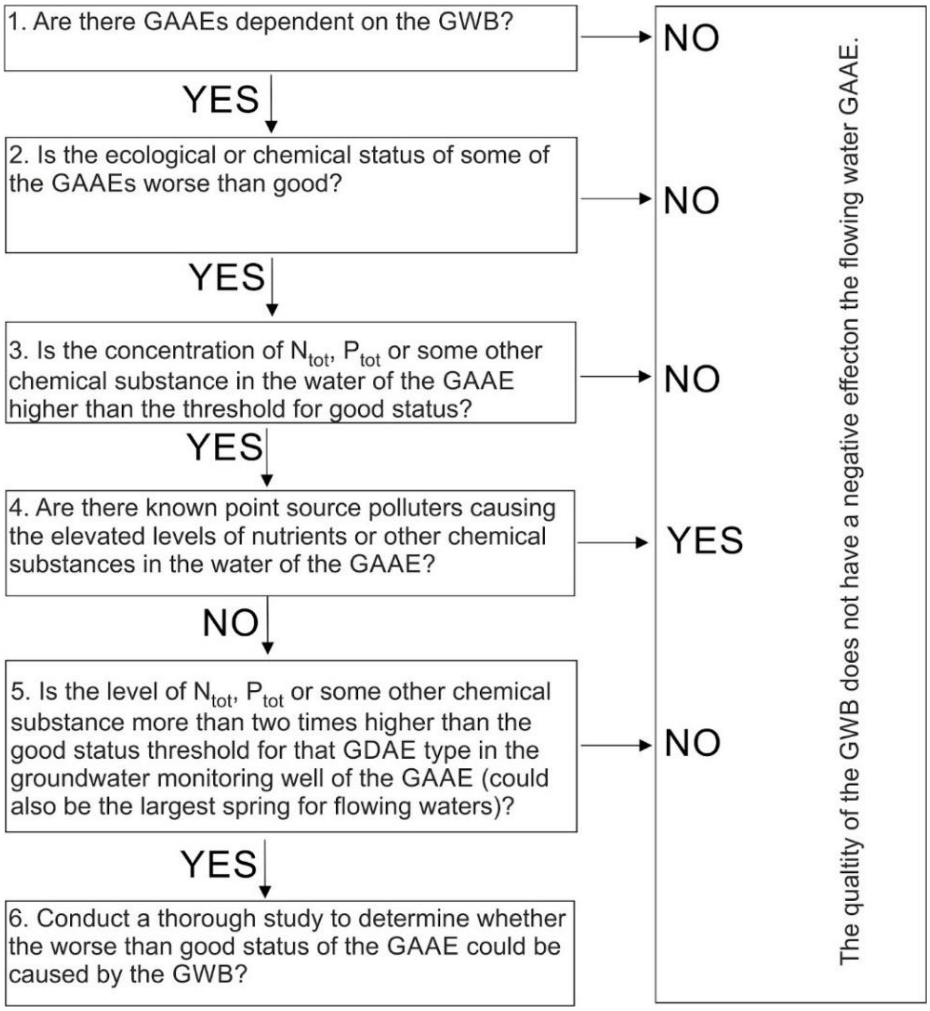


FIGURE 1.4.3.3 **Assessment scheme for the qualitative effect of a GWB on GAAEs** (Terasmaa et al., 2015)

1.5. Groundwater vulnerability assessment to nitrates pollution

Council Directive 91/676/EEC (the Nitrates Directive) aims to reduce water pollution caused by nitrates from agricultural sources and to prevent further such pollution. The Nitrates Directive forms an integral part of the WFD and is one of the key instruments in the protection of waters against agricultural pressures. The Nitrates Directive sets a number of steps to be fulfilled by MS (EC, 2018):

- water monitoring of all water body types with regard to nitrate concentrations and trophic status;
- identification of waters that are polluted or at risk of pollution, on the basis of the criteria defined in Annex I to the Nitrates Directive;
- designation of nitrate vulnerable zones, which are areas that drain into waters and which contribute to pollution;
- establishment of codes of good agricultural practices, implemented on a voluntary basis throughout the MS territory;

- establishment of action programs, which include a set of measures to prevent and reduce water pollution by nitrates and are implemented on an obligatory basis within designated nitrates vulnerable zones or throughout the entire national territory;
- review and possible revision of the designation of nitrate vulnerable zones and of action programs at least every four years;
- submission to the Commission of a progress report on the implementation of the Nitrate Directive every four years with information on codes of good agricultural practice, nitrate vulnerable zones, water monitoring results, relevant aspects of action programs.

1.5.1. Groundwater vulnerability assessment to nitrates pollution in Estonia

The Nitrate vulnerable zone in Estonia is located in the central part of Estonia and this area coincides with high vulnerability of groundwater (in this region, mostly limestones and karst areas are common with unprotected groundwaters). About one fifth of the area is unprotected and the Northern Pandivere part is also an important groundwater supply area for the whole country. On the other side, there are one of the most fertile soils in the country, which promotes agricultural activity in this area. This results with a nitrogen pressure, which is uneven, depending on the groundwater vulnerability, usage of land and livestock units in certain areas (FIGURE 1.5.1.1).

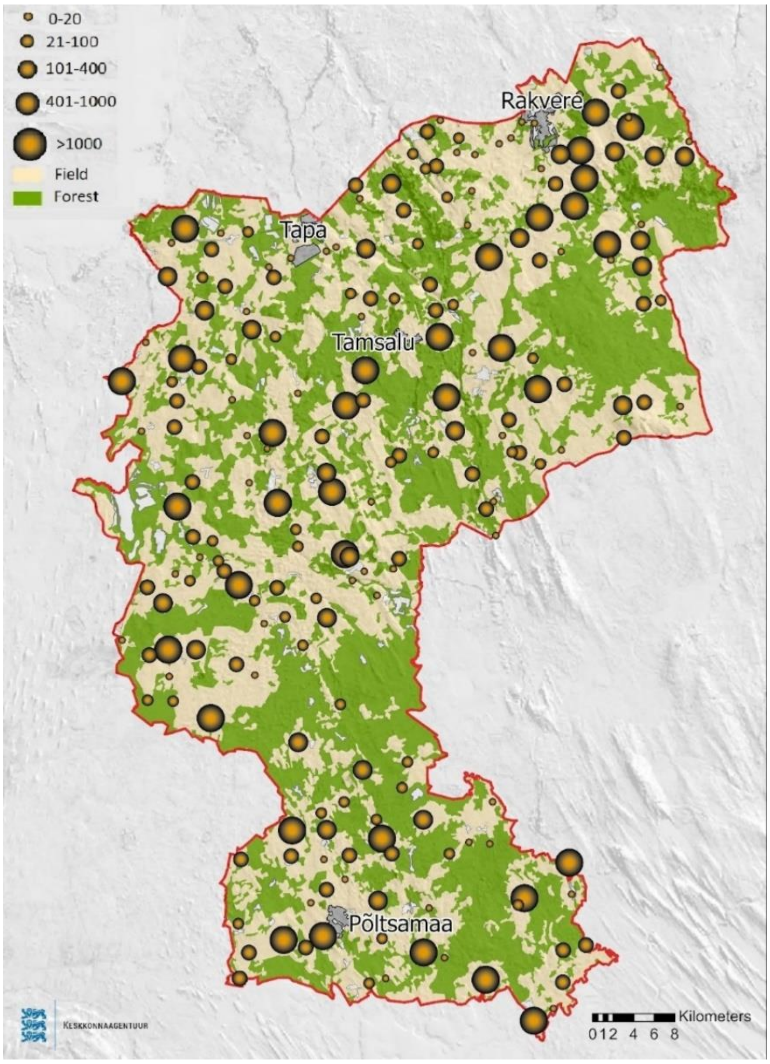


FIGURE 1.5.1.1 **Nitrate vulnerable zone in Estonia** (land is used a lot for fields (yellow area) and livestock units (brown dots))

In Estonia, the main task of groundwater monitoring in the Nitrate vulnerable zone is to assess the impact of nitrogen pollution from agriculture and to explain changes in the concentrations of nitrogen compounds at different depth intervals and sources, and to assess the impact of other pollution from agricultural activities.

Groundwater monitoring consists of 93 observation wells, 29 springs, and 2 karst stations. Most of the stations are located in the nitrate vulnerable zone, but some are located outside the area, but still are influenced by agricultural pressure. Monitoring stations observe different depths of groundwater (TABLE 1.5.1.1). Monitoring frequency varies from four times per year to once in four years. Sampling is based on the Estonian Environmental Monitoring Act, the Water Act, and Regulation No.30 of the Minister of the Environment of May 6, 2002 "Sampling Methods".

TABLE 1.5.1.1

Depths of monitoring stations

Depth/station type	Number of monitoring stations	Ratio (%)
≤ 5 m*	29	23.4
5-15 m	13	10.5
15-30 m	67	54.0
> 30 m	13	10.5
Karst	2	1.6

*Springs are considered as 0 meters as the actual depth is not known

The results below are provided considering guidelines of the Nitrate Directive, where nitrate average and maximum concentrations, as well as growth trends, are calculated for the data monitored between 2016 and 2019.

The Northern Pandivere area has fewer monitoring sites with high nitrate contents than in the southern Adavere-Põltsamaa region due to hydrogeological conditions - Pandivere region is affected by groundwater movement, the spread of agricultural pressures and karst processes are widespread in this area. While in the Pandivere region the maximum nitrate content exceeded 50 mg/l at 28% MPs, in the Adavere-Põltsamaa region exceedances were 39%. The average nitrate concentration during the period exceeded 50 mg/l at one Pandivere MP, Adavere had 16% of such monitoring sites.

Compared to the previous period in 2012-2015, the share of MPs in 2016-2019 with the highest NO_3^- concentrations in Pandivere has increased by almost half, but in the Adavere- Põltsama region has decreased by 17%. Average nitrate concentrations, which exceed 50 mg/l have been the same in the Pandivere region and have decreased about a quarter in the Adavere-Põltsamaa region. Looking at the vertical variability of nitrate content in groundwater in both Pandivere and Adavere-Põltsamaa regions at depths of 0 to 5 m and in 5-15 m wells/springs, the average nitrate content is in the range of 22-25 mg/l. As the depth increases (> 30 m), the average NO_3^- content increases to 28 mg/l. This means that nitrate pollution is quickly washed away by rainwater into deeper aquifers. An important part of nitrate reaching deeper water layers is during snow-poor winters, which have been more common in Estonia in recent periods. In the last two years, there has been almost no snow cover during the winter, but precipitation in the rain quickly washes the nitrate into deeper layers. This is also reflected in higher NO_3^- values in winter groundwater samples.

The increase in groundwater nitrogen in Pandivere is due to more intensive tillage and higher rainfall in the last reporting period. The number of animals has not changed significantly, but the herd has been concentrated in larger and larger barns. It is not possible to compile a long-term time series of all wells and springs, because the monitoring stations have often changed and new wells have been built in the area, so the old wells that have been monitored have been liquidated or are no longer in use.

1.5.2.Groundwater vulnerability assessment to nitrates pollution in Latvia

In Latvia, the Nitrate vulnerable zone is located in the central part of the country, and it is not delineated by the results of a specific study; it is delineated by administrative boundaries, superficially taking into account the spread of agricultural land and excluding the largest cities (Rīga and Jelgava) (FIGURE 1.5.2.1). Nitrate groundwater monitoring is provided both inside and outside the Nitrate vulnerable zone, as the main objective of nitrate monitoring is to detect any nitrate pollution to ensure good drinking water quality throughout the country, as well as to reduce the impact of nitrate pollution on small and large rivers whose waters flow into the Baltic Sea (VARAM, 2020).

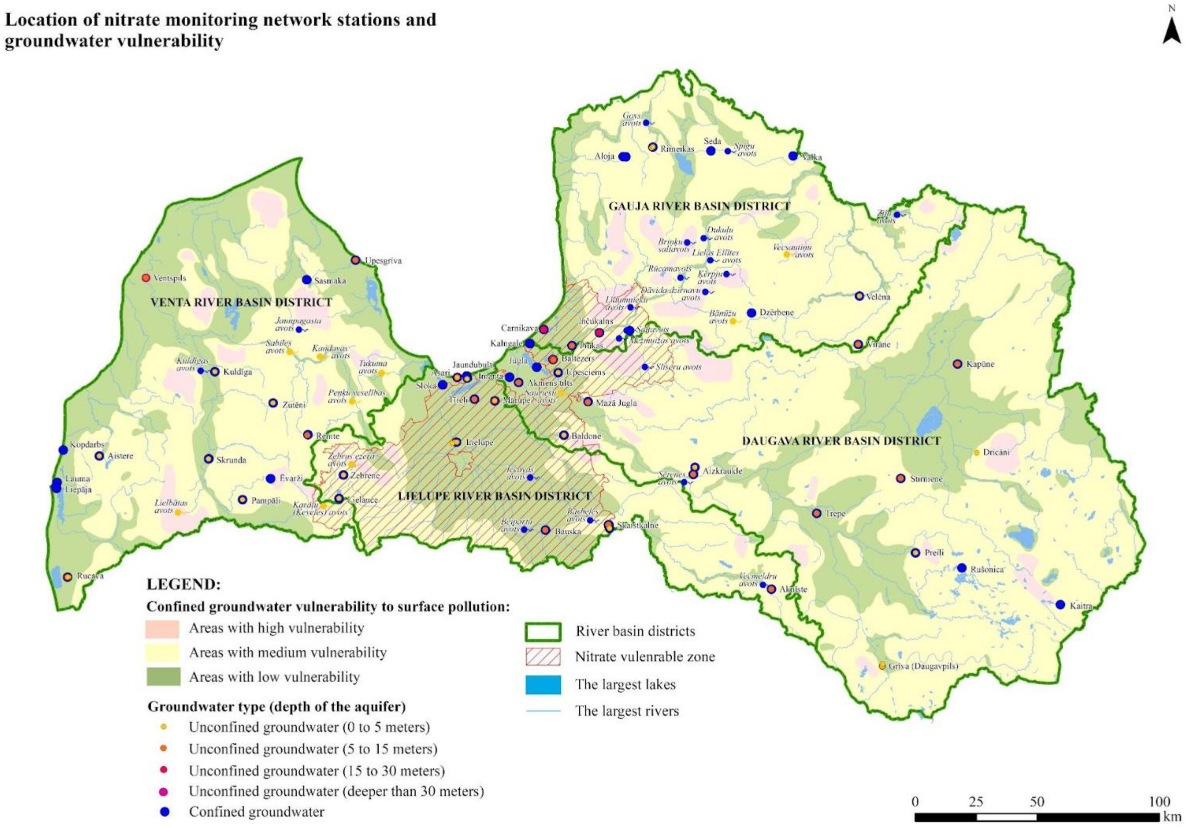


FIGURE 1.5.2.1 **Location of nitrate vulnerable zone and nitrate groundwater monitoring network stations in Latvia concerning confined groundwater vulnerability** (VARAM, 2020)

Nitrate groundwater monitoring is provided by the National Monitoring Network, which carries out surveillance and operational groundwater monitoring in 53 monitoring stations with 218 wells and 30 springs, focusing mainly on groundwater aquifers that are mainly exploited for drinking water abstraction (FIGURE 1.5.2.1). Therefore, the existing National Monitoring Network is not optimal for assessing the impact of agricultural pollution on groundwater, as most MPs (70%) are located in confined aquifers, but only 17% of MPs are installed in the most vulnerable, shallow groundwater (groundwater depth up to 5 m). Similarly, the number of observation points in the nitrate vulnerable zone, especially in the south and south-west, is too low (VARAM, 2020).

There are 85 MPs of the National Monitoring Network directly inside the nitrate vulnerable zone, of which there are 10 springs and 18 are monitoring stations with a total of 75 wells (FIGURE 1.5.2.1). As well as 5 monitoring stations with 17 wells, for which additional monitoring has been performed. Inside the Nitrate vulnerable zone, 54% of all monitoring wells represent confined aquifers and only 24% of all monitoring wells represent shallow groundwater up to 5 m, which is more exposed to nitrate pollution (VARAM, 2020).

The groundwater monitoring program during the relevant periods is being gradually adapted to the requirements of the Nitrates Directive, for example (VARAM, 2020):

1) improving the number of observation wells in the National Monitoring Network inside the nitrate vulnerable zone;
2) extending agricultural runoff monitoring network;
3) related research projects and studies are also being continued, for example, the recently implemented project by the University of Latvia “New data on nitrate loads on groundwater in standard sediments in Latvia” and the study “Assessment of seasonal changes in spring water chemistry for national groundwater monitoring optimization in Latvia”.

The need for nitrate monitoring is mainly determined by the Nitrates Directive and Cabinet Regulation No.834 "Requirements Regarding the Protection of Water, Soil and Air from Pollution Caused by Agricultural Activity" (adopted in October 9, 2018). These regulations determine the nitrate vulnerable zone and the procedure for its management.

Nitrate monitoring in the country is ensured mainly by the MPs in the National Monitoring Network within the framework of surveillance and operational monitoring. The frequency of water sampling at MPs depends on the degree of protection of the monitoring and the observed nitrate concentrations at the MPs, as well as on the seasonality of the MPs. Accordingly, in shallow wells and springs, which are poorly protected from pollution and where nitrate concentrations are found above 25 mg/l, the sampling frequency increases to 1 to 4 times a year, while in deeper wells (confined aquifer) with a very good degree of protection decreases to 1 time in 6 years (VARAM, 2020).

Well pumping, sampling, storage, transportation, standardized methods used for testing samples for water status analysis and monitoring are following the procedure provided for in Article 8, Paragraph 3 of the WFD, as well as taking into account the essential requirements of EC Guidance Document No.15. Most of the analysis is performed by Latvian Environment, Geology and Meteorology Center accredited laboratory following the requirements of LVS EN ISO/IEC 17025 standard. Sampling is guided by current international standards; sampling techniques are based on ISO 5667 series of standards: (1) ISO 5667-11 Water quality - Sampling - Part 11: Guidance on groundwater sampling and (2) ISO 5667-14 Water quality - Sampling - Part 14: Guidance on quality assurance in water sampling and handling. During sampling, the oxygen content, electrical conductivity, temperature, pH, total iron, and oxidation-reduction potential of the groundwater are determined on-site in all MPs (wells and springs) (VARAM, 2020)

The frequency of water sampling at additional MPs provided is usually 4 times a year, in some years it decreases to 2-3 times a year. No information is available on the methods used for groundwater sampling and analysis, as monitoring is provided by another organization (VARAM, 2020).

The data obtained at the groundwater MPs of the national monitoring network are entered into the existing monitoring information system and can be viewed and downloaded by anyone. Following the requirements of the Nitrates Directive, the Nitrates Report is prepared once every 4 years. In 2020, the Nitrate report for the period from 2016 to 2019 was prepared. Nitrate pollution was mainly observed only in shallow MPs, which mainly characterize groundwater at depths up to 5-15 m. Nitrate concentrations in these wells range from 0.09 mg/l to 360 mg/l (for most samples it does not exceed 25 mg/l, in most cases it does not even reach 9 mg/l). In contrast, in groundwater deeper than 30 m and a confined aquifer, nitrate pollution has still not been detected and the average NO3- concentration has remained unchanged (NO_3^- value ranges from 0.09 mg/l to 1.5 mg/l) (VARAM, 2020).

The Nitrates Directive value (50 mg/l) was exceeded at only 9 MPs, of which 4 are national MPs and 5 are additional MPs. It should be noted that most of these exceedances are local, where rapid fluctuations in nitrate content have been noted in the past. In general, in the current reporting period, there is no significant increase in nitrate pollution of groundwater at the sampled MPs. And currently, there is no reason to predict that the NO_3^- concentration in groundwater in Latvia could increase in the next reporting period (VARAM, 2020).

1.6. Conceptual models of groundwater bodies

Even though various European guidance documents (EC, 2009) state that conceptual models must be used during the implementation of the WFD, there is no overall definition of the conceptual model in the WFD itself. Also, the GWD states the need of using the conceptual models as a basis for GWB assessment. The definition of conceptual model can be found from the Common Implementation Strategy (CIS) guidelines No.26 (EC, 2010) and is stated as follows: "*a conceptual model is a means of describing and optionally quantifying systems, processes and their interactions. A hydrogeological conceptual model describes and quantifies the relevant geological characteristics, flow conditions, hydrogeochemical and hydrobiological processes, anthropogenic activities and their interactions*".

All the conceptual models are created with specific aims. In regards to the WFD, the main topic is risk assessment in water management. But here, the risk assessment is not classical - it is rather an assessment of risk not to achieve the environmental objectives of the WFD, or in this case, the groundwater protection objectives:

- prevent or limit the input of pollutants;
- prevent the deterioration of the status of GWBs;
- achieve good groundwater status (both chemical and quantitative);

- implement measures to reverse any significant and sustained upward trend;
- meet the requirements of protected areas.

All the GWBs are unique - they all have specific features, e.g. different scales, objectives, pressures, etc. Thus, the conceptual model of each GWB is also unique and must be compiled considering specific features. A common approach, however, is proposed by the commission to ensure that all the conceptual models are comparable to some extent. Therefore the methodology of the Source-Pathway-Receptor (SPR) model is proposed in the CIS guidelines No.26 (EC, 2010). The same guidelines also give a thorough description of the conceptual model development process.

Conceptual models can be used for several purposes within the groundwater management cycle and specific tasks, e.g. understanding the significance of pressures, design of a monitoring network and interpreting monitoring data, evaluating the monitoring network, establishing TVs, status, and trend assessment, plan of measures and stakeholder involvement (EC, 2010).

According to guidelines No.26 (EC, 2010), four major aspects with specific actions are important during the set-up of a conceptual model. The first step includes the main characterization of the conceptual model: determination of the degree of detail and complexity of it, determination of the relevant area, the definition of vertical and horizontal structuring units (hydrogeological units), and land-use distribution. Only after that parameterization and quantification can be possible: description and quantification of important hydraulic, geochemical, and hydrochemical parameters (where possible and necessary), consideration of processes with slow kinetics (e.g. solution processes, unsaturated zone flow, changes in surface conditions, climate variations), description of the most important climatic and unsaturated zone parameters and identification of emerging issues that could pose a potential risk.

After taking into account two previously mentioned aspects, the conceptual model also must address the assessment of potential uncertainties, variability, and whether the available data are representative. It is advisable to start with a simple model, then analyze its performance and, by stepwise improvements, make a more complex conceptual model if the simpler model is not sufficient. It might be necessary to return to the previous steps if it turns out that the conceptual model is not consistent with actual data (EC, 2010).

It has to be kept in mind that the process of conceptual model set-up and maintenance is a cycling process that starts with a simple model set-up and then follows with data collection, analysis of data, and uncertainty assessment, and starts again with the refinement of the model. In the WFD water management cycle, it has to be done once in 6 years (EC, 2010).

1.6.1. Conceptual model development in Estonia

As a part of the water management cycle, the inventory of GWBs was performed and all the borders and conceptual models of all GWBs were reviewed in 2019 (Marandi et al., 2019). During the study, the number of GWBs in Estonia was changed, the review of pressures and receptors was performed, and the assessment of existing monitoring systems was given.

The reviewed conceptual models are composed of two main parts in Estonia (Marandi et al., 2019). The first part consists of natural features of the hydrology system (e.g., geology, hydrodynamics, natural background chemistry, groundwater vulnerability, GDTEs and GAAEs) while the other part is presenting the human activities in the area (e.g., groundwater use, point and diffuse sources of pollution).

All the data concerning the conceptual models are given in tables that have the same structure for each GWB (see Annex 4) to help the information-seeking process and also on the illustrative maps and cross-sections (examples of them given in FIGURE 1.6.1.1).

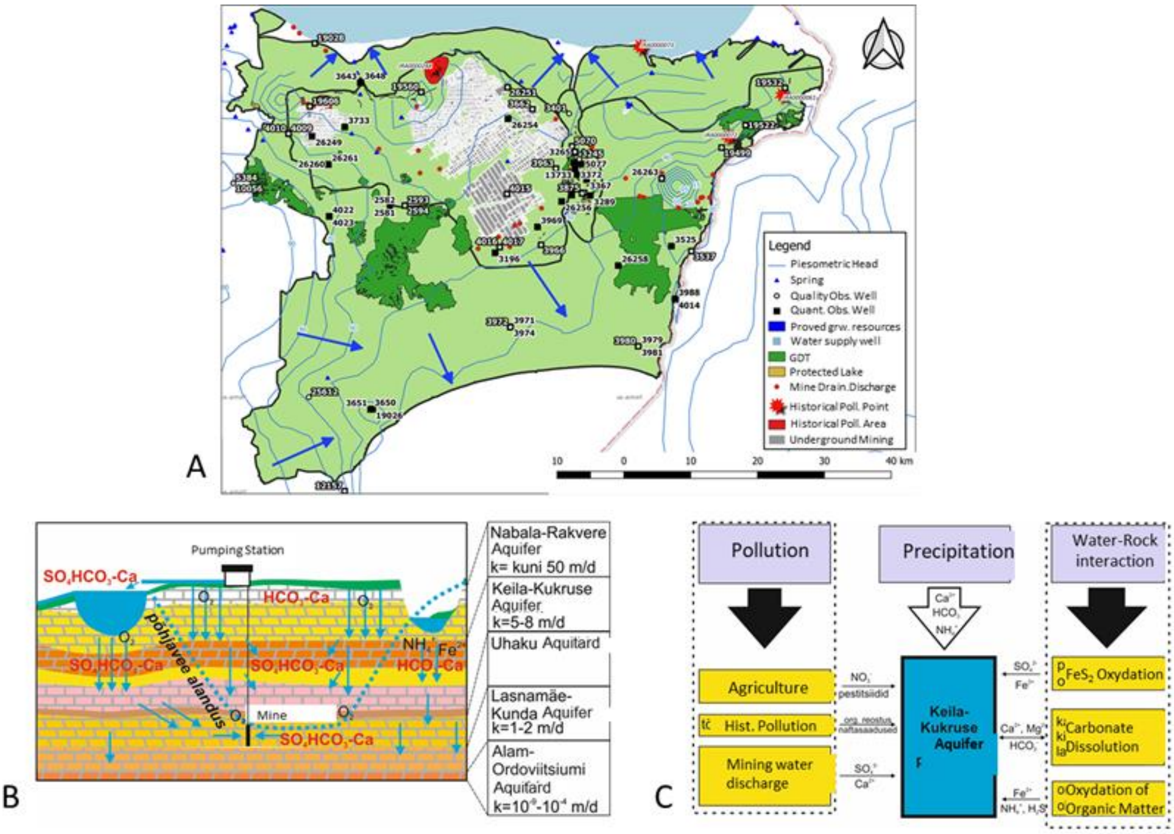


FIGURE 1.6.1.1 **Examples of the illustrative map (A), cross-section (B), and the conceptual diagram of the formation of water chemistry (C), which were made for each GWB separately** (Marandi et al., 2019)

1.6.2. Conceptual model development in Latvia

Similarly as in Estonia, the inventory of GWBs in Latvia was performed and all the borders and conceptual models of all GWBs were reviewed from 2018 to 2020 (Kārkliņa et al., 2020). After the inventory, the review was performed for all GWBs in Latvia.

The reviewed conceptual models (as same as in the case of Estonia) are composed of two main parts (Kārkliņa et al., 2020). The first part consists of natural features of the hydrology system (e.g. geology, hydrodynamics, groundwater vulnerability), while the other part is presenting the human activities in the area (e.g., land use, groundwater abstraction, monitoring network).

All the data concerning the conceptual models are given in tables that have the same structure for each GWB (see Annex 5) to help the information-seeking process and also on the illustrative maps and cross-sections (examples of them given in FIGURE 1.6.2.1).

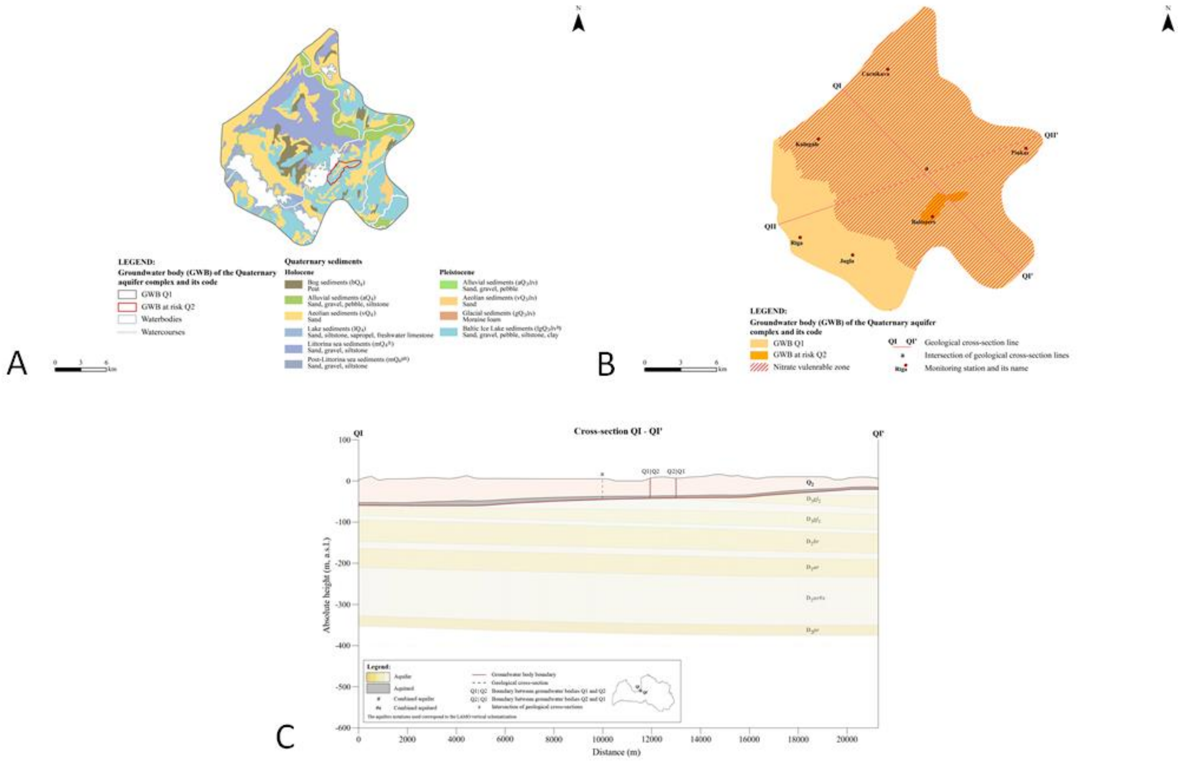


FIGURE 1.6.2.1 **Examples of geological sediment map (A), monitoring stations and geological cross-section's location map (B) and geological cross-section (C), which were made for each GWB separately**
(Kārkliņa et al., 2019)

1.7. Trend assessment

The trend assessment of pollutants is part of the GWB chemical status assessment procedure. The WFD and the GWD require the MS to identify any significant and sustained upward trend in concentrations of pollutants, groups of pollutants, or indicators of pollution found in GWBs or groups of bodies identified as being at risk (the WFD Annex V 2.4.4 and GWD Article 5). In Guidance Document No.18 on the Groundwater Status and Trend Assessment (EC, 2009) a significant and sustained upward trend is defined as "*any statistically and environmentally significant increase of concentration of a pollutant, group of pollutants, or indicator of pollution in groundwater for which trend reversal is identified as being necessary for accordance with Article 5*" (the GWD, Article 2(3)). This means that consideration of any significant increase of contaminants that poses risk to ecosystems, human health, and the use of groundwater is necessary. The occurrence of significant and sustained upward contaminant trends in monitoring data should be incorporated into the GWB chemical status assessment methodology as an assessment criterion.

1.7.1.Trend assessment in Estonia

In Estonia, the latest GWB status assessment with trend assessment based on monitoring data from 2014 to 2019 was performed in 2020 (Marandi et al., 2020). Significant and sustained upward trends were identified and reported according to the instructions from the CIS Guidance Document No.18 "Guidance on Groundwater status and Trend Assessment" (EC, 2009).

Trend plots over the full assessment period of 6 years (2014-2019) for all monitored contaminants in all monitoring stations were generated. Similar trend plots were generated for aggregated monitoring wells in all GWBs. For the generation of trend plots and p-values, the R software function lm() was used. Linear regression was calculated between the year and the mean value of the chemical parameter. An average value from the period of 2007 to 2009 was used as a baseline. The sustained upward trend was defined by a positive R-value. The trend was regarded to be statistically significant in cases when P-values were less than 0.05. The trend was regarded as environmentally significant in cases where the trend line was above 75% of the TV (FIGURE 1.7.1.1).

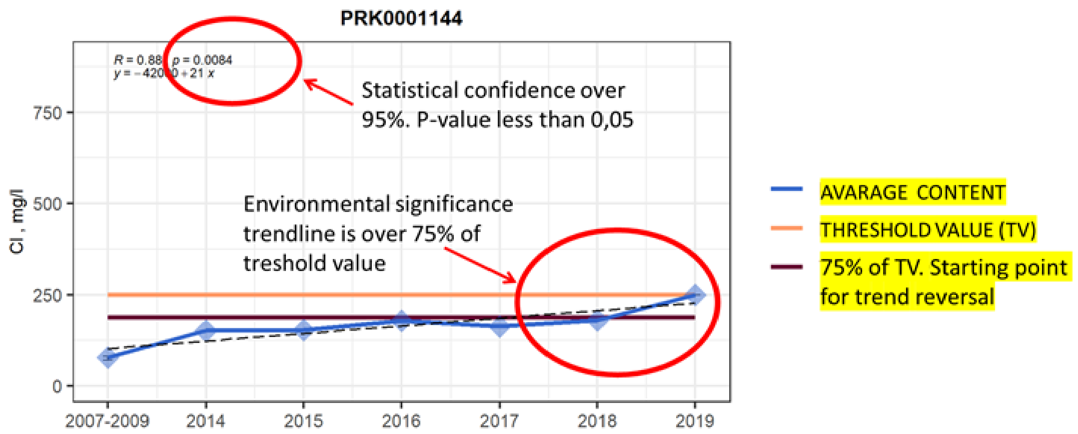
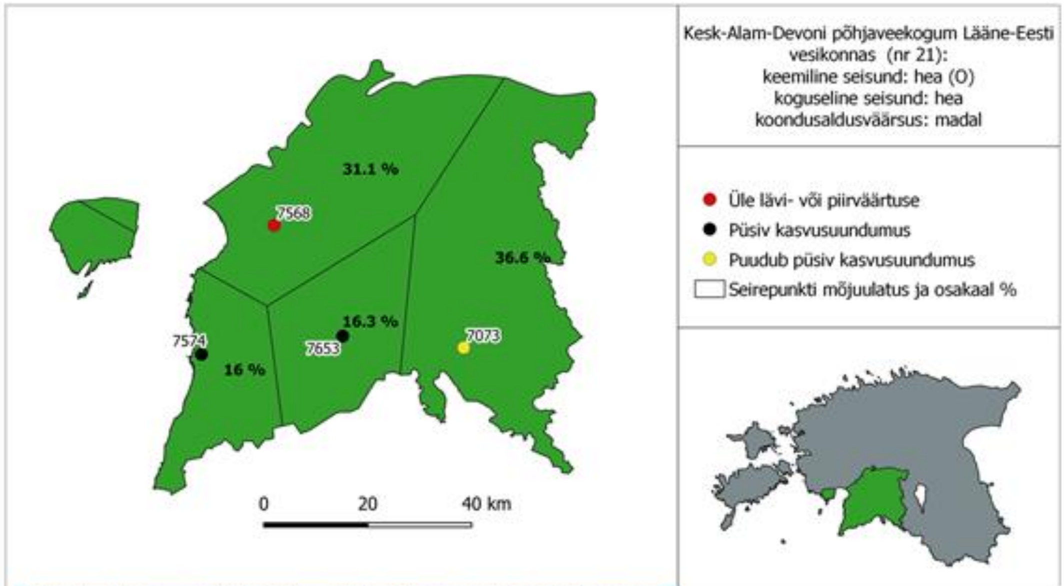


FIGURE 1.7.1.1 **Statistically and environmentally significant sustained upward chloride content trend in monitoring well no PRK0001144** (modified after Marandi et al., 2020)

The occurrence of significant and sustained upward trend in monitoring wells and in GWB as a whole were considered in GWB chemical status assessment tests “General quality assessment”, “Saline or other intrusions” and “Drinking water protected areas” as important assessment criteria (Marandi et al., 2020).

Reporting of the results is provided in Guidance Document No.18 “Guidance on Groundwater status and Trend Assessment” (EC, 2009) which states that all significant trends should be presented on the GWB map as black dots (in the case of Estonia, all monitoring wells with significant and sustained upward trends were plotted as black dots). The MPs that exceeded any monitoring period aggregated contaminant content were plotted as red dots and wells with no exceedances and significant trends were plotted as yellow dots (EC, 2009). FIGURE 1.7.1.2 illustrates which parameter in the monitoring well has exceeded the TV or has an upward trend.



KKR kood	Näitaja	Lähtetase	Keskm	LV/PV	Ühik	p-väärtus	Trend	Kasvusuundumus
PRK0007653	NH4	0.035	0.107	1.5	mg/l	0.018	0.035	püsiv
PRK0007574	Cl	124.1	270.167	Puudub	mg/l	0.001	16.335	püsiv
PRK0007568	PHT(KHTMn)	2.6	8.6	5	mgO/l	0.331	3.257	Üle PV

FIGURE 1.7.1.2 **Trend assessment results in GWB No.21** (monitoring wells with significant and sustained upward trends are plotted as black dots and the table below shows which parameter has an upward trend) (modified after Marandi et al., 2020)

1.7.2.Trend assessment in Latvia

In Latvia, the last GWB status assessment with trend assessment based on monitoring data from 2000 to 2019 was performed in 2021. To assess whether the chemical status of GWB tends to deteriorate, trend analysis was performed at MPs where TVs or GQS were already exceeded (LVĢMC, 2021).

Data and their pre-processing

For the trend analysis, data from 2000 to 2019 were used, if necessary, extending the period to the minimum number of observations required for analysis (6 samples), because not all MPs have the same sampling frequency (for some MPs, the number of observations during the whole sampling period was two to four measurements, therefore it was not possible to perform trend analysis. The annual average concentration for each parameter was calculated for each MP, as the sampling frequency in the monitoring network varies depending on the degree of protection of the aquifer and the rate of groundwater recharge. In shallow groundwater, seasonality can occur, so the sampling frequency can reach four times a year, while the passive groundwater exchange zone is characterized by slow changes and is representative of a sample taken from once a year to once every six years. Extremely high and/or low (i.e., outlier) parameter concentrations, based on expert judgment, were not used in the further analysis (LVĢMC, 2021).

Before trend analysis, data were evaluated for each sample using the ion balance equation (Güler et al., 2002):

$$Deviation\ (\%) = \frac{(\sum Cations - \sum Anions)}{(\sum Cations + \sum Anions)}$$

as a result, those samples with ion balance error of more than ±10% were selected and excluded from the dataset used for trend assessment (LVĢMC, 2021).

In cases where the concentration of a parameter in a sample was below the method detection limit (MDL) of the analytical method used, the results of such measurements were calculated as half of the relevant limit of quantification for the calculation of the arithmetic mean. For example, if the analytical result was reported as less than 0.1 µg/l, then this value was replaced with a value of 0.05 µg/l (LVĢMC, 2021).

Trend assessment

To evaluate the significance and evolution of the trend, regression analysis (*Data – Data Analysis – Regression*) was performed in an *MS Excel* environment and a graph (chart) with a trend line was created. To assess the significance of trends, R-squared (R^2) value, statistical significance (F value), and significance level (p-value) value (with 95% confidence level) were used. If the R^2 value was greater than 0.5 and closer to 1, then the selected dataset was considered to be suitable for regression analysis. To assess the reliability (statistical significance) of the results of the regression analysis, regression was considered statistically significant if the F-value was less than 0.05 and the p-value was less than 0.05 so that the obtained results could be considered statistically significant. Accordingly, if R^2 was > 0.5, but the F-value and p-value were < 0.05, then the identified trend was considered statistically significant. In contrast, if R^2 was < 0.5, but the F-value and p-value were > 0.05, then the identified trend was considered statistically insignificant (example given in TABLE 1.7.2.1).

TABLE 1.7.2.1

Example of identifying the significance of a trend (LVĢMC, 2021)

MP	R-squared (R^2)	F value	p-value	Significance
Akmens tilts, 3	0.644	0.0165	0.017	Significant
Iecavas avots, 920	0.245	0.1752	0.175	Insignificant

After obtaining the results of the regression analysis and evaluating the significance of the trend, a plot with a trend line and an equation was created, which indicates/allows to identify a positive (upward) or negative (downward) trend (FIGURE 1.7.2.1 and FIGURE 1.7.2.2).

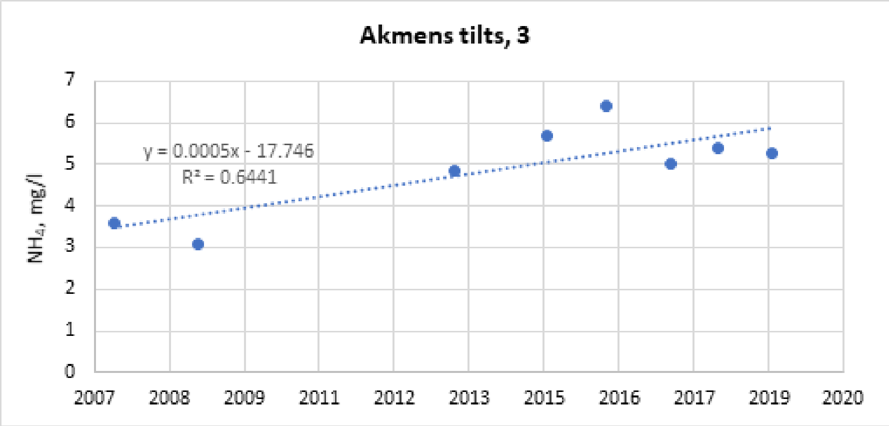


FIGURE 1.7.2.1 **Changes in NH_4^+ concentration at MP Akmens tilts, 3 in the period from 2007 to 2019 with a significant upward trend** (modified after LVĢMC, 2021)

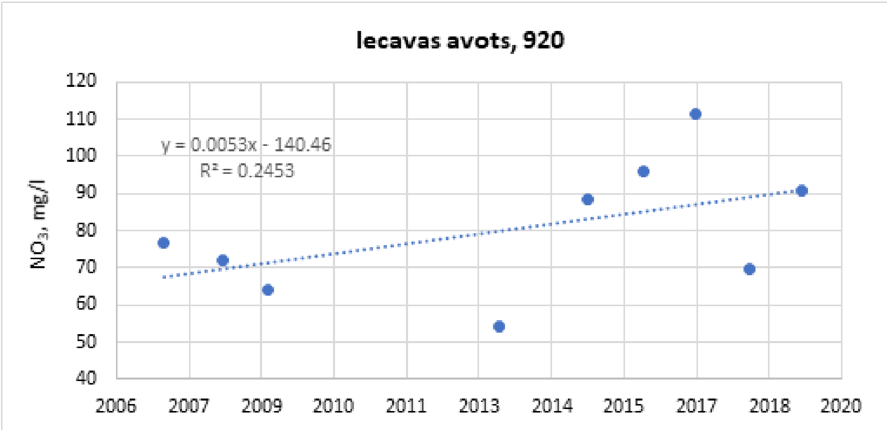


FIGURE 1.7.2.2 **Changes in NO_3^- concentration at MP Iecavas avots, 920 in the period from 2006 to 2019 with an insignificant upward trend** (modified after LVĢMC, 2021)

1.8. Groundwater body status assessment

According to the WFD, all GWBs must be in good status by 2026. To achieve that, all MS must set the environmental objectives for each GWB and monitor the process during the River Basin Management cycles. At the end of each cycle (6-year period), the status of all GWBs must be assessed to see the progress.

To assess the status of GWB, a methodology must be developed by all MS. To help the process, a methodological CIS Guidance Document No.18 "Guidance on groundwater status and trend assessment" is compiled by EC (EC, 2009). The GWB status assessment is the risk assessment on how human activities can endanger the achievement of environmental objectives of the groundwater. The risk assessment is supported by the development of conceptual models or conceptual understanding of the system, which is a base of the selection of EQS and monitoring principles (Annex III of the GWD).

In the CIS Guidance Document No.18, a tiered approach with 9 tests (FIGURE 1.8.1) is suggested for the chemical and quantitative status assessment of GWBs (EC, 2009). Each relevant test is to be carried out independently and the results to be combined to give an overall assessment of GWB's chemical and quantitative status. The worst-case test will define the overall status of GWB.

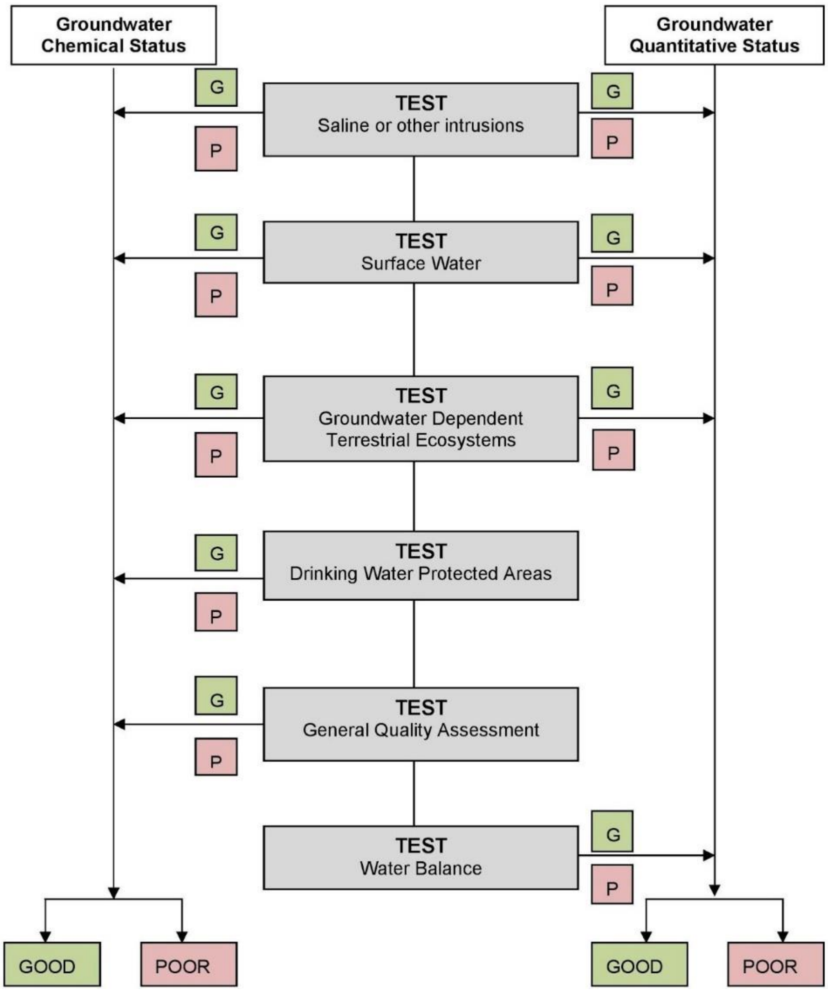


FIGURE 1.8.1 **Overall procedure of tests for assessing groundwater status** (EC, 2009)

1.8.1.Chemical status assessment

The WFD contains comprehensive provisions for the protection and conservation of groundwater. In accordance with Article 17 of the WFD, criteria for the assessment of good groundwater chemical status, as well as criteria for the identification of significant and sustained upward trends and the identification of starting points for trend reversals, are to be adopted. For its part, the GWD already lays down certain quality criteria for nitrates and pesticides and technical rules for carrying out all the above tasks. The WFD also stipulates that the MS of TGWBs must uniformly coordinate their activities concerning monitoring, setting of TVs, and identification of dangerous substances, as well as the development of programs of measures.

The WFD states that the good chemical status of GWB is achieved if the chemical status of GWB meets all the conditions set out in Table 2.3.2 of Annex V (does not affect associated ecosystems, does not cause intrusion, etc.). Point 2.4.5 of Annex V states that the average values at each MP must be calculated when assessing the chemical status of GWB, and following Article 17, these average values shall be used to demonstrate compliance with good groundwater chemical status. Following the requirements of point 1 of Annex III to the GWD, the chemical status assessment must be carried out only for those GWBs or groups of GWBs identified as having significant anthropogenic pressures or risks, and only for those pollutants, groups of pollutants, or indicators, which would characterize it as that. GWBs that are not at risk (no significant anthropogenic pressure has been identified) are automatically classified as in good status. Additional characterization is also mandatory for all TGWBs (Annex II, point 2.3 of the WFD).

The following criteria need to be used to assess the chemical status of GWB or a group of GWBs in accordance with Chapter 2.3 of Annex V to Directive 2000/60/EC, as well as based on the recommendations of CIS Guidance Documents No.18 (EC, 2009):

- ***GQS***[8] referred to in Annex I of Directive 2006/118/EC for parameters - nitrates and pesticides, the values of which may be reduced if the MS itself considers that it will prevent achieving the objectives of the Directive (for example, adversely affect the condition of associated ecosystems); in Estonia and Latvia, GQS presented in Annex I of Directive 2006/118/EC are adopted for GWB chemical status assessment (TABLE 1.8.1.1):

TABLE 1.8.1.1

GQS adopted in Estonia and Latvia
(Marandi et al., 2020; LVĢMC, 2021)

Pollutant	Quality standards
Nitrates	50 mg/l
Active substances in pesticides, including their relevant metabolites, degradation and reaction products (1)	0.1 µg/l 0.5 µg/l (total) (2)

(1) "Pesticides" means plant protection products and biocidal products as defined in Article 2 of Directive 91/414/EEC and in Article 2 of Directive 98/8/EC, respectively

(2) "Total" means the sum of all individual pesticides detected and quantified in the monitoring procedure, including their relevant metabolites, degradation and reaction products.

- ***TVs***[9] set by the MS following Article 3 of the GWD only for those GWBs where the risk of failure to achieve good chemical status has been identified. TVs should be set for parameters that pose a risk or are recognized as indicators of risk. Recommended parameters (but not mandatory) are given in Annex II - As, Cd, Pb, Hg, NH_4^+, Cl^-, SO_4^{2-}, NO_2^-, phosphorus (total) or phosphates, trichloroethene, tetrachloroethene, and electrical conductivity (as intrusion indicator); in Estonia and Latvia, TVs were determined individually for each GWB as presented in Chapter 1.3.1 and Annex 1 (in case of Estonia) and Chapter 1.3.2 and Annexes 2 and 3 (in case of Latvia).

Following the recommendations of the CIS Guidance Document No.18 (EC, 2009), several tests must be developed to assess the chemical status. Each relevant test (taking into account the risk qualification elements) should be performed individually and the results of each test should be combined to obtain an overall assessment of the chemical status of the GWB.

The assessment of the chemical status of GWB is a two-step procedure. In the first step, the compliance of the chemical status of GWB with the EQS and/or TVs is assessed - if no exceedances are detected at any of the MPs, the chemical status of GWB is considered as good. If exceedances are observed, the second step follows - a detailed assessment of the chemical status of the GWB using appropriate tests (general quality assessment, saline or other intrusions, surface waters, groundwater dependent terrestrial ecosystems, drinking water protected areas) to assess GWB's compliance with the required environmental conditions of the beneficiary concerned. According to CIS Guidance Document No.18 (EC, 2009), the spread of pollutants is significant if it occurs in 20% or more of the area or volume of a GWB.

[8] an EQS expressed as the concentration of an individual pollutant or group of pollutants or indicator of pollution in groundwater, which should not be exceeded in order to protect human health and the environment
[9] GQS

1.8.1.1. Chemical status assessment in Estonia

Chemical status assessment in Estonia is a two-step procedure. During the first step, exceedances of GQS, threshold values, and/or LVs were identified at all MPs. If the relevant quality standards were not exceeded at any MP, the chemical status of the GWB was considered to be good and the remaining chemical status assessment tests were not performed for that particular GWB. However, if GQS, threshold value, and/or the LV were exceeded in one (or more) cases, further chemical status assessment tests were performed (Marandi et al., 2020).

The chemical status assessment of GWBs used groundwater quality data collected during the national groundwater monitoring, company self-monitoring, nitrate vulnerable zone (NVZ) groundwater monitoring, and the data from hazardous substances survey in 2018, but only from MPs included in the national groundwater monitoring network, which ensures the consistency of the time series of the monitoring data and the uniformity and comparability of the data over the different assessment periods. The monitoring data were compiled and the annual average concentrations of the relevant pollutants for the whole reference period (2014-2019) were calculated at all MPs in the GWB. For pollutants whose concentrations were below the limit of quantitation (LoQ), they were replaced with values that are ½ of this LoQ value. In turn, only quantified concentrations were used to calculate average concentrations of pesticides (values lower than LoQ value were excluded from the dataset), following the recommendations of the CIS Guidance Document No.18 (Marandi et al., 2020).

According to the regulation of the Minister of the Environment No.48 (adopted on 01.10.2019), the quality indicators used to determine the chemical status class of GWBs is GQS (as presented in TABLE 1.8.1.1), threshold values (as presented in Chapter 1.3.1 and Annex 1), as well as electrical conductivity, pH, dissolved oxygen content, chemical oxygen demand (COD), ammonium (NH_4^+), chlorides (Cl^-), sulfates (SO_4^{2-}); as well as hazardous substances, including concentrations of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), trichloroethylene (TCE), tetrachlorethylene (PCE) and other synthetic substances (Marandi et al., 2020).

In addition to GQS and threshold values, in case of Estonia, for GWB to be in good chemical status it must comply with the quality indicators listed in § 7(1) of the regulation of the Minister of the Environment No.48 (adopted on 01.10.2019) (Marandi et al., 2020):

- the concentration of chloride (Cl^-) and sulphate (SO_4^{2-}) ions as well as the concentration of total dissolved solids (TDS) measured by electrical conductivity do not show an upward trend indicating anthropogenic pollution or saline intrusion;
- the pH is in the range of 6-9;
- the dissolved oxygen (O_2) content does not show a downward trend due to human activity or the chemical oxygen demand (COD) content is ≤5 mg/lO_2 or, if the value of the quality indicator is exceeded, the natural origin of the dissolved oxygen in the groundwater has been proven;
- the content of ammonium (NH_4^+) ions in naturally aerobic groundwater does not exceed 0.5 mg/l or does not exceed 1.5 mg/l in naturally anaerobic aquatic environment, or, if the value of a quality indicator is exceeded, the natural origin of ammonium (NH_4^+) ions in groundwater should been proven;
- hazardous substances, including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), trichlorethylene (TCE), tetrachlorethylene (PCE) and synthetic substances should be absent in groundwater, or their concentration does not exceed the groundwater quality LVs for hazardous substances, or the natural origin of these hazardous substances in groundwater should been established;
- the concentration of pollutants should not impede the achievement of the environmental objectives set for the surface waters associated with the GWB and should not cause significant damage to the ecological or chemical status of the surface waters or to terrestrial ecosystems directly dependent on that GWB.

In Estonia, GWB is considered to be with aerobic groundwater if it includes the first aquifer from the ground surface, and for the GWBs the quality limit of ammonium (NH4+) ions is set as 0.5 mg/l. Accordingly, in Estonia GWBs with aerobic groundwaters are considered to be No.6, No.7, No.8, No.9, No.10, No.11, No.12, No.13, No.14, No.15, No.16, No.19, No.20, No.22, No.23, No.24, No.25, No.26, No.27, No.28, No.29 and

No.31. Anaerobic conditions exist in deeper GWB (No.1, No.2, No.3, No.4, No.5a, No.5b, No.17, No.18, and No.21) and for the GWBs the quality limit of ammonium (NH_4^+) ions is set as 1.5 mg/l (Marandi et al., 2020).

The GQS for hazardous substances are expressed through EQS and threshold values. The EQS indicates the concentration of a hazardous substance in groundwater at a value equal to or less than the quality of groundwater in the area. The threshold value indicates the concentration of a hazardous substance in groundwater above which groundwater is considered to be contaminated and measures must be taken to eliminate the pollution and improve the quality of the groundwater, except in the case of natural pollution. In the case of hazardous substances (TABLE 1.8.1.1.1), the threshold values provided in the regulation of the Minister of the Environment No.39 (adopted on 04.09.2019) were used in assessing the chemical status of GWBs in agreement with the contracting authority (Marandi et al., 2020).

TABLE 1.8.1.1

Groundwater quality standards adopted in Estonia and Latvia
(Marandi et al., 2020; LVĢMC, 2021)

Pollutant		Threshold value (μg/l)
Arsenic (As)		*100*
Cadmium (Cd)		*10*
Mercury (Hg)		*2*
Lead (Pb)		*200*
Chlorinated Aliphatic Hydrocarbons (CAHs)	Trichlorethylene (TCE)	*70*
	Tetrachlorethylene (PCE)	*70*

If during the first stage of the assessment (*the background check*) it is identified that the average values of the parameters during the period 2014-2019 have not been exceeding the respective EQS and/or threshold values at any MP, the chemical status of GWB is considered to be good and no other chemical status assessment tests were performed. If any exceedances are identified, the chemical status assessment was continued with other chemical status tests, which, among other things, assessed the variability of pollutant concentrations affecting groundwater status during the assessment period (2014-2019) and variability from baseline levels (Marandi et al., 2020).

The baseline level is the average pollutant concentration in the GWB measured in the course of groundwater monitoring in 2007–2009 (Riigikogu, 2019). The values of the baseline levels of the chemical parameters used in the groundwater chemical status assessment tests have been calculated based on data collected by the Estonian Geological Survey during the work of GWBs (Marandi et al., 2019). If there was no data on the pollutant at the MPs before, the first annual average concentration measured during the assessment period has been taken as the baseline (Marandi et al., 2020).

The chemical status tests and the reporting of the results shall assess whether there is a statistically significant upward trend in the concentrations of pollutants in groundwater during the assessment period (steady upward trend). The Water Act defines that "*a significant or sustained increase in the pollutant content of groundwater indicates a statistically reliable and environmentally significant increase in the pollutant content in an endangered GWB*". In the event of an increase in the pollutant concentration, a threshold for reducing the pollutant concentration of groundwater must be established (indicating that the pollutant concentration of the endangered GWB has increased by 75% of the pollutant threshold value), to stop the increase in pollutant content or reduce the pollutant content (Riigikogu, 2019).

A significant increase in the pollutant concentration is an increase in the average annual pollutant concentration in an endangered GWB for more than 20% of the baseline level for two consecutive years (Riigikogu, 2019). An environmentally significant increase in pollutant concentration could not be implemented in the assessment according to this definition. For example, a 20% increase in chloride (Cl^-) ions concentration is not environmentally significant if the initial chloride level is only 3 mg/l. An increase in the concentration of the indicator will become important if it starts to approach the threshold value of the GWB. In agreement with the contracting authority, it was found that environmentally significant growth needs to be redefined in legislation, and in this case, only the criterion of a sustainable growth trend is used to assess trends. One option in the future is to consider an increase above the pollutant reduction threshold (75% of the threshold value) as an environmentally significant increase. The use of a pollutant reduction threshold as an additional criterion was necessary to screen for large percentage fluctuations caused by low baseline levels and natural groundwater chemistry variability (Marandi et al., 2020).

A steady increase in the pollutant content of groundwater is defined in the Water Act as an increase in the average annual pollutant content in an endangered GWB for six consecutive years compared to the baseline level (Riigikogu, 2019). As recommended by the EC's Groundwater Assessment Guidelines (EC, 2009), only an increase in pollutant concentration with statistical reliability of a linear growth trend of more than 95% (p-value < 0.05) was considered a sustainable growth trend in the status assessment (see Chapter 1.7.1). In the assessment, the pollutants for which threshold values have been set for the GWB were considered. The monitoring of pesticides has been too insufficient to observe trends. Different pesticides have been identified from different observation wells and thus it is not yet possible to monitor statistically reliable growth trends during this assessment period. The significant growth trend found in the monitoring wells is marked with a black dot in the figure of the assessment result of each GWB. Different pesticides have been identified from different observation wells and thus it is not yet possible to monitor statistically reliable growth trends during this assessment period (Marandi et al., 2020).

The general quality assessment test (Test 1) partly overlaps with the collection of background information on the chemical composition of the GWB – *the background check*. If the GQS, threshold, and/or LVs were exceeded, the status assessment was continued with the next steps (FIGURE 1.8.1.1.1).

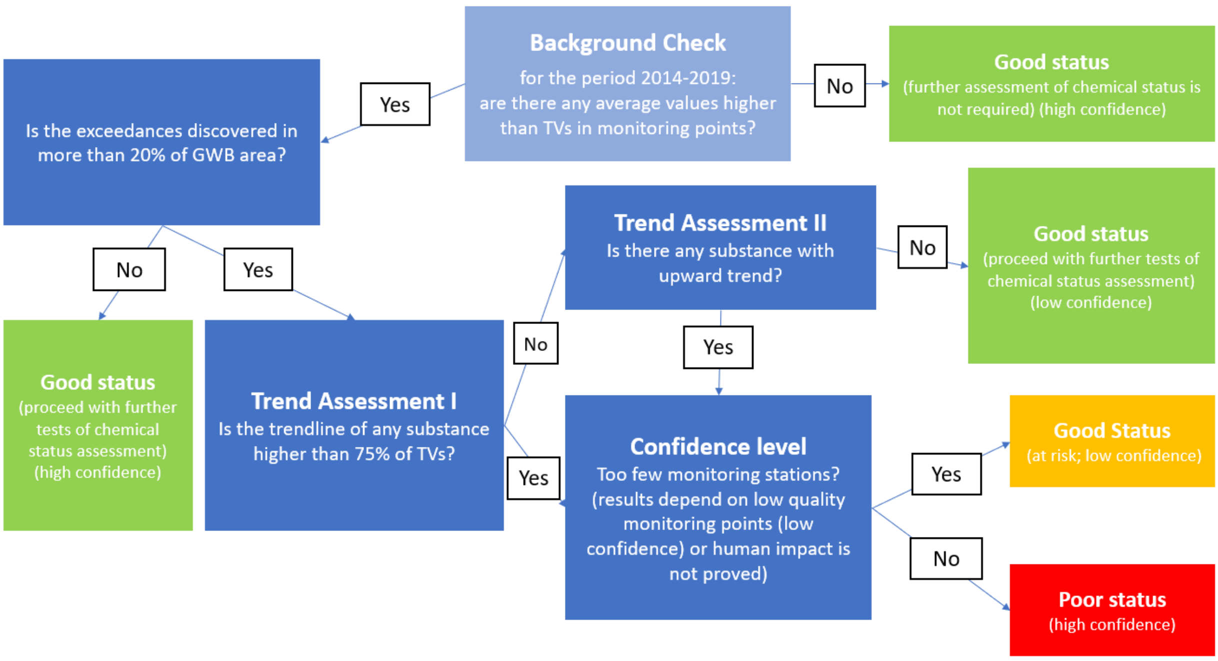


FIGURE 1.8.1.1.1 **Flow diagram of the background check and the general quality assessment test**
(modified after Marandi et al., 2020)

First, the share of MPs in the GWB where GQS, threshold values, and/or LVs were exceeded for the average concentration of pollutants in the period of 2014-2019 was assessed. According to CIS Guidance Documents No.18, the spread of pollutants is significant if it occurs in 20% or more of the area or volume of a GWB (EC, 2009). To assess this extent, a spatial analysis of the location of the MPs was used, during which the impact ranges on the MPs of the Thiessen polygons (Schumann, 2006) were determined by the surface generation method. As a result of the application of the Thiessen polygons, the GWB was subdivided into smaller and larger units, which characterize the scope of impact of a certain MP (FIGURE 1.8.1.1.2).

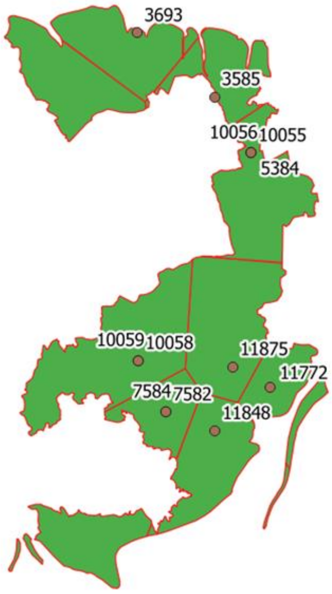


FIGURE 1.8.1.1.2 **The example of the use of the Thiessen polygon method to define the share of the importance of each MP in GWB No.13** (Marandi et al., 2020)

If the share of the MPs with exceedances of GQS, threshold values and/or LVs was less than 20% of the GWB area, the GWB was considered to be in good status, according to the general quality assessment test and the assessment was continued with the following status assessment tests. However, if the share of these MPs reached more than 20% of the GWB area, the trend assessment (aggregated data by whole GWB) for relevant pollutants was carried out (FIGURE 1.8.1.1.1, Trend Assessment I). If during this assessment the linear trend line exceeded 75% of the threshold or LV established for any relevant pollutant, the GWB was considered to be in poor status. However, attention was also paid to the reliability of the monitoring network (FIGURE 1.8.1.1.1, Confidence level), which means that it was assessed whether there were an insufficient number of MPs, and if pollutant concentrations and growth trends were affected by poor quality MPs and/or human impact was identified (Marandi et al., 2020).

In a situation where the trend lines of aggregated data by GWB of the pollutants in question in all MPs did not exceed 75% of the threshold and/or LV, the next step was to perform the trend assessment of these pollutants in each MP. If a statistically significant upward trend was identified at least at one MP, the GWB was considered to be in poor status (high confidence) based on a reliable monitoring network and analytical data. If the monitoring data were affected by insufficient or poor-quality MPs and no human impact was detected, the GWB was considered to be in good status, but at risk. The confidence level of this result was low, as in the next observation period it has to be determined whether the high concentrations of pollutants in MPs are local or pose a threat to the whole GWB. Therefore, also, in this case, the status assessment was based on the quality of the specific MP and the corresponding monitoring data, and the configuration of the monitoring network on the GWB level (Marandi et al., 2020).

A test to identify the risk of ***saline or other intrusions*** (Test 2) and to assess its impact on the chemical status of GWB was performed only in GWBs where threshold values have been established for chloride (Cl^-) and sulfate (SO_4^{2-}) ions, characterizing intrusion processes. The first step was to determine whether a statistically significant upward trend in the annual average chloride (Cl^-) and sulfate (SO_4^{2-}) ion concentrations (aggregated data by whole GWB) have been identified and whether these concentrations have exceeded the established threshold values (by single MP) (FIGURE 1.8.1.1.3). If there were no statistically significant upward trends identified (in the aggregated data by whole GWB) and the average concentrations in the individual MPs were lower than the threshold values, the GWB was considered to be in good chemical status, according to this test (Marandi et al., 2020).

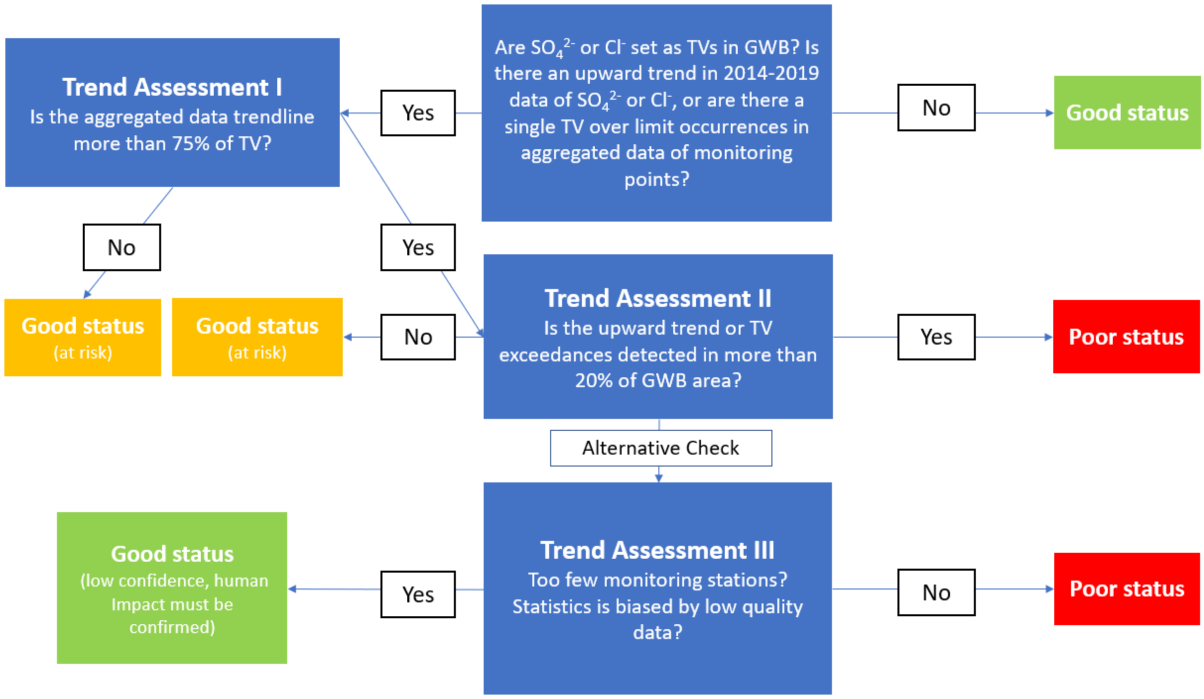


FIGURE 1.8.1.1.3 **Flow diagram of the saline or other intrusions test**
(modified after Marandi et al., 2020)

If there was a statistically significant upward trend identified based on chloride (Cl^-) and sulfate (SO_4^{2-}) ions concentrations in the aggregated data by whole GWB, verification was made whether the trend line exceeds 75% of the threshold value (FIGURE 1.8.1.1.3, Trend Assessment I). If the trend line remained below the 75% mark of the threshold value, the GWB was considered to be in good status, but at risk. However, if the upward trend of chloride (Cl^-) and sulfate (SO_4^{2-}) ions exceeded the 75% mark of the threshold value and/or there were monitoring wells with the average concentration above the threshold value, the assessment proceeded with the trend assessment in single MP (FIGURE 1.8.1.1.3, Trend Assessment II).

The further assessment did determine whether the MP or MPs, where the threshold value was exceeded, characterizes an area larger or smaller than 20% of the whole GWB area. In the case of MPs with an impact area of less than 20% of the whole GWB area, the GWB was considered to be in good status, but at risk (If the concentration of chloride (Cl^-) and sulfate (SO_4^{2-}) ions will continue to increase). Otherwise, the GWB was considered to be in poor status based on this test (Marandi et al., 2020).

In Estonia, there are several GWBs potentially affected by intrusion processes, where the number of MPs is insufficient and, as a result, the share of one MP in the assessment is very high (for example, GWBs on islands). To avoid situations where, based on the data of one MP, the GWB qualifies as being in poor status, the peculiarities of the monitoring network were alternatively studied (FIGURE 1.8.1.1.3, Alternative Check). If a MP with high chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentration and with a significant share of GWB area did not show an upward trend in the annual average concentrations and the high concentrations was of natural origin, the GWB was considered to be in good status according to this test (Marandi et al., 2020).

The purpose of the ***surface water*** test (Test 3) is to assess whether the chemical quality characteristics of groundwater may cause unfavorable status for SWBs. The connections of groundwater associated SWB with GWBs were outlined in the 2015 study of the Institute of Ecology of Tallinn University (TU) (Terasmaa et al., 2015). In the absence of SWBs associated with groundwater, the GWB was considered to be in good status (FIGURE 1.8.1.1.4).

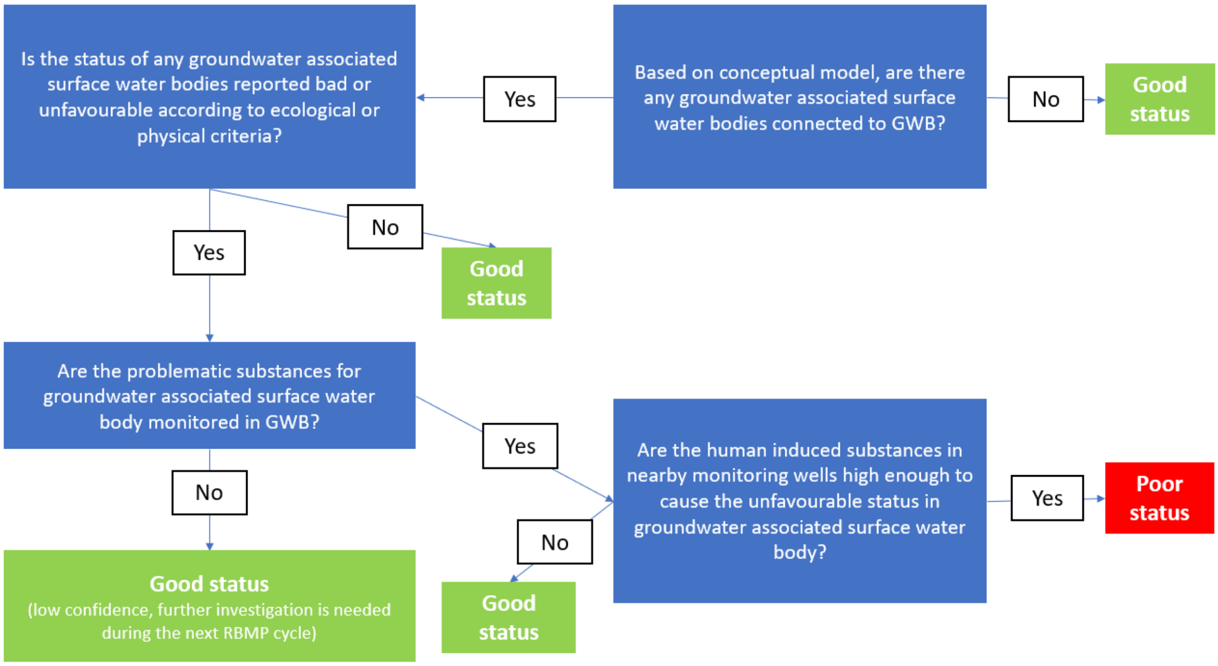


FIGURE 1.8.1.1.4 **Flow diagram of the surface waters test**
(modified after Marandi et al., 2020)

SWBs (watercourses and lakes) that have been identified as significantly dependent on groundwater in the development of conceptual models of GWBs were identified. Following that the status of these SWBs (based on the results of an assessment carried out during the preparation of RBMPs) were linked to the associated GWBs (Marandi et al., 2020).

If groundwater associated SWBs were identified in the GWB, the next step was the assessment of the status of these SWBs (FIGURE 1.8.1.1.4). In the course of RBMPs, SWBs were assessed for their ecological and chemical status, based on which they have been assigned an integrated status. In those groundwater dependent SWBs where the chemical status was assessed as poor, it was examined whether the pollutants causing poor status have been determined in the groundwater MPs. If the groundwater monitoring contained data on these pollutants, the spatial location of groundwater MPs and groundwater associated SWBs and their catchment areas, as well as the proportion of the SWB supplied by the groundwater was further analyzed. Where available monitoring data allowed, the analysis of the test resulted in a status assessment and reliability on the GWB (Marandi et al., 2020).

Among the quality elements of the ecological status of SWBs, the nutrients (mainly P_{tot} and N_{tot}) and river basin-specific life quality elements (mainly Ba and Hg) were taken into account in this test. In those SWBs where the quality elements of physicochemical quality indicators and river basin specific pollutants caused unfavorable status (worse than good), the monitoring data of the GWB was considered whether the pollutant content in the nearest national monitoring well is so high due to human impact that it could cause the unfavorable status of surface waters (Marandi et al., 2020).

The purpose of the ***groundwater dependent terrestrial ecosystems*** (GDTEs) test (Test 4) is to assess whether the chemical quality of groundwater may lead to the disadvantage of these ecosystems. The connections of GDTEs with GWBs have been highlighted in the 2015 study of the Institute of Ecology of Tallinn University (TU) (Marandi et al., 2020).

The TU study provided a list of terrestrial ecosystems that may depend on groundwater. The results of this study were used as the first step to identify if there were any GDTEs connected to the GWB. In the absence of GDTEs associated with a GWB (e.g., deep GWBs), the GWB was considered to be in good status (FIGURE 1.8.1.1.5).

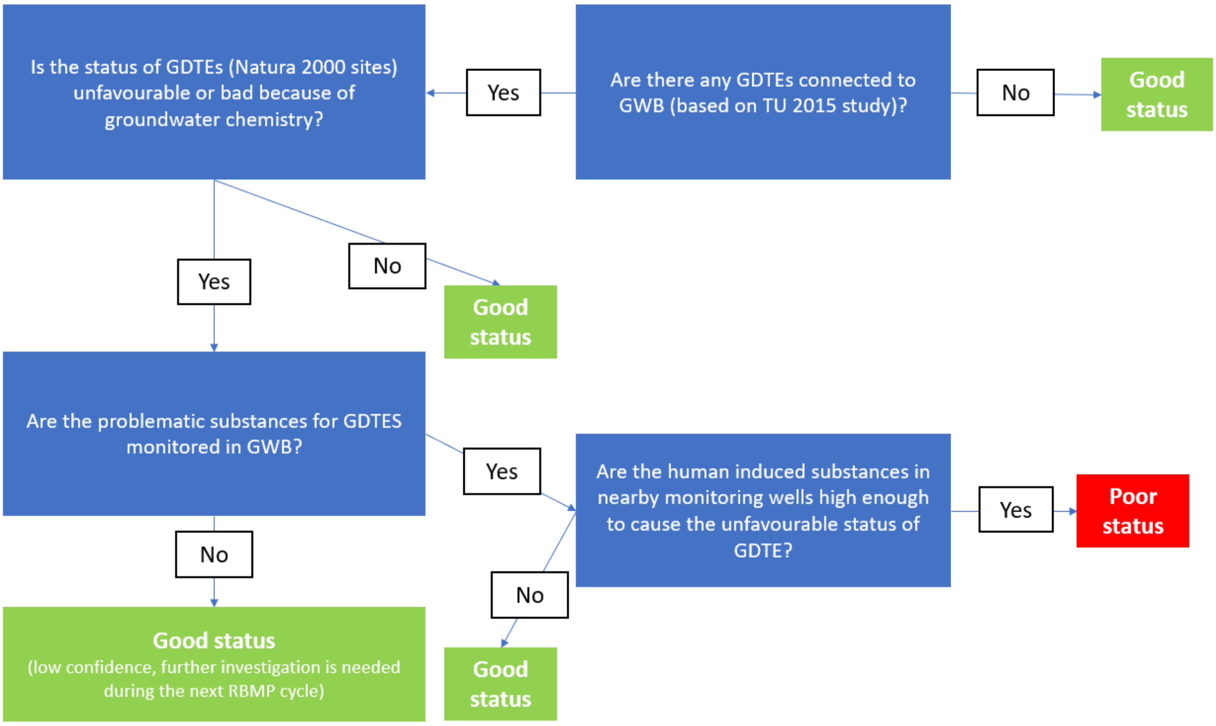


FIGURE 1.8.1.1.5 **Flow diagram of the GDTEs test** (modified after Marandi et al., 2020)

As a next step, it was clarified whether the deterioration of the ecosystem has been caused by changes in groundwater chemistry, but in the absence of such monitoring data, it was usually not possible to make a further assessment. However, the Natura 2000 assessment results for unsatisfactory GDTEs and the factors causing their disadvantage were reviewed. If necessary, further monitoring recommendations were provided for the next assessment period. Due to human activities, the status of GDTEs is more likely to be affected by the decrease in groundwater levels due to groundwater abstraction, rather than due to changes in the chemical composition of groundwater (Marandi et al., 2020).

In the course of the ***drinking water protected areas*** test (Test 5), it is assessed whether there are significant upward trends of pollutants due to human impact in large drinking water intakes (groundwater well fields), which would have forced the water companies to close groundwater intakes, change groundwater intake locations or apply more efficient groundwater treatment methods; the test does not assess whether the groundwater quality meets the quality requirements for drinking water (Marandi et al., 2020).

Groundwater intakes (groundwater well fields) with an abstraction rate greater than 500 m^3/d were included in this test. Another important criterion was whether the problems with drinking water quality have been referred to the Groundwater Commission in the period 2014-2019 (FIGURE 1.8.1.1.6). If groundwater abstractions of this magnitude did not occur within the GWB and the problems related to drinking water had not been reported to the Groundwater Commission, the chemical status of the GWB was considered to be good. In the event of quality problems, it was determined whether the GWB is in poor or at-risk status based on the results of general quality assessment and saline or other intrusions tests; if the results of these tests confirmed it, GWB was also considered to be in poor status in this test. However, if the results of those two tests showed that poor or at-risk status was indicated by a quality indicator that has not been addressed in previously mentioned tests, the behavior of this content in the nearest groundwater MP was investigated. If there was an upward trend in the pollutant in the nearest monitoring wells identified (FIGURE 1.8.1.1.6, Trend Assessment I), it was assessed concerning the 75% mark of the threshold value. If this value was exceeded, the GWB was considered to be in poor status (high confidence), otherwise, it was considered to be in good status (in the latter case, this was probably a local groundwater intake-specific problem, the cause of which should be determined by research) (Marandi et al., 2020).

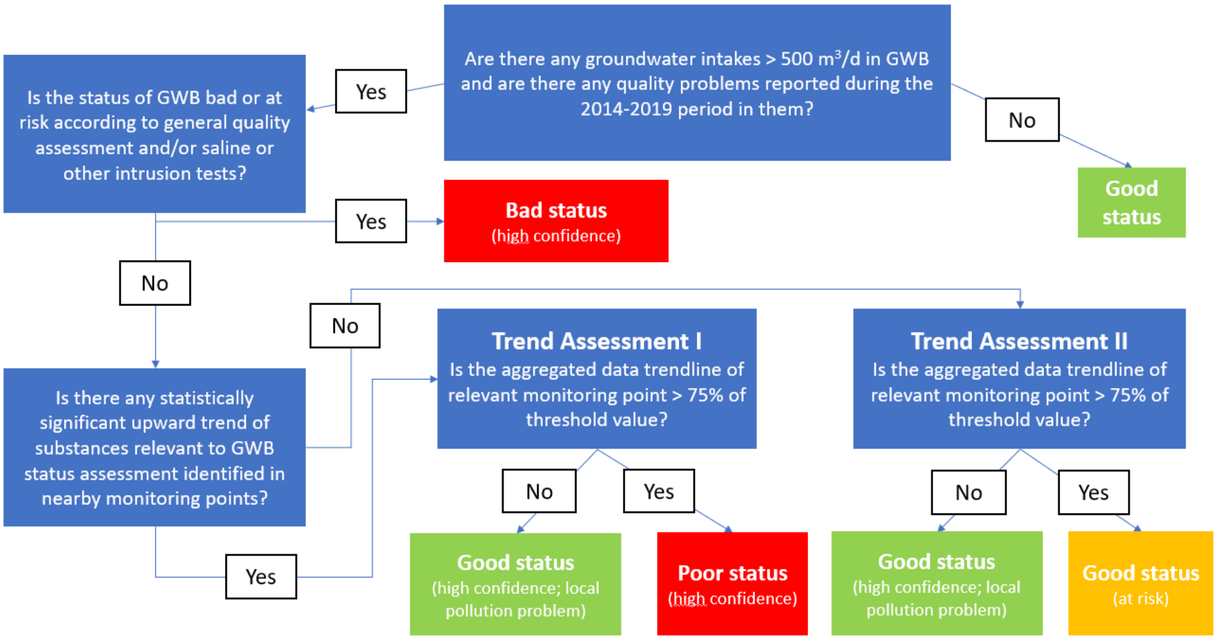


FIGURE 1.8.1.1.6 **Flow diagram of the DWPAs test**
(modified after Marandi et al., 2020)

If there was no upward trend of the pollutant in the monitoring wells closest to the problematic groundwater intake identified (FIGURE 1.8.1.1.6, Trend Assessment II) and the trend line of the pollutant remained below the 75% mark of the threshold value, then the chemical status of the GWB was considered to be good (the presence of the pollutant is related to groundwater intake and it does not affect the GWB more broadly). If the pollutant trend line value was above the 75% mark of the threshold value, the GWB was considered to be in good chemical status, but at risk (Marandi et al., 2020).

1.8.1.2. Chemical status assessment in Latvia

The methodology development and assessment of the chemical status of GWBs in Latvia was performed in 2021 for preparation of the 3rd cycle RBMPs (LVĢMC, 2021). During the development of assessment procedures in Latvia, in the framework of the WaterAct project Estonian partners have already provided chemical status assessment procedures in Estonia and the development of the Latvian approach was heavily inspired by assessment procedures described in Chapter 1.8.1.1. Based on the above, it can be affirmed that the harmonization of methodologies in the case of Latvia has already taken place during its development. The main differences that arose during the development of the chemical status assessment procedures in Latvia are related to the amount and quality of available data, which limited the use of comprehensive chemical status assessment processes and trend analysis.

The assessment of the chemical status in Latvia was performed for all GWBs based on the requirements set out in the CIS Guidance Document No.18 (EC, 2009). In GWBs, which do not currently have any monitoring stations, the grouping principle was used to assess the chemical status; otherwise (if the grouping principle could not be applied) the chemical status of GWB was considered to be good (with low confidence). In Latvia, assessment procedures were developed for only two tests (general quality assessment and saline or other intrusions), but these two tests were divided into separate subtests: the general quality assessment test was divided into three separate tests, considering previously identified pressures in each GWB, but saline or other intrusions test was divided into seawater intrusion test and saline water intrusion test (LVĢMC, 2021). The overall quality assessment test was performed for all GWBs, regardless of the pressures identified in them, while the other tests were selected for each GWB individually, depending on the anthropogenic pressure identified by the GWB and its impact on groundwater quality:

- ***diffuse pressure assessment*** test was performed for GWBs in which significant diffuse pressure has previously been identified;

- ***point pressure assessment*** test was performed for GWBs in which significant point pressure has previously been identified;
- ***seawater intrusion assessment*** test was performed for GWBs which are bordering the sea and are exposed on the ground surface, in which a significant groundwater abstraction pressure has previously been identified that may cause seawater intrusion;
- ***saline water intrusion assessment*** test was performed for GWBs located above, below or adjacent to high mineralization zones, where significant groundwater abstraction pressure has previously been identified that may activate freshwater mixing with high mineralization waters.

Each test used its own individual parameters and quality criteria. The overall quality assessment test (GWBs with no significant pressures) used the parameters and quality criteria listed in Annex I of the GWD: nitrates and pesticides. In other tests, taking into account the previously identified pressures within each GWB, only those parameters that pose a risk or were recognized as risk indicators were assessed by delineated threshold values (see Chapter 1.3.2 and Annex 2). For the synthetic parameters, following the widely used BRIDGE methodology (Müller et al., 2006), the LVs were set as ½ from EQS (according to Cabinet Regulation No.118 of March 12, 2003 "Regulations on Surface water and Groundwater quality" (hereinafter - Cabinet Regulation No.118)). Full environmental quality criteria were used as the LV for parameters such as permanganate index, total nitrogen, and nitrites, which occur in nature but for which threshold value could not be determined due to limited data set. It should be noted that if the general quality assessment test overlapped with the diffuse pressure assessment test, the strictest quality criteria were used for the assessment of nitrates and pesticides. The list of parameters used in each test is given in TABLE 1.8.1.2.1, but the LVs of additional parameters are given in TABLE 1.8.1.2.2.

TABLE 1.8.1.2.1

Parameters used to assess the chemical status of GWBs according to each assessment test
(LVĢMC, 2021)

Assessment test (subtest)		Parameters
General quality assessment	**Without significant pressure**	nitrates (NO_3^-), pesticides (in total), pesticides (separately)
	With significant diffuse pressure	nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), pesticides
	With significant point pressure	nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), chlorides (Cl^-), sulfates (SO_4^{2-}), total phosphorus (P_{tot}), total nitrogen (N_{tot}), cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), nickel (Ni), permanganate index (CODMn), sum of benzene, toluene, ethylbenzene and xylenes (BTEX), trichlorethylene (TCE), tetrachlorethylene (PCE)
Saline or other intrusions	**Seawater intrusion**	chlorides (Cl^-)
	Saline water intrusion	chlorides (Cl^-), sulfates (SO_4^{2-})

Remarks: black color - GWB-specific threshold values were applied (except in general quality assessment test for GWBs without significant pressures where GQS set by the GWD were applied); **blue color** - quality standards specified in the Cabinet Regulation No.118 were applied; **red color** - ½ from quality standards specified in the Cabinet Regulation No.118 were applied

TABLE 1.8.1.2.2

LVs of additional parameters (to GQS and TVs) used to assess the chemical status of GWBs
(LVĢMC, 2021)

Parameter	Unit of measurement	EQS (according to Cabinet Regulation No.118)	LV (used in chemical status assessment of GWBs)	Pressure type
Nitrates (NO_3^-)	mg/l	0.5	0.5	point/diffuse
Total nitrogen (N_{tot})	mg/l	3	3	point
Permanganate index (CODMn)	mg/l	5	5	point
Sum of benzene, toluene, ethylbenzene and xylenes (BTEX)	µg/l	10	5	point

Parameter	Unit of measurement	EQS (according to Cabinet Regulation No.118)	LV (used in chemical status assessment of GWBs)	Pressure type
Trichlorethylene (TCE)	µg/l	10	5	point
Tetrachlorethylene (PCE)	µg/l	10	5	point
Pesticides (total)	µg/l	0.5	0.25	diffuse
Aldrin, dieldrin, heptachlor and heptachlor epoxide (separately)	µg/l	0.03	0.015	diffuse
Other pesticides (separately)	µg/l	0.1	0.05	diffuse

The assessment was performed individually for each GWB, using appropriate tests, identified pressure parameters or groups of parameters, as well as the established GQS and/or threshold values. To assess the compliance of GWB with good or poor chemical status, the results of groundwater monitoring for the period from 2014 to 2019 were compiled, calculating the average concentrations of previously identified parameters for each GWB in every MP. Samples with ionic balance discrepancies (deviations greater than ±10%) as well as extremely high and/or low values (outliers) were excluded from the data set. For parameters whose concentrations were below the limit of quantitation (LoQ), they were replaced with values that are ½ of this LoQ value. In turn, only quantified concentrations were used to calculate average concentrations of pesticides (values lower than LoQ value were excluded from the dataset), following the recommendations of the CIS Guidance Document No.18 (LVĢMC, 2021).

If no exceedances were identified at any of the MPs and tests performed, the chemical status of the GWB was considered to be good (high or medium confidence). If at least in one of the tests exceedances were identified in at least one of the MPs, an in-depth data analysis was performed for GWB and the significance of the detected exceedance at the GWB level was initially assessed (it was examined whether the prevalence of pollutants represented more than 20% of the total area of GWB) (LVĢMC, 2021).

Using the Thiessen polygon method, the area (as a percentage) of the total GWB area was determined for each monitoring station, which represents the prevalence or significance of the detected exceedance. The areas determined by groundwater monitoring stations were summarized if the exceedances were marked in several monitoring wells, which represent different monitoring stations (FIGURE 1.8.1.2.1). It should be noted that the area occupied by the exceedances was calculated for the group of pollutants that characterize the specific pressure, and not for each parameter separately (LVĢMC, 2021).

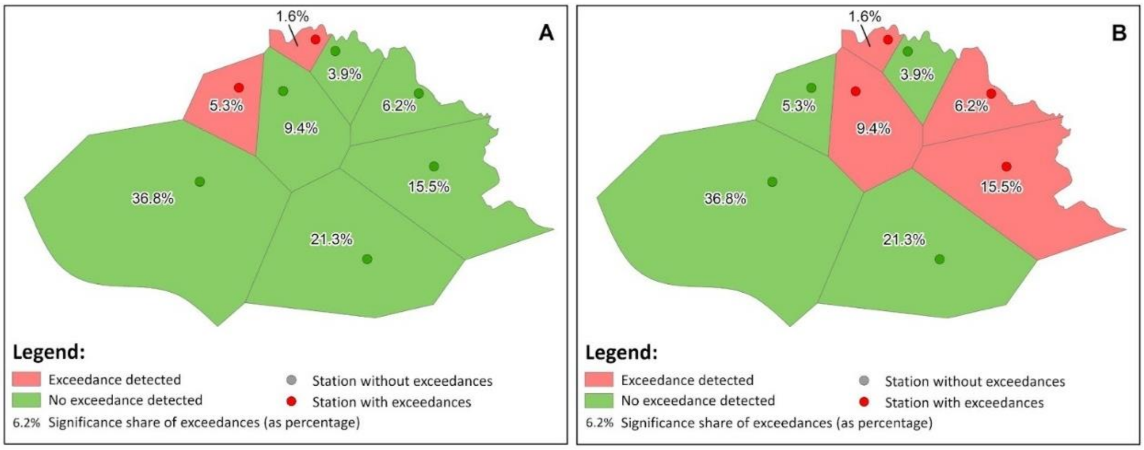


FIGURE 1.8.1.2.1 **A - exceedances identified at two monitoring stations, representing 6.9% of the total area of GWB; B - exceedances identified at four stations, representing 32.7% of the total area of GWB** (modified after LVĢMC, 2021)

If the identified exceedances of the pollutant threshold values did not exceed 20% of the total area of the GWB, then GWB was considered to be in good chemical status (with high or medium confidence). If the identified exceedances represented more than 20% of the total GWB area, an additional assessment and trend analysis (see Chapter 1.7.2) was performed for each MP with the identified exceedance. GWB was considered to be in good chemical status (high or medium confidence) if no statistically significant upward trend was identified at any of these MPs or the identified exceedances did not pose a significant risk to the chemical status of GWB, and good status (with medium confidence) if trends could not be assessed due to lack of data. Otherwise, GWB was considered to be in poor status (with high confidence) if it could not be proved that the identified exceedances did not pose a significant risk to the overall chemical status of GWB, or were representative only of local effects, or of groundwater natural status/quality (LVĢMC, 2021). The test procedure is given in FIGURE 1.8.1.2.2.

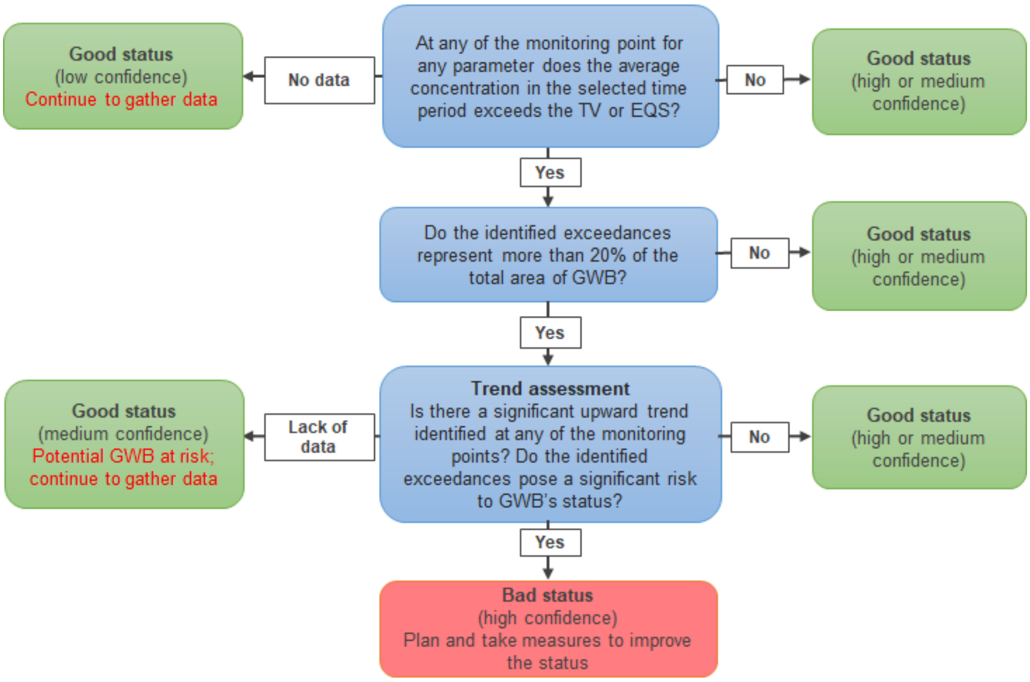


FIGURE 1.8.1.2.2 **Schematic procedure for tests used to assess the chemical status of GWB** (modified after LVĢMC, 2021)

Each test was performed individually and the results of each test were summarized to obtain an overall assessment of the chemical status of the GWB: the worst result of all the chemical status assessment tests performed was considered to be the total chemical status of GWB. The results of the chemical status assessment were used to assess the level of confidence based on the number of MPs (monitoring network coverage), the number of groundwater samples collected, as well as the identified exceedances (LVĢMC, 2021).

1.8.2. Quantitative status assessment

The definition of good quantitative status of the GWB is set out in the Annex V 2.1.2 of the WFD. As noted in this Annex, good groundwater quantitative status is achieved when the available groundwater resources in the GWB are not exceeded by the long-term annual average groundwater abstraction. It can be concluded that the quantitative status of the GWB can be described as the extent to which the GWB is affected by the direct or indirect groundwater abstraction (EC, 2009).

For the GWB to be in good quantitative status, each of the objectives covered by the definition of good status must be met: available groundwater resources must not be exceeded by the long-term annual average groundwater abstraction, no significant diminution of surface water chemistry and/or ecology must be done resulting from anthropogenic groundwater level alterations or changes in flow directions for any associated SWBs, no significant damage must be done to GDTEs resulting from an anthropogenic groundwater level alterations as well as no saline or other intrusions must occur resulting from anthropogenically induced sustained changes in groundwater flow directions (EC, 2009).

To determine the overall quantitative status of the GWB, several tests (water balance, saline or other intrusions, surface waters, and groundwater dependent terrestrial ecosystems) should be applied that considers the impacts of anthropogenically induced long-term alterations in groundwater level and/or flow.

Each test must assess whether the GWB is meeting the relevant environmental objectives. Not all environmental objectives apply to every GWB, therefore, only the relevant tests should be applied as necessary (EC, 2009).

An overlap between the chemical status assessment for certain elements of the quantitative status assessment exists, in particular the assessment relating saline or other intrusions. In this case the assessment for chemical and quantitative status for this element can and should be combined. For other tests there is a need to share information between the chemical and quantitative assessments (EC, 2009).

An assessment of quantitative status is required for all GWBs, however, where there is a high degree of confidence that the GWB is currently not at risk of failing quantitative status objectives then it is reasonable to assume that the GWB is in good status, based on the assessment of pressures and impacts (accordingly - no significant groundwater abstraction pressure or any other groundwater levels altering impacts have been identified). This is consistent with adopting a risk-based approach (EC, 2009).

The monitoring network for assessment of the quantitative status of GWBs must be following the conceptual model (EC, 2009), which allows the assessment of groundwater balance, groundwater quantity and quality interactions with the associated risks of SWBs, as well as to assess the potential water exchange between groundwater and surface water.

1.8.2.1. Quantitative status assessment in Estonia

The quantitative status assessment is based on the calculation of the natural balance of the GWB and on the evaluation of how the disturbances caused by human activity would affect that (Marandi et al., 2020). The level of disturbances is defined via the available groundwater resource in the WFD: "*Available groundwater resources' means the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems*".

Therefore the first test in GWB quantitative status assessment was ***water balance*** test (Test 6) (FIGURE 1.8.2.1.1), where the natural groundwater resources (natural balance) was assessed against the approved (calculated) groundwater resources and the groundwater abstraction (total abstraction and abstraction in groundwater well fields) (Marandi et al., 2020).

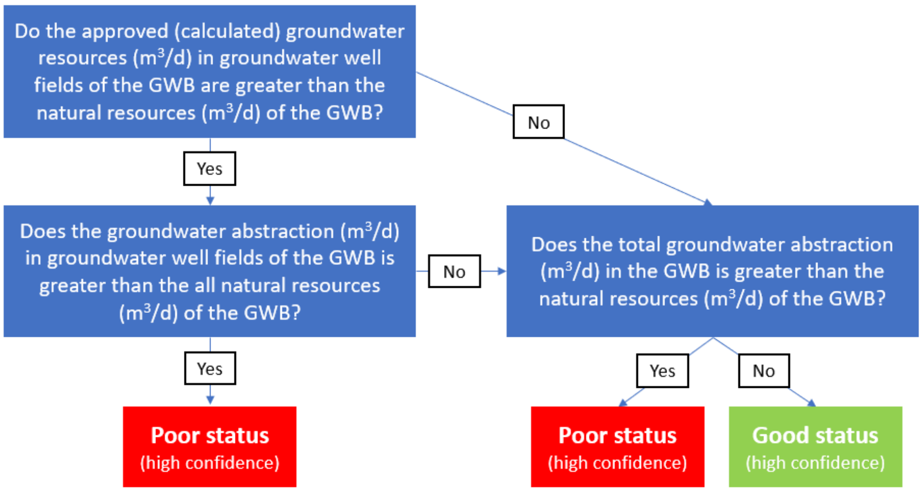


FIGURE 1.8.2.1.1 **The flow diagram of the water balance test**
(modified after Marandi et al., 2020)

If the groundwater abstraction in groundwater well fields was greater than the natural groundwater resources of the GWB, the GWB was considered to be in poor status (high confidence). If the groundwater abstraction in groundwater well fields was lower than the natural groundwater resources of the GWB, the test was continued with the overall (total) groundwater abstraction from the GWB (FIGURE 1.8.2.1.1).

In the assessment of overall (total) groundwater abstraction, the quantities of groundwater natural resources of the GWB and total groundwater abstraction in the GWB were compared. If the overall (total) groundwater abstraction was less than the natural groundwater resources of the GWB, the GWB was considered to be in good status (high confidence). Otherwise, the GWB was considered to be in poor status (high confidence).

Further tests were evaluating more local resources to assess whether the groundwater abstraction can affect saline or other intrusions (FIGURE 1.8.2.1.2), surface waters (GAAEs) (FIGURE 1.8.2.1.3) and groundwater dependent terrestrial ecosystems (GDTEs) (FIGURE 1.8.2.1.4).

A test to identify the risk of ***saline or other intrusions*** (Test 7) and to assess its impact on the quantitative status of GWB was performed only in those GWBs where threshold values have been established for chloride (Cl^-) and/or sulfate (SO_4^{2-}) ions, characterizing intrusion processes. The first step was to determine whether a statistically significant upward trend in the annual average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations (aggregated data by whole GWB) have been identified and/or whether these concentrations have exceeded the established threshold values (by single MP) (FIGURE 1.8.2.1.2). If there were no statistically significant upward trends identified (in the aggregated data by whole GWB) and the average concentrations in the individual MPs were lower than the threshold values, the GWB was considered to be in good chemical status (high confidence), according to this test (Marandi et al., 2020).

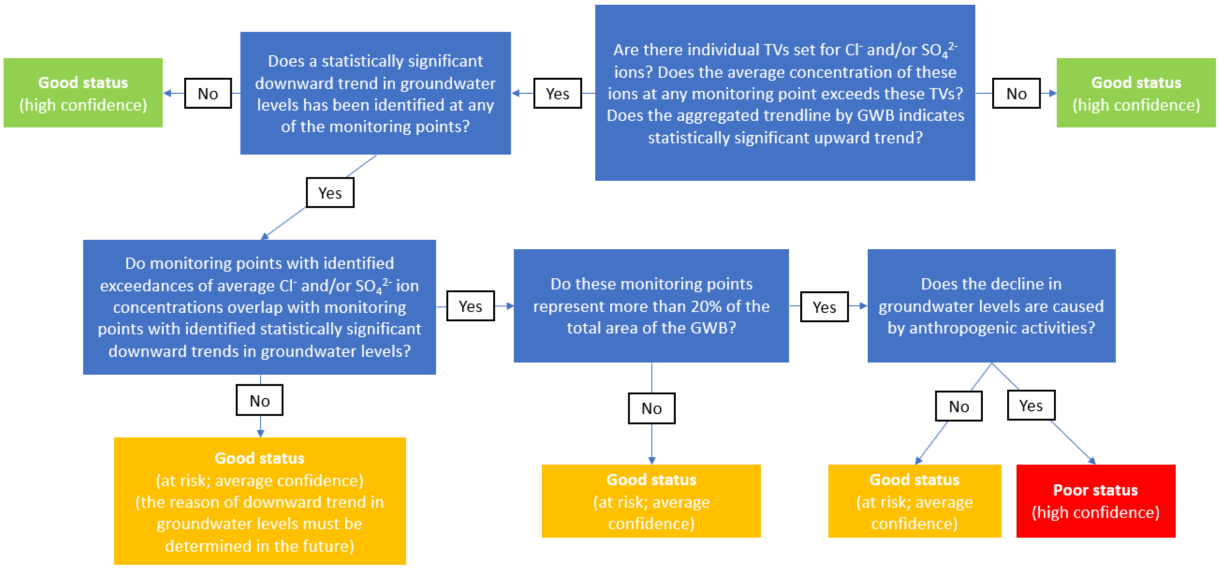


FIGURE 1.8.2.1.2 **Flow diagram of the saline or other intrusions assessment test**
(modified after Marandi et al., 2020)

If there was a statistically significant upward trend identified based on chloride (Cl^-) and/or sulfate (SO_4^{2-}) ions concentrations in the aggregated data by whole GWB and/or if these concentrations have exceeded the established threshold values (by single MP), it was determined whether statistically significant downward trend in groundwater levels has been identified at any of the MPs. If no statistically significant downward trend in groundwater levels was identified at any of the MPs, the GWB was considered to be in good quantitative status (high confidence). However, if a statistically significant downward trend in groundwater levels was identified at any of the MPs, the relationship between the downward trend in groundwater levels and exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations was inspected (FIGURE 1.8.2.1.2).

If MPs with identified exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations did not overlap with MPs with identified statistically significant downward trends in groundwater levels, the GWB was considered to be in good status but at risk (average confidence) (additional studies must be carried out in the future to determine the reason for the increase in concentrations of pollutants in the GWB). However, if MPs with identified exceedances overlapped with MPs with identified downward trends in groundwater levels, the extent of it was assessed (FIGURE 1.8.2.1.2).

If the overlap between the two processes was identified, it was further determined whether such MPs represent more than 20% of the total area of the GWB (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in a good quantitative status but at risk (average confidence). In a situation where such MPs represented more than 20% of the total area of the GWB, the interrelationship between the upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations, the downward trend in groundwater levels and groundwater abstraction was examined (FIGURE 1.8.2.1.2).

If there was no link between intensive groundwater abstraction and downward trend in groundwater levels identified, the GWB was considered to be in good quantitative status but at risk (low confidence). But if the downward trend in groundwater levels and the associated upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations was linked to the pressure of groundwater abstraction, the GWB was considered to be in poor quantitative status (high confidence) (FIGURE 1.8.2.1.2).

The purpose of the ***surface waters*** test (Test 8) was to assess whether the lowering of groundwater levels due to groundwater abstraction may result in unfavorable status of GAAEs/SWBs. The test initially included groundwater associated watercourses (Terasmaa et al., 2015; Vainu et al., 2019; Marandi et al., 2019) which have previously undergone a hydromorphological assessment (Auväärt et al., 2019). As the status assessment for standing water bodies regarding water abstraction has not been previously done and the water levels of lakes was generally not constantly monitored in Estonia, the assessments of groundwater associated standing water bodies presented in the work by Tallinn University (Vainu et al., 2019) were taken into account.

The first step of the surface waters assessment test was the selection of GWBs in which GAAEs (SWBs) have been previously identified. If no GAAEs were previously identified in the GWB, it was considered to be in good status (high confidence). If otherwise, the test was continued with the next step – assessment of groundwater contribution to surface waters (FIGURE 1.8.2.1.3).

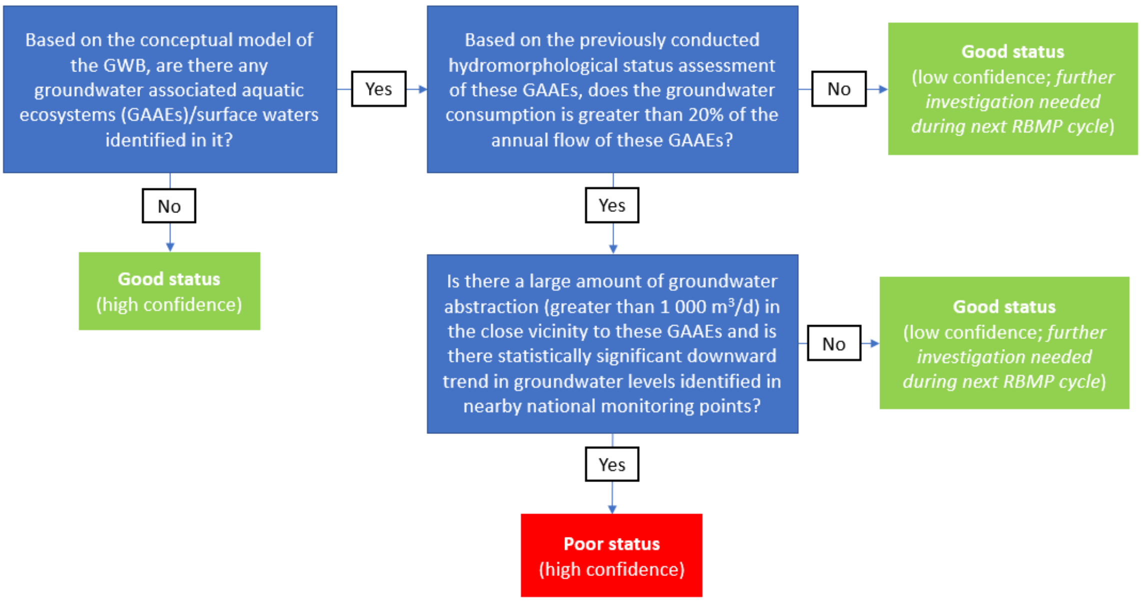


FIGURE 1.8.2.1.3 **Flow diagram of the surface waters assessment test**
(modified after Marandi et al., 2020)

If, based on results of hydromorphological assessment, groundwater consumption was less than 20% of the surface waters annual flow, GWB was considered to be in good status (low confidence; further investigation needed during next RMBP cycle). If otherwise, the test was continued with the next step - groundwater abstraction assessment (FIGURE 1.8.2.1.3).

If no large amount of groundwater abstraction (greater than 1000 m^3/d) was identified in the close vicinity to in the previous step identified GAAEs and no statistically significant downward trend in groundwater levels was identified in nearby monitoring wells, the GWB was considered to be in good quantitative status (low confidence; further investigation needed during the next RBMP cycle). But if the opposite conditions were met, the GWB was considered to be in poor quantitative status (high confidence) (FIGURE 1.8.2.1.3).

The purpose of the ***groundwater dependent terrestrial ecosystems*** (GDTEs) test (Test 9) was to assess whether the groundwater abstraction may lead to the disadvantage of these ecosystems. The connections of GDTEs and with GWBs have been highlighted in the 2015 study of the Institute of Ecology of Tallinn University (Terasmaa et al., 2015).

The first step of the GDTEs assessment test was the selection of GWBs in which such ecosystems have been previously identified. If no GDTEs were previously identified in the GWB, it was considered to be in good status (high confidence). If otherwise, the test was continued with the next step - condition of GDTEs according to the assessment based on the Habitats Directive (FIGURE 1.8.2.1.4).

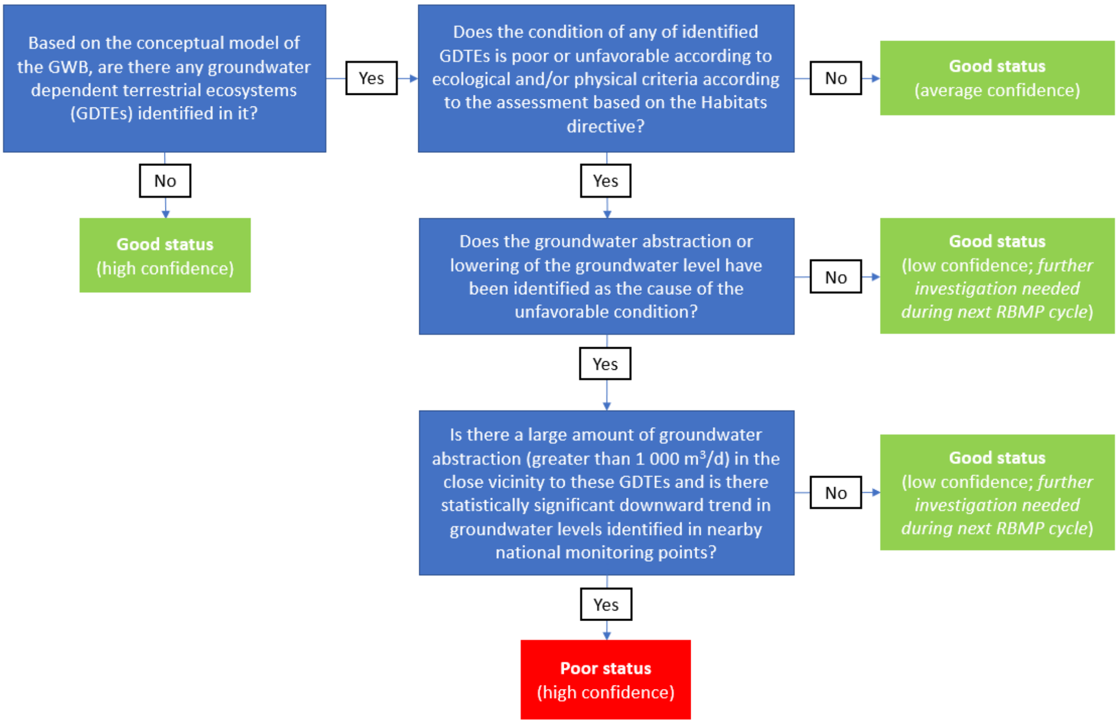


FIGURE 1.8.2.1.4 **Flow diagram of the GDTEs assessment test** (modified after Marandi et al., 2020)

If the condition of all identified GDTEs was good (greater than poor or unfavorable) according to ecological and/or physical criteria according to the assessment based on the Habitats Directive, the GWB was considered to be in good status (average confidence). However, if at least one GDTE was in poor or unfavorable condition, the test was continued with the next step - assessment of groundwater contribution to GDTEs in poor or unfavorable condition (FIGURE 1.8.2.1.4).

If during the assessment of based on the Habitats Directive no groundwater abstraction and no lowering of the groundwater levels have been identified as the cause of the unfavorable condition of respective GDTEs, the GWB was considered to be in good status (low confidence; further investigation needed during next RBMP cycle). But if the opposite conditions were met, the test was continued with the last step - groundwater abstraction assessment (FIGURE 1.8.2.1.4).

If no large amount of groundwater abstraction (greater than 1000 m^3/d) was identified in the close vicinity to in the previous step identified GDTEs and no statistically significant downward trend in groundwater levels was identified in nearby monitoring wells, the GWB was considered to be in good status (low confidence; further investigation needed during the next RBMP cycle). But if the opposite conditions were met, the GWB was considered to be in poor status (high confidence) (FIGURE 1.8.2.1.4).

1.8.2.2. Quantitative status assessment in Latvia

Following the recommendations (EC, 2009), assessment of the quantitative status must be carried out for all GWBs, but in cases where there is a high probability that GWB is not at risk of not achieving a good quantitative status, the GWB can be assessed as being in good quantitative status. Accordingly, in Latvia, the in-depth assessment of the quantitative status was performed only for GWBs for which a significant groundwater abstraction pressure has been identified (LVĢMC, 2021).

For GWBs where no significant groundwater abstraction pressure was previously identified, the quantitative status was assessed as good (average confidence). Additional criteria were also set: if in none of the groundwater well fields of the respective GWB no depletion of groundwater resources was detected in the respective period (2014-2019), as well as no exceedances of the calculated maximum groundwater level reduction were observed, then GWB was assessed with good quantitative status (with an average level of confidence). For other GWBs where exceedances were observed and groundwater abstraction pressures were identified, an in-depth quantitative status assessment was performed by performing groundwater balance, as well as seawater and/or saline intrusion tests (according to the characteristics of each GWB) (LVĢMC, 2021).

In the ***groundwater balance*** test, primarily the average groundwater abstraction (m^3/d) for the period from 2015 to 2019 was compared with the total approved (calculated) groundwater resources (m^3/d) in groundwater well fields, expressed as a ratio (%). GWB was assessed being in good quantitative status (average confidence) if this ratio did not exceed the 75% threshold value (the 75% threshold value was adapted for the assessment of groundwater balance from Guidance Document No.18 (EC, 2009), where this threshold value is used in trend assessment as a starting point for irreversible deterioration in quality). In case of exceeding this threshold value, additional data analysis were performed - long-term data on changes in groundwater levels in State Monitoring Network monitoring wells were collected and assessed whether statistically significant downward trends are observed. GWB was considered to be in good quantitative status (high confidence) if no statistically significant downward trends were observed in any of the monitoring wells. If a statistically significant downward trend was identified in one or more monitoring wells, it was assessed whether the identified monitoring wells represented more than 20% of the total GWB area (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in good quantitative status (high confidence). If the 20% threshold was exceeded, GWB was considered to be in poor quantitative status (high confidence) (LVĢMC, 2021). The schematic procedure of the groundwater balance assessment test is given in FIGURE 1.8.2.2.1.

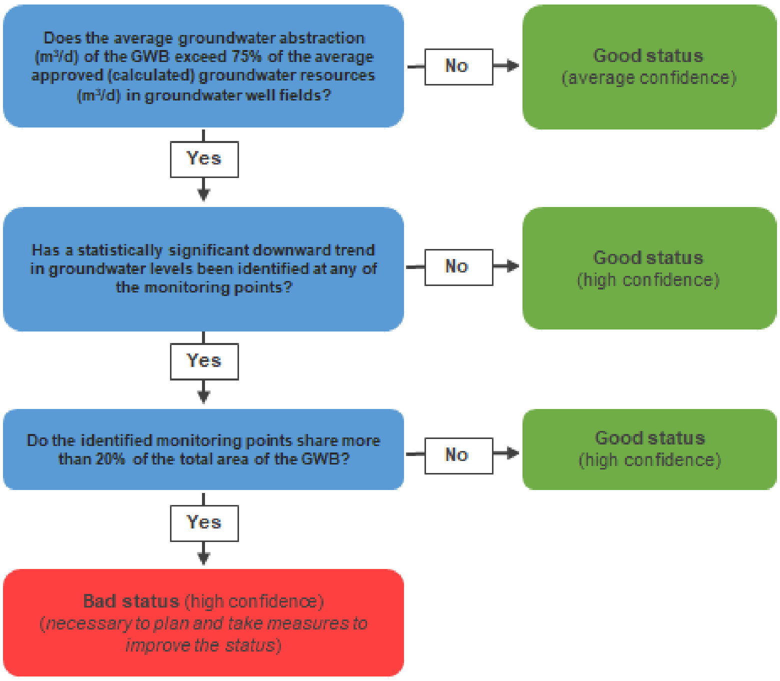


FIGURE 1.8.2.2.1 **Schematic procedure of groundwater balance test**
(modified after LVĢMC, 2021)

It should be noted that in the groundwater balance test, none of the GWBs reached the step of assessing trends in groundwater levels, as the 75% threshold value for approved (calculated) groundwater resources was not exceeded. In the future, it is necessary to develop a detailed methodology for the assessment of trends in groundwater levels and to intensify the arrangement of groundwater level measurement data series, because, with current knowledge and available data quality, the assessment is heavily based on expert judgment in each case (LVĢMC, 2021).

Saline or other intrusions test was also performed only for GWBs for which significant groundwater abstraction pressure was previously identified. As a starting point for both tests, the results of the respective tests from the chemical status assessment were used – if the poor chemical status of GWB was not identified in the corresponding test during the chemical status assessment, then GWB was assigned with a good quantitative status (average confidence) in the relevant quantitative test (FIGURE 1.8.2.2.2).

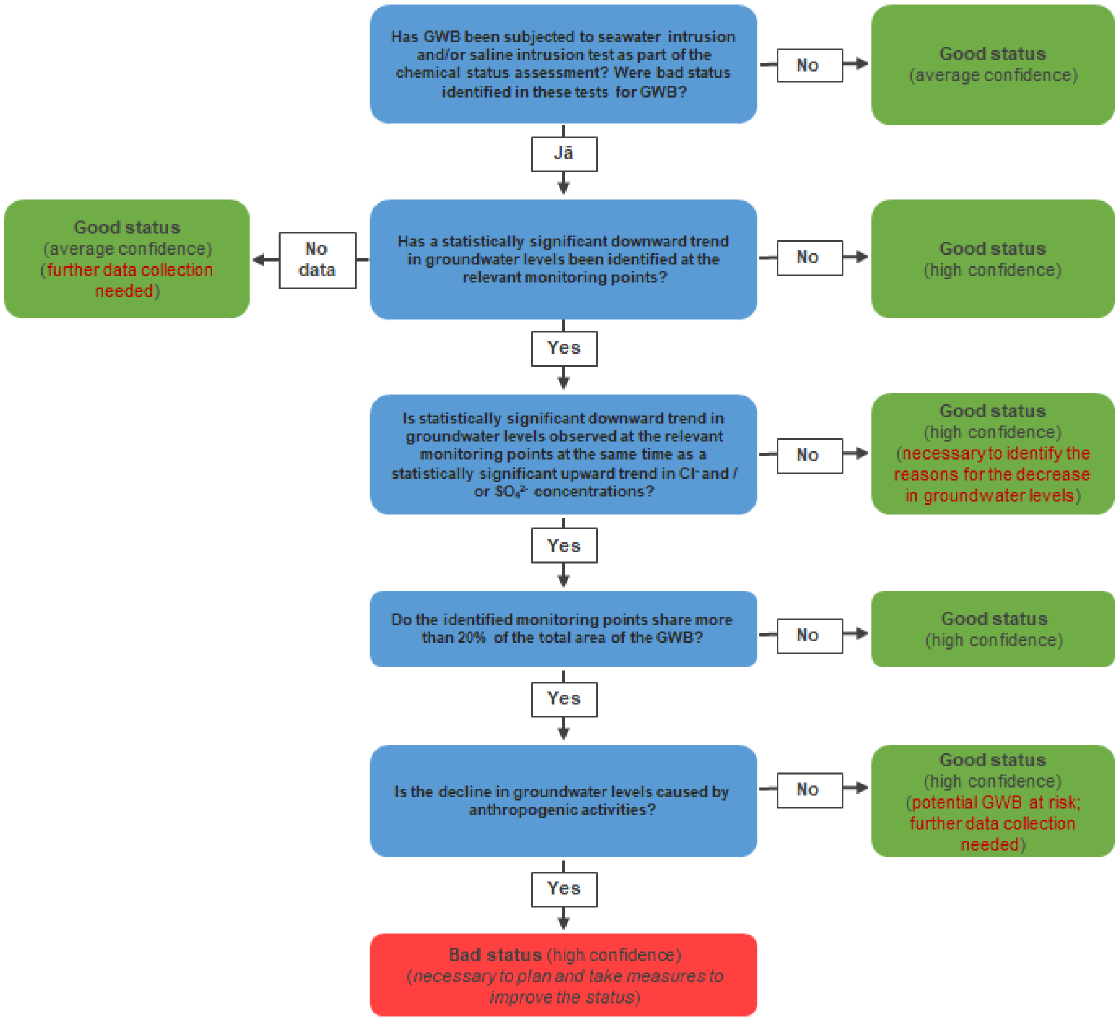


FIGURE 1.8.2.2.2 **Schematic procedure of saline or other intrusion tests**
(modified after LVĢMC, 2021)

In case poor chemical status was identified for GWB in saline or other intrusion tests as part of the GWB chemical status assessment, an in-depth saline or other intrusion test was performed on GWB by analyzing trends in groundwater levels, identifying statistically significant downward trends. If no such trends were identified, GWB was considered to be in good quantitative status (high confidence). If it was not possible to assess trends in groundwater levels due to a lack of data, GWB was also considered to be in good quantitative status but with an average level of confidence (FIGURE 1.8.2.2.2).

If statistically significant downward trends in groundwater levels were identified at one of the relevant MPs, then based on the results of the chemical status assessment in the relevant test, it was determined whether they are observed simultaneously with statistically significant upward trends in Cl^- and/or SO_4^{2-} concentrations. If no such overlap was identified, GWB was considered to be in good quantitative status (high confidence), but with the side-note of the need to clarify the reasons for the decrease in groundwater levels in the future (FIGURE 1.8.2.2.2).

If an overlap between the two processes was observed, it was further identified whether such MPs share more than 20% of the total area of the GWB (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in a good quantitative status (high confidence) (FIGURE 1.8.2.2.2).

If the 20% threshold was exceeded, it was additionally assessed whether the decrease in groundwater levels was due to local anthropogenic impacts. If no link was identified, GWB was considered to be in a good quantitative status (high confidence), but GWB could be potentially at risk. If anthropogenic effects were identified, then GWB was considered to be in poor quantitative status (high confidence) (FIGURE 1.8.2.2.2).

It should be noted that in saline or other intrusion tests, the step of assessing trends in groundwater levels was reached only for GWBs at risk. The long-term groundwater level data series were used in the trend assessment, calculating the average value of groundwater levels each year to assess the development of the overall groundwater level situation (respectively: an increase or decrease in groundwater levels). In the end, based on the mathematical results of the regression analysis, the results were used only from those monitoring wells where statistically significant trends (upward or downward) were observed. In the future, it is necessary to develop a detailed methodology for assessing trends in groundwater levels and to focus more on arranging data series for groundwater level measurements, because, with current knowledge and the quality of available data, the assessment is heavily based on expert judgment in each case (LVĢMC, 2021).

The tests were performed individually and the results of each individual test were summarized to obtain an overall assessment of the quantitative status of GWB. The worst result from each test was considered to be the total quantitative status of GWB (LVĢMC, 2021).

2. Studies of EU level guidelines and best practices from other countries on common groundwater resources management and assessment

Studies of EU level guidelines and best practices from other countries on common groundwater resources management and assessment was done by the external expert Enn Karro from University of Tartu (Institute of Ecology and Earth Sciences, Department of Geology). The purpose of the expert assessment was to analyze how TGWBs have been defined in the MS of the EU in order to provide recommendations for the establishment of joint Estonian and Latvian GWBs within the WaterAct project.

Chapter 2.1. "The requirements of European water policy for the establishment of transboundary groundwater bodies" is related to the principles of formation and definition of TGWBs in the countries of the EU. Based on the literature review, the requirements of European water policy for the establishment of TGWBs, the assessment of the status of common GWBs and the joint reporting of these data to the EC are presented. Chapter 2.2. "International River Basins and transboundary groundwater bodies in Europe" and Chapter 2.3. "Transboundary groundwater bodies in Danube RBD – examples of TGWBs delineation and assessment" discuss the establishment and status assessment of two TGWBs in the EU MS under the WFD and point out the problems that have arisen and their possible solutions.

Chapter 2.4. "Recommendations for WaterAct project partners" is aimed to describe what practical experience, based on literature review and the two case studies, could be used in the identification and management of Estonian-Latvian TGWBs.

This expert assessment was based in particular on the GWD, the EU WFD and its Guidance Documents, reports from the Commission to European Parliament and the Council, River Basin Management Plans, different project materials, scientific publications, presentations as well as the experiences and opinions of foreign experts involved in the delineation process of TGWBs in Europe

2.1. The requirements of European water policy for the establishment of transboundary groundwater bodies

The first part of the expert assessment is related to the principles of formation and definition of TGWBs in the countries of the EU. Based on the literature review, the requirements of European water policy for the establishment of TGWBs, the assessment of the status of common GWBs and the joint reporting of these data to the EC are presented. This chapter is based in particular on the GWD, the WFD and its Guidance Documents.

On October 23, 2000, the WFD was finally adopted. The Directive was published in the Official Journal (OJ L 327) on 22 December 2000 and entered into force the same day. The GWD has been developed in response to the requirements of Article 17 (Strategies to prevent and control pollution of groundwater) of the WFD.

2.1.1. Groundwater in the Water Framework Directive

The components of the WFD dealing with groundwater cover a number of different steps for achieving good quantitative and chemical status of groundwater by 2015. They require MS to:

- define GWBs within RBDs to be designated and reported to the EC by MS. They must classify them by analyzing the pressures and impacts of human activity on the quality of groundwater with a view to identifying GWBs presenting a risk of not achieving the WFD environmental objectives. MS were obliged to carry out this classification between 2004 and 2005 and report the results back to the EC.
- establish registers of protected areas within each RBD for those groundwater areas or habitats and species directly dependent on water. The registers must include all bodies of water used for the extraction of drinking water and all protected areas covered under the following directives: the Bathing Water Directive (76/160/EEC), the vulnerable zones under the Nitrates Directive (91/676/EEC) and the sensitive areas under the Urban Wastewater Directive (91/271/EEC), as well as areas designated for the protection of habitats and species including relevant Natura 2000 sites designated under Directives 92/43/EEC and 79/409/EEC. Registers shall be reviewed under the RBMPs updates.

- establish groundwater monitoring networks based on the results of the classification analysis so as to provide a comprehensive overview of groundwater chemical and quantitative status. MS are also obliged to design a monitoring programme that had to be operational by the end of 2006.
- set up a RBMP for each RBD which must include a summary of pressures and impacts of human activity on groundwater status, a presentation in map form of monitoring results, a summary of the economic analysis of water use, a summary of protection programmes, control or remediation measures etc. The first RBMPs were published at the end of 2009, links to them can be found in the Commission website. The updated RBMPs were due by the end of 2015 and their review is expected every six years thereafter.
- take into account by 2010 the principle of recovery of costs for water services, including environmental and resource costs in accordance with the polluter pays principle.
- established by the end of 2009 a programme of measures for achieving the WFD environmental objectives (e.g. abstraction control, prevent or control pollution measures) that would be operational by the end of 2012. Basic measures include, in particular, controls of groundwater abstraction, controls (with prior authorization) of artificial recharge or augmentation of GWBs (providing that it does not compromise the achievement of environmental objectives). Point source discharges and diffuse sources liable to cause pollution are also regulated under the basic measures. Direct discharges of pollutants into groundwater are prohibited subject to a range of provisions listed in the Article 11. The programme of measures has to be reviewed and if necessary updated by 2015 and every six years thereafter.

The GWD establishes a regime which sets GQS and introduces measures to prevent or limit inputs of pollutants into groundwater. The directive establishes quality criteria that takes account local characteristics and allows for further improvements to be made based on monitoring data and new scientific knowledge. The GWD thus represents a proportionate and scientifically sound response to the requirements of the WFD as it relates to assessments on chemical status of groundwater and the identification and reversal of significant and sustained upward trends in pollutant concentrations. MS should establish standards at the most appropriate level and take into account local or regional conditions.

2.1.2. The Groundwater Directive

The GWD complements the WFD. It requires:

- GQS to be established by the end of 2008;
- pollution trend studies to be carried out by using existing data and data which is mandatory by the WFD (referred to as *baseline level* data obtained in 2007-2008);
- pollution trends to be reversed so that environmental objectives are achieved by 2015 by using the measures set out in the WFD;
- measures to prevent or limit inputs of pollutants into groundwater to be operational so that WFD environmental objectives can be achieved by 2015;
- reviews of technical provisions of the directive to be carried out in 2013 and every six years thereafter;
- compliance with good chemical status criteria (based on EU standards of nitrates and pesticides and on TVs established by MS).

The guidance documents and technical reports have been produced to assist stakeholders to implement the WFD. Guidance Documents are intended to provide an overall methodological approach, but will need to be tailored to the specific circumstances of each EU MS. All these documents and other results of the work under the Common Implementation Strategy (CIS), for instance key events and additional resource documents related to different aspects of the implementation process, can be found in the WFD Communication and Information Resource Centre for Administrations, Businesses and Citizens (CIRCABC) library. Thus, also the published CIS Guidance Documents and other CIS thematic documents (a total of 60 reports) available on CIRCABC were examined to find the information on TGWBs. The following is an overview of the guidelines found in the Directives and guidance documents.

The GWD states that in order to ensure consistent protection of groundwater, MS sharing GWBs should coordinate their activities in respect of monitoring, the setting of TVs, and the identification of relevant hazardous substances. The Article 3 (Criteria for assessing groundwater chemical status) of this directive determines, that MS shall ensure that, for GWBs shared by two or more MS and for GWBs within which groundwater flows across a MS's boundary, the establishment of TVs is subject to coordination between the MS concerned, in accordance with Article 3(4) of the GWD. Where a body or a group of GWBs extends beyond the territory of the Community, the MS concerned shall endeavor to establish TVs in coordination with the non-MS concerned, in accordance with Article 3(5) of Directive 2000/60/EC.

December 22, 2000 will remain a milestone in the history of water policies in Europe: on that date, the WFD was published and thereby entered into force (EC, 2003a).

2.1.3. Guidance documents

According to ***WFD CIS Guidance Document No.2*** (EC, 2003b), the WFD covers all waters, including inland waters (surface water and groundwater) and transitional and coastal waters up to one sea mile from the territorial baseline of a MS. This totality of waters is, for the purpose of the implementation of the directive, attributed to geographical or administrative units, in particular the river basin, the RBD, and the "water body" (Articles 2 (13), (15), (10), and (12) respectively). In addition, groundwaters and stretches of coastal waters must be associated with a river basin (district).

The application of the term GWB must be understood in the context of the hierarchy of relevant definitions provided under Article 2 of the WFD:

- Article 2.2: Groundwater means all water, which is below the surface of the ground in the saturated zone and in direct contact with the ground or subsoil;
- Article 2.11: Aquifer means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater;
- Article 2.12: Body of groundwater means a distinct volume of groundwater within an aquifer or aquifers.

The WFD's definition of the term GWB does not provide explicit Guidance on how GWBs should be delineated (EC, 2003b). The delineation of GWB must ensure that the relevant objectives of the WFD can be achieved. This does not mean that a GWB must be delineated so that it is homogeneous in terms of its natural characteristics, or the concentrations of pollutants or level alterations within it. However, GWBs should be delineated in a way that enables an appropriate description of the quantitative and chemical status of groundwater. Article 7 requires the identification of all GWBs used, or intended to be used, for the abstraction of more than 10 m^3 of drinking water a day as an average. By implication, this volume could be regarded as a significant quantity of groundwater. The WFD's definitions of aquifer and GWB permit GWBs to be identified either separately within different strata overlying each other in the vertical plane, or as a single body of groundwater spanning the different strata. To facilitate the estimation of quantitative status, the upper and lower boundaries should be based first on geological boundaries and then on other hydraulic boundaries such as flow lines. Also, GWBs must be assigned to a RBD (Article 3.1).

WFD CIS Guidance Document No.3 (EC, 2003c) states that the construction of basic conceptual models of groundwater flow and chemical systems, and then of GWBs must be undertaken early in the process of initial groundwater characterization. This will include the delineation of the GWB boundaries and an initial understanding of the nature of the flow and geochemical system and interaction with SWBs and terrestrial ecosystems. It will also involve water quality information and an early assessment of pressures. In essence the model should describe the nature of the aquifer system, both in terms of quantity and quality, and the likely consequences of pressures. It is vital, even at the stage of GWB delineation, that a coherent understanding of the body is reached. All data concerning the nature of the GWB collected during the characterization process should be tested against the conceptual model, both to refine the model and to check for data errors.

WFD CIS Guidance Document No.7 (EC, 2003d), which is dedicated on the monitoring under the WFD says, that the requirements for the WFD (Annex V) also indicates that monitoring information from groundwater is required for estimating the direction and rate of flow in GWBs that cross Member States boundaries.

The WFD requires Member States to estimate groundwater flows across their boundaries. This is a separate requirement from the assessment of the status of GWBs. It will provide management information to Member

States on how groundwater and its associated surface ecosystems may be affected by pressures in neighboring States, and therefore how the measures needed to achieve the WFD's objectives should be apportioned between those States. To provide estimates of flows across a national border, conceptual models/understandings tested using water balances will be needed for the groundwater systems on both sides of the border. The degree of accuracy and precision needed in such models will be proportional to the difficulty in reliably judging the status of water bodies on either side of the border and in assessing the achievement of other relevant objectives, and should be such as to enable effective measures to be designed.

For TGWBs, harmonization of coordinate systems is an important issue, which is handled in the ***WFD CIS Guidance Document No.9*** (EC, 2003e). Document states that special attention should be given in case of transboundary harmonization of GIS datasets. In this context, the possibility to use as far as possible already harmonized data is recognized. This is especially true for the case of large iRBs (e.g. the Rhine or the Danube River basin), where the harmonization work could be substantial. An example of such a database could be EuroGlobalMap at a scale of 1 : 1 000 000.

WFD CIS Guidance Document No.15 on the groundwater monitoring (EC, 2007a) acknowledges, that the specific provisions concern those GWBs which cross the boundary between two or more Member States. Bilateral agreement should be reached on monitoring strategies, which requires coordination of conceptual model development, the exchange of data and quality assurance (QA) and quality control (QC) aspects (in line with the requirements of Article 13(2) of the WFD). The provisions for the surveillance monitoring require TGWBs to be monitored for those parameters which are relevant for the protection of all uses supported by the groundwater flow.

The surveillance monitoring programme will also be useful for defining NBLs (as defined in the daughter the GWD) and characteristics within the GWB. This will enable future changes in conditions to be assessed, reference data to be acquired and typologies to be investigated. This information will be useful for characterizing TGWBs and as a basis for European-wide reporting (EC, 2007a).

WFD CIS The Guidance Document No.16 on the Groundwater in Drinking Protected Areas (EC, 2007b) explains the obligations for Protected Areas that apply to groundwater, in particular the requirements for DWPAs that are introduced under Article 7 of the WFD. It does not cover the requirements of the source Directives under which individual Protected Areas are designated. The guidance explains the relationship between the objectives for protected areas and other the WFD objectives. In particular it clarifies the requirements for DWPAs. In addition to explanatory materials, the guidance includes the example of groundwater protection in TGWBs between Hungary and Romania (Maros/Mures alluvial plain - central part of the Western Plain in Romania and south-eastern part of the Great Hungarian Plain). The Mures/Maros alluvial fan group of GWBs is designated as an important TGWB in the Danube River Basin, which is an important drinking water resource in both countries.

WFD CIS Guidance Document No.18 on the Groundwater Status and Trend Assessment (EC, 2009a) states, that the GWD establishes a requirement for Member States to derive TVs for pollutants (or groups of pollutants) that are related to the pressures identified as putting GWBs at risk. These TVs and standards are then to be used to assess groundwater chemical status, as defined in the WFD. In addition to assessing the impacts of pollutants, the WFD also requires consideration of the impacts of groundwater abstraction on GWBs, dependent SWBs and ecosystems, and an assessment of quantitative status. The WFD and the GWD also require that trends in pollutant concentrations are identified and that these trends are assessed to determine whether they are environmentally significant. Where significant upward trends exist, they must be reversed through the application of programs of measures to ensure that there are no future failures of environmental objectives. The GWD starting point for trend reversal must be defined as a proportion of the TV or quality standard (75% by default).

Annex V of the WFD and the GWD specify how Member States have to report chemical and quantitative status and trends in the RBMPs. All reporting requirements are considered within the set of Reporting Sheets which were developed by Working Group D (Reporting). Reporting for the first river basin cycle was required in 2010. For TGWBs the relevant Reporting Sheet requires information about the steps put in place to coordinate the establishment of TVs, status assessment and trend assessment for TGWBs (EC, 2009a).

The guidance (EC, 2009a) also emphasizes that the Member States sharing TGWBs shall ensure that the establishment of TVs is subject to coordination between the Member States concerned (Article 3.3 of the

GWD). For GWBs shared between one or more Member States and one or more Non-Member States, the concerned Member State(s) shall endeavor to establish TVs in coordination with the non-Member State(s) concerned (Article 3.4 of the GWD).

Reporting requirements for GWBs are described in Chapter 6 of the ***WFD CIS Guidance Document No.21*** (EC, 2009b). Among the relevant information, for TGWBs, a summary of the steps put in place to coordinate the objectives (establishment of TVs, status and trend assessment) should be provided. Guidance also mentions that for each RBD the data are required to enable the maps of TGWBs, which have been assigned to the RBDs, to be produced.

WFD CIS Guidance Document No.26 (EC, 2010) is dedicated on the Risk Assessment and the Use of Conceptual Models for Groundwater. A conceptual model is the basis for reliable decisions in groundwater risk assessment and management. In the context of this guidance, a conceptual model is a means of describing and optionally quantifying systems, processes and their interactions. A hydrogeological conceptual model describes and quantifies the relevant geological characteristics, flow conditions, hydrogeochemical and hydrobiological processes, anthropogenic activities and their interactions. The degree of detail is based on the given problems and questions. It is one of the basic steps for the management of GWBs. Conceptual models are needed to describe groundwater quantity (linked to quantitative status) as well as chemical composition (chemical status) of groundwater, as referred to in the WFD. Conceptual models can be developed to different degrees of complexity, from simple qualitative descriptions of the geology to complex combinations of qualitative and quantitative descriptions of the hydrogeological processes and the impacts. To cover the different needs for management of GWBs, spatial investigation scales vary from small (10-100's m^2) to large (km^2) and time resolution from hours/days to months/years. It depends on specific tasks and problems (e.g. groundwater quantity, chemical composition, point source pollution, diffuse pollution, interaction with surface waters, land use). The Guidance Document emphasizes that for TGWBs it is highly recommended that jointly agreed conceptual models are developed.

WFD CIS Guidance document No.35 (EC, 2016) has been endorsed by EU Water Directors at their meeting in Heraklion on 6 June, 2014. The purpose of this document is to provide Member States with guidance on how the various aspects of the WFD should be reported to the EC. This the WFD Reporting Guidance brings together and updates the various elements of existing guidance documentation and materials into a single guidance document that can be used by those responsible for reporting data and information. The document confirms, that in addition to the areal variability, the vertical variability makes homogenization work at the pan-European scale very complex, particularly for TGWBs where the connected GWBs may be differently delineated by the Member States because of different national approaches, focuses or management constraints. However, also in the light of this new guidance, if TGWBs are identified, it should be indicated whether the establishment of TVs has been coordinated with the neighboring countries concerned.

Transboundary groundwater monitoring aspects are also discussed in a technical report on groundwater management in the Mediterranean area by the Mediterranean Groundwater WG (MED-EUWI, 2007). The report specifies that groundwater monitoring obligations under the WFD concern quantitative and chemical aspects (EC, 2007a). Regarding the quantitative status, the monitoring programmes will have to be designed so as to provide a reliable assessment of the quantitative status of all GWBs or groups of bodies including assessment of the available groundwater resource. The network will have to consider the representativeness of MPs, taking into account short and long-term variations in recharge, and the frequency that should be sufficient for quantitative assessments (in particular for evaluating the impacts of abstractions and discharges on the groundwater level, and – for TGWBs – estimating the direction and rate of groundwater flow across the Member State boundary).

Because the borders between riparian countries do not necessarily coincide with the natural boundaries of groundwater aquifers, groundwater may flow from one state to another. Moreover, abstractions or other activities on one side of the border may adversely affect groundwater functions on the other side. To be able to distinguish natural characteristics from anthropogenic effects, information is required about the aquifer and flow conditions on both sides of the border. Moreover, on a regional basis, the shared use of groundwater resources can also cause conflict between nations, either due to groundwater over-exploitation or contamination. Such conflicts must be avoided by planning and coordinating efficient development and sustainable management of water resources both with respect to quantity and quality. This is impossible to accomplish without a reliable database on aquifers. The possible existing monitoring networks on each side of a national border may have been set up with different objectives, the measurement locations, times and frequencies might not match and the assessment and presentation may be different. Furthermore, it is often very difficult to obtain the required data because of logistical difficulties. Consequently, without proper establishment of cross-border groundwater monitoring and assessment, errors may occur in aquifer characterization and in the prediction and evaluation of changes in groundwater flow and quality (MED-EUWI, 2007).

To develop and evaluate strategic policies for groundwater management it is a prerequisite that the monitoring and assessment of groundwater in the riparian countries is performed in a comparable way. This means, for example, in order to assess trends in groundwater quality, the definition of trends, the sampling procedures and chemical and numerical analysis should be comparable on both sides of the border. Existing monitoring networks are mostly operated and maintained with application of national standards and quality control procedures. Harmonization of network design, measurement frequency, standards, quality control and data storage and processing will be needed for setting up transboundary groundwater monitoring (MED-EUWI, 2007).

The document focused on TV variability analysis (CIS WG GW, 2018) was endorsed by CIS Working Group – Groundwater (WG GW) and the Strategic Coordination Group members in 2018. This report provides an analysis of how EU Member States use a certain element of the EU water aquis called TVs, which concerns the protection and management of groundwater quality, and how the use of this element can be compared across Member States. Member States need to set TVs to assess the chemical status of GWBs, as required by the WFD and the GWD. Previous analyses by the EC and by the Working Group Groundwater of the Common Implementation Strategy for the WFD have found that there is considerable variation in the TVs used by Member States across Europe. Several factors make comparisons of groundwater status between Member States difficult. These include variable NBL of inorganic substances, the fact that TVs for all elements of groundwater chemical status are reported to the EC without differentiation and can therefore only be analyzed together, differences in the aggregations methods used to determine GWB status based on individual monitoring results and the application of different criteria for defining TVs.

This report begins with an introduction consisting of background information on previous analyses of TV variability, the objectives of the present analysis, and an overview of the legal basis for TVs. After a brief outline of the applied methodology it describes the results of the analysis of the collected data in the context of previously analyzed TVs for inorganic substances. Following a discussion of the results, the report provides conclusions and recommendations for a way forward for improving the comparability of TVs.

Concerning the transboundary aquifers, this technical report emphasizes, that Member States need to decide on which spatial scales to set TVs at, with options ranging from individual GWBs through groups of GWBs, to RBDs or the part of a transboundary RBD within the Member States, and finally to the national level (the GWD Article 3(2)). TVs for GWBs which are shared between two or more Member States and for GWBs within which groundwater flows across a Member State's boundary need to be coordinated between these Member States (GWD Article 3(3)). Coordination is encouraged when GWBs are shared with non-EU Member States (GWD Article 3(4)).

The WFD asks Member States to identify trends in contaminant concentrations in groundwater and to take measures to reach a good chemical status by 2015, 2021 and 2027. In 2019, Technical Report on Groundwater Quality Trend and Trend Reversal Assessment (CIS WG GW, 2019) was published by CIS WG GW – Voluntary Group "Trend in Groundwater".

The report states that the synthesis of the procedures applied by Member State to assess trends in groundwater quality for the first RBMP reveals the high diversity of procedures and methods that can be applied to respond to a simple and unique question: what are the trends in groundwater quality? Member States have thought a great deal about this not so simple question and have proposed a variety of solutions to assess trends in groundwater quality. This compilation exercise enables comparison of methodologies and highlights the need to go further in analyzing all existing methodologies, in order to identify the best practices and to provide recommendations for groundwater quality assessment under the WFD.

For the first RBMP cycle, a majority of Member States has chosen to apply statistical methods to comply with the trend assessment requirement. The methods used vary between RBMPs dependent on data, procedure or trend and trend reversal assessment methodology applied. Statistical methods used by Member States to identify trends in contaminant concentrations in groundwater could be divided in 2 groups: parametric test ANOVA, based (or not) on the LOESS smoother and/or non-parametric Mann-Kendall test (and derivate Seasonal Kendall and Regional Kendall tests). However, non-parametric statistical tests generally are preferred to parametric tests when the analysis of environmental data is involved, particularly in the absence of pre-treatment of raw data (CIS WG GW, 2019).

Environmental significance was mainly estimated based on exceedance of a TV or a percentage of a TV for a predicted concentration. The date for the prediction was often defined as the date when the trend line exceeds the starting point for trend reversal. These dates vary between Member States from 2017 to 2021 or 2027. Major issues remain difficult to tackle: the improvement of monitoring design for trend identification, values reported below the limit of quantification for micro-pollutants trend assessment, and the spatial distribution and scaling of trends from single monitoring sites to GWBs scale.

Although the different tools developed make it possible to identify trends, they cannot be used alone. Authors of the report (CIS WG GW, 2019) conclude that Member States must still seek to explain trends in order to be able to address the causes and attempt to reverse them if the trends are upward. This complex work often requires searching for and compiling local data, notably on anthropogenic pressure and climate changes, and a better understanding of local hydrogeology and hydrodynamics. The main idea of the report is aimed at harmonizing methodologies, but in particular TGWBs are not addressed in this work.

Transboundary aquifer or transboundary aquifer system means respectively, an aquifer or aquifer system, part of which is situated in different States (UN ILC, 2008). The international aspect of a transboundary aquifer makes its management more complex than in the case of an aquifer located within the State borders. An informed and sustainable management of commonly shared aquifers asks for adequate knowledge of its characteristics, present state and trends. In order to acquire this knowledge, regular monitoring and assessment of the transboundary aquifer need to be performed. As a result, the topic is very widely discussed in world literature. For example, several reports (UN/ECE, 2000; IGRAC and UNESCO-IHP, 2015) present the methodology for the assessment of transboundary aquifers. The methodology aims to provide guidelines for conducting an aquifer assessment comprising collection, storage, processing and sharing of groundwater related data and information. As such, the proposed methodology covers various aspects relevant for management/governance of transboundary aquifers, including the state of the aquifer (in terms of groundwater quantity and quality) as well as the associated socio-economic, legal and institutional facets. However, the term *TGWB* is not reflected in these reports and therefore these publications have of limited use in this study and in the context of European legislation, which defines and focuses its attention in particular to TGWBs.

2.1.4. Main conclusions of the literature review

An analysis of the revised EU directives and their Guidance Documents showed that these documents do not provide much explicit and detailed guidance concerning the TGWBs. These documents are addressed to "GWBs as such", but they deal only in very general terms with the delineation of TGWBs, the assessment of their status and the bases for the criteria on which the status assessment should be performed. Guidance Documents are intended to provide an overall methodological approach, but will need to be tailored to the specific circumstances of each EU Member State. Even the GWD's definition of the term *GWB* does not provide explicit Guidance on how GWBs should be delineated (EC, 2003b). Thus, the literature review leaves an understanding that the ways, how to delineate and assess the TGWBs is largely a matter for the Member States themselves and the expert committees and working groups set up by those states. The next chapters of this report discuss the establishment and status assessment of two TGWBs in the EU and point out the problems that have arisen and their possible solutions.

2.2. International River Basins and transboundary groundwater bodies in Europe

The WFD stipulates that Member States shall ensure that a river basin covering the territory of more than one Member State is assigned to an iRBDs. Appropriate administrative arrangements, including the identification of the appropriate competent authority for the iRBD shall be established by the Member States. Member States shall ensure that the environmental objectives of the Directive are met in iRBDs. To this end, Member States shall coordinate at the international level on a programme of measures. In the case of an iRBD falling entirely within the Community, Member States shall ensure coordination with the aim of producing a single iRBMP, including involving third countries. If an iRBMP is not produced, Member States shall produce river basin management plans covering at least those parts of the iRBD falling within their territory to achieve the objectives of the WFD (EC, 2019).

The EC is required to report to the European Parliament and Council in 2018 on progress made by Member States with implementing the WFD. The document referred below (EC, 2019) is part of this reporting and comprises a series of fact sheets for the iRBD which are describing the application of the WFD at iRBD. The factsheets for the iRBMPs cover a wide range of issues and are not identical in all. This is because information for some issues may be available in some iRBDs but not in others, depending on the level of cooperation.

The International Basin Assessment fact sheets were drafted on the basis of the national RBMPs, iRBMPs (where available), as well as information that was reported by the Member States through the Water Information System for Europe (WISE) electronic reporting.

2.2.1. International river basin districts and their coordination mechanisms

iRBs in the EU are either shared exclusively between EU Member States or between EU Member States and third countries. There are 75 iRBDs and 30 sub-basins in the EU (EC, 2019). International coordination mechanisms (agreements, working groups etc.) under the WFD vary among the different iRBs. Based on their level of cooperation, four main categories were identified. An overview of different types of international cooperation is given in TABLE 2.2.1.1.

TABLE 2.2.1.1

Different types of international coordination in relation to the WFD (EC, 2019)

Category	Formal international agreement	International coordinating body	iRBMP produced
1	Yes	Yes	Yes
2	Yes	Yes	No
3	Yes	No	No
4	No	No	No

2.2.1.1. International River Basins (Category 1)

The short overview below (TABLE 2.2.1.1.1) is based on Category 1 iRBs, as they have the longest and closest level of international cooperation and iRBMP have been produced. The facts from the extensive report (EC, 2019) presented here is intended to reflect the information related to TGWBs within those iRBDs.

TABLE 2.2.1.1.1

List of Category 1 iRBDs according to the factsheets for the iRBDs (EC, 2019)

Category	iRBs	EU Member States/Non-EU countries
1	Danube	Austria, Bulgaria, Czech Republic, Germany, Croatia, Hungary, Italy, Poland, Romania, Slovenia, Slovakia *Non-EU: Switzerland, Albania, Bosnia and Herzegovina, Serbia, Ukraine, Moldova, Montenegro, Macedonia*
	Elbe	Austria, Czech Republic, Germany, Poland
	Ems	Germany, The Netherlands
	Meuse	Belgium, Germany, France, Luxembourg, The Netherlands
	Odra	Czech Republic, Germany, Poland
	Rhine	Austria, Belgium, Germany, France, Italy, Luxembourg, The Netherlands *Non-EU: Switzerland, Liechtenstein*
	Sava	Croatia, Slovenia *Non-EU: Albania, Bosnia and Herzegovina, Montenegro and Serbia*

Category	iRBs	EU Member States/Non-EU countries
	Scheldt	Belgium, France
	Teno/Tana	Finland *Non-EU: Norway, Russia*

2.2.1.1.1. Danube River Basin District

The Danube iRBD is shared by Albania, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Germany, Hungary, Italy, Macedonia, Moldova, Montenegro, Poland, Romania, the Republic of Serbia, Slovenia, the Slovak Republic, Switzerland and the Ukraine. 14 countries with territories > 2,000 km^2 in the Danube River Basin are, together with the EU, Contracting Parties to the Danube River Protection Convention. The Convention established the International Commission for the Protection of the Danube River (ICPDR). The Convention was signed on June 29, 1994 in Sofia (Bulgaria) and came into force in 1998. It aims to ensure that surface waters and groundwater within the Danube River Basin are managed and used sustainably and equitably.

In the field of groundwater coordination has taken place on the delineation for TGWBs. According to the iRBMP, TGWBs are made up of national parts (which comprise individual national GWBs that have been aggregated). The iRBMP and the Danube Basin Analysis (ICPDR, 2015; ICPDR, 2021) provide an overview of important TGWBs in the Danube River Basin, which are defined because they are important due to the size of the GWB (which means an area > 4000 km^2) or important due to various criteria e.g. socio-economic importance, uses, impacts, pressures interaction with aquatic ecosystem. The criteria were agreed bilaterally. Other GWBs, i.e. those with an area larger than 4000 km^2 and fully situated within one country of the iRBD, are dealt with at the national level.

Information on 11 aggregated TGWBs of basin-wide importance with eight countries concerned (Germany, Austria, Slovak Republic, Hungary, Serbia, Bulgaria, Romania and Moldova) is provided in the iRBMP (ICPDR, 2015; EC, 2019). These aggregated GWBs have been agreed by all countries sharing their parts. The most frequent method applied for the delineation of the aggregated GWBs is based on geological boundaries in combination with a hydrogeological approach. In some countries, other criteria like importance for water supply, groundwater quality, water temperature or surface water catchment areas were additionally considered.

The iRBMP states that monitoring of the 11 aggregated TGWBs of basin-wide importance has been integrated into the Transnational Monitoring Network of the ICPDR. For groundwater monitoring in the frame of the transnational network, a 6-year reporting cycle has been set, which is in line with reporting requirements under the WFD. The monitoring program includes both quantitative and chemical (quality) monitoring. It shall provide the necessary information to:

- identify trends in pollutant concentrations;
- support GWB characterization and the validation of the risk assessment;
- assess whether DWPA objectives are achieved and support the establishment;
- assessment of the programs of measures and the effective targeting of economic resources.

According to the iRBMP, to select the monitoring sites, a set of criteria has been applied by the countries, such as aquifer type and characteristics (porous, karst and fissured, confined and unconfined groundwater) and depth of the GWB (for deep GWBs, the flexibility in the design of the monitoring network is very limited). The flow direction was also taken into consideration by some countries, as well as the existence of associated DWPAs or ecosystems (aquatic and/or terrestrial).

As regards quantitative monitoring, the WFD requires only the measurement of groundwater levels but the ICPDR has also recommended monitoring of spring flows, flow characteristics and/or stage levels of surface water courses during drought periods, stage levels in significant groundwater dependent wetlands and lakes and water abstraction as optional parameters.

According to the iRBMP, the Danube countries used different methodologies for the assessment of quantitative and chemical status, and the establishment of TVs, trend and trend reversal assessment. Despite there being overall coordination facilitated by the ICPDR Groundwater Task Group, further harmonization of the national methodologies is still needed. Data gaps and inconsistencies are still available in the collected data, resulting in uncertainties in the interpretation of data. To achieve a harmonization of data sets for TGWBs, there is a need for intensive bi- and multilateral cooperation. In addition, the interaction of groundwater with surface water or directly dependent ecosystems need further attention.

The results of the status assessment of the 11 aggregated TGWBs of basin-wide importance are provided for the whole national part of a particular GWB (so called: aggregated GWB). If a national part of an aggregated GWB consists of several individual national-level GWBs, then poor status in one national-level part is decisive in characterizing the whole national part of aggregated TGWB as having poor status.

To indicate the diversity of different status results of individual GWBs within aggregate GWBs a concept of the aggregation confidence levels was developed by the ICPDR. The reason for introducing these specific confidence levels for the iRBMP was the need to distinguish between the cases when all individual GWBs in an aggregated GWBs have the same status (high confidence) or not (medium confidence) or the assessment is based on the risk assessment data (low confidence). Information about the WFD-related confidence levels of status assessment for the individual national (non-aggregated) GWBs can be found in the national plans and in WISE.

2.2.1.1.2. Elbe River Basin District

The Elbe iRBD is shared by Austria, the Czech Republic, Germany and Poland. The Elbe iRBD is allocated to cooperation Category 1, which means that an international agreement, a permanent co-operation body and an iRBMP under the WFD is in place.

The report by EC (2019) provides information on the international coordination efforts of transboundary SWBs in the iRBD. TGWBs have not been delineated and therefore information on GWBs is not part of this report.

2.2.1.1.3. Ems River Basin District

This report (EC, 2019) provides information on the international coordination efforts of transboundary SWBs in the iRBD. Only transitional and coastal surface waters are transboundary in this iRBD. TGWBs have not been delineated and therefore information on GWBs is not part of this report.

2.2.1.1.4. Meuse River Basin District

The Member States did not report GIS data to WISE for TGWBs, as there are none designated as TGWBs in this river basin (EC, 2019).

2.2.1.1.5. Odra River Basin District

No TGWBs were delineated in the Odra iRBD according to EC (2019).

2.2.1.1.6. Rhine River Basin District

GWB delineation was carried out separately in the Member States using different approaches, which has led to difference in the sizes of the GWBs (EC, 2019). However, the 2004 report mentions that the delineation of TGWBs was coordinated between the relevant Member States and indicates that this coordination is apparent in the GWB map for the Rhine.

The Rhine does not have a joint monitoring programme for GWBs. The iRBMP mentions that monitoring networks were established to monitor the quantitative and chemical status in GWBs in accordance with the WFD but it does not mention whether any coordination has taken place. The iRBMP does not provide information regarding the coordination or harmonization of the classification of quantitative and chemical status for GWBs (EC, 2019).

2.2.1.1.7. Sava River Basin District

The Sava iRBD, which is a sub-basin of the Danube iRBD, is shared by Albania, Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia. The Sava iRBD is allocated to cooperation Category 1, which means that an international agreement, a permanent co-operation body and international WFD RBMP is in place. The first international RBMP for the Sava was published on 2 December 2014 (EC, 2019).

The criteria for delineation of GWBs vary among the countries, reflecting different local geological and hydrogeological conditions and data availability on natural conditions and pressures. In general, the approach (groundwater – aquifer – GWB) recommended by CIS Guidance document on Identification of Water Bodies (EC, 2003b) was followed by all countries. The GWBs were generally delineated according to a combination of criteria including the geological type, borders of the surface catchment areas and present anthropogenic pressures. Due to the late involvement of Montenegro in the process of WFD implementation, the country has not delineated GWBs thus far.

The following common criteria were applied regarding the selection of GWBs:

- transboundary and national GWBs which are important due to the size of the GWB (area > 1000 km²), or
- for those < 1,000 km² TGWBs which are important due to various other criteria, e.g. socio-economic importance, uses, impacts, pressures, interaction with aquatic ecosystems.
- 20 out of the 41 GWBs are transboundary.

Currently there is no joint monitoring network in the Sava iRBD for GWBs. According to the background document on GWBs (Sava, 2013), a future Sava Commission GWB monitoring network will be based on the existing national monitoring networks, assuming that most of the necessary information for a basin wide level assessment will be obtained by making minimum adjustments of existing monitoring programs which are (or will be) WFD compliant (EC, 2019). Existing national monitoring programs are in some cases still under adaptation to the requirements of Article 8 WFD.

According to the iRBMP (Sava, 2013), the major identified gaps in groundwater monitoring in Sava countries for different aspects are:

a) Legal and organizational aspects:
    - legal background for groundwater monitoring does not exist in all countries;
    - ambiguous responsibilities of different state institutions concerning the monitoring, data flow;
    - results of monitoring for other different purposes (drinking water production etc.) are often not used for the purpose of status assessment.
b) Concept of establishment of monitoring networks:
    - locations of monitoring sites are mostly based on local hydrogeological settings and not on the conceptual model (understanding of the groundwater system), existing pressures (quantitative and chemical), vulnerability of aquifer and land use;
    - unequal spatial distribution of monitoring sites does not represent the overall status of a GWB;
    - large areas are not covered by monitoring;
    - abstraction wells and springs are generally not included in the monitoring network.
c) Concept of monitoring programs (parameters and frequency):
    - measurement frequency and parameters are often not in accordance with existing pressures and possibility of entering the underground media;
    - list of analyzed chemical parameters is not reviewed and adjusted periodically;
    - monitoring parameters are usually not focused on pressures affecting the overall state of the GWB.

According to the background document on GWBs (Sava, 2013), the main focus in the future bilateral activities of Sava countries sharing the same aquifers should be (EC, 2019):

- development of conceptual models of GWBs,
- achievement of harmonized monitoring networks,
- establishing criteria for the selection of parameters.

In the Sava iRBD, the process of establishing status (or risk) assessment methodologies for determining the chemical and quantitative status of GWBs is still being developed (EC, 2019). 11 GWBs are possibly at risk or have poor chemical status and 30 GWBs are in good chemical status. Three GWBs are possibly at risk or do not have good quantitative status and 38 GWBs have good quantitative status or are not at risk. Monitoring results concerning the chemical and quantitative status of GWBs in large parts of the Sava River Basin are limited or absent. The present absence of information on groundwater quantity and quality parameters resulted in low confidence of GWB status assessment, in many cases allowing only the assessment risk of not achieving environmental goals stated in Article 4 of the WFD (EC, 2019).

2.2.1.1.8. Scheldt River Basin District

The Scheldt iRBD is shared between Belgium, France and the Netherlands. The iRBD is allocated to cooperation Category 1, which means that an international agreement, a permanent co-operation body and iRBMP is in place.

The Member States and Regions coordinated through a consultation process on the production of a map of GWBs in the Scheldt, in which a horizontal as well as vertical agreement was reached regarding national and regional boundaries. The methodologies for delineation have not been harmonized. The Member States and Regions use similar criteria with minimal differences. The approach taken by the different parties has led to the differing delineation of GWBs regarding size and superposition. According to the current, three different coordinated systems continue to be in use by the parties and the storage of data and differing approaches between parties continue to form a challenge (EC, 2019).

In the Scheldt, there are 22 GWBs part of the transboundary aquifer. For GWBs, national networks are used for monitoring. Member States have compared their monitoring methods but there is no joint monitoring program in the iRBD. Information has been exchanged on the groundwater monitoring networks for surveillance monitoring, with a particular focus on the transboundary aquifers (EC, 2019).

The GWBs' status assessment is based on the results of the monitoring networks, the density, the nature (wells, piezometers, sources etc.) and the extraction depth, which may vary among the Member States/Regions. For the assessment of the quantitative status, the trend analyses of the piezometric measurement series were considered, along with a survey of the hydrogeological state. A joint methodology for quantitative status assessment is not used in the Scheldt (EC, 2019).

For the assessment of chemical status, each MS/Region has defined criteria, including nitrate, pesticides and polluting parameters that are causing GWBs to be designated as at risk. The impact of salt water intrusion on the quality of surface water or terrestrial ecosystems depending on groundwater, or on the quality of the extracted groundwater intended for human consumption, has also been studied. There are joint case studies monitoring the carboniferous limestone aquifer and salt water intrusion in the Flemish-Dutch polder aquifer. Chemical status has not been harmonized. There are several explanations for the divergence of chemical status assessments among the MS/Regions (EC, 2019):

- differences in the use of GWBs;
- differences in TVs fixed by the MS/Regions;
- the monitoring networks' particularities.

2.3. Transboundary groundwater bodies in Danube River Basin District – examples of TGWBs delineation and assessment

The previous chapter showed that, given the length and nature of international cooperation, the level of research and the existence of joint projects, there is reason to look for examples of TGWBs from the Danube RBD. In addition to the numerous online resources on the Danube Basin (FIGURE 2.3.1), several experts from the region agreed to share the information and personal experiences about the process of establishing TGWBs in involved countries. Although the request for information was forwarded to relevant experts in several countries, specialists from Romania, Hungary and Slovak Republic responded to the request. Thus, the compilation of this chapter is based on various online sources and personal comments and recommendations from national experts. The author of the report is particularly grateful to Rossitza Gorova from Executive Environment Agency, Bulgaria, Peter Malik from Geological Survey of Slovak Republic and Réka Gaul from Ministry of Interior, Hungary. Thus, in this chapter the establishment and status assessment of two TGWBs in the EU (Bulgaria-Romania and Hungary-Slovakia) is presented and the problems arise and their possible solutions are discussed.

FIGURE 2.3.1 **Danube River Basin. TGWBs of basin wide importance** (ICPDR, 2021b). The numbering of TGWBs is in accordance with TABLE 2.3.1: 1 - Deep Thermal, 2 - Upper Jurassic-Lower Cretaceous, 3 - Middle Sarmatian-Pontian, 4 - Sarmatian, 5 – Mures/Maros, 6 – Somes/Szamos, 7 - Upper Pannonian-Lower Pleistocene/Vojvodina/Duna-Tisza köze déli r., 8 - Podunajska Basin, Zitny Ostrov/Szigetköz, Hanság-Rábca, 9 - Bodrog, 10 - Slovensky kras/Aggtelek-hgs., 11 -Komarnanska Kryha/Dunántúli-khgs. északi r., 12 – Ipel/Ipoly.

The Danube River Basin (DRB) has a long history of transboundary cooperation and is often known as the most iRBs in the world (FIGURE 2.3.1). The basin includes 19 countries, over 81 million people, some 20 percent of the EU land area (approximately 800 000 km^2), a wide range of diverse landscapes, and major socio-economic differences among the many nations. This river basin has a long history of transboundary cooperation and this has been built upon to provide strong professional and institutional capacity that can cope with the demands of growing nations. It is a model of good practice that is used by many other river basins both within Europe and across the world (GWP, 2015).

The analysis and review of GWBs in the DRB district, as required under Article 5 and Annex II of the WFD, was updated in 2021 (ICPDR, 2021a) and it confirmed 12 TGWBs or groups of GWBs of basin wide importance listed in TABLE 2.3.1 and illustrated in FIGURE 2.3.1.

TABLE 2.3.1

Nominated TGWBs of Danube basin wide importance (ICPDR, 2021a)

GWB	National part	Area (km²)	Aquifer characteristics		Main use	Overlying strata (m)	Criteria for importance
			Aquifer type	Confined			
1	AT-1	1 650	K	Yes	SPA, CAL	100-1 000	Intensive use
	DE-1	4 250					
2	BG-2	13 034	F, K	Yes	DRW, AGR, IND	0-600	> 4000 km²
	RO-2	11 340					
3	MD-3	9 662	P	Yes	DRW, AGR, IND	0-150	> 4000 km², GW use, GW resources
	RO-3	12 646					
4	BG-4	3 308	K, F-K	No	DRW, AGR, IND	0-10	> 4000 km²
	RO-4	2 187		Yes			
5	HU-5	4 989	P	No	DRW, IRR, IND	2-30	> 4000 km², GW resource, DRW protection
	RO-5	2 227					
6	HU-6	1 034	P	No	DRW, AGR, IRR	5-30	GW resources, DRW protection
	RO-6	1 459					
7	HU-7	7 098	P	No	DRW, AGR, IND, IRR	0-125	> 4000 km², GW use, GW resources, DRW protection
	RO-7	11 355		Yes			
	RS-7	10 506		No			
8	HU-8	1 152	P	No	DRW, IRR, AGR, IND	2-5	GW resources, DRW protection, dependent ecosystems
	SK-8	2 186					
9	HU-9	750	P	No	DRW, IRR	2-10	GW resources, DRW protection, dependent ecosystems
	SK-9	1 470		Yes			
10	HU-10	493	K	No	DRW, OTH	0-500	GW resources, DRW protection, dependent ecosystems
	SK-10	598	K, F				
11	HU-11	3 337	K	Yes	DRW, SPA, CAL	0-2 500	Thermal water resources
	SK-11	563	F, K				
12	HU-12	146	P	No	DRW, AGR	0-10	DRW protection, dependent ecosystems, GW resources
	SK-12	198					

Aquifer type: P = porous, K = karst, F = fissured;
Main use: DRW = drinking water, AGR = agriculture, IRR = irrigation, IND = Industry, SPA = balneology, CAL = caloric energy, OTH = other

All 14 countries sharing over 2000 km² of the DRB, as well as the EU, are Contracting Parties to the Danube River Protection Convention – nine of these 14 countries are EU MS. Two EU MS (Italy and Poland) and three non-EU MS (Albania, Macedonia and Switzerland) are not Contracting Parties (share below 2,000 km²) (ICPDR–GW TG, 2020).

FIGURE 2.3.2 shows all 14 countries which are Contracting Parties – the blue shaded are EU MS. The matrix indicates common borders (white and yellow cells); the common share of the 12 TGWBs of Danube basin-wide importance (ICPDR-GWBs) is marked in yellow, including the number of shared GWBs.

	AT	BA	BG	CZ	DE	HR	HU	MD	ME	RO	RS	SI	SK	UA
AT					1									
BA														
BG										2				
CZ														
DE	1													
HR														
HU										3	1		5	
MD										1				
ME														
RO			2				3	1						
RS							1							
SI														
SK							5							
UA														

FIGURE 2.3.2 **The 14 countries which are Contracting Parties to the ICPDR with the indication of common borders (white and yellow cells) and common share of ICPDR-GWBs (number of GWBs)** (ICPDR–GW TG, 2020).
AT - Austria, BA- Bosnia and Herzegovina, BG -Bulgaria, HR - Croatia, CZ - Czech Republic, DE - Germany, HU - Hungary, MD - Moldova, ME - Montenegro, RO - Romania, RS - Serbia, SK - Slovakia, SI – Slovenia, UA – Ukraine

At each meeting of the International Commission for the Protection of the Danube River (ICPDR) Groundwater Task Group (GW TG) the participating countries report about the main bilateral activities with the neighboring countries in the Danube RBD (DRBD). The document by ICPDR–GW TG (2020) summarizes all bilateral harmonization activities in the management of the 12 ICPDR-GWBs since the publication of the 2nd River Basin Management Plan in 2015 (for the period of 2016 to 2020). The recent activities concerning the TGWBs shared between Bulgaria-Romania and Hungary-Slovak Republic are presented below.

Countries: Bulgaria – Romania (GWB-2, GWB-4):

- a bilateral meeting in 2015 aimed at comparing the groundwater TVs. It showed that the TVs in Bulgaria are lower than those of Romania;
- In 2016 a bilateral meeting took place and the working group on RBMPs reviewed the established bilateral GWB monitoring network (in terms of monitoring frequency and parameters) which is subject to bilateral data exchange. Romania had no intention to change the GWB delineation;
- In the frame of the JOINTISZA project, the Tisza RBMP update was produced in 2019 which includes groundwater elements;
- there is a regular (annual) data exchange between Romania and Bulgaria.

Countries: Hungary – Slovak Republic (GWB-8, GWB-9, GWB-10, GWB-11, GWB-12):

- bilateral harmonization of GWBs is ongoing - in 2016 Slovakia suggested the nomination of a new GWB of basin-wide importance on the Ipel River as the 12th ICPDR-GWB. Hungary supported this nomination. In 2019, the transboundary commission adopted the proposal of creating the new GWB-12 on Ipel/Ipoly and adopted the thermal Hungarian GWB as an additional part of GWB-11; in 2020, the bilateral harmonization and characterization of GWB-12 was completed;
- in 2017 a new bilateral expert group on the WFD was established;
- In 2018, the transboundary water committee discussed an increased water abstraction from the transboundary karstic GW body;
- Slovakia also participates in the JOINTISZA project;
- there is a regular data exchange in the frame of the bilateral transboundary commission (twice per year); in 2018, Hungary delivered data from 126 GW monitoring stations to Slovakia.

The most recent and up-to-date information on TGWBs in the DRB can be found in the report prepared by the International Commission for the Protection of the Danube River in 2021. This report (ICPDR, 2021a) includes a comprehensive overview about the 12 TGWBs or groups of GWBs of basin wide importance in the DRBD – their characterization, monitoring details, established groundwater TVs, risk and status information as well as the methodologies of status and trend assessment of the ICPDR GW-bodies. The assessment of those GWBs has been performed also earlier (ICPDR, 2004; 2009; 2015); however, in the context of current expert assessment, the most up-to-date information is required and therefore the latest report (ICPDR, 2021a) is referred below.

2.3.1. GWB-2: Upper Jurassic – Lower Cretaceous GWB

Regarding the 18 Romanian TGWBs, bilateral agreements were signed in case of the 8 GWBs – 4 with Hungary, 1 with Serbia, 2 with Bulgaria and 1 with Moldova Republic, which pursued the establishment of TGWBs which are considered to be important (with a surface larger than 4000 km^2 or important from the point of view of water supply) and the harmonization of TGWBs characterization with neighboring countries (Bretorean et al., 2010).

Generally, these agreements pursue the following objectives (Bretorean et al., 2010):

- evaluation of groundwater resources from the qualitative and quantitative point of view;
- design of a monitoring system with information exchange;
- establishing the necessary measures for the protection of GWBs;
- promotion of an integrated water management based on sustainable protection and adequate use of groundwater resources;
- increase in the local decisional degree regarding sustainable water management (evaluation, monitoring, exploitation and protection).

And the necessary measures to achieve these objectives were in 2010:

- the analysis of the national monitoring network and its resizing in accordance to specific situations, important in GWBs at risk and TGWBs;
- equipping the national monitoring network with measuring and data transmission equipment (quality data for the indicators requested by the WFD: oxygen content, pH, electric conductivity, nitrates, ammonia);
- intensifying the protected areas setting-up process;
- implementation of certain adequate agricultural practices for the protection of the environment, including GWBs;
- initiation of a national education program for the protection of GWBs and the environment in general.

Upper Jurassic – Lower Cretaceous TGWB is shared by Romania and Bulgaria. GWB-2 (TABLE 2.3.1.1) is ICPDR GWB code, which is a unique identifier of TGWB (ICPDR, 2021a). National codes mark the individual GWBs forming the national part of a TGWB of basin wide importance.

TABLE 2.3.1.1

GWB codes (ICPDR, 2021a)

GWB-2	National share	BG-2, RO-2
List of individual GW-bodies forming the whole national share (national code incl. country code)	BG-2	BG1G0000J3K051
	RO-2	RODL06

2.3.1.1. Description of the ICPDR GWB

According to Bulgaria the starting point for identifying the geographical boundaries of the GWB BG1G0000J3K051 (Upper Jurassic-Lower Cretaceous) is the geological boundaries. After that additional sub-division on the basis of groundwater flow lines and piezometric heads. The lithological composition of GWB is: limestones, dolomitic limestones and dolomites. Overlying strata consist of marls, clays, sands, limestones, pebbles and loess. The age of the above-mentioned deposits is Hauterivian, Sarmatian, Pliocene and

Quaternary. With the exception of small cropped out areas the GWB is very well protected. There is no significant impact on the GWB. The main use of groundwater is for drinking water, agriculture and industry supply.

Criteria for GWB delineation in Romania is the development of Upper Jurassic-Lower Cretaceous permeable deposits and water content in these deposits. The lithological composition is limestones, dolomitic limestones and dolomites. Overlying strata consist of marls, clays, sands, limestones, pebbles and loess. The age of the above-mentioned deposits is Hauterivian, Sarmatian, Pliocene and Quaternary.

GWB RODL06 – Valachian Platform has a great extension and partially covers Valah platform. It is a TGWB of great potential, the depth aquifer having partially a free level (in the sector adjacent to the Danube) and is quartered in calcareous formations, sometimes fissured and karstic, with regional extension in the whole South Dobrogea. These deposits are characterized by a hydraulic communication through an aquitard.

From the geological point of view, this aquifer complex has a complex structure, being divided by a system older than the Sarmatian fault with orientations approximately NNE-SSW and WNW-ESE. Excluding small cropped out areas the GWB is very well protected. The main use is for drinking water supply, agriculture and industry supply. In Romania the GWB has an interaction with Lake Siutghiol situated near the Black Sea.

The criterion for selection as 'important' is for both GWBs the size which exceeds 4,000 km² (TABLE 2.3.1.1.1).

TABLE 2.3.1.1.1

Characteristics of Upper Jurassic – Lower Cretaceous TGWB (ICPDR, 2021a)

GWB	National part	Area (km²)	Area (km²)	Aquifer characteristics		Main use	Overlying strata (m)	Criteria for importance
				Aquifer type	Confined			
GWB-2 Upper Jurassic – Lower Cretaceous	BG-2	24 374	13 034	F, K	Yes	DRW, AGR, IND	0–600	> 4000 km²
	RO-2		11 340					

Aquifer type: P = porous, K = karst, F = fissured;
Main use: DRW = drinking water, AGR = agriculture, IRR = irrigation, IND = Industry, SPA = balneology, CAL = caloric energy, OTH = other

2.3.1.2. Description of status assessment methodology

2.3.1.2.1. Chemical status

In Bulgaria, the assessment of the chemical status of GWBs has been done by carrying out the following tests and steps:

- **Step 1**: Calculation of arithmetic means per MP for each indicator for the period 2017-2020. Values below the limit of quantitation (LoQ) are replaced by ½ LoQ.
- **Step 2**: Comparison of arithmetic means with the lowest EQS or TVs (EQS, intrusion of salt or polluted waters, drinking water standard or other).
- **Step 3**: Assessment of the chemical status in the area of the MP:
    - if for all indicators the status is "good", then the GWB in the area of the MP is "good";
    - if for one or more indicators, the status is "poor", then the GWB in the area of the MP is "poor". In this case, a careful analysis was carried out of the primary hydrochemical data. If the data are doubtful or insufficiently reliable, the indicator (indicators) are rejected from the final assessment and a respective justification for this is presented.
- **Step 4**: If in the areas of all MP the status is good, the GWB is determined "good" and no other tests are needed.
- **Step 5**: The confidence of the assessment is determined by the following criteria:
    - density of the MPs in GWB: low (1 MP on area > 200 km²); medium (1 MP on area 50–200 km²), high (1 MP on area <50 km²);
    - data have to meet the following requirements: all analytical methods are validated in accordance with standard BDS EN ISO/IEC-17025 or other equivalent internationally

recognized standard. Accredited laboratories shall ensure minimum criteria for all applied analytical methods. Minimum length of the time series.

- **Step 6**: The extent of exceedance was calculated. If the status is determined as "poor" for one or more indicators in one or more MP, then an assessment of the affected area was performed:
  - based on the conceptual model, it is determined whether the MPs are located in the recharge zone or in the transit zone or in the drainage zone of GWB;
  - the areas of GWB in which the average annual concentrations of pollutants exceed EQS or TV have been delineated. Each area of GWB affected by pollution includes the area located between the MP areas where EQS or TV have been exceeded. Further, a 1 km buffer zone was delineated around this zone or around the contaminated MP.
- **Step 7**: If the polluted area is more than 20% of the total area of the GWB, the confidence assessment was made according to Step 5.
- **Step 8**: The places of the exceedances are connected with the groundwater receptors. Depending on the identified locations and GW receptors, relevant tests have been applied: saline or other intrusion, SWBs with deteriorated status, directly GDTEs, drinking and household water supply located in polluted areas.
- **Step 9**: Local conceptual models have been developed for each exceedance point considering the possibility for the pollutant to move through the GWB, identification of pressures, additional trend assessment.

A GWB is in good chemical status when the extent of exceedance is less than 20% and the remaining tests show that: the quality of groundwater used for drinking and domestic water supply has not deteriorated, the GW status-related to surface waters and terrestrial ecosystems (directly dependent of groundwater) has not deteriorated and there is no intrusion of salt or polluted waters; no significant and sustainable upward trends in concentrations of pollutants and pollution indicators have been identified.

In Romania, the methodology for the chemical status assessment followed the requirements of the GWD as well as the recommendations of the CIS Guidance Document No.18.

The first step was to check any exceedances of the EQS and TVs which were established taking into consideration the NBL values. If no exceedances of the quality standards and TVs have been recorded, the GWB has been considered as being in good chemical status. If exceedances of TVs were recorded the following relevant tests were carried out:

- **General assessment of the chemical status**: Data aggregation was performed and it was checked whether the total area of exceedance was greater than 20% of the total area of the GWB. The test showed a good status for the water body if no exceeding occurs.
- **Saline or other intrusion**: not relevant.
- **Significant diminution of associated surface water chemistry and ecology due to transfer of pollutants from the GWB**: The location of the exceedance of the relevant TVs was not found in areas where pollutants might be transferred to surface waters. A comparison of the pollutant load transferred from the GWB to the SWB with the total load in the SWB did not exceed 50%. The test showed a good status for the water body.
- **Significant damage to GDTEs due to transfer of pollutants from the GWB**: No GDTEs was found to be damaged. The test showed a good status for the water body.
- **Meets the requirements of the WFD Article 7(3) – DWPAs**: there is no evidence of increased treatment due to changes in water quality. The test showed a good status for the water body.

To assess the chemical status of the GWBs, the following steps are considered:

- for each MP the annual average concentrations for each indicator was calculated; for the metals the concentration of the dissolved form was considered;
- for each MP the annual average concentration of each parameter was compared with the TVs (determined for each GWB) or EQS value (nitrates and pesticides);
- the GWB is of good chemical status when no EQS or TV is exceeded in any MP;
- the GWB is of poor chemical status when EQS or TV are exceeded at MPs representing more than 20% of the GWB area.

2.3.1.2.2. Quantitative status

The assessment considered data from national and self-monitoring of groundwater abstraction facilities according to the issued permits ***in Bulgaria***. The main criteria for assessing good quantitative status are the exploitable (available) groundwater resources of GWB and the groundwater level. To verify compliance with the requirements of the WFD, various tests were performed. The assessment was based on data from 2017–2020 and trends were assessed, with data from 2007–2020. The following tests were performed:

- **Water balance test**: the assessment of the GW level downward trend is an indication that, the available GW resources were exceeded and the GWB is in poor status;
- **Surface water test and terrestrial ecosystem test**: both not applicable in BG-2 as SWBs and terrestrial ecosystems are not associated/connected;
- **Saline intrusion test**: not relevant.

In Romania, the criterion for risk assessment of the quantity status is based on trend assessment evolution of the groundwater levels. The quantitative status has been assessed taking into account the CIS Guidance no.18. The following criteria have been used:

- water balance;
- the connection with surface waters;
- the influence on the terrestrial ecosystems which depend directly on the GWB;
- the effects of saline or other intrusions.

The quantitative status analysis has been done for the GWB level by comparing the average of the hydrostatic level from 2017 (reference year) with the multiannual average during the whole observation period.

2.3.1.3. Groundwater threshold value relationships

The methodology for TV establishment ***in Romania*** has been developed according to CIS Guidance No.18. NBLs are the key elements in the process of TVs setting. As described above, during the TVs establishment, the NBLs have been compared with the drinking water standards. The maximum allowable concentrations (MAC) provided by the Law No.458/2002 as amended, were chosen as TV where NBL are smaller than MAC. Where NBLs are higher than MAC, a small addition of 0.2 NBL was used, in order to avoid misclassification of the respective GWB (TV = NBL + 0.2 NBL = 1.2 NBL).

The updated list of TVs established for each GWB was published in the new Order of the Minster No.621/2014 (Order, 2014) approving TV for GWBs from Romania.

The methodology for TVs determination ***in Bulgaria*** has been developed according to CIS Guidance No.18. TVs are determined by comparing NBLs with criteria values (CVs). CVs is the concentration of a pollutant (without taking into account the NBLs), which, if exceeded, could lead to a distortion of the criteria for good status. CVs should take into account the risk assessment and receptors of groundwater.

The NBLs were established for each GWB as a result of the project report "Assessment of the natural hydrochemical background of the substances composition of groundwater in Bulgaria" (GEOFUND V-402), 1998. NBLs are available for Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, HCO_3^-, total hardness, Cu, Pb, Zn, As, Fe_{tot}, F, Al, Mn, Cr, Co, V, I, Ag, Ni, Na^+ and K^+. The NBLs were determined for each hydrogeological classes (5 classes) in the 90^{th} percentile and 50^{th} percentile (median) of the statistical sample.

Criterial values (CVs) have been drinking water standards according to the Bulgarian Regulation No.N-9 (Regulation, 2001):

- when NBL > CV, the TV is equal to NBL;
- when CV > NBL, the TV = NBL + Ktv* (CV-NBL). 0 < Ktv < 1.

Ktv is usually between 0.5 and 0.75, as recommended and providing reasonable assurance. Ktv < 0.5 has a large certainty and is used for GWBs, which have important economic significance and are the sole source of drinking water supply of settlements. This value should be used for such GWB to which they are attached, particularly valuable wetlands presence of dependent terrestrial ecosystems. The higher value (0.75) is used in all other cases or GWBs already classified as bodies at risk.

TVs and NBLs established for Upper Jurassic – Lower Cretaceous TGWB (GWB-2) are presented in TABLE 2.3.1.3.1.1. The table shows the differences in the list of the pollutants and their TVs and NBLs set by the countries.

TABLE 2.3.1.3.1.1

TVs of GWB-2 (ICPDR, 2021a)

Country	Pollutant/indicator	TV (or range)	NBL (or range)	Level of TV establishment (national, RBD, GWB)
Romania	Nitrates (NO_3^-)	50 mg/l	-	National
Romania	Benzene	10 µg/l	-	National
Romania	Trichloroethylene (TCE)	10 µg/l	-	National
Romania	Tetrachloroethylene (PCE)	10 µg/l	-	National
Romania	Ammonium (NH_4^+)	0.7 mg/l	0.504 mg/l	GWB
Romania	Chlorides (Cl^-)	250 mg/l	189 mg/l	GWB
Romania	Sulphates (SO_4^{2-})	250 mg/l	120.5 mg/l	GWB
Romania	Nitrites (NO_2^-)	0,5 mg/l	0.069 mg/l	GWB
Romania	Phosphates (PO_4^{2-})	0,5 mg/l	0.21 mg/	GWB
Romania	Nickel (Ni)	0,02 mg/l	0.035 mg/l	GWB
Romania	Zinc (Zn)	5 mg/l	0.355 mg/l	GWB
Romania	Cadmium (Cd)	0.005 mg/l	0.000202 mg/l	GWB
Romania	Mercury (Hg)	0.001 mg/l	0.00012 mg/l	GWB
Romania	Lead (Pb)	0.01 mg/l	0.001 mg/l	GWB
Romania	Arsenic (As)	0.01 mg/l	0.0013 mg/l	GWB
Bulgaria	Nitrates (NO_3^-)	39.87 mg/l	9.49 mg/l	GWB
Bulgaria	Pesticides (total)	0.375 µg/l	-	GWB
Bulgaria	Arsenic (As)	0.0077 mg/l	0.0007 mg/l	GWB
Bulgaria	Lead (Pb)	0.0076 mg/l	0.0005 mg/l	GWB
Bulgaria	Cadmium (Cd)	0.0039 mg/l	0.0005 mg/l	GWB
Bulgaria	Mercury (Hg)	0.0008 mg/l	0.0002 mg/l	GWB
Bulgaria	Ammonium (NH_4^+)	0.3758 mg/l	0.0031 mg/l	GWB
Bulgaria	Chlorides (Cl^-)	188.75 mg/	5 mg/l	GWB
Bulgaria	Sulphates (SO_4^{2-})	189 mg/l	6 mg/l	GWB
Bulgaria	Trichloroethylene (TCE) + Tetrachloroethylene (PCE)	7.5 µg/l	-	GWB
Bulgaria	Conductivity	1713.6 µS/cm	854.5 µS/cm	GWB
Bulgaria	Manganese (Mn)	0.0379 mg/l	0.016 mg/l	GWB
Bulgaria	Iron (total) (Fe_{tot})	0.1513 mg/l	0.005 mg/l	GWB
Bulgaria	Nitrites (NO_2^-)	0.375 mg/l	0.0001 mg/l	GWB
Bulgaria	Sodium (Na^+)	158.25 mg/l	33 mg/l	GWB
Bulgaria	Chromium (Cr)	8.25 mg/l	3 µg/l	GWB
Bulgaria	Copper (Cu)	0.1501 mg/l	0.003 mg/l	GWB
Bulgaria	Nickel (Ni)	15.5 µg/l	2 µg/l	GWB
Bulgaria	Zink (Zn)	0.7537 mg/l	0.015 mg/	GWB
Bulgaria	Permanganate index (CODMn)	3.8625 mgO_2/l	0.45 mgO_2/l	GWB
Bulgaria	Phosphates (PO_4^{2-})	0.3798 mg/l	0.0195 mg/l	GWB

Country	Pollutant/indicator	TV (or range)	NBL (or range)	Level of TV establishment (national, RBD, GWB)
Bulgaria	Cyanides	0.04 mg/l	0.01 mg/l	GWB

2.3.1.4. Description of the trend assessment methodology

The trend analysis ***in Bulgaria*** is based on recognized statistical methods such as regression method and a time series of data from 2012 to 2019 (using annual values, semi-annual or quarterly values).

Based on regression analysis is assessed whether there is a break in the trend i.e. after sustained upward trend follows sustained downward trend or the opposite case the sustained downward trend is followed by sustained upward trend:

- initially, the entire curve of the experimental data is approximated by a polynomial curve of degree 2 (quadratic regression curve).;
- if there is detected a maximum in the polynomial curve it means that a change of the direction of the trend is available - from ascending to descending;
- if there is detected a minimum in the polynomial curve it means that a change of the direction of the trend is available - from descending to ascending;
- then, (in case of available maximum) the entire curve is divided into two branches: the 1st branch – till the date of the maximum and the 2nd branch - after the peak;
- in case with available minimum: the 1st branch – till the date of the minimum and the 2nd branch - after the minimum;
- data from the 1st and 2nd branch are considered separately and are approximated by linear trends (straight lines); the date at which it crossed the two approximating straight lines corresponds to the date at which it changes the direction of the linear trend - from ascending to descending or from descending to ascending.

By extrapolation of the second (falling) trend can be predicted the date at which the starting concentration (75% GWQS in our case 60% TV) will be reached.

In order to assess the trend in pollutant concentrations ***in Romania***, the results of the chemical analysis from the MPs have been used. Minimum period of analysis was at least 17 years (2000–2017).

The methodology for identifying significant upper trends consists in adjustment and aggregation of the data from each MP on GWBs. The trend analysis was done using the Gwstat program.

The steps used for trend assessment were:

- identifying the MPs and the associated results of chemical analysis, assessment of data series, for each year of reference period (2000–2017);
- establishment of baseline concentration for each parameter as the average concentration registered during the year 2000;
- calculation of annual average for the available data in each MP.

Significant upward trends were identified by Gwstat software, based on Anova Test.

2.3.1.5. Description of the trend reversal assessment methodology

In Bulgaria, the starting point for trend reversal should be placed where the concentration of the pollutant reaches 75% of the GQS or 75% of the TV of the relevant pollutant. Selected starting points should be possible to reverse trends in the most effective way before pollutant concentrations can cause irreversible changes in groundwater quality. When we have GWBs which respond too slowly to changes, there may be a need for an early starting point and vice versa - for responsive GWB should be chosen as a starting point at a later moment.

Initially, the entire curve of the experimental data is approximated by a polynomial curve of degree 2 (quadratic regression curve):

- if there is detected a maximum in the polynomial curve it means that a change of the direction of the trend is available - from ascending to descending;

- if there is detected a minimum in the polynomial curve it means that a change of the direction of the trend is available - from descending to ascending;
- then, (in case of available maximum) the entire curve is divided into two branches: the 1st branch – till the date of the maximum and the 2nd branch - after the peak.

In case with available minimum: 1st branch – till the date of the minimum and the 2nd branch - after the minimum.

Data from the 1st and 2nd branch are considered separately and are approximated by linear trends (straight lines). The date at which it crossed the two approximating straight lines corresponds to the date at which it changes the direction of the linear trend - from ascending to descending or from descending to ascending.

By extrapolation of the second (falling) trend can be predicted the date at which the starting concentration (75% GWQS in our case 60% TV) will be reached. Practically for the second RBMP Bulgaria used 60% from the TV.

In Romania, the trend reversal assessment methodology consists also in the use of Gwstat software. This method assumes that the time series can be characterized by two linear trends with a slope change within the time interval (analysis period). Thus, by applying the 95% quantile of the distribution, a reversal of the trend is identified, if in the first section the slope of the trend is positive, and in the second section the slope of the trend is negative. The stages of the method of reversing the pollutant concentration tendency:

- optimizing the choice of time sections regarding the shape of the resulting model;
- examining the significance of the rift for the simple linear regression model based on the square of the residue sum;
- conducting a statistical test to verify that the 2-section model is significantly more than a simple regression model.

2.3.2. GWB-12: Ipel/Ipoly GWB

The Ipel/Ipoly TGWB is shared by Hungary and the Slovak Republic. GWB-12 (TABLE 2.3.2.1) is ICPDR GWB code, which is a unique identifier of TGWB (ICPDR, 2021a). National codes mark the individual GWBs forming the national part of a TGWB of basin wide importance.

TABLE 2.3.2.1

GWB codes (ICPDR, 2021a)

GWB-12	National share	HU-12, SK-12
List of individual GW-bodies forming the whole national share (national code incl. country code)	HU-12	HUAIQ583
	SK-12	SK1000800P

2.3.2.1. Description of the ICPDR GWB

The Ipoly-valley is situated on the border of Slovakia and Hungary, east of the Danube River. Its area is 145.8 km^2, the elevation varies between 290 m to 128 m a.s.l. The middle Ipoly-valley has an east to west direction, while the lower Ipoly-valley is a north to south one. Left side of the river belongs to Hungary. The middle-Ipoly valley formed by several young refilling trenches, on the south is separated by a defined morphological barrier showing terrace-like river valley. Several river terraces form the lower-Ipoly-valley between the Börzsöny and Helemba hills. Morphologically, it is a diverse pediment surface from the level of the river up to 200 m a.s.l.

The surrounding area of this aquifer suffers from lack of water, while these GWBs are important local drinking water resources in Slovakia and Hungary. Therefore, collaboration between SK and HU to delineate the HU and SK GWBs as common TGWB is a key to maintain safe water supply in sufficient quantities (TABLE 2.3.2.1.1). The alluvial deposits of the Ipel/Ipoly River extend on both sides of the Hungarian-Slovakian border. The aquifer supplies drinking water to a population of approx. 170 000 inhabitants in Slovakia and 50 000 inhabitants in Hungary. On the Hungarian side, due to the lowland character and upward flow system, the terrestrial ecosystems (Natura 2000 site) require surplus transpiration from groundwater; 7% of the area of the water body is under nature conservation. The recharge zone is in Slovakia and Hungary; thus the available groundwater resource and the status of the terrestrial ecosystems depend on the lateral flow from the neighboring countries. Both sides of the GWBs have issues with groundwater quality problems. The Ipel/Ipoly River had formed a 0-10 meters thick alluvial deposit, along the stretch of approximately 80km of the river, which forms a natural boundary between Slovakia and Hungary. More importantly, hydraulic connection between the SK100080OP – HUAIQ583 GWBs is anticipated (http://www.all-in.sk/enwat/ipel.html).

TABLE 2.3.2.1.1

Characteristics of Ipel/Ipoly TGWB (ICPDR, 2021a)

GWB	National part	Area (km²)	Area (km²)	Aquifer characteristics: Aquifer type	Aquifer characteristics: Confined	Main use	Overlying strata (m)	Criteria for importance
GWB-12 Ipel/Ipoly	HU-12	344	146	P	No	DRW, AGR	0–10	DRW protection, dependent ecosystems, GW resources
	SK-12		198					

Aquifer type: P = porous, K = karst, F = fissured;
Main use: DRW = drinking water, AGR = agriculture, IRR = irrigation, IND = Industry, SPA = balneology, CAL = caloric energy, OTH = other

The middle and the lower part of the Ipoly-valley significantly differ in geology. In the area of upper-Ipoly-valley, the maximum 10 meters thick soil covers the alluvial sand, sandy gravel sediments. Below the maximum few tenth meters thick Holocene-Pleistocene sequence, several hundred meters thick Oligocene schlier, sandstone, clay sequence (Szécsényi schlier, Pétervásárai sandstone, Kiscelli clay and Hárshegy sandstone) covers the schist and gneiss basement. In the area of lower-Ipoly-valley below the few meters thick alluvial sand and gravel sediment few hundred meters thick Miocene marl, limestone sequence (Lajta limestone, Szilágy clayey marl) covers the magmatic tuffs (Nagyvölgyi Dacite tuff) sediments.

The lower boundary of the GWB is formed by the thick low permeability schlier and sandstone formations, respectively thick clayey marl aquitard (Szilágyi clayey marl). In the river terraces the Pleistocene fluvio-eolian sand and loess is a good water bearing strata, however the main aquifer is a few meters thick (4 m in average) Holocene fluvial sand and gravel along the river. The recharge of the upper part of the river is in Slovakia, while the middle and lower part of it is recharged on both sides of the river.

The area of interest is delimited by the extent of the youngest alluvium of the river Ipoly/Ipel and partially also of some of its tributaries. The alluvium lies on the impermeable clayey sediments of the Neogene filling of the Juhoslovenská and Podunajská panva basins in the Slovakian side. In the GWB there are mainly alluvial and terrestrial gravel, sandy gravel, sand, stratigraphic classification of Pleistocene - Holocene as collector rocks. In hydrogeological collectors of the formation, the inter-grain permeability prevails. The general direction of groundwater flow in the alluvial floodplain of the quaternary formation SK1000800P is more or less parallel to the course of the main flow. Intergranular GWB of Quaternary sediments of the Ipel River is in the Hron watershed area. The evaluated area (agricultural land including arable land, grassland, pastures and permanent crops plantations) shares 86.69% of total GWB area, rest of GWB area land cover is represented by forests, semi-natural land, surface water tables and artificial surfaces. Within the GWB area, the evaluated area creates large and compact patterns which regularly cover the whole area. In general, GWBs show lowered potential of soil regarding possible negative influence of surface contamination to groundwater.

The main aquifer is the alluvial sediments of the river Ipoly/Ipel and the connecting terraces. Their thickness is about 4-10 m, or more. The gravels and sands are covered with 1.5-4 m of clayey flood sediments. The changing thickness sometimes causes the occurrence of the confined groundwater. The gravels and sands have high transmissivity. The width of the river floodplain is about 1-2 km, but in some places, it is only tens of meters. Groundwater recharge occurs by infiltration of precipitations and infiltration of surface water at high water levels. The changing (decreasing) surface water level of the river has a negative impact on the water supply possibilities. Strong variability of groundwater chemical composition and quality is characteristic for the Ipel region. Ca-Mg-HCO_3 groundwater type dominates as the result of dissolution of carbonates. Groundwater qualitative properties in the region reflect either the natural character of the area or the addition of compounds due to anthropogenic activities.

Anthropogenic contamination of groundwater is mostly originated by agricultural activities and production of waste waters. It is mainly contamination of the uppermost groundwater horizons that occurs in the area. Deteriorated groundwater quality is mainly characterized by high contents of nitrates, chlorides, ammonia ions, phosphates or specific organic parameters (PAH, COD) and occasionally pesticides. Locally high pesticide concentrations (> 0.5 mg/l) are found in both surface water and in groundwater along the Ipoly/Ipel valley. Pesticides in unsaturated soils can be released by erosion, which can be increased by climate change. Nitrates also have a substantial impact on the shallow parts (0-20 m) of the groundwater systems. In general, detected pesticide concentrations suggest that water quality can be considered to be at risk until further investigations will be made and the additional measures as defined by WFD, will be taken. Furthermore, besides the anthropogenic pressures the locally important drinking water resource has high natural sulphate content and electric conductivity. The whole GWB is highly sensitive to climatic changes.

2.3.2.2. Description of status assessment methodology

2.3.2.2.1. Chemical status

Assessment of the chemical status of groundwater ***in Hungary*** was conducted by analyzing the chemical data of individual MPs within each of the GWBs and by identifying the pressures - sources of pollution (ICPDR, 2021a). The NBLs were calculated and used to determine TVs. TVs have been determined according to CIS Guidance No.18. Contamination limits have been determined for all indicators listed in Annex II Part B of the GWD and indicators of the report under Article 5 of the GWD.

The following parameters were investigated:

- the NBL was determined for the following components: nitrates, ammonium, specific conductivity, sulphates, chlorides, arsenic, cadmium, lead, mercury, phosphates;
- for each MP the median concentration of each parameter of the studied period was compared to the TVs (determined for each GWB) or standard values (in the case of nitrates, metals and pesticides);
- different tests were conducted to assess GWB status: diffuse pollution test (nitrate, ammonium, and orthophosphate), drinking water supply tests for numerous elements or components in both drinking water wells and monitoring wells and trend analysis based on the data of the surveillance monitoring system; studied components of these tests are: nitrate, ammonium, chloride, sulphate, specific conductivity, mercury, lead, cadmium, pesticides and organics, furthermore in the trend analysis pH and dissolved oxygen;
- based on these tests, GWB was evaluated

The methodology for assessing chemical status ***in Slovak Republic*** followed the requirements of the GWD as well as the recommendations of the CIS Guidance Document No.18. The assessment of the chemical status of GWB in the conditions of the Slovak Republic consisted of the following tests (ICPDR, 2021a):

- General quality assessment (GQA) test - years 2016-2017;
- drinking water protected areas (DWPAs) test - period 2008-2017;
- test of significant diminution of associated surface water chemistry and ecology due to transfer of pollutant from the GWB - named as Surface water test - period 2013-2018.

For all tests, the procedure was based on a comparison of the arithmetic means of the concentration of the individual component with quality standards (QS) or thresholds values (TV) for each MP. If no exceedances of the QS/TV were recorded in all MPs, the whole GWB was evaluated in good chemical status. If exceedances of QS/TVs were recorded than the methodologies were as follows:

- in the GQA or DWPA test, data aggregation to the whole GWB was performed. If the calculated total area of exceedance of the QS/TV was less than 20% of the total area of the GWB, the GWB was evaluated in good status. If the exceedance of more than 20% of the total area of the GWB was recorded and based on expert judgment, the GWB was evaluated in poor chemical status;

- in the Surface water test, each GWB (with the relevant groundwater MP) associated with the SWB was assessed individually, taking into account the hydrological criterion, the hydrogeological criterion, the groundwater and surface water concentration profile, dilution (if data available) and that the estimated load of pollutant from groundwater transferred to associated surface water could be more than 50%, the GWB was evaluated in poor chemical status.

2.3.2.2.2. Quantitative status

To determine the overall quantitative status for a GWB, a series of tests should be applied that considers the impacts of anthropogenically induced long-term alterations in groundwater level and/or flow. Each test will assess whether the GWB is meeting the relevant environmental objectives. The quantitative status in Hungary has been assessed taking into account CIS Guidance No.18. The following criteria have been used (ICPDR, 2021a):

- groundwater alteration (drawdown) test;
- water balance test;
- surface water flow test;
- GDTEs test;
- saline or other Intrusion test.

Assessment of groundwater quantitative status in Slovak Republic consists of 4 tests (ICPDR, 2021a):

- balance assessment of GWBs for the period 2013-2017 and evaluation of the long-term trend of development of balance levels of GWBs for the period 2004-2018;
- evaluation of the existence of significant declining trends in the groundwater level and spring yield in GWBs for the period 2007-2016 processed by aggregation of point results of groundwater quantity monitoring in the facilities of the state hydrological network of the SHMI;
- assessment of the impact of groundwater quantity on the status of terrestrial ecosystems dependent on groundwater;
- assessment of the impact of groundwater quantity on surface water.

2.3.2.3. Groundwater threshold value relationships

In the Slovak Republic, the NBL was determined and used to derive the TV. The TV were determined for all indicators listed in Part B of Annex II to Directive 2006/118/EC and in Directive 2014/80/EU. The TV for the inorganic substances were derived according to the formula: TV = (NBL + DWS)/2. The TV for organic compounds were derived using the formula: TV = 0.75 * DWS. These TVs were used for GQA and DWPA tests.

An updated list of the TV established for each GWB was published in the amended Regulation of the Government of the Slovak republic No.282/2010 (Regulation, 2010).

For the Surface water test, the TV were derived as follows: TV = CV = AF * EQS (surface water standard)/DF, where AF (Attenuation factor) and DF (Dilution factor) are equal to 1 (the worst case). For that GWB where the NBL was higher than the TV due to natural hydrogeological reasons, the TV was set up as TV = NBL.

In Hungary, EQS for herbicides and total pesticides, tri- and tetrachloroethylene based on 201/2001 (X.25.) governmental decree (Governmental, 2001) and the 6/2009. (IV.14.) KvVM-EüM-FVM common ministerial decree (KvVM-EüM-FVM, 2009) in correspondence to I. Annex of the 2006/118/EC Directive.

In Hungary, more than 95% of drinking water is from subsurface waters, so for all other components the DWS is applicable. For those GWBs where the NBL was higher than the DWS due to natural hydrogeological reasons, the TVs for ammonium, SO4 and EC were defined by taking into account these higher values, as described in Guidance Document No.18.

TVs and NBLs established for the Ipel/Ipoly TGWB (GWB-12) are presented in TABLE 2.3.2.3.1. As in the case of the Upper Jurassic – Lower Cretaceous TGWB (GWB-2) shared by Romania and Bulgaria, remarkable differences in the list of the pollutants and their TVs and NBLs set by Hungary and Slovak Republic are visible.

TABLE 2.3.2.3.1

TVs of GWB-12 (ICPDR, 2021a)

Country	Pollutant/indicator	TV (or range)	NBL (or range)	Level of TV establishment (national, RBD, GWB)
Hungary	Nitrates (NO_3^-)	50-no TV mg/l	9.5 mg/l	GWB
Hungary	Ammonium (NH_4^+)	2-no TV mg/l	1.1 mg/l	GWB
Hungary	Conductivity	2500-no TV µS/cm	570 µS/cm	GWB
Hungary	Sulphates (SO_4^{2-})	500-no TV mg/l	284 mg/l	GWB
Hungary	Chlorides (Cl^-)	50-no TV mg/l	119 mg/l	GWB
Hungary	Phosphates (PO_4^{2-})	2mg/l	0.91 mg/l	GWB
Hungary	Cadmium (Cd)	5-no TV µg/l	0.07 µg/l	National
Hungary	Lead (Pb)	10-no TV µg/l	0.293 µg/l	National
Hungary	Mercury (Hg)	1-no TV µg/l	0.005 µg/l	National
Hungary	Trichloroethylene (TCE)	10-no TV µg/l	-	National
Hungary	Tetrachloroethylene (PCE)	10-no TV µg/l	-	National
Hungary	Absorbed organic halogens (AOX)	20-no TV µg/	-	National
Hungary	Pesticides (by components)	0.1-no TV µg/l	-	National
Hungary	Pesticides (total)	0.5-no TV µg/l	-	National
The Slovak Republic	Ammonium (NH_4^+)	0.9 mg/l	0.9 mg/l	GWB
The Slovak Republic	Arsenic (As)	6 µg/l	2 µg/l	GWB
The Slovak Republic	Benzene	0.8 µg/l	-	National
The Slovak Republic	Cadmium (Cd)	2.9 µg/l	0.7 µg/l	GWB
The Slovak Republic	Chlorides (Cl^-)	135.7 mg/l	21.3 mg/l	GWB
The Slovak Republic	Chromium (Cr)	26 µg/l	2 µg/l	GWB
The Slovak Republic	Copper (Cu)	1003 µg/l	6 µg/l	GWB
The Slovak Republic	Iron (total) (Fe_{tot})	0.15 mg/l	0.10 mg/l	GWB
The Slovak Republic	Lead (Pb)	7 µg/l	5 µg/l	GWB
The Slovak Republic	Manganese (Mn)	0.1 mg/l	0.1 mg/l	GWB
The Slovak Republic	Mercury (Hg)	0.6 µg/	0.1 µg/l	GWB
The Slovak Republic	Nitrates (NO_3^-)	50 mg/l	1.5 mg/l	GWB
The Slovak Republic	Nitrites (NO_2^-)	0.26 mg/l	0.02 mg/l	GWB
The Slovak Republic	Phosphates (PO_4^{2-})	0.24 mg/l	0.08 mg/l	GWB
The Slovak Republic	Sodium (Na^+)	119.8 mg/l	39.6 mg/l	GWB
The Slovak Republic	Sulphates (SO_4^{2-})	140.8 mg/l	31.6 mg/l	GWB
The Slovak Republic	Tetrachloroethylene (PCE) + Trichloroethylene (TCE)	7.5 µg/l	-	National

2.3.2.4. Description of the trend assessment methodology

Trend is assessed separately for groundwater quality and quantity ***in the Slovak Republic*** at which for trends in quantity the procedure applies for all GW quantity monitoring sites. The assessment follows a stepwise procedure. Consisting of the evaluation of the data sets and the MPs (no gaps in time series are allowed and data from 2007–2016 were used), consisting of the performance of the non-parametric Mann-Kendall trend test (95% confidence level) and the regression analysis. GWBs with decreasing trends but with no evidence of abstraction are excluded from assessment in the 2nd RBMP.

For assessing trends in concentrations of pollutants in groundwater the evaluation period was 2007-2016. The results of surveillance and operational monitoring were applied for the assessment. Monitoring frequency depends on the GWB type. In the analysis the values < LoQ are replaced by $LoQ_{max}/2$. Trend assessment is only performed if the number of values < LoQ is less than 50%. Non-parametric Mann-Kendall test with 5% significance level was applied for trend evaluation. For time series showing a normal distribution, the statistical significance of the trend was also tested by the parametric method (ANOVA) with 5% significance level. Then for all times series with statistically significant upwards trends, the statistically significant upward trend was evaluated and identified if the median of the values measured over the last 2 years was higher than 0.75*QS/TV or the calculated predicted value of the linear trend up to 2026 (regression model calculated by the least squares method or Sen's nonparametric procedure) was higher than QS/TV. The significant sustained upward trends of pollutant concentrations were identified at the level of MPs and at the GWB level.

The starting point for trend reversal was placed where the concentration of the pollutant reaches 75% of the QS/TV of the relevant pollutant.

To assess the trend of pollutant concentrations ***in Hungary***, chemical data of the surveillance monitoring systems were used for the period of 2000 to 2012. The trend analysis was done using the Matlab program package of Mann-Kendall method with fitted Sen's slope. The steps used for trend assessment were:

- during the trend assessment of all components for all monitoring objects were created using yearly average data and excluding time series with less than 4 data points;
- the trend of GWB level aggregates of yearly data was assessed as well.

Significant upward or downward trends were identified on 95% significance level using Mann-Kendall method with Sen's slope.

2.3.2.5. Description of the trend reversal assessment methodology

Trend reversal assessment methodology ***in the Slovak Republic*** consists also based on GWstat software. Time series were included in the assessment, on the basis of which significant sustained upward trends at the level of GWBs were classified. The time series entering the evaluation were supplemented by data monitored in previous years so that the evaluation period was 14 years. The evaluation was performed by dynamically dividing the time series into two sections with different lengths and then evaluating the statistical significance of the trends separately for each allocated section.

A reversal of the trend was indicated if the following conditions were met at the same time: the statistical significance of the trends evaluated within individual sections is higher than the statistical significance of the trend evaluated on the basis of all data forming the evaluated time series, the section representing the results of monitoring in the older period shows a statistically significant upward trend, which is followed by a statistically significant decreasing trend evaluated on the basis of the results of monitoring in the newer period.

In the case of Hungary, it has been only mentioned that in order to assess the trend reversal of pollutant concentrations two consecutive time periods were compared and evaluated (ICPDR, 2021a).

2.3.3. Additional comments and suggestions from the experts of the Slovak Republic and Hungary

As can be seen, the information in the internet sources and project materials is relatively general and therefore the opinion of the dedicated experts and the detailed information in their possession are essential in the context of the WaterAct project. It should be mentioned that it was very difficult to reach people already involved in the process of establishing TGWBs at EU level, as they are likely very busy experts who did not have enough time to share detailed and very specific information.

Below is a summary of the experiences and opinions of two external experts involved in the delineation process of TGWBs in the Slovak Republic and Hungary. Valuable comments referred to here are provided by

Réka Gaul from the Ministry of Interior, Hungary and Peter Malik from the Geological Survey of the Slovak Republic.

According to Gaul Réka (personal communication) the main principles of GWB in Hungary were:

- separation of the main geological features: porous aquifers in the basins, karstic aquifers, mixed formations of the mountainous regions, other than karstic aquifers;
- thermal GWBs were separated according to the temperature greater than 30°C. In the case of porous aquifers it is done vertically, while in karstic aquifers horizontally. There are no thermal aquifers in the mountainous regions other than karstic;
- further division is related to the subsurface catchment areas and vertical flow system (in the case of porous aquifers) and to the structural and hydrological units (in the case of karstic aquifers and mountainous regions).

The entire territory of Hungary lies in the Danube River Basin, where the ICPDR coordinates RBM planning at basin level. For each RBMP cycle – in addition to the RBMPs prepared by the countries – a so-called roof report is prepared and sent to the EC including all relevant information on Danube Basin countries at basin level. The roof report also includes TGWBs, but only those that are bi- or trilaterally agreed by neighboring countries and nominated for Danube level. The draft of the last roof report including the most recent information (ICPDR, 2021a) has been referred to in the previous chapter of this report. The older editions of WFD reports can be found on the following website: http://icpdr.org/main/activities-projects/river-basin-management.

First TGWBs were delineated in the process of 1st DRBMP preparation, by contacting neighboring countries. Hungary has bilateral water agreements (water commissions) with all 7 neighboring countries, which were the main forum of TGWBs (and also SWBs) delineation and harmonization. Subgroups were established to deal with the WFD tasks, in case of neighboring countries willing to cooperate. Gaul Réka mentioned that no TGWBs were established with Austria or Slovenia in lack of political interest from the Austrian or Slovenian side. In the subgroups the representatives of the relevant ministries and experts of the background institutes responsible for delineation were present. The main idea behind the delineation of TGWBs was to forego conflicts with neighboring countries, because it seemed to be easier to find solutions as early as possible in order to avoid future problems if TGWBs are already set.

Peter Malík from the Geological Survey of the Slovak Republic also confirmed (personal communication), that TGWBs were delineated, if both partner countries decided to do so. If one "transboundary country" decides not to delineate the TGWBs, the TGWBs do not exist (formally, of course). Slovakia has agreement only with Hungary and up to now, there are 5 possible TGWBs. Austria did not enter the negotiations with the Slovak Republic (there was one possible TGWB) and the Czech Republic considered the groundwater exchange to be too small to delineate TGWBs. The Slovak Republic had negotiations with the official Polish delegation too, but until now both possible TGWBs are not mutually agreed officially.

According to Hungarian expert (Gaul Réka, personal communication), during the delineation as a first step horizontal boundaries of the TGWBs were agreed on at state borders based on the available geological, hydrogeological information (available from international bi- or multilateral projects). These delineations were considered as an aggregate of GWBs at national level, to be able to harmonize national delineation criteria with transboundary criteria. Due to different approaches in GWB delineation, it was not possible to harmonize GWB boundaries, therefore aggregates – hydrogeological units were delineated and are reported on at Danube level, whereas at national level countries provide data and carry out assessment at GWB level; e. g. in case of porous aquifers vertical delineation of TGWBs has not been agreed upon until now due to different national approaches, so in case of problems the whole unit has to be investigated.

Peter Malík mentioned that the process of delineation was simple – GWBs delineated in respective countries were administratively connected. The problem was that the methodology of GWBs' delineation was very different in Hungary and the Slovak Republic – Hungary applied "Tothian" theory, but the Slovak Republic, similarly to the Czech Republic, re-classification of groundwater administrative units, which existed already for decades. Peter Malík also stressed that the hydrogeologists in both countries had to discuss together and with "water officers" at respective water administration that groundwater exchange occurs at distinct places with sufficiently relevant intensity – this is an important aspect for the delineation of TGWBs. Furthermore, problems arose in the early years due to the need to unify the units of measurement, reporting layouts and coordinate systems used in the neighboring countries.

Between 2006 and 2008, the Geological Institute of Hungary - MÁFI and the State Geological Institute of Dionýz Štur - ŠGÚDŠ cooperated in data and information collection and exchange to contribute to a water management plan for three TGWBs in Northern Hungary and Southern Slovakia. These three regions were the Ipoly/Ipel river region, Aggtelek - Slovak Karst region and Bodrog river region. The project "Monitoring and assessment of Hungarian-Slovak TGWBs; Environmental state and sustainable management of Hungarian-Slovakian TGWBs (ENWAT)" was founded by the INTERREG IIIA Programme and was a step forward in the creation of a joint Hungarian-Slovakian water management plan by supplying basic data and fresh information on TGWBs (Brezsnyánszky et al., 2008). As a result of this project the list of monitoring objects, water quality maps, transboundary groundwater models were elaborated, but the responsibility is now in the hands of water administrators (Peter Malík, personal communication).

The harmonization of status assessment of TGWBs (TVs, trend assessment, monitoring network) is rather formal (Gaul Réka, personal communication), in the course of the preparation of the DRBMP the Groundwater Task Group of ICPDR collects data of national status assessments and prepares a river basin assessment for the TGWBs aggregates. However, negotiations for adjustment in case of differences are rare.

Unfortunately, after the first RBMP capacity and enthusiasm has decreased, not much progress has been made, except for Hungary and the Slovak Republic relations, where a new TGWB (GWB-12: Ipel/Ipoly – discussed in previous chapter) was delineated and the boundaries of an existing TGWBs were modified recently. The main reason behind (in case of Hungary) is the lack of capacity, but also a lack of real interest and strong requirement of the EC on transboundary harmonization (Gaul Réka, personal communication). It is emphasized even more broadly (Lipponen & Chilton, 2018), that although the legal basis for cooperation in managing transboundary waters in the pan-European region is well developed, most existing agreements do not explicitly refer to groundwaters or their application to groundwaters remains limited. There is a need to improve the legal frameworks for cooperation and strengthen institutions for the management and protection of groundwaters.

The experts pointed out that in case of difficulties bilateral water commissions are the forum for negotiations. And finally, one important lesson learnt was that expert level is not enough to have TGWBs, political willingness at both sides (countries) is essential to take on responsibility for the share and common use of groundwaters and to ensure adequate capacity at both sides to deal with tasks and possible problems that may arise.

2.4. Recommendations for the WaterAct project partners

This chapter of the report (expert assessment) is aimed to describe what practical experience, based on literature review and the two cases (Upper Jurassic – Lower Cretaceous GWB and the Ipel/Ipoly GWB) could be used in the identification and management of Estonian-Latvian TGWBs.

Within the WaterAct project close cooperation continues between the Estonian and Latvian organizations involved in the preparation of RBMPs to improve the efficiency of joint groundwater resources management in the transboundary area. Joint transboundary management of the Gauja/Koiva and Salaca/Salatsi river basins is necessary for both countries to implement the requirements of the EU water policy. The project will ensure a harmonized approach to the management of groundwater resources and the assessment of the status of GWBs in the Latvian-Estonian transboundary area.

To develop harmonized principles for joint assessment and management of groundwater resources, several meetings have been already organized. These meetings covered methodologies and approaches in both partner countries, ranging from strategies for conceptual understanding and modeling to delineation of GWBs and assessment of their overall status, pressures identification and assessment (WaterAct, 2020; 2021). It was concluded that there are differences between shared methodologies and approaches between the two partner countries, and some methodologies are only available in one country (e.g. trend assessment strategies are only available to Estonian partners), but in general the approaches are considered related. The last WaterAct meeting on harmonization of approaches took place on 17.06.2021 as an online event (MS Teams platform), where the issues related conceptual model development, pressure assessment approaches and GWB chemical and quantitative status assessment approaches were discussed (Krauze, 2021). The meeting showed that in many cases harmonization of methodologies is possible, but in some cases (e.g. GAAEs, water balance assessment test) it is outside the scope of the WaterAct project in terms of time and lack of data. It also turned out that further data and information exchange is key to the success of the harmonization process.

For groundwater resource management across Latvia-Lithuania border, Lithuanian Geological Survey and Latvian Environment, Geology and Meteorology Centre have an institutional cooperation, within which many factors were considered – differences between aquifer vertical boundaries, delineated GWBs, not unified hydro-stratigraphic classifications, groundwater level distribution and strategies for groundwater monitoring (LGS-LEGMC, 2019). As a result of this project, 5 groups of TGWBs have been delineated and agreed to be further managed as joint GWBs. The report discusses the following subjects – national GWB delineation principles in transboundary areas, harmonization of groundwater management units and preliminary status assessment of common GWB groups. However, the authors are forced to admit that addressing the above listed problems and assessing the necessity of harmonization requires large financial investment that can be realized only in the long run. The results of the cooperation on Latvian-Lithuanian border could also provide some tips and examples for the delineation of Estonian and Latvian TGWBs. However, given the fact that the geological and administrative delineation of Estonian-Latvian TGWBs is in principle nearing completion and that harmonization, which is the basis for the status assessment, is under way, this project may not provide much support in case of WaterAct activities.

During Interreg Estonia-Latvia project "Joint management of groundwater dependent ecosystems in transboundary Gauja/Koiva river basin (GroundEco)", joint methodology for identification and assessment of GDTEs was developed which was used to identify GDEs in transboundary Gauja/Koiva river basin. The project was focused primarily on the assessment of GDTEs in line with the WFD, as well as for better understanding of GDTEs functioning and linkage with groundwater resources. However, some findings of the project also apply to Estonian-Latvian TGWBs more broadly. The final report of this project (Retiķe et al, 2020) brings out that the number and location of MPs for the quantitative status of TGWBs must additionally allow to evaluate the direction and quantity of groundwater flow across the state border. This finding is in line with the Slovakian expert's statement, referred above, that groundwater exchange with sufficiently relevant intensity is an important aspect for the delineation of TGWBs. The authors of the report (Retiķe et al, 2020) also proposed that transboundary groundwater monitoring between Estonia and Latvia is encouraged to harmonize monitoring approaches and improve the usage potential of shared national groundwater datasets and encourage transboundary cooperation. It was also noted that groundwater monitoring stations could be installed at the Latvian-Estonian border for transboundary groundwater monitoring and laboratory intercalibration needs. The author of the current report agrees with their suggestions.

As it has been mentioned earlier, the EC provides very general and non-binding guidance on how to delineate GWBs (EC, 2003b). Due to varying hydrogeological conditions, data availability and local knowledge base, the chosen methodologies and final amount of GWBs vary significantly within MS (EC, 2004).

An analysis of the revised EU Directives and their guidance documents during this study showed also that these documents do not provide much explicit and detailed guidance concerning the TGWBs and they mention in very general manner the issues like the delineation of TGWBs, the assessment of their status and the bases for the criteria on which the status assessment should be performed. Thus, the Guidance Documents provide only an overall methodological approach, but will need to be tailored to the specific circumstances of each EU MS. Thus, the literature review leaves an understanding that the ways, how to delineate and assess the TGWBs is largely a matter for the MS themselves and the expert committees and working groups set up by those states. This fact was also confirmed by the external experts questioned, who declared that in order to move forward with the theme, the water commissions (having bilateral agreements) have been established and act as the main forum of TGWBs delineation and harmonization. In places subgroups have been established to deal with specific the WFD tasks, in case of neighboring countries willing to cooperate. In the case of the WaterAct project, this condition is met because both Latvian and Estonian specialists, as well as water politicians, participate in the project. Continued cooperation and exchange of information within the WaterAct project team is a key solution to the problems that have arisen and as the current assessment also shows that detailed guidance is not available, harmonization issues need to be addressed on the basis of the expertise and best judgment of the project team's specialists. Guidance

Documents discussed in the first chapter of this report provide an overall methodological approach, but will need to be tailored to the specific circumstances of "transboundary MS".

Depending on the region, the delineation and assessment of TGWBs within the European countries, is at a different stage. First TGWBs in the Danube River Basin were delineated in the process of 1st Danube River Basin Management Plan (DRBMP1) preparation, by contacting neighboring countries. Today, already the draft of the 3rd roof report (DRBMP3) has been prepared (ICPDR, 2021a), but as it is seen from the case studies presented, bilateral harmonization of GWBs is still ongoing process. The assessment methodologies applied in Upper Jurassic – Lower Cretaceous GWB and Ipel /Ipoly GWB differ significantly in transboundary countries. Therefore, these example TGWBs do not provide detailed guidance that could be implemented under the WaterAct project. As can be seen from the opinions of external experts, technical details are likely to be disseminated in local working groups (water commissions) and not published or shared externally. This is also the reason why the author of the current expert opinion did not reach such detailed instructions even through thorough internet searches and by contacting the experts from other EU countries.

According to external experts, the harmonization of status assessment of TGWBs (TVs, trend assessment, monitoring network) is rather formal (Gaul Réka, personal communication), as in the course of the preparation of the DRBMP the Groundwater Task Group of ICPDR collects data of national status assessments and prepares a river basin assessment for the TGWB aggregates. One reason here is probably already mentioned the lack of capacity, but the lack of real interest and strong requirement of EC on transboundary harmonization.

Hopefully this will provide the WaterAct partners with some background information on TGWBs, their delineation and assessment in the EU context. The author of this expert opinion has not been involved in the process of establishing TGWBs itself and this work is based solely on the information gathered from literature sources and by interviewing external experts.

The author is thankful to Rossitza Gorova from Executive Environment Agency, Bulgaria, Peter Malik from Geological Survey of Slovak Republic and Réka Gaul from Ministry of Interior, Hungary for their valuable comments concerning TGWBs. Kersti Türk from the Ministry of the Environment of Estonia and Kristiina Ojamäe from Estonian Environment Agency are acknowledged for their help in finding the necessary information and international contacts as well as for the fruitful discussions during the project.

3. Development of joint principles on common groundwater resources management and assessment is the cross-border Gauja/Koiva and Salaca/Salatsi river basins

For further joint assessment of common groundwater resources management and assessment in the transboundary Gauja/Koiva and Salaca/Salatsi river basins, it was necessary to develop harmonized principles. Using the information and knowledge gained during exchanging experiences within consortium on groundwater resources management in each country (see Chapter 1), studying EU level guidelines and best practices from other countries (see Chapter 2), as well as exchanging and acquiring information during WP1 Activity T1.4 "Experience exchange and trainings at EGU General Assembly 2021" (Annex 14) and Activity T1.3 "Capacity building at Nordic Hydrological Conference 2022" (Annex 15), development of harmonized principles (in cases where that was possible due to available data amount and also taking into account the available resources: both human and financial, as well as the national legislation already in force in each country) took place. In scope of this chapter, attempt to develop harmonized principles was made for the following aspects of groundwater resources management and assessment: (1) conceptual model/understanding development of TGWBs, (2) NBLs and TVs delineation, (3) pressure assessment, (4) trend assessment and (5) GWB status assessment - chemical and quantitative.

Within the framework of the exchange of experiences, a decision was made within the consortium that it will not be possible to harmonize some of the methodologies within the WaterAct project. These include the identification and assessment of GAAEs (see Chapter 1.4) and the assessment of groundwater vulnerability to nitrates pollution (see Chapter 1.5).

In Latvia, identification and assessment of GAAEs was an ongoing process during the parallel project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies"[10] during which the development of methodologies for the identification and assessment of these ecosystems was developed, as well as their identification and assessment throughout the territory of Latvia (also including the Gauja and Salaca river basins). This project reached conclusion only at the very end of 2021 and the results of it were available only at the beginning of 2022, as a result of which possible harmonization regarding the identification and assessment of these ecosystems was no longer possible considering the timeline of the WaterAct project. Also an important factor to take into account is the fact that surface water specialists (whose knowledge are vital for the harmonization of these methodologies) were not involved in the WaterAct project from the Latvian side. But considering the fact that during the aforementioned project the methodologies suitable for Latvia were developed strongly based on the experiences of Estonia (see Chapter 1.4), it is also possible to affirm that the methodologies used in both countries for the identification and assessment of GAAEs have already been harmonized to the nearest possible level.

It was also decided that harmonization of groundwater vulnerability assessment to nitrates pollution during the WaterAct project is not necessary as in both countries such assessment is already carried out with accordance of Council Directive 91/676/EEC (the Nitrates Directive) and the nitrate vulnerable zones are not distributed in identified TGWBs on the Estonian side, but on the Latvian side it occupies a small part of the identified TGWBs D6 and A8 (central part of Latvia) where direct transboundary interaction was not identified (Borozdins et al, 2022).

This report does not focus on TGWBs delineation and common groundwater monitoring principles and strategy development as these topics are the main focus of WP2 activities T2.2 "Assessment of the status of transboundary groundwater bodies according to harmonized principles" and activity T2.3 "Development of strategy for transboundary groundwater monitoring in Gauja/Koiva and Salaca/Salatsi river basins". More information on these topics are available in the joint report of WP2 "Assessment of common groundwater resources in Gauja/Koiva and Salaca/Salatsi river basins" (Borozdins et al, 2022).

[10] Project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies" (financed by Latvian Environmental Protection Fund). Available: https://lvafa.vraa.gov.lv/projects/1-08_205_2020

3.1. Conceptual models of transboundary groundwater bodies

After reviewing various European guidance documents (see Chapter 2), it was concluded that no overall definition of the conceptual model can be found, even though both the WFD and the GWD state that conceptual models must be used as the basis for GWB status assessment. The CIS Guidance Document No.26 (EC, 2010) states that "*a hydrogeological conceptual model describes and quantifies the relevant geological characteristics, flow conditions, hydrogeochemical and hydrobiological processes, anthropogenic activities and their interactions*". In regard to the WFD, the main topic of the conceptual model is assessment of risk of the GWB not achieving the environmental and groundwater protection objectives:

- prevent or limit the input of pollutants,
- prevent the deterioration of the status of GWBs,
- achieve good groundwater status (both chemical and quantitative);
- implement measures to reverse any significant and sustained upward trend;
- meet the requirements of the protected areas.

Conceptual models can be used for several purposes within the groundwater management cycle - to understand the significance of pressures, to design and evaluate monitoring networks and to interpret monitoring data, to establish TVs, to perform status and trend assessment, and to plan measures. It also has to be kept in mind that the process of conceptual model development and maintenance is a cycling process which starts with a simple model and then follows with data collection and analysis, uncertainty assessment, and starts again with the refinement of it. Within the groundwater management cycle it has to be done once in 6 years (EC, 2010).

In order to develop a common and harmonized structure for the conceptual models of identified Estonian-Latvian TGWBs, comparison of currently applied conceptual models (see Chapter 1.6) in both countries was initially carried out (Annex 6). During the comparison it was established that the development of conceptual models in more detail has taken place in Estonia. In both Estonia and Latvia, conceptual models are structured in two main parts - the first part consists of natural features of the hydrogeological system (e.g., geology, hydrodynamics, natural baseline chemistry, groundwater vulnerability etc.) while the other part is presenting the human activities in the area (e.g., groundwater abstraction, point/diffuse sources of pollution, etc.). All the data is structured in tables with the same structure for all GWBs to prevent misunderstandings during information interpretation between different GWBs. More detailed information could be found in conceptual models used in Estonia, while in the case of Latvia, the available information was somewhat sparser, but additional information (which is available in the case of Estonia) in most cases can be obtained from internal databases and/or the State Geological Fund. Therefore, within the framework of the WaterAct project, the decision within the consortium was made to adopt the Estonian conceptual model structure, transforming and supplementing it with additional elements from the conceptual model structure applied in the case of Latvia, in cases where such information was not included in the Estonian conceptual model structure. The final version and structure of joint and harmonized conceptual model structure is given in Annex 7.

Comparison also revealed that in both countries conceptual models are accompanied with additional visual materials (see Chapter 1.6). Taking into account that visual materials differ in both countries, the decision within the consortium was reached that within the framework of the WaterAct project visual materials will be developed jointly for the hydrogeologically connected TGWBs. The overall content and visual solution was adopted from the Estonian visual materials, modifying and adapting them to the specifics and needs of the WaterAct project. The final versions of the prepared additional visual materials, as well as the prepared conceptual models of Estonian-Latvian TGWBs are available in the joint WP2 report (Borozdins et al, 2022).

3.2. Natural background levels and threshold values of transboundary groundwater bodies

The GWD, following Article 17 (1) and (2) of the WFD, lays down specific measures to prevent and control groundwater pollution. One of these measures include criteria for assessing groundwater good chemical status. Article 3 of the GWD depicts the criteria for assessing the chemical status of GWBs, including the GQS for nitrates and pesticides listed in Annex I to the Directive, as well as the TVs set by each MS following the procedure set out in Annex II. Each MS must define TV for pollutants, groups of pollutants, or indicators of pollution identified as being capable of being characterized as GWBs or groups of sites as risk groups or groups, taking into account at least the list in Part B of Annex II.

Under the GWD, TVs may be set at the national level, at the level of a RBD, or in a part of an iRBD lying within the territory of a MS, or at the level of a GWB. Each MS must ensure that setting of TVs for GWBs where groundwater crosses a national border is established in cooperation between the concerned MS, following Article 3 (4) of the WFD. If the risk of not achieving good groundwater status is not identified in the GWB during the initial characterization, further characterization and setting of TVs are not mandatory.

In order to assess the current situation in both countries regarding the determination and use of NBLs and TVs for GWBs, comprehensive comparison of the currently used approaches used by both countries was initially carried out (Annex 8). The comparison showed that differences can be found between the approaches used in both countries and based on these differences recommendations for possible harmonization were developed. Major differences between approaches used in both countries were found in the first steps – the preparation of the data set (treatment of samples under detection limits (DLs), as well as treatment of time series) and the treatment of anthropogenic influences (saline intrusion and agricultural influence). While at the EU level suggested approaches (which were also used in the case of Latvia) are to use ½ of the DL to treat values under DLs and calculate median values for the same MP (Wendland et al., 2006), in the case of Estonia, the full DL value was used in the dataset and instead of median values, average values were calculated for the same MP. Although both techniques are the most common, the chosen methodological approach could become significant for the case where there are a lot of values under DLs and a lot of MPs with time series with significant trends. Also, in the case of Estonia, when preparing the data set, anthropogenic influence was not taken into account (regarding saline intrusion and agricultural influence), while the suggested approach at EU level is to remove samples with Na^+ and Cl^- concentrations sum higher than 1000 mg/l (in the case of saline intrusion) and to remove samples with NO_3^- concentrations > 10 mg/l and samples with known presence of synthetic compounds (Wendland et al., 2006), all of which was done in the case of Latvia. Other identified differences were considered to be minor in the context of the WaterAct project, as both countries have relied on the BRIDGE methodology (Wendland et al., 2006; Annex 8).

Taking into account the differences listed above in methodological approaches in both countries and seemingly necessary harmonization, it should be noted that with regard to the identified TGWBs and the NBLs and TVs set for them, in practically none of the cases defined TVs are used in the chemical status assessment (mostly in the case of Latvia), or they have not been determined at all (in the case of Estonia). This situation has arisen because (1) practically none of the identified TGWBs gave been identified as being at risk of not achieving good chemical status and/or no significant pressures have been identified in them (Borozdins et al, 2022), as well as (2) other EQS and LVs have been set at the national level in both countries, which have a higher priority and which are already being used in the chemical status assessment and are applicable to all GWBs (in the case of Estonia) (see Chapter 1.8.1.1) or applicable to GWBs identified as being at risk of not achieving good chemical status and/or with significant pressures (in the case of Latvia) (see Chapter 1.8.1.2). In Latvia, this is the case with GWB A8, for which the risk of not achieving good chemical status due to significant point pressure has been identified, as a result of which GWB-specific thresholds values are used for pressure-related indicators in chemical status assessment. From a transboundary perspective, it is necessary to emphasize that GWB A8 has a considerably large area and the identified significant point pressures are distributed in the Riga agglomeration area and they have no impact in a transboundary context – it is physically impossible for any kind of pollution to reach the territory of Estonia due to geological conditions (Borozdins et al, 2022). In the future, it would be necessary to consider the possibility to delineate the area of the Riga agglomeration as a separate GWB from GWB A8, which would facilitate and improve the management of this territory and would not create a false impression of the common chemical status of GWB A8.

In view of the above, an agreement was reached within the consortium that further harmonization of used methodologies is not necessary at this stage. The EQS and LVs set in the existing legislation at the national level in both countries and used in chemical status assessment of TGWBs will not be tackled and changed within the framework of the WaterAct project, as making changes to national legislative acts is not possible at this stage. For further status assessment of identified TGWBs, already applied EQS and LVs will be used during the WaterAct project (additionally in the case of GWB A8, individual TVs applied for pressure-related indicators will be used). It should also be taken into account that in the cases of other countries and transboundary river basins the harmonization process has been rather formal than practical – the countries have exchanged data on the applied EQS, LVs and TVs, and a decision has been made between the parties involved that they will be used in the future TGWBs status assessment (see Chapter 2.3).

A summary of GQS, LVs and TVs that have been applied in both countries and will be used within the framework of the WaterAct project to assess the status of the identified TGWBs, is given in TABLE 3.2.1.

TABLE 3.2.1

Summary of GQS, LVs and TVs of identified Estonian-Latvian TGWBs for further chemical status assessment

Pollutant/ indicator	Unit of measure-ment	TV (EQS, LV)			TGWB code
		Estonia	Latvia	Level of TV establishment (national, GWB)	
Nitrates (NO_3^-)	mg/l	50		National	21, 23, 25, 26 D6, A10, P
		-	27 (aerobic) 25.2 (anaerobic)	GWB	A8
Active substances in pesticides, including their relevant metabolites, degradation and reaction products(1)	µg/l	0.1 0.5 (total)(2)		National	21, 23, 25, 26 D6, A8, A10, P
Nitrites (NO_2^-)	mg/l	-	0.5	National(3)	A8
Total nitrogen (N_{tot})	mg/l	-	3	National(3)	A8
Ammonium (NH_4^+)	mg/l	0.5 (aerobic) 1.5 (anaerobic)	0.425	National GWB	23, 25, 26 (aerobic) 21 (anaerobic) A8
Chlorides (Cl^-)	mg/l	-	134	GWB	A8
Sulphates (SO_4^{2-})	mg/l	-	165	GWB	A8
Permanganate index (CODMn)	mgO_2/l	-	5	National(3)	A8
Sum of benzene, toluene, ethylbenzene and xylenes (BTEX)	µg/l	-	5	National(3)	A8
Chemical oxygen demand (COD)	mgO_2/l	≤ 5	-	National	21, 23, 25, 26
pH level	[pH]	6-9	-	National	21, 23, 25, 26
Trichlorethylene (TCE)	µg/l	70	5	National National(3)	21, 23, 25, 26 A8
Tetrachlorethylene (PCE)	µg/l	70	5	National National(3)	21, 23, 25, 26 A8
Arsenic (As)	µg/l	100	7.45	National GWB	21, 23, 25, 26 A8
Cadmium (Cd)	µg/l	10	2.65	National GWB	21, 23, 25, 26 A8
Mercury (Hg)	µg/l	2	0.58	National GWB	21, 23, 25, 26 A8
Lead (Pb)	µg/l	200	5.83	National GWB	21, 23, 25, 26 A8
Nickel (Ni)	µg/l	-	11.1	GWB	A8

(1) "Pesticides" means plant protection products and biocidal products as defined in Article 2 of Directive 91/414/EEC and in Article 2 of Directive 98/8/EC, respectively

(2) "Total" means the sum of all individual pesticides detected and quantified in the monitoring procedure, including their relevant metabolites, degradation and reaction products.

(3) LV in Latvia is established at the national level, but only for GWBs with significant point pressure.

3.3. Pressure assessment of transboundary groundwater bodies

Article 5 of the WFD requires each MS to identify the significant pressures likely to cause GWB to be in less than good chemical and/or quantitative status. The WFD requires the identification of significant pressures (can contribute to an impact resulting in not meeting environmental objectives, e.g. good status of a GWB) from point and diffuse sources.

In order to determine the current situation in both countries regarding the pressure assessment of GWBs, comprehensive comparison of the currently used methodologies by both countries was initially carried out (Annex 9). The comparison showed that only in the case of point pressures assessment both methodologies can be compared at the initial level – the preparation of the list of these pressures (both countries have used *WFD Reporting Guidance 2016, Annex 1a: List of Pressure Types* as the basis), but after this step, the methodologies are practically incomparable.

In the case of ***point pressures assessment***, although both countries have used the approach of assessing the impact of these pressures at the level of SWBs, in the case of Latvia this has only been the first step, which has been followed by a much more detailed and manual assessment by an expert, taking into account the individual geological and hydrogeological conditions of each site (detailed description available in Chapter 1.2.2, comparison in Annex 9).

Regarding the assessment of diffuse pressures, as well as groundwater abstraction pressure, applied methodologies in both countries are currently not comparable due to their significant differences. In the case of ***diffuse pressures assessment***, while in the case of Estonia, the same approach as in the assessment of point pressures assessment is used (assessment is done at the level of SWBs), in the case of Latvia, the assessment of diffuse pressures is carried out in a multiple steps procedure (five steps in total), where the assessment at the level of SWBs is only one of the steps, other steps including land use and livestock data analysis, as well as distribution of Nitrate vulnerable zone is also taken into account (detailed description available in Chapter 1.2.2, comparison in Annex 9). Regarding ***groundwater abstraction pressure assessment***, the applied methodologies in each country are even more different - while in the case of Estonia, a hydrodynamical hydrogeological model is used comparing groundwater abstraction volumes with the natural groundwater balance of the GWB, in the case of Latvia, due to fact that hydrodynamical hydrogeological model has still not been developed, groundwater abstraction pressures was evaluated at the level of the GWB in the context of its intensity and distribution (detailed description available in Chapter 1.2.2, comparison in Annex 9).

Due to significant differences in applied methodologies in both countries concerning all types of pressures and their impact assessment (differences have arisen between methodologies due to the level of detail of the datasets available in each country and their quality, as well as due to differences in the knowledge base and technical solutions), an agreement was reached within the consortium that creation of harmonized approach would be too time and resources consuming, therefore no harmonization is recommended during the WaterAct project. Harmonization should preferably be carried out within the framework of a separate project, starting with development of a hydrodynamical model in Latvia, at first, at least for the identified TGWBs, but ideally – for the entire territory of Latvia; only after development of mutually comparable hydrodynamical models in both countries it will be possible to develop a harmonized approach of assessing the pressure of groundwater abstraction, as well as point and diffuse pressures.

It should also be taken into account that in the cases of other countries and transboundary river basins the harmonization process has been rather formal than practical – the involved countries have exchanged the data on identified significant pressures of all types, and a decision has been made that they will be incorporated in the TGWBs status assessment (see Chapter 2.3).

3.4. Trend assessment of transboundary groundwater bodies

According to the WFD, as well as the GWD, the MS must identify any significant and sustained upward trends in concentrations of pollutants, groups of pollutants, or indicators of pollution found in GWBs identified as being at risk (the WFD Annex V 2.4.4 and GWD Article 5). In Guidance Document No.18 on the Groundwater Status and Trend Assessment (EC, 2009) a significant and sustained upward trend is defined as "*any statistically and environmentally significant increase of concentration of a pollutant, group of pollutants, or indicator of pollution in groundwater for which trend reversal is identified as being necessary for accordance* *with Article 5*" (the GWD, Article 2(3)). This means that consideration of any significant increase of contaminants that poses risk to ecosystems, human health, and the use of groundwater is necessary. The occurrence of significant and sustained upward contaminant trends in monitoring data should be incorporated into the GWB chemical status assessment methodology as an assessment criterion.

In order to determine the current situation in both countries regarding the trend assessment of pollutants in GWBs, comprehensive comparison of the currently used methodologies by both countries was initially carried out (Annex 10). The comparison confirmed that the approaches used in each country are different and it was clarified that in the case of Latvia it may even be classified as not having been carried out in accordance with EU requirements. An agreement was reached between the project partners that in the case of Latvia, the approach currently used in Estonia will be adopted in order to achieve a harmonized trend assessment approach in both countries (allowing deviation in the case of Latvia from the Estonian approach only in cases where adoption is not possible due to a lack of data or due to other historically arising deficiencies).

The main and most important points the harmonization of which was agreed between the project partners, are as follows:

1) in the harmonized approach for the trend assessment needs in the identified TGWBs, to use groundwater monitoring data for the ***common time period from 2014 to 2019*** for the *relevant pollutants* at all MPs. Under the designation *relevant pollutants* are understood parameters for which GWB-specific EQS, TVs and/or LVs have been previously determined (see Chapter 1.8.1.1 and Chapter 1.8.1.2). In cases when an insufficient amount of data will be identified at the MP(s) (less than 3 measurements during selected time period), to use remark that the trends assessment is not possible at this particular MP due to lack of monitoring data;
2) to use ***the average value of the pollutant in the period from 2007 to 2009 as baseline*** for the harmonized trend assessment, adopting the Estonian approach in the case of Latvia. If no monitoring data is available for the specific pollutant and/or MP for the selected time period, to extend this selected time period (but not including monitoring data older than 2000 in the selection);
3) to assesses ***both statistical and environmental significance*** of the pollutant trend. For the harmonized trend assessment procedure, the Estonian approach is adopted where statistically and environmentally significant sustained upward trend is defined by a positive R-value (by calculating linear regression between the year of observation and the average value of the chemical parameter in this particular year). The trend is regarded to be statistically significant in cases when P-values are less than 0.05. The trend is regarded as environmentally significant in cases where the trend line is above 75% of the EQS, TV and/or LV.
4) for the generation of trend plots and p-values, to use the ***R software*** function lm(), as the joint R software training and development of appropriate harmonized scripts has been intended during the WP1 activity A.T1.5, resulting that both countries will be able to perform the trend assessment using R software and these common scripts and functions;
5) the occurrence of significant and sustained upward trend in single MPs (both countries) and in GWB as a whole (in the case of Estonia) is ***considered in GWB chemical status assessment tests*** *General quality assessment*, *Saline or other intrusions*, as well as *Drinking water protected areas*.

The biggest identified difference between the applied trend assessment methodologies in Estonia and Latvia is that in the case of Estonia trend plots are generated in two levels: (1) for single MPs for parameters with determined EQS, TVs and/or LVs and (2) for aggregated MPs for the whole GWB – average concentration for every single year is calculated for parameters with determined EQS, TVs and/or LVs for all MPs.

Trend assessment in the case of Latvia cannot be fully implemented at this stage according to EU requirements (EC, 2009), considering the fact that in most of the cases the amount of data available is insufficient. It is related to the monitoring strategy implemented so far in Latvia that the MPs sampled within a GWB vary from year to year; as a result, the calculated average concentration of a parameter in each year for the whole GWB would not reflect the overall situation of the whole GWB, but rather the situation at various different MPs each year. This factor affects not only the performance of trend assessment at the single MP level (insufficient amount of data in a certain time series as monitoring is not performed every year, but with certain interruptions which are also variable for each monitoring cycle), but it also makes it impossible to perform trend assessment with aggregated data trend plots at the GWB level (the variable number of points monitored each year and their correspondingly variable geographical distribution at GWB level do not allow for reliable data aggregation, as the calculated average concentrations for each year would change and more likely reflect local situations than the overall situation at GWB level).

In view of the above, the project partners mutually agreed that during the WaterAct project complete harmonization of trend assessment methodologies is currently not possible. Accordingly, it was decided that the trend assessment in the harmonized approach would follow the approaches used so far by both countries: in the case of Estonia with a two-level procedure (trend plots by single MPs and aggregated trend plots by GWB) and in the case of Latvia - with a one-level procedure (single MP trend plots). Complete harmonization of trend assessment procedures could only be achieved after a longer period of time by developing a common monitoring strategy (with common approach to the selection of MPs and the frequency of sampling) in both countries which will provide uniform data structure and volume on identified TGWBs in the Estonia-Latvian transboundary area.

3.5. Status assessment of transboundary groundwater bodies

Providing and developing joint principles for the status assessment of the identified TGWBs between Latvia and Estonia is one of the main objectives as WP2 Activity T.2.2 "Assessment of the status of transboundary groundwater bodies according to harmonized principles" is fully based on the results obtained during WP1 Activity T.1.1 "Exchange of good practices and development of harmonized principles for groundwater assessment". While comparing the national approaches of Latvia and Estonia on the status assessment of GWBs, it was concluded that although in both countries approaches are mainly based on CIS Guidance Document No.18 (EC, 2009), the approaches used in each of the countries differ, which is due to various factors, for example, in case of Latvia they are the amount and quality of the available data, the knowledge base, as well as human and financial resources (LVĢMC, 2021).

In order to develop a common approach to the assessment of the status of identified TGWBs, comprehensive comparison of the currently used approaches used by each country was initially carried out, which provide a detailed comparison of the Estonian and Latvian approaches, taking into account a tiered approach with nine characterization tests (in accordance with CIS Guidance Document No.18). In the case of Latvia, not all the necessary assessment tests were developed and implemented previously, as a result of which a comparison was not always possible - in such cases the Estonian approach or an equivalent solution was considered (if possible, taking into account the amount and quality of available data and existing knowledge base in case of Latvia). The comparison also includes comments on possible solutions that could be adapted to harmonize the approaches of both countries. In cases where the differences between the two available approaches were very minimal or related to local factors in each country and significantly did not affect the evaluation process, no harmonization was proposed. In cases where the differences were so significant that harmonization was not possible within the WaterAct project, it was also noted and recommendations were made for possible solutions in the future.

3.5.1. Chemical status assessment of transboundary groundwater bodies

The WFD states that the good chemical status of the GWB is achieved if it meets all the requirements set out in Table 2.3.2 of the Annex V (respectively: does not affect associated ecosystems, does not cause intrusion etc.). Point 2.4.5 of the Annex V also states that the average values/concentrations for selected time periods at each MP must be calculated when assessing the chemical status of GWB, and in accordance with Article 17, these average values/concentrations must be used to prove compliance with good groundwater chemical status.

In accordance with the requirements of the Annex III of the GWD, the chemical status assessment must be carried out only for those GWBs which are identified as having significant anthropogenic pressure or risk, and only for those pollutants, groups of pollutants or indicators, which would characterize it as that. GWBs that are not at risk (no significant anthropogenic pressure has been identified) are classified as in good status.

In accordance with the Annex V of the Directive 2000/60/EC, the criteria which must be used to assess the chemical status of GWB are: ***groundwater quality standards*** (referred to in Annex I of Directive 2006/118/EC for nitrates and pesticides) and ***threshold values*** (set by MS in accordance with Article 3 of Directive 2006/118/EC only for those GWBs with a risk of failure to achieve good chemical status).

In view of the above, the assessment of the chemical status of GWB can be classified as a two-step procedure within which initially the compliance of the chemical status of GWB with the GQS and/or TVs is assessed (hereinafter referred to as *the background check*). If no exceedances are detected at any of the MPs (expressed as average concentration in a given time period), the GWB is considered to be in good status and no further assessment is necessary. If exceedances are discovered, a detailed assessment of the chemical status of the GWB using five assessment tests (general quality assessment, saline or other intrusions, surface waters, GDTEs and DWPAs) must be taken to assess GWB's compliance with the required environmental conditions (EC, 2009).

In both Latvia and Estonia, in accordance with Chapter 2.3 of Annex V to Directive 2000/60/EC, as well as based on the recommendations of CIS Guidance Documents No.18 (EC, 2009), during ***the background check*** GQS (see Chapter 1.8.1), as well as the TVs developed individually for each GWB (see Chapter 1.3) are already in use (comparison between Estonian and Latvian approaches is given in Annex 11).

In addition to GQS and TVs, additional quality criteria (LVs) have been established in each country with national legislation. In Estonia, according to the regulation of the Minister of the Environment No.48 (adopted on 01.10.2019), the quality indicators used to determine the chemical status of every GWB also include electrical conductivity, pH index, dissolved oxygen (O_2), chemical oxygen demand (COD), ammonium (NH_4^+), chloride (Cl^-) and sulphate (SO_4^{2-}) ions, as well as hazardous substances, including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), trichlorethylene (TCE) and tetrachlorethylene (PCE) (more detailed information provided in Chapter 1.8.1.1). In Latvia, additional or stricter quality criteria (in case of significant point and/or diffuse pressures) were taken from the Cabinet Regulation No.118 (adopted on 12.03.2003.) for nitrite (NO_2^-) ions, total nitrogen (N_{tot}), permanganate index (CODMn), sum of benzene, toluene, ethylbenzene and xylenes (BTEX), trichlorethylene (TCE), tetrachlorethylene (PCE) and also pesticides (total and separately) (more detailed information provided in Chapter 1.8.1.2).

It was concluded that although the quality criteria chosen in both countries and their threshold and LVs differ (see Chapter 3.2), the evaluation approach at its core is based on the requirements of both directives (Directives 2000/60/EC and Directive 2006/118/EC): assessment is based on GQS (same in both countries) and TVs which in both countries were established based on the pressure and risk assessment of GWBs, also taking into account local hydrogeological conditions and regional groundwater quality variability. Additional quality criteria (LVs) in both countries were selected and used during the assessment on the basis of the existing legislation acts, amendments of which within the WaterAct project is not currently possible. It was agreed between the project partners that no further harmonization is needed and possible at this stage, taking into account that similar approaches were taken also in other countries (see Chapter 2.3).

It was agreed between the WaterAct project partners that during the background check, however, two small changes should be made to the background check assessment procedure used in Latvia in order to harmonize it with the Estonian approach and to comply with the requirements of CIS Guidance Document No.18 (EC, 2009): in the case of Latvia, parameters characterizing intrusion processes (Cl^- and SO_4^{2-} ions) for corresponding GWBs were also included in the background check step to eliminate necessity of performing saline or other intrusion test if no exceedances of these parameters were identified during the background check step; as well as considering identified Estonian-Latvian TGWBs, the procedure in the case of lack of data were removed as it was not relevant for identified TGWBs in both countries.

Concerning ***the data aggregation and processing***, both countries have already chosen a common time period and data source: only data from MPs included in the national groundwater monitoring network in the period from 2014 to 2019 were used to assess the chemical status of GWBs. In both countries, the annual average concentrations of all relevant pollutants (GQS, TVs and/or additional quality criteria) for the whole reference period were calculated for all MPs in all GWBs. Both countries had also already taken the approach for pollutants whose concentrations were below the limit of quantitation (LoQ) to be replaced with values that are ½ of this LoQ value; in turn, only quantified concentrations were used of pesticides (values lower than LoQ value were excluded from the dataset). The project partners mutually agreed that the only thing that should be harmonized and adopted from the Latvian approach during the WaterAct project would be to exclude from the dataset samples with ionic balance discrepancies (deviations greater than ±10%) as well as exclude outlier values to ensure more reliable and accurate dataset and results.

3.5.1.1. General quality assessment (Test 1)

Comparing the approaches used by Estonia and Latvia for the general quality assessment test (detailed comparison given in Annex 11), it was found that there are differences between the approaches not all of which were possible to resolve and harmonize within the WaterAct project, mainly taking into account the amount and quality of available monitoring data in Latvia.

In both Estonia and Latvia, the results obtained during the background check served as the starting point for the general quality assessment test. In both countries, as a first step ***assessment of exceedances*** was performed for the relevant parameters/pollutants in each GWB to identify whether exceedances affect more than 20% of the total area/volume of GWB using Thiessen polygon method for defining the share of the importance of MPs of GWB (in detailed described in Chapter 1.8.1.1 and Chapter 1.8.1.2). If exceedances did not affect more than 20% of the total area of GWB, it was considered to be in good status (high confidence). In contrast, if exceedances did affect more than 20% of the total area of GWB, the assessment procedure was continued with trend assessment (see FIGURE 3.5.1.1.1).

The only difference in the approaches of both countries was observed that while in the case of Estonia the assessment of exceedances was performed separately for each identified parameter, in the case of Latvia it was performed for all parameters together. It was agreed between the project partners that in the case of Latvia, each parameter should also be assessed separately in the same way it was done in the case of Estonia. In this way, harmonization was achieved between the approaches of the two countries in this evaluation step (see FIGURE 3.5.1.1.1).

The biggest differences in the approaches of both countries were observed in ***the use of the trend assessment results***. While in the case of Estonia they were used as a two-step procedure firstly, as aggregated data trend plots by the whole GWB and secondly, as trend plots by single MPs for relevant parameters/pollutants, in the case of Latvia, trend assessment results were used only as a one-step procedure, using only trend plots by single MPs for relevant parameters/pollutants (see FIGURE 3.5.1.1.1).

In practice, this meant that, in the case of Estonia, aggregated data trend plots by whole GWB for relevant parameters/pollutants were used to identify whether the trend line for any relevant parameter/pollutant exceeded the 75% threshold mark of EQS, TV and/or LV, and only in the cases when aggregated data trend plot line did not exceed this 75%-mark, trend plots by single MPs were used to determine statistically significant upward trends for relevant parameter/pollutant at single MPs. In the cases when aggregated data trend plots for any relevant parameter/pollutant exceeded the 75% mark of EQS, TV and/or LV, assessment was followed with the next step (confidence level assessment). If aggregated data trend plots for any parameter did not exceed the 75% mark of EQS, TV and/or LV, and also trend plots by single MPs did not indicate statistically significant upward trend, GWB was considered to be in good status (low confidence) (see FIGURE 3.5.1.1.1).

In the case of Latvia, if no statistically significant upward trend was identified at any MP (using trend plots by single MP) for any relevant parameter/pollutant, GWB was considered to be in good status (high or average confidence), whereas if a statistically significant upward trend was identified at any MP for any relevant parameter/pollutant, additional investigation was done whether the upward trend is the result of anthropogenic influence and whether it poses significant risk to GWB. If the statistically significant upward trend could be justified with anthropogenic influence which also could cause significant risk to the GWB, it was considered to be in poor status (high or average confidence). Additionally, in the case of Latvia, if there was not enough monitoring data for the trend assessment, GWB was considered to be in good status (potentially at risk; average confidence) (see FIGURE 3.5.1.1.1).

Trend assessment in the case of Latvia cannot be fully implemented at this stage according to CIS Guidance Document No.18 (EC, 2009), considering the fact that in most of the cases the amount of data available is insufficient. It is related to the monitoring strategy implemented so far in Latvia that the MPs sampled within a GWB vary from year to year; as a result, the calculated average concentration of a parameter in each year for the whole GWB would not reflect the overall situation of the whole GWB, but the situation at various different MPs each year. This factor affects not only the performance of trend assessment at the single MP level (insufficient amount of data in a certain time series as monitoring is not performed every year, but with certain interruptions which are also variable for each monitoring cycle), but it also makes it impossible to perform trend assessment with aggregated data trend plots at the GWB level (the variable number of points monitored each year and their correspondingly variable geographical distribution at GWB level do not allow for reliable data aggregation, as the calculated average concentrations for each year would change and more likely reflect local situations than the overall situation at GWB level).

In view of the above, the project partners mutually agreed that during the WaterAct project harmonization of the use of trend assessment results in the general quality assessment test is currently not possible. Accordingly, it was decided that the use of trend assessment results in the harmonized general quality assessment test would follow the approaches used so far by both countries: in the case of Estonia with a two-step procedure and in the case of Latvia - with a one-step procedure (see FIGURE 3.5.1.1.1). Complete harmonization of the use of trend assessment results could only be achieved after a longer period of time by developing a common monitoring strategy (with common approach to the selection of MPs and the frequency of sampling) in both countries which will provide uniform data structure and volume on identified TGWBs in the Estonia-Latvian transboundary area .

It was also agreed between project partners that additional investigation which is done in the case of Latvia (whether the statistically significant upward trends are the result of anthropogenic impact) should be moved to the last step (evaluation of the confidence level) to ensure a common approach in both countries, as in the case of Estonia such investigation is done at the last step (see FIGURE 3.5.1.1.1).

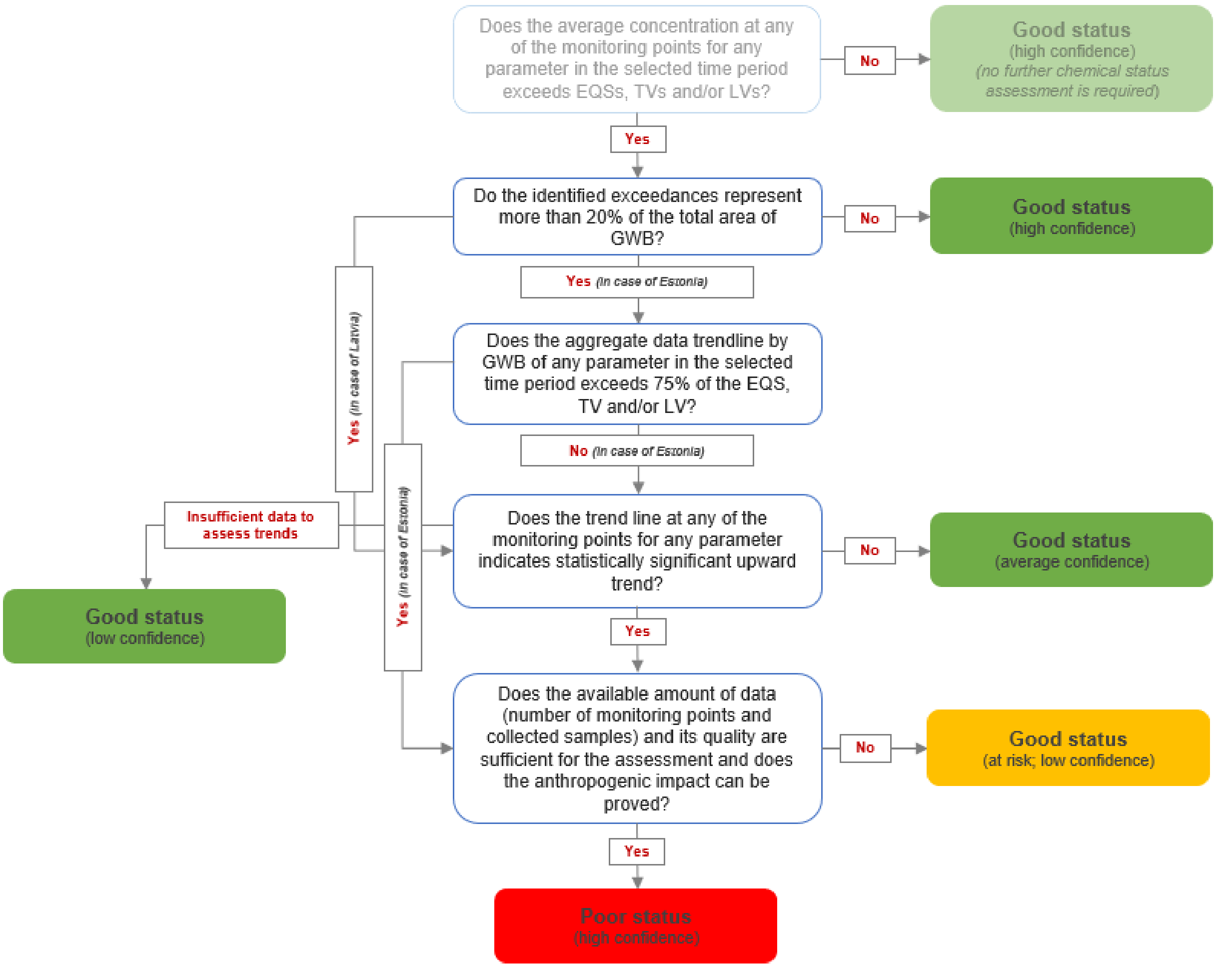


FIGURE 3.5.1.1.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the general quality assessment test (Test 1)**

Regarding ***the evaluation of the confidence level*** of the test results, it was concluded that differences between the Estonian and Latvian approaches can also be discovered: while in the case of Estonia confidence level was evaluated as the last step after trend assessment results, in the case of Latvia it was evaluated in the step at which general quality assessment test was concluded. Furthermore, while in the case of the Estonia confidence level assessment incorporated both data sufficiency and quality, as well as anthropogenic impact, in the case of Latvia only the data sufficiency and quality was tackled (as investigation of anthropogenic impact in the case of Latvia is done in previous step). It was agreed between project partners that evaluation of the confidence level should be distinguished as a separate step, addressing available data sufficiency and quality, as well as anthropogenic impact (see FIGURE 3.5.1.1.1).

The harmonized Estonian-Latvian approach of the general quality assessment test (Test 1) is given in FIGURE 3.5.1.1.1.

3.5.1.2. Saline or other intrusions (Test 2)

Comparing the approaches used by Estonia and Latvia for the saline or other intrusions test (detailed comparison given in Annex 12), it was concluded that there are many differences between the approaches not all of which were possible to resolve and harmonize within the WaterAct project, mainly taking into account the amount and quality of available monitoring data in Latvia.

In both countries, the first step of saline or other intrusions test was ***the selection of GWBs*** for which individual TVs have been set for Cl^- and/or SO_4^{2-} ions (main ions, that characterize intrusion processes), as well as the assessment of exceedances of average concentrations of these ions (using the data obtained in *the background check* step) at all MPs to identify whether any of these exceedances can be identified at any MP.

One of the biggest differences observed between the two countries during this first step was that in the case of Estonia *the use of trend assessment results* was already incorporated in the first step of the test, using trend plots by single MPs to identify statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations while in the case of Latvia the use of trend assessment results were incorporated only in the last step of the test. It was agreed between the project partners that trend assessment by single MPs in the case of Latvia should be moved up from the last step and incorporated in the first step of the test to ensure a harmonized approach in both countries. As a result, the harmonized approach for both countries in the first step include comparison of aggregated data (the background check results) by each MP to individual TVs, as well as evaluation of trend plots by single MPs with identification of statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations. If calculated average concentrations are below individual TVs and also no statistically significant upward trends are identified at any MP, GWB is considered to be in good status (high confidence). In case of any exceedances and statistically significant upward trends at least one MP, assessment procedure is continued with the next step (trend assessment by aggregated data trend plots by whole GWB) (see FIGURE 3.5.1.2.1).

Regarding the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment by single MPs, it was agreed between the project partners that this step should also be included in the harmonized approach (see FIGURE 3.5.1.2.1).

The biggest difference in the approaches of both countries was identified after the first step. While in the case of Estonia the test was continued with ***the use of trend assessment results***, in the procedure incorporating aggregated data trend plots by GWB for Cl^- and/or SO_4^{2-} ion concentrations, in the case of Latvia the test was immediately continued with ***the treatment of exceedances***. As mentioned previously, trend assessment in the case of Latvia cannot be fully implemented at this stage according to CIS Guidance Document No.18 (EC, 2009), considering the fact that in most of the cases the amount of data available is insufficient. In view of the above, the project partners mutually agreed that during the WaterAct project harmonization of the use of trend assessment results also in saline or other intrusions test is currently not possible. Accordingly, it was decided that the use of trend assessment results in the harmonized saline or other intrusions test will be incorporated as follows: in the case of Estonia trend assessment results will be included as a two-step procedure (firstly, by single MPs in the first step of the test as described above and secondly, by aggregated data trend plots by whole GWB in the second and separate step of the test), but in the case of Latvia - with a one-step procedure (by single MPs in the first step of the test) (see FIGURE 3.5.1.2.1). Complete harmonization of the use of trend assessment results will only be achieved after a longer period of time with development of a common monitoring strategy (with common approach to the selection of MPs and the frequency of sampling) in both countries which will provide uniform data structure and amount on identified TGWBs in the Estonia-Latvian transboundary area.

In practice this means that in the case of Estonia, with harmonized approach aggregated data trend plots by whole GWB for Cl^- and/or SO_4^{2-} ion concentrations are used in the second step of the test to identify whether the trend line for Cl^- and/or SO_4^{2-} ion concentrations exceeds the 75% threshold mark of the TV. In cases when the aggregated data trend line for Cl^- and/or SO_4^{2-} ion concentrations exceeds the 75% mark of the TV, assessment is continued with the next step (the treatment of exceedances), but if the aggregated data trend line for Cl^- and/or SO_4^{2-} ion concentrations do not exceed the 75% mark of the TV, GWB is considered to be in good status (average confidence). In the case of Latvia, this assessment step is skipped and the assessment procedure continues with the third step (the treatment of exceedances) (see FIGURE 3.5.1.2.1).

The third step in the harmonized approach of the saline or other intrusions test is ***the treatment of exceedances***. In the case of Latvia, initially this step in the national approach was the second step, but in order to ensure a harmonized approach between the two countries, the use of trend assessment results was moved to the first step of the test also in the case of Latvia. In this third harmonized step, it is examined whether in previous steps identified exceedances and statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations at single MPs represent more than 20% of the total area/volume of the specific GWB (using Thiessen polygon method for defining the share of the importance of MPs of GWB). If identified exceedances and statistically significant upward trends represent less than 20% of the total area of GWB, it is considered to be in good status (average confidence), but if identified exceedances and statistically significant upward trends represent more than 20% of the total are of GWB, assessment is followed with the last step (the evaluation of the confidence level) (see FIGURE 3.5.1.2.1).

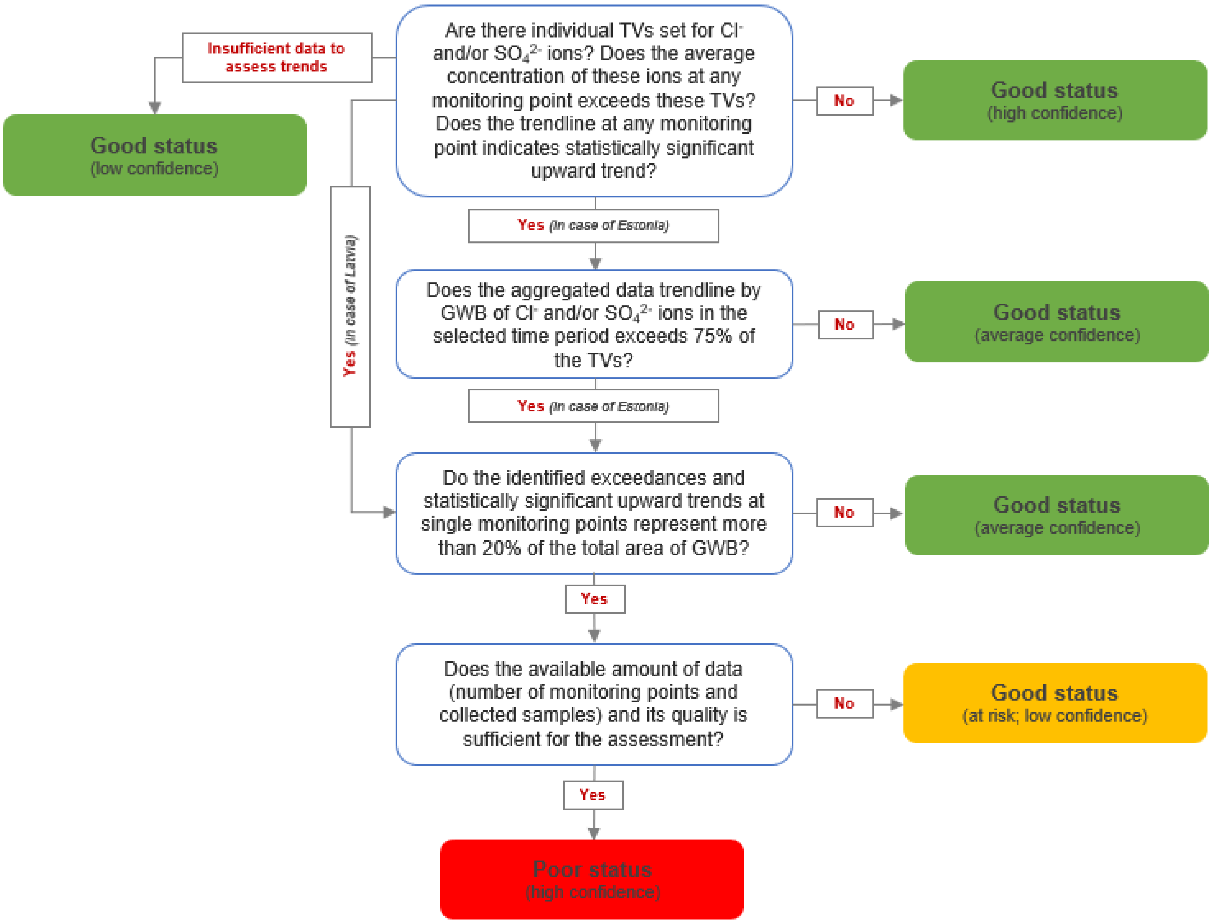


FIGURE 3.5.1.2.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the saline or other intrusions assessment test (Test 2)**

As the last step in the harmonized approach the evaluation of the confidence level of the test results was included. While in the case of Estonia this step was only considered as an alternative step which was not always applied and in the case of Latvia the evaluation of the confidence level was done after the step in which assessment test was concluded, in the harmonized approach it was agreed between project partners that evaluation of the confidence level should be distinguished as a separate step, addressing available data sufficiency and quality. If the available amount of data and its quality is sufficient for the assessment, GWB is considered to be in poor status (high confidence), but the available amount of data and its quality is not sufficient for the assessment, GWB is considered to be in good status and potentially at risk (low confidence) (see FIGURE 3.5.1.2.1).

The harmonized Estonian-Latvian approach of the saline or other intrusions test (Test 2) is given in FIGURE 3.5.1.2.1.

3.5.1.3. Surface waters (Test 3)

During comparison of the approaches used by Estonia and Latvia for the surface waters test, it was discovered that in the case of Latvia, the procedure of this test has not been developed yet and comparison before the development of the harmonized approach is not possible. In the case of Latvia, the development and implementation of surface waters test for chemical status assessment previously was not possible due to lack of data on GAAEs. GAAEs identification and their status assessment at the national level throughout the all territory of Latvia (including Gauja and Salaca river basins) was carried out during 2021 within another project[11] and the results of this project were available at the beginning of 2022. In view of this, an agreement between the project partners was reached that within the WaterAct project, the results of the aforementioned project of GAAEs identification and their status assessment will be used for the development of a harmonized approach to the development of the surface waters assessment test.

Since the procedure for the surface waters assessment test was already developed in the case of Estonia, it was agreed between the project partners that the Estonian approach will be adopted for the development of a harmonized assessment approach for this test, modifying it for the needs and goals of the WaterAct project.

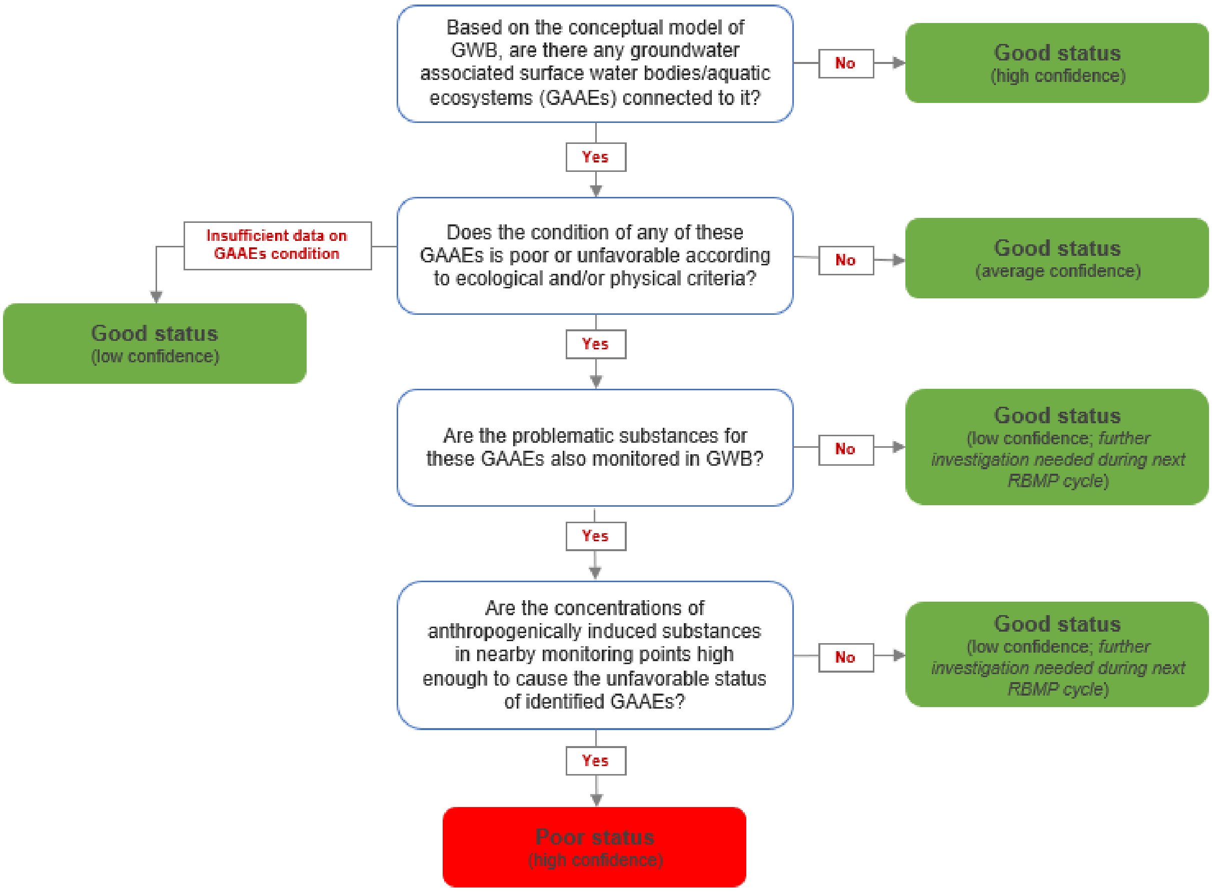


FIGURE 3.5.1.3.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the associated SWBs assessment test (Test 3)**

[11] Project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies" (financed by Latvian Environmental Protection Fund). Available: https://lvafa.vraa.gov.lv/projects/1-08_205_2020

The first step in the harmonized approach of surface waters test is ***the identification of GWBs*** with GAAEs (watercourse and lakes alike) that have been identified as significantly dependent on groundwater. If such GAAEs have previously not been identified in the particular GWB, it is considered to be in good status (high confidence). If any GAAE have been identified in the GWB, assessment procedure is continued with the next step (use of GAAEs assessment results) (see FIGURE 3.5.1.3.1).

The next steps of the harmonized approach include the ***use of GAAEs assessment results***, as well as ***assessment of groundwater monitoring data***. For this purpose, results from other studies and projects of the ecological and chemical condition assessment of GAAEs are considered. For those GAAEs where the status have previously been assessed as poor or unfavorable according to chemical and/or ecological criteria, it is examined whether the pollutants causing this unfavorable status have also been monitored and determined in the nearest national groundwater MPs of the particular GWB (if such data is not available, GWB is considered to be in good status (low confidence)) (see FIGURE 3.5.1.3.1).

If such data is available, at the last step of the harmonized approach it is further determined whether the concentrations of anthropogenically induced substances in the nearest national MPs are high enough to cause the unfavorable status of identified GAAEs (***evaluation of anthropogenic impact***). If the available amount of data leads to the above conclusion, GWB is considered to be in poor status (high confidence), otherwise GWB is considered to be in good status (low confidence) (see FIGURE 3.5.1.3.1).

The harmonized Estonian-Latvian approach of the surface waters test (Test 3) is given in FIGURE 3.5.1.3.1.

3.5.1.4. Groundwater dependent terrestrial ecosystems (Test 4)

During comparison of the approaches used by Estonia and Latvia for the GDTEs test, it was discovered that in the case of Latvia, the procedure of this test has not been developed yet and comparison before the development of the harmonized approach is not possible. In the case of Latvia, the development and implementation of this test for chemical status assessment previously was not possible due to lack of data on GDTEs. In the case of Latvia, GDTEs have previously been identified only in the Gauja river basin (Retiķe et al., 2020), but GDTEs identification and their status assessment at the national level throughout the all territory of Latvia (except Gauja and Salaca river basins) was carried out during 2021 within another project and the results of this project were available at the beginning of 2022, but GDTEs in Gauja and Salaca river basins were identified and assessed during the WaterAct project WP2 activity T2.2 "Assessment of the status of transboundary groundwater bodies according to harmonized principles" (Borozdins et al., 2022). In view of this, an agreement between the project partners was reached that within the WaterAct project, the results of the aforementioned projects and the WaterAct project other activities of GDTEs identification and their status assessment will be used for the development of a harmonized approach to the development of the GDTEs assessment test.

Since the procedure for the GDTEs assessment test was already developed in the case of Estonia, it was agreed between the project partners that the Estonian approach will be adopted for the development of a harmonized assessment approach for this test, modifying it for the needs and goals of the WaterAct project.

The first step in the harmonized approach of the GDTEs test is ***the identification of GWBs*** with GDTEs that have been identified as significantly dependent on groundwater. If such GDTEs have previously not been identified in the particular GWB, it is considered to be in good status (high confidence). If any GDTE have been identified in the GWB, assessment procedure is continued with the next step (use of GDTEs assessment results) (see FIGURE 3.5.1.4.1).

The next steps of the harmonized approach include ***the use of GDTEs assessment results***, as well as ***assessment of groundwater monitoring data***. For this purpose, results from other studies and projects, as well as the results from the other activities of the WaterAct project of the chemical condition assessment of GDTEs are considered. For those GDTEs where the status have previously been assessed as poor or unfavorable according to chemical criteria, it is examined whether the pollutants causing this unfavorable status have also been monitored and determined in the nearest national groundwater MPs of the particular GWB (if such data is not available, GWB is considered to be in good status (low confidence)) (see FIGURE 3.5.1.4.1).

If such data is available, at the last step of the harmonized approach it is further determined whether the concentrations of anthropogenically induced substances in the nearest national MPs are high enough to cause the unfavorable status of identified GDTEs (***evaluation of anthropogenic impact***). If the available amount of data leads to the above conclusion, GWB is considered to be in poor status (high confidence), otherwise GWB is considered to be in good status (low confidence) (see FIGURE 3.5.1.4.1).

The harmonized Estonian-Latvian approach of the GDTEs test (Test 4) is given in FIGURE 3.5.1.4.1.

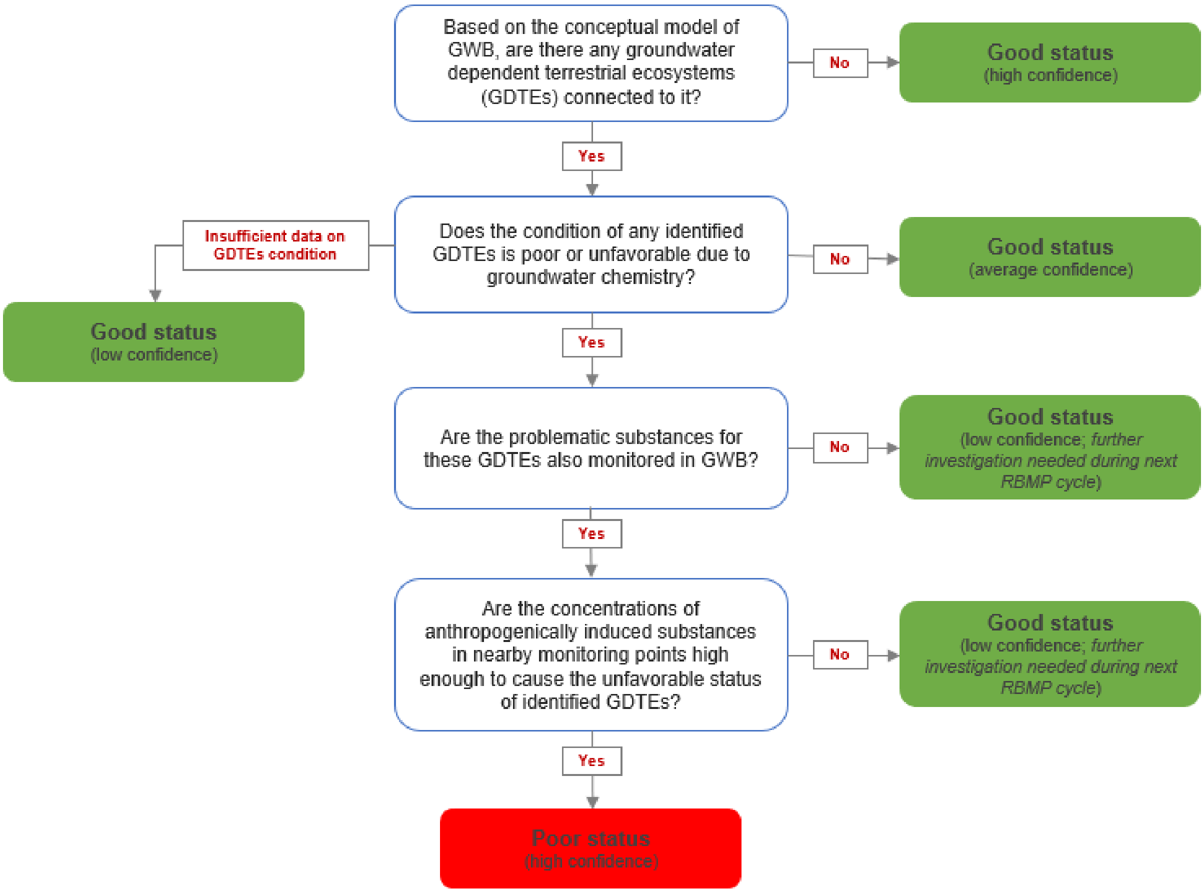


FIGURE 3.5.1.4.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the GDTEs assessment test (Test 4)**

3.5.1.5. Drinking water protected areas (Test 5)

During comparison of the approaches used by Estonia and Latvia for the DWPAs test, it was discovered that in the case of Latvia, the procedure of this test has not been developed yet and comparison before the development of the harmonized approach is not possible. But since the procedure for this assessment test was already developed in the case of Estonia, it was agreed between the project partners that the Estonian approach will be adopted for the development of a harmonized assessment approach for DWPAs test, modifying it for the needs and goals of the WaterAct project, as well as taking into account national legislative acts and their requirements in each country.

It is necessary to emphasize that, as in the case of Estonia, also in the harmonized approach, DWPAs test does not assesses whether the groundwater meets the quality requirements for drinking water – it is designed to assess whether there are significant upward trends of pollutants caused by anthropogenic activities in major drinking water intakes (groundwater well fields) that would have forced the groundwater abstraction companies to close and/or change location of these intakes, or apply new and more efficient treatment methods for the abstracted groundwater.

The first step in the harmonized approach of the DWPAs test is ***the identification of GWBs*** with major drinking water intakes (hereafter – *groundwater well fields*). Since the amount of groundwater abstraction from which the groundwater abstraction site is recognized as a groundwater well field (determined by legislation at the national level) is different in both countries, the harmonized approach retained the threshold of groundwater abstraction determined by national legislation in each country – in the case of

Estonia 500 m³/d, but in the case of Latvia – 100 m³/d (in the future, it would be advisable to harmonize this threshold in both countries by making changes in the national legislative acts).

During this step, ***identification of drinking water quality problems*** is also carried out – it is assessed whether the problems with drinking water quality have been observed in the selected time period. If there are no groundwater well fields within the GWB and the problems related to drinking water have not been observed during the selected time period, GWB is considered to be in good status (high confidence). In the event of drinking water quality problems, the assessment procedure is continued with the next step (use of results of general quality and saline or other intrusion assessment tests) (see FIGURE 3.5.1.5.1).

The second step of the harmonized approach includes ***the use of general quality assessment and/or saline or other intrusion tests***. In the event of identified quality problems in groundwater well fields in the first step, it is further determined whether the GWB is in poor or at-risk status based on the results from these two chemical status assessment tests. If the results of any (or both) of these tests confirm it, GWB is considered to be in poor status (high confidence) also in this test. However, if the GWB status in general quality assessment and/or saline or other intrusion tests is considered to be good and/or these two tests do not address parameters relevant to problems in groundwater well fields, the test is continued with the next steps (use of trend assessment results) (see FIGURE 3.5.1.5.1).

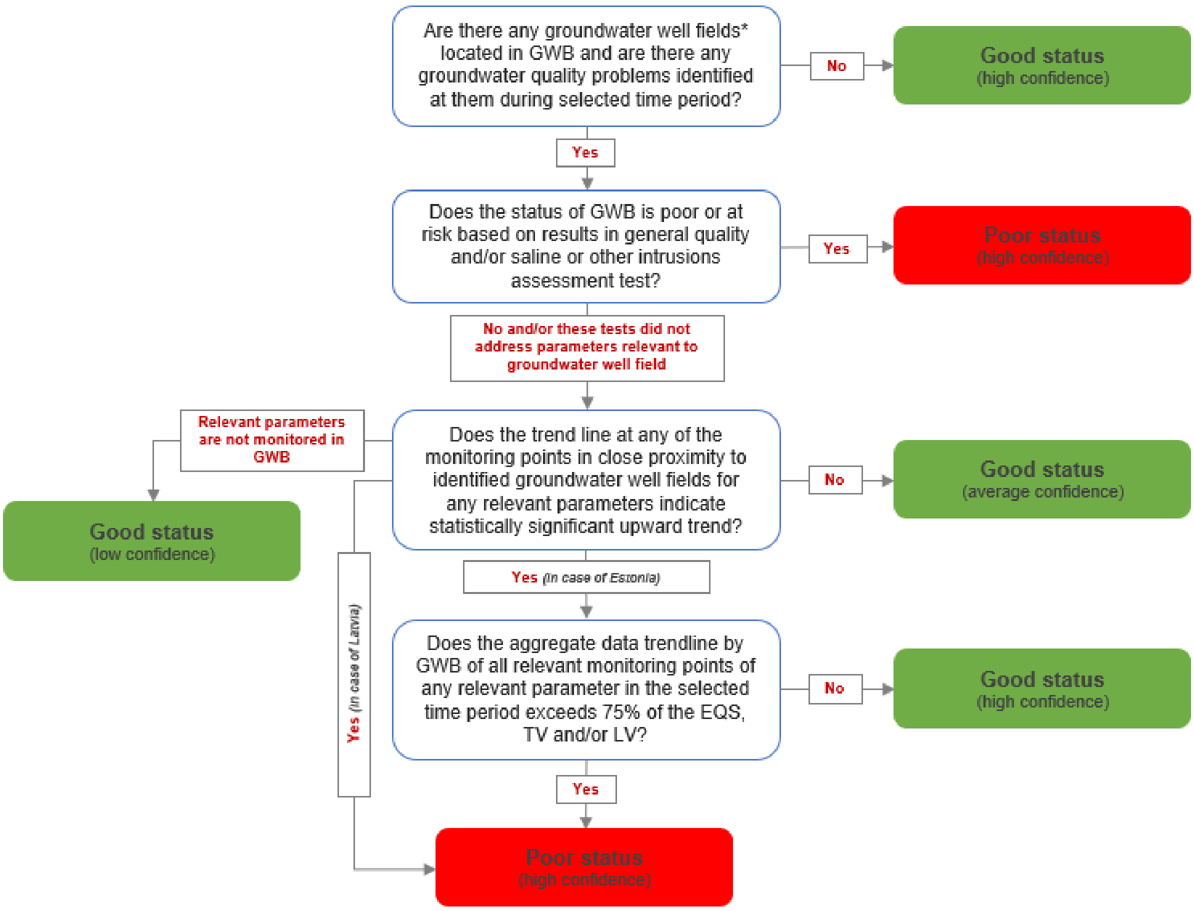


FIGURE 3.5.1.5.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the DWPAs assessment test (Test 5)**

The third and the fourth steps of the joint and harmonized approach include ***the use of trend assessment results***. In the third step of the harmonized test, trend plots by single monitorings points are used to determine whether the trend line at any of the monitorings points in the close proximity to groundwater well field for relevant parameter(s) indicate statistically significant upward trend. If the statistically significant trend is identified, three possible solutions are applied. If the relevant parameters are not monitored in the nearby MPs, GWB is considered to be in good status (low confidence) in the case of both countries. If no statistically significant trends are identified at any of the nearby MPs, GWB is considered to be in good status (average confidence). If statistically significant trends are identified in the nearby monitoring well, there are two possible outcomes, depending from the country: in the case of Latvia, GWB is considered to be in poor status (high confidence), but in the case of Estonia, the test is continued with the last step, during which aggregated data trend plots by GWB are used (see FIGURE 3.5.1.5.1) (in the case of Latvia, creation of aggregated trend plots is currently not possible, as described in Chapters 3.5.1.1 and 3.5.1.2).

In the last step (which is performed only in the case of Estonia) of the harmonize approach, results of the aggregated data trend plots by GWB are used. If the aggregated data trend line by GWB of any relevant parameter(s) exceeds 75% mark of applied EQS, TV and/or LV, GWB is considered to be in poor status (high confidence); otherwise GWB is considered to be in good status (high confidence) and the problems in relevant groundwater well field(s) are considered to be local and the cause of which should be determined by independent and local case studies (see FIGURE 3.5.1.5.1).

The harmonized Estonian-Latvian approach of the DWPAs test (Test 5) is given in FIGURE 3.5.1.4.1.

3.5.2. Quantitative status assessment of transboundary groundwater bodies

The definition of good quantitative status of the GWB is set out in the Annex V 2.1.2 of the WFD: good groundwater quantitative status is achieved when the available groundwater resources in the GWB are not exceeded by the long-term annual average groundwater abstraction (EC, 2009).

For the GWB to be in good quantitative status, such objectives must be met: available groundwater resources must not be exceeded by the long-term annual average groundwater abstraction, no significant damage to GWB associated surface water chemistry and/or ecology, as well as to GDTEs must be done resulting from an anthropogenic groundwater level alterations, and also no saline or other intrusion must occur resulting from anthropogenically induced sustained changes in groundwater flow directions (EC, 2009).

To determine the overall quantitative status of the GWB, several tests (water balance, saline or other intrusions, surface waters, and GDTEs) should be applied that considers the impacts of anthropogenically induced long-term alterations in groundwater level and/or flow. Each test must assess whether the GWB is meeting the relevant environmental objectives, but not all of these objectives apply to every GWB, therefore, only the relevant tests should be applied as necessary (EC, 2009).

An assessment of quantitative status is required for all GWBs, however, where there is a high degree of confidence that the GWB is currently not at risk of failing quantitative status objectives then it is reasonable to assume that the GWB is in good status, based on the assessment of pressures and impacts (accordingly - no significant groundwater abstraction pressure or any other groundwater levels altering impacts have been identified). This is consistent with adopting a risk-based approach (EC, 2009).

3.5.2.1. Water balance (Test 6)

Comparing the approaches used by Estonia and Latvia for the groundwater balance assessment test, it was discovered that applied methodologies in both countries are significantly different – while in the case of Estonia the assessment of the groundwater balance is based on the data of a dynamic hydrogeological model, in the case of Latvia the assessment is based on approved groundwater resources and changes in groundwater levels. Due to that, side-by-side comparison of the nationally applied approaches in not possible as well as agreement between the project partners was reached that harmonization of the groundwater balance test during the WaterAct project is not possible. Harmonization of this test should preferably be carried out within the framework of a separate project, starting with development of a dynamic hydrogeological model in Latvia at least for the identified TGWBs, but ideally – for the entire territory of Latvia; only after development of mutually comparable dynamic hydrogeological models in both countries, it will be possible to develop harmonized approach of water balance test.

Taking into account the above, within the framework of the WaterAct project agreement between project partners was reached that the approaches already applied in both countries for the water balance test will be preserved (see FIGURE 3.5.2.1.1).

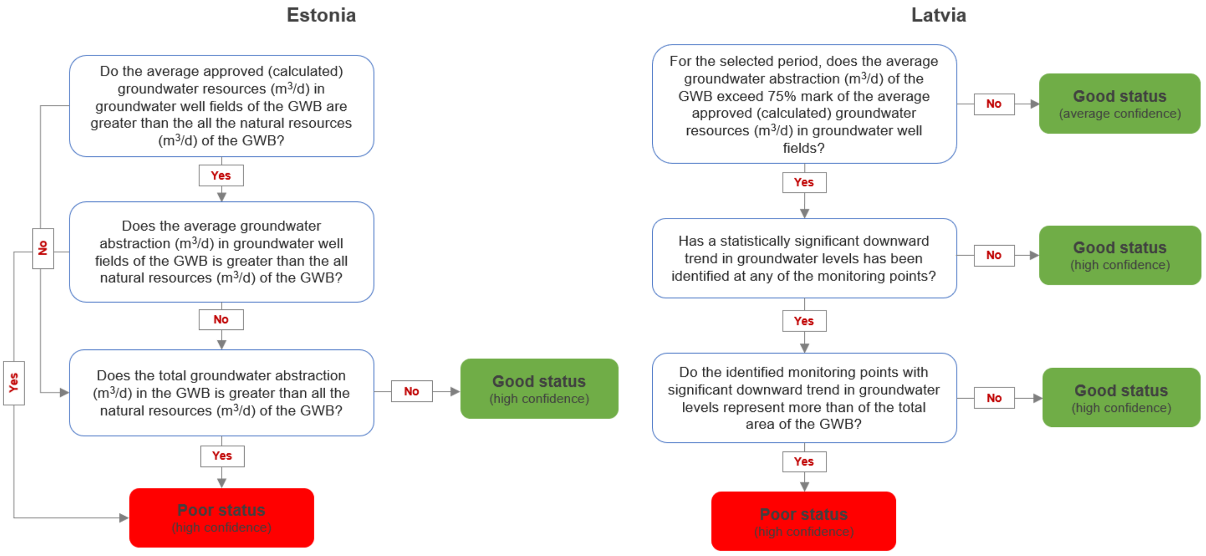


FIGURE 3.5.2.1.1 **Flow chart diagrams of the Estonian and Latvian approaches of the water balance assessment test (Test 6)**

In the case of Estonia, during the water balance test the natural groundwater resources (natural balance) is assessed against the approved (calculated) groundwater resources and the groundwater abstraction (total abstraction and abstraction in groundwater well fields). If the groundwater abstraction in groundwater well fields is greater than the natural groundwater resources of the GWB, the GWB is considered to be in poor status (high confidence). If the groundwater abstraction in groundwater well fields is lower than the natural groundwater resources of the GWB, the test is continued with the overall (total) groundwater abstraction from the GWB. In the assessment of overall (total) groundwater abstraction, the quantities of groundwater natural resources of the GWB and total groundwater abstraction in the GWB are compared. If the overall (total) groundwater abstraction is less than the natural groundwater resources of the GWB, the GWB is considered to be in good status (high confidence). Otherwise, the GWB is considered to be in poor status (high confidence) (see FIGURE 3.5.2.1.1).

In the case of Latvia, primarily the average groundwater abstraction (m^3/d) is compared with the total approved (calculated) groundwater resources (m^3/d) in groundwater well fields, expressed as a ratio (%). GWB is considered to be in good status (average confidence) if this ratio do not exceed the 75% TV. In case of exceeding this TV, additional data analysis are performed – long-term data on changes in groundwater levels in MPs are collected and assessed whether statistically significant downward trends are observed. GWB is considered to be in good quantitative status (high confidence) if no statistically significant downward trends are observed in any of the MPs. If a statistically significant downward trend is identified at any MP, it is assessed whether these MPs represent more than 20% of the total GWB area (according to the Thiessen polygon method). If the 20% threshold is not exceeded, GWB is considered to be in good status (high confidence). If the 20% threshold is exceeded, GWB is considered to be in poor status (high confidence) (see FIGURE 3.5.2.1.1).

3.5.2.2. Saline or other intrusions (Test 7)

Comparing the approaches used by Estonia and Latvia for the saline or other intrusions test (detailed comparison given in Annex 13), it was concluded that there are some differences found between the approaches not all of which were possible to resolve and harmonize within the WaterAct project, mainly taking into account the amount and quality of available monitoring data in Latvia.

In both countries, the first step of saline or other intrusions test was ***the selection of GWBs*** for which individual TVs have been set for Cl^- and/or SO_4^{2-} ions (main ions, that characterize intrusion processes), as well as the assessment of exceedances of average concentrations of these ions (using the data obtained in *the background check* step in chemical status assessment) at all MPs to identify whether any of these exceedances can be identified at any MP.

One of the biggest differences observed between the two countries during this first step was that in the case of Estonia *the use of trend assessment results* was already incorporated in the first step of the test, using trend plots by single MPs to identify statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations while in the case of Latvia the use of trend assessment results were incorporated only in the last step of the test. It was agreed between the project partners that trend assessment by single MPs in the case of Latvia should be moved up from the last step and incorporated in the first step of the test to ensure a harmonized approach in both countries. As a result, the harmonized approach for both countries in the first step include comparison of aggregated data (*the background check* results) by each MP to individual TVs, as well as evaluation of trend plots by single MPs with identification of statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations. If calculated average concentrations are below individual TVs and also no statistically significant upward trends are identified at any MP, GWB is considered to be in good status (high confidence). In case of any exceedances and statistically significant upward trends at least one MP, assessment procedure is continued with the next step (groundwater level trend assessment at single MPs). Regarding the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment by single MPs, it was agreed between the project partners that this step should be included in the harmonized approach, in case of GWB is considered to be in good status (low confidence) (see FIGURE 3.5.2.2.1).

The second step of the harmonized approach includes ***the assessment of groundwater level trends***. During this step assessment is performed whether statistically significant downward trends in groundwater levels have been identified at any of the MPs in particular GWB. If no statistically significant downward trends in groundwater levels are identified at any of the MPs, the GWB is considered to be in good status (high confidence). However, if a statistically significant downward trend in groundwater levels is identified at any of the MPs, the relationship between the downward trend in groundwater levels and exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations is further inspected (see FIGURE 3.5.2.2.1).

If during the third step of the harmonized approach MPs with identified exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations do not overlap with MPs with identified statistically significant downward trends in groundwater levels, the GWB is considered to be in good status (average confidence) (but at risk and in the future additional case studies must be carried to determine the reason for the increase in concentrations of pollutants in the GWB). However, if MPs with identified exceedances overlapped with MPs with identified downward trends in groundwater levels, the extent of it is assessed (see FIGURE 3.5.2.2.1).

The fourth step in the harmonized approach of the saline or other intrusions test is ***the treatment of exceedances***. If the overlap between the two processes is identified in the previous step, it is further determined whether such MPs represent more than 20% of the total area of the GWB (according to the Thiessen polygon method). If the 20% threshold is not exceeded, GWB is considered to be in a good status, but at risk (average confidence). In situations where such MPs represent more than 20% of the total area of the GWB, the interrelationship between the upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations, the downward trend in groundwater levels and groundwater abstraction was examined (see FIGURE 3.5.2.2.1).

If there is no link between intensive groundwater abstraction and downward trend in groundwater levels identified, the GWB is considered to be in good status, but at risk (low confidence). Otherwise, if the downward trend in groundwater levels and the associated upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations is linked to the pressure of intensive groundwater abstraction, the GWB is considered to be in poor status (high confidence) (see FIGURE 3.5.2.2.1).

The harmonized Estonian-Latvian approach of the saline or other intrusions test (Test 7) is given in FIGURE 3.5.2.2.1.

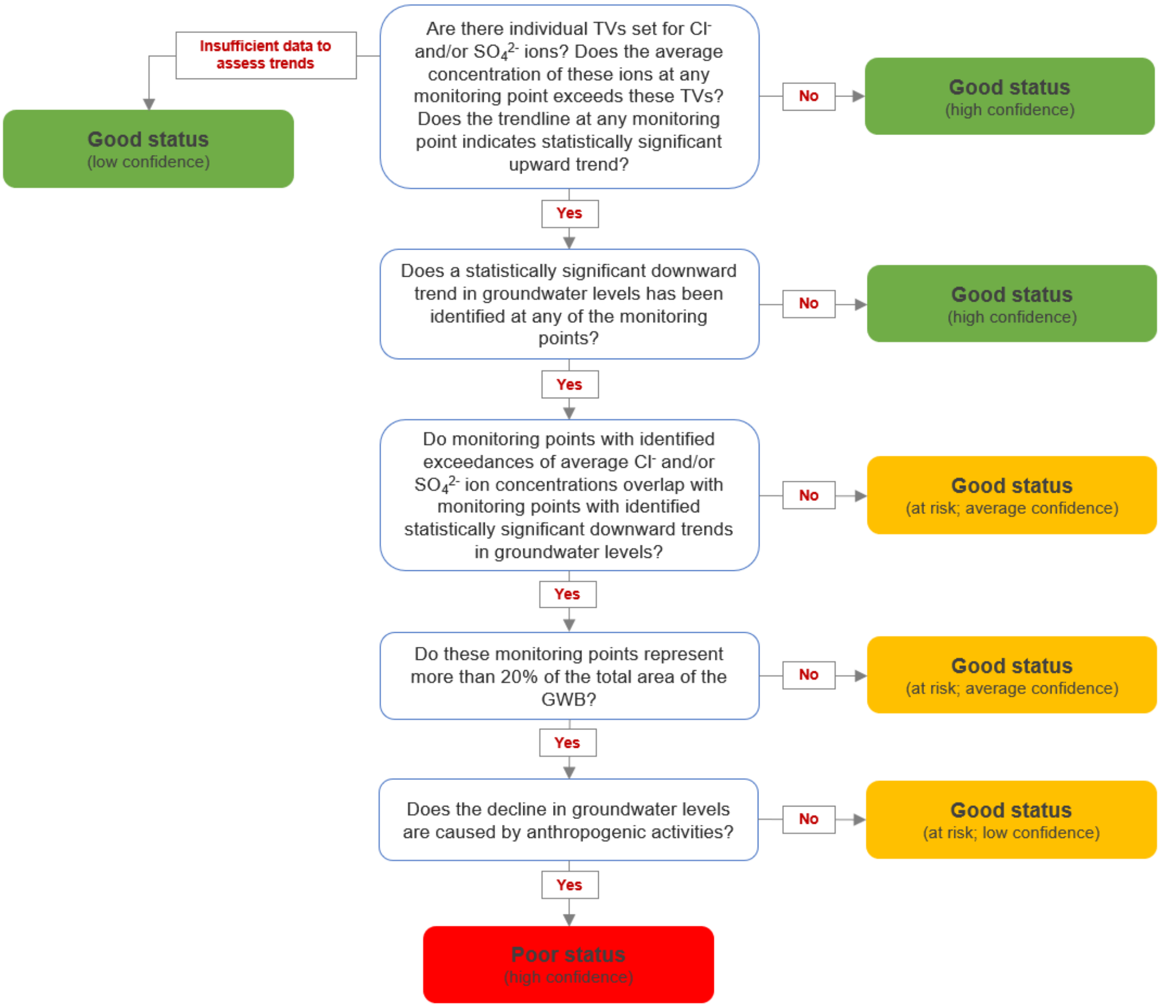


FIGURE 3.5.2.2.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the saline or other intrusions assessment test (Test 7)**

3.5.2.3. Surface waters (Test 8)

During comparison of the approaches used by Estonia and Latvia for the surface waters test, it was discovered that in the case of Latvia, the procedure of this test has not been developed yet and comparison before the development of the harmonized approach is not possible. In the case of Latvia, the development and implementation of surface waters test for quantitative status assessment previously was not possible due to lack of data on GAAEs. GAAEs identification and their status assessment at the national level throughout the all territory of Latvia (including Gauja and Salaca river basins) was carried out during 2021 within another project[12] and the results of this project were available at the beginning of 2022. In view of this, an agreement between the project partners was reached that within the WaterAct project, the results of the aforementioned project of GAAEs identification and their status assessment will be used for the development of a harmonized approach to the development of the surface waters assessment test.

Since the procedure for the surface waters assessment test was already developed in the case of Estonia, it was agreed between the project partners that the Estonian approach will be adopted for the development of a harmonized assessment approach for this test, modifying it for the needs and goals of the WaterAct project.

The first step in the harmonized approach of surface waters test is ***the identification of GWBs*** with GAAEs (watercourse and lakes alike) that have been identified as significantly dependent on groundwater. If such

[12] Project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies" (financed by Latvian Environmental Protection Fund). Available: https://lvafa.vraa.gov.lv/projects/1-08_205_2020

GAAEs have previously not been identified in the particular GWB, it is considered to be in good status (high confidence). If any GAAE have been identified in the GWB, assessment procedure is continued with the next step (use of GAAEs assessment results) (see FIGURE 3.5.2.3.1).

The next steps of the harmonized approach include the ***use of GAAEs assessment results***. For this purpose, initially results from other studies and projects are considered. For those GAAEs where the status have previously been assessed as poor or unfavorable according to ecological and/or physical criteria, it is further examined whether the anthropogenically induced changes in the quantitative status of the GWB adversely affect identified GAAEs. Otherwise, GWB is considered to be in good status (average confidence). If there are insufficient amount of data on GDTEs conditions, GWB is considered to be in good status (low confidence) (see FIGURE 3.5.2.3.1).

In further steps of the test, complete harmonization of assessment procedures could not be reach, therefore an agreement between project partners was reached that the results of studies carried out at the national level in each country would be incorporated in the next steps for the harmonized approach.

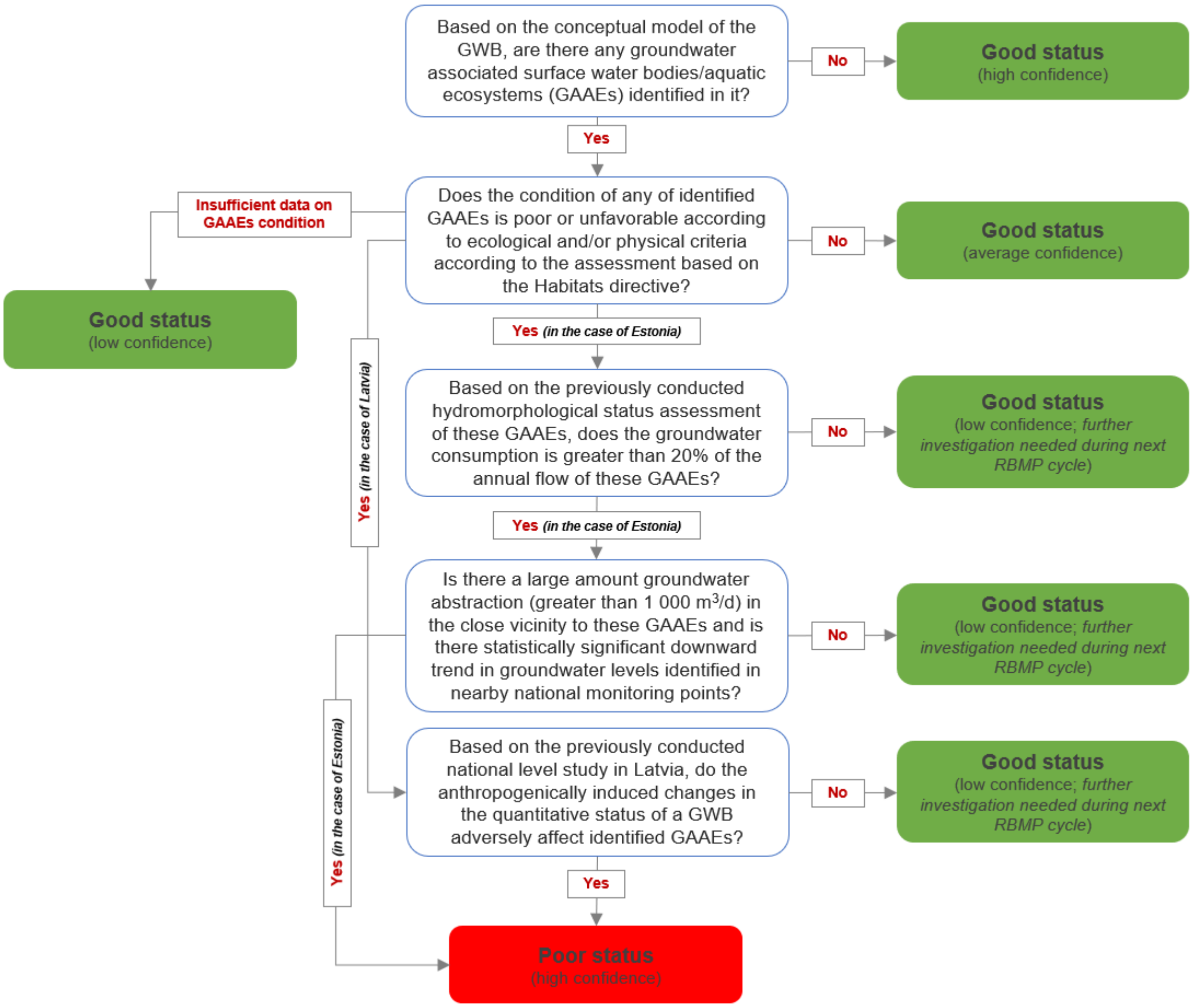


FIGURE 3.5.2.3.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the associated SWBs assessment test (Test 8)**

In the case of Estonia, initially assessment of groundwater contribution to surface waters is carried out. If, based on results of hydromorphological assessment, groundwater consumption is less than 20% of GAAEs annual flow, GWB is considered to be in good status (low confidence; further investigation needed during next RMBP cycle). Otherwise, the test is continued with the next step – assessment of groundwater abstraction and changes in groundwater levels. If no large amount of groundwater abstraction (greater than 1000 m^3/d) has been identified in the close vicinity to previously identified GAAEs and no statistically significant downward trends in groundwater levels have been identified in nearby monitoring wells, the GWB is considered to be in good quantitative status (low confidence; further investigation needed during the next RBMP cycle). Otherwise, GWB is considered to be in poor status (high confidence) (see FIGURE 3.5.2.3.1).

In the case of Latvia, based on previously conducted national level study, it is further clarified, whether anthropogenically induced changes in the quantitative status of GWB adversely affect identified GAAEs. If anthropogenically induced changes in the quantitative status of the GWB adversely affect identified GAAEs, GWB is considered to be in poor status (high confidence); otherwise, GWB is considered to be in good status (high confidence) (see FIGURE 3.5.2.3.1).

The harmonized Estonian-Latvian approach of the GDTEs test (Test 8) is given in FIGURE 3.5.2.3.1.

3.5.2.4. Groundwater dependent terrestrial ecosystems (Test 9)

During comparison of the approaches used by Estonia and Latvia for the GDTEs test, it was discovered that in the case of Latvia, the procedure of this test has not been developed yet and comparison before the development of the harmonized approach is not possible. In the case of Latvia, the development and implementation of this test for quantitative status assessment previously was not possible due to lack of data on GDTEs. In the case of Latvia, GDTEs have previously been identified only in the Gauja river basin (Retiķe et al., 2020), but GDTEs identification and their status assessment at the national level throughout the all territory of Latvia (except Gauja and Salaca river basins) was carried out during 2021 within another project[13] and the results of this project were available at the beginning of 2022, but GDTEs in Gauja and Salaca river basins were identified and assessed during the WaterAct project WP2 activity T2.2 "Assessment of the status of transboundary groundwater bodies according to harmonized principles" (Borozdins et al., 2022). In view of this, an agreement between the project partners was reached that within the WaterAct project, the results of the aforementioned projects and the WaterAct project other activities of GDTEs identification and their status assessment will be used for the development of a harmonized approach to the development of the GDTEs assessment test.

Since the procedure for the GDTEs assessment test was already developed in the case of Estonia, it was agreed between the project partners that the Estonian approach will be adopted for the development of a harmonized assessment approach for this test, modifying it for the needs and goals of the WaterAct project.

The first step in the harmonized approach of the GDTEs test is ***the identification of GWBs*** with GDTEs that have been identified as significantly dependent on groundwater. If such GDTEs have previously not been identified in the particular GWB, it is considered to be in good status (high confidence). If any GDTE have been identified in the GWB, assessment procedure is continued with the next step (use of GDTEs assessment results) (see FIGURE 3.5.2.4.1).

The next steps of the harmonized approach include ***the use of GDTEs assessment results***. For this purpose, initially results from other studies and projects are considered. For those GDTEs where the status have previously been assessed as poor or unfavorable according to ecological and/or physical criteria, it is further examined whether the anthropogenically induced changes in the quantitative status of the GWB adversely affect identified GDTEs (using the results from WaterAct project other activities). Otherwise, GWB is considered to be in good status (average confidence). If there are insufficient amount of data on GDTEs conditions, GWB is considered to be in good status (low confidence) (see FIGURE 3.5.2.4.1).

During the third and final step of the harmonized approach, results from the WaterAct project WP2 activity T2.2 "Assessment of the status of transboundary groundwater bodies according to harmonized principles" (Borozdins et al., 2022) are used. If anthropogenically induced changes in the quantitative status of the GWB adversely affect identified GDTEs, GWB is considered to be in poor status (high confidence); otherwise, GWB is considered to be in good status (high confidence) (see FIGURE 3.5.2.4.1).

The harmonized Estonian-Latvian approach of the GDTEs test (Test 9) is given in FIGURE 3.5.2.4.1.

[13] Project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies" (financed by Latvian Environmental Protection Fund). Available: https://lvafa.vraa.gov.lv/projects/1-08_205_2020

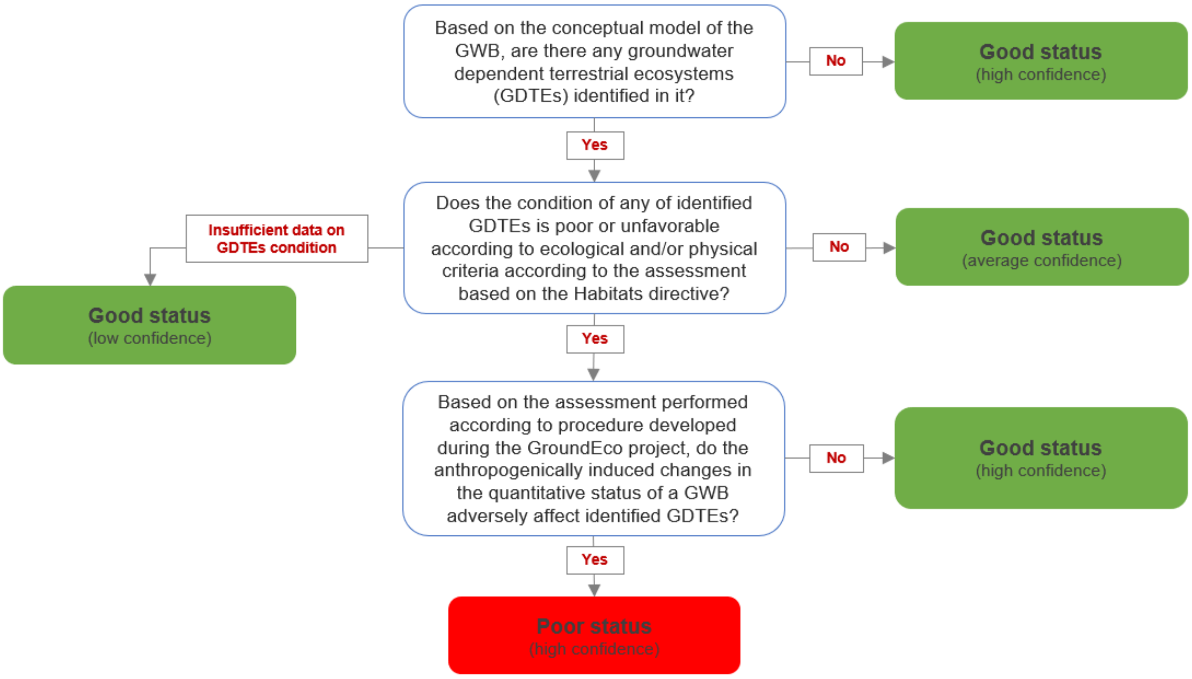


FIGURE 3.5.2.4.1 **Flow chart diagram of the harmonized Estonian-Latvian approach of the GDTEs assessment test (Test 9)**

CONCLUSIONS AND RECOMMENDATIONS

Conclusions about WP1 activities T1.1-T1.4:

- groundwater assessment methodologies and approaches used by project partners at national level (addressing such principles as GWB delineation, NBLs and TVs delineation, strategies of conceptual model development, GWB status assessment methodologies and others) were collected, translated and exchanged;
- extensive literature studies were carried out to gain an in depth understanding of the requirements of European water policies with an emphasis on common groundwater assessment according the WFD and the GWD;
- guidelines and available best practices from other countries were analyzed and recommendations for further steps were developed, which were taken into account creating joint harmonized approaches for groundwater resources assessment;
- the summaries on acquired knowledge during EGU General Assembly 2021 and Nordic Hydrological Conference 2022 were developed and circulated around all project partners to transfer the gained knowledge;
- joint principles on how to manage common groundwater resources in transboundary Gauja/Koiva and Salaca/Salatsi river basins were chosen and agreed, creating joint and harmonized approaches, addressing topics which could be solved during the WaterAct project, taking into account data availability and quality in both countries, as well as available human resources and project timeline.

Recommendations concerning transboundary groundwater resources management:

- to improve transboundary groundwater resources management between Latvia and Estonia, close cooperation should be continued between Latvian and Estonian authorities;
- work on the harmonization of TGWBs assessment methodologies should be continued, as well as development of unified approach of assessment of significant anthropogenic pressures (point and diffuse, as well as groundwater abstraction);
- the common dynamic hydrogeological model should be developed for Estonian-Latvian TGBWs, in order to assess the groundwater balance, as well as specify the areas to which more attention should be paid to;
- a working group should be established and periodic meetings and discussions should be held for the development of a joint transboundary groundwater management plan.

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ANNEXES

Annex 1

Background levels and threshold values of Estonian groundwater bodies

(Marandi et al., 2019)

GWB	Substance	Unit	Previous TV	BL (90th percentile; 2004-2017)	BL (Tšeban, 1968; other data)	New TV (Marandi et al., 2019)	Receptor	Adapted in legislation
No.1	*Chlorides (Cl^-)*	mg/l	**350**	548.3	421	**500**	Saltwater intrusion	**YES**
No.2	*Chlorides (Cl^-)*	mg/l	**250**	244.0	157	**250**	Drinking water/ Saltwater intrusion	**YES**
No.3	*Chlorides (Cl^-)*	mg/l	**250**	366.3	122	**250**	Drinking water/ Saltwater intrusion	**YES**
No.4	*Chlorides (Cl^-)*	mg/l	-	60.3	450	**250**	Drinking water/ Saltwater intrusion	**YES**
No.5a	*Sulphates (SO_4^{2-})*	mg/l		90.9	18	**100**	Drinking water	**YES**
No.5b	*Chlorides (Cl^-)*	mg/l		333.8	132	**350**	Saltwater intrusion	**YES**
No.6	*Sulphates (SO_4^{2-})*	mg/l	**250**	28.1	*0*	**50**	Drinking water	**YES**
	Phenols	µg/l	**1**		*<2 µg/l*	**1**	Drinking water	**YES**
	Benzene	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**3**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)				**0.08**	Surface water/ GDEs	**NO**
No.7	*Sulphates (SO_4^{2-})*	mg/l	**250**	440.1	22	**250**	Drinking water	**YES**
	Phenols	µg/l	**1**	907.0	*<2 µg/l*	**1**	Drinking water	**YES**
	Benzene	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.05**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**3**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)				**0.08**	Surface water/ GDEs	**NO**
No.8	*Chlorides (Cl^-)*	mg/l	**250**	601.3	178	**250**	Drinking water	**YES**
	Benzene	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
No.9	*Chlorides (Cl^-)*	mg/l	**250**	1427.5	701	**250**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.10	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Phenols	µg/l	**1**		*<2 µg/l*	**1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**1**	Surface water/	**NO**

GWB	Substance	Unit	Previous TV	BL (90th percentile; 2004-2017)	BL (Tšeban, 1968; other data)	New TV (Marandi et al., 2019)	Receptor	Adapted in legislation
							GDEs	
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.11	*Chlorides (Cl^-)*	mg/l	**188**	55.3	246	**250**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**2.5**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.12	*Chlorides (Cl^-)*	mg/l	**250**	117.2	147	**250**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**3**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.08**	Surface water/ GDEs	**NO**
No.13	*Total nitrogen (N_{tot})*	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.06**	Surface water/ GDEs	**NO**
No.14	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Phenols	µg/l	**1**		*<2 µg/l*	**1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**2.5**	Surface water/GWDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/GWDEs	**NO**
No.15	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/L	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
No.15	*Phenols*	µg/L	**1**		*<2 µg/l*	**1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.16	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Phenols	µg/l	**1**		*<2 µg/l*	**1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**2.5**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.17	*Chlorides (Cl^-)*	mg/l	**188**	42.2		**250**	Drinking water	**YES**
No.19	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Chlorides (Cl^-)	mg/l	**250**	716.6		**250**	Drinking water/ Saltwater intrusion	**YES**
No.20	*Chlorides (Cl^-)*	mg/l	**250**	471.0		**450**	Drinking water/	**YES**

GWB	Substance	Unit	Previous TV	BL (90th percentile; 2004-2017)	BL (Tšeban, 1968; other data)	New TV (Marandi et al., 2019)	Receptor	Adapted in legislation
							Saltwater intrusion	
No.22	*Total nitrogen (N_{tot})*	mg/l(N)				**1**	Surface water/ GDEs	**NO**
No.23	*Total nitrogen (N_{tot})*	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.06**	Surface water/ GDEs	**NO**
No.24	*Benzene*	µg/l	**1**		*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/L	**20**		*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	PAHs	µg/L	**0.1**		*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/l*	**0.06**	Surface water/ GDEs	**NO**
No.25	*Total nitrogen (N_{tot})*	mg/l(N)				**3**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/L*	**0.08**	Surface water/ GDEs	**NO**
No.26	*Total nitrogen (N_{tot})*	mg/l(N)				**1**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)			*<0.01 µg/L*	**0.06**	Surface water/ GDEs	**NO**
No.27	*Sulphates (SO_4^{2-})*	mg/l	**250**	106.6	*4*	**100**	Drinking water	**YES**
	Phenols	µg/l	**1**	2.2	*<2 µg/l*	**1**	Drinking water	**YES**
	Benzene	µg/l	**1**	0.3	*<0.2 µg/l*	**1**	Drinking water	**YES**
	Petroleum products	µg/l	**20**	37.3	*<10 µg/l*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/l	**0.1**	0.0	*<0.1 µg/l*	**0.1**	Drinking water	**YES**
	Total nitrogen (N_{tot})	mg/l(N)				**0.5**	Surface water/ GDEs	**NO**
	Total phosphorus (P_{tot})	mg/l(P)		*0.14*	*<0.01 µg/l*	**0.02**	Surface water/ GDEs	**NO**
No.28	*Phenols*	µg/L	**1**	2.0	*<2 µg/L*	**1**	Drinking water	**YES**
	Benzene	µg/L	**1**	0.09	*<0.2 µg/L*	**1**	Drinking water	**YES**
	Petroleum products	µg/L	**20**	22.0	*<10 µg/L*	**20**	Drinking water/ Surface water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/L	**0.1**	0.02	*<0.1 µg/L*	**0.1**	Drinking water	**YES**
	Chlorides (Cl^-)	mg/L	**250**	54.6	*28*	**60**	Drinking water	**YES**
	Nitrates (NO_3^-)	mg/L	**38**	29.4		**38**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/L		59.5		**50**	Drinking water	**YES**
No.29	*Benzene*	µg/L	**1**	0.09	*<0.2 µg/L*	**1**	Drinking water	**YES**
	Petroleum products	µg/L	**20**	22.0	*<10 µg/L*	**20**	Drinking water	**YES**
	Polycyclic Aromatic Hydrocarbons (PAHs)	µg/L	**0.1**	0.02	*<0.1 µg/L*	**0.1**	Drinking water/ Surface water	**YES**
	Chlorides (Cl^-)	mg/L	**250**	180.0		**250**	Drinking water	**YES**

Abbreviations:

TV - threshold value

BL - background level

- identified TGWBs (according to results from WP2)

Annex 2

Background levels and threshold values of Latvian groundwater bodies

(Retiķe and Bikše, 2019)

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
Q1	*Calcium (Ca^{2+})*	mg/l	80.0	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4.0	**27.0**	Drinking water	**YES**
Q1	*Sodium (Na^+)*	mg/l	75.0	**137.5**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30.0	-	-	-
Q1	*Potassium (K^+)*	mg/l	8.7	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
Q1	*Magnesium (Mg^{2+})*	mg/l	29.0	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**YES**
Q1	*Chlorides (Cl^-)*	mg/l	130.0	**190.0**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**YES**
Q1	*Bicarbonate (HCO_3^-)*	mg/l	250.0	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.58**	Drinking water	**YES**
Q1	*Sulphates (SO_4^{2-})*	mg/l	50.0	**150.0**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**YES**
Q1	*Ammonium (NH_4^+)*	mg/l	0.45	**0.475**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**YES**
Q1	*Manganese (Mn)*	mg/l	0.16	**0.16**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4.0	**27**	Drinking water	**NO**
Q1	*Iron (total) (Fe_{tot}) (anaerobic)*	mg/l	3.8	**3.8**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10.0	**10**	Drinking water	**NO**
Q1	*Iron (total) (Fe_{tot}) (aerobic)*	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
Q1	*Nitrates (NO_3^-) (anaerobic)*	mg/l	0.4	**25.2**	Drinking water	**YES**						
F1	*Calcium (Ca^{2+})*	mg/l	95.0	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4.0	**27.0**	Drinking water	**NO**
F1	*Sodium (Na^+)*	mg/l	18.0	**109**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
F1	*Potassium (K^+)*	mg/l	11.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.50**	Drinking water	**NO**
F1	*Magnesium (Mg^{2+})*	mg/l	36.0	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
F1	*Chlorides (Cl^-)*	mg/l	18.0	**134**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
F1	*Bicarbonate (HCO_3^-)*	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
F1	*Sulphates (SO_4^{2-})*	mg/l	50.0	**150**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
F1	*Ammonium (NH_4^+)*	mg/l	0.85	**0.85**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.20	**11.1**	Drinking water	**NO**
F1	*Manganese (Mn)*	mg/l	0.07	**0.07**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4.00	**27**	Drinking water	**NO**
F1	*Iron (total) (Fe_{tot}) (anaerobic)*	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
F1	*Iron (total) (Fe_{tot}) (aerobic)*	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
F1	*Nitrates (NO_3^-) (anaerobic)*	mg/L	0.4	**25.2**	Drinking water	**NO**						
F2	*Calcium (Ca^{2+})*	mg/l	105	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4.0	**27.0**	Drinking water	**NO**
F2	*Sodium (Na^+)*	mg/l	13	**106.5**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
F2	*Potassium (K^+)*	mg/l	7.4	-	Drinking water	-	*Fluorides (F^-)*	mg/l	0.54	**1.50**	Drinking water	**NO**
F2	*Magnesium (Mg^{2+})*	mg/l	36	-	Drinking water	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
F2	*Chlorides (Cl^-)*	mg/l	18	**134**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Bicarbonate (HCO_3^-)	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	50	**150**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.45	**0.457**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.20	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4.00	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
F3 (zone F3a)	*Calcium (Ca^{2+})*	mg/l	105	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	24	**112**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	7.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.50**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	36	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	470	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.450	**0.457**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.10	**0.10**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
F3 (zone F3b)	*Calcium (Ca^{2+})*	mg/l	230	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	24	**112**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	13.8	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.50**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	67	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	25	**135.7**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	630	**630**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.65	**0.65**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
F4	*Calcium (Ca^{2+})*	mg/l	115	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	18	**109**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	8.7	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.50**	Drinking water	**NO**

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Magnesium (Mg^{2+})	mg/l	42	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^{-})	mg/l	18	**134**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^{-})	mg/l	530	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^{+})	mg/l	0.65	**0.65**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	Drinking water	-
	Nitrates (NO_3^{-}) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
D6	*Calcium (Ca^{2+})*	mg/l	130	-	-	-	*Nitrates (NO_3^{-}) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^{+})	mg/l	13	**106.5**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^{+})	mg/l	6	-	-	-	*Fluorides (F^{-})*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	32	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^{-})	mg/l	18	**134**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^{-})	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^{+})	mg/l	0.450	**0.475**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^{-}) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
D7	*Calcium (Ca^{2+})*	mg/l	115	-	-	-	*Nitrates (NO_3^{-}) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^{+})	mg/l	18	**109**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^{+})	mg/l	7.4	-	Drinking water	-	*Fluorides (F^{-})*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	36	-	Drinking water	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^{-})	mg/l	18	**134**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^{-})	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^{+})	mg/l	0.450	**0.475**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	Drinking water	-
	Nitrates (NO_3^{-}) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
	Calcium (Ca^{2+})	mg/l	105	-	-	-	*Nitrates (NO_3^{-}) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
D8	*Sodium (Na^+)*	mg/l	18	**109**	DW	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	7.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	36	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	NO
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	NO	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	NO
	Bicarbonate (HCO_3^-)	mg/l	470	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	NO
	Sulphates (SO_4^{2-})	mg/l	50	**150**	Drinking water	NO	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	NO
	Ammonium (NH_4^+)	mg/l	0.65	**0.65**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	NO						
D9	*Calcium (Ca^{2+})*	mg/l	105	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	NO
	Sodium (Na^+)	mg/l	18	**109**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	7.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	42	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	NO
	Chlorides (Cl^-)	mg/l	25	**137.5**	Drinking water	NO	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	NO
	Bicarbonate (HCO_3^-)	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	NO
	Sulphates (SO_4^{2-})	mg/l	50	**150**	Drinking water	NO	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	NO
	Ammonium (NH_4^+)	mg/l	0.65	**0.65**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	NO						
D10	*Calcium (Ca^{2+})*	mg/l	105	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	27	Drinking water	NO
	Sodium (Na^+)	mg/l	18	**109**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	6	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	36	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	NO
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	NO	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	NO
	Bicarbonate (HCO_3^-)	mg/l	470	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	NO
	Sulphates (SO_4^{2-})	mg/l	50	**150**	Drinking water	NO	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	NO
	Ammonium (NH_4^+)	mg/l	0.85	**0.85**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.16	**0.16**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	NO						
D11 (zone D11a)	*Calcium (Ca^{2+})*	mg/l	130	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	24	**112**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	8.7	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	48	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**YES**
	Chlorides (Cl^-)	mg/l	25	**137.5**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**YES**
	Bicarbonate (HCO_3^-)	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	240	**245**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**YES**
	Ammonium (NH_4^+)	mg/l	0.45	**0.475**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**YES**
	Manganese (Mn)	mg/l	0.10	**0.10**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
D11 (zone D11b)	*Calcium (Ca^{2+})*	mg/l	580	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	75	**137.5**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	16	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	117	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**YES**
	Chlorides (Cl^-)	mg/l	130	**190**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**YES**
	Bicarbonate (HCO_3^-)	mg/l	530	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	1330	**1330**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**YES**
	Ammonium (NH_4^+)	mg/l	0.85	**0.85**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**YES**
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
A1	*Calcium (Ca^{2+})*	mg/l	95	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	NO
	Sodium (Na^+)	mg/l	32	**116**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	6	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	36	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	NO
	Chlorides (Cl^-)	mg/l	25	**137.5**	Drinking water	NO	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	NO
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	NO
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	NO	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	NO
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
A2	*Calcium (Ca^{2+})*	mg/l	80	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^+)	mg/l	62	**131**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	6	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	29	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	50	**150**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	330	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	30	**140**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.19	**0.19**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
A3	*Calcium (Ca^{2+})*	mg/l	95	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^+)	mg/l	18	**109**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	6	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	32	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	25	**137.5**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	50	**150**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.45	**0.475**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.10	**0.10**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
A4	*Calcium (Ca^{2+})*	mg/l	150	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^+)	mg/l	32	**116**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	13.8	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	57	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	50	**150**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	330	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	450	**450**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	NO						
A5	*Calcium (Ca^{2+})*	mg/l	150	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	YES
	Sodium (Na^+)	mg/l	75	**137.5**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	11.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	67	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	YES
	Chlorides (Cl^-)	mg/l	130	**190**	Drinking water	YES	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	YES
	Bicarbonate (HCO_3^-)	mg/l	360	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	YES
	Sulphates (SO_4^{2-})	mg/l	450	**450**	Drinking water	YES	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	YES
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	YES	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	YES
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	YES						
A6	*Calcium (Ca^{2+})*	mg/l	115	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	NO
	Sodium (Na^+)	mg/l	62	**131**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	11.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	42	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	NO
	Chlorides (Cl^-)	mg/l	50	**150**	Drinking water	NO	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	NO
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	NO
	Sulphates (SO_4^{2-})	mg/l	240	**245**	Drinking water	NO	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	NO
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	NO	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	NO
	Manganese (Mn)	mg/l	0.07	**0.07**	Drinking water	NO	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	NO
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	NO	*Copper (Cu)*	µg/l	10	**10**	Drinking water	NO
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	NO	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	NO						
A7	*Calcium (Ca^{2+})*	mg/l	95	-	Drinking water	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	YES
	Sodium (Na^+)	mg/l	32	**116**	Drinking water	NO	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	6	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	NO
	Magnesium (Mg^{2+})	mg/l	32	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	YES
	Chlorides (Cl^-)	mg/l	25	**137.5**	Drinking water	YES	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	YES

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Bicarbonate (HCO_3^-)	mg/l	440	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	30	**140**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**YES**
	Ammonium (NH_4^+)	mg/l	0.85	**0.85**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**YES**
	Manganese (Mn)	mg/l	0.16	**0.16**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
A8	*Calcium (Ca^{2+})*	mg/l	95	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	32	**116**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	8.7	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	36	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**YES**
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**YES**
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	80	**165**	Drinking water	**YES**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**YES**
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**YES**
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.9	**2.9**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
A9	*Calcium (Ca^{2+})*	mg/l	80	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**YES**
	Sodium (Na^+)	mg/l	13	**106.5**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	-	-
	Potassium (K^+)	mg/l	7.4	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	32	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	**YES**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	390	-	Drinking water	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	30	**140**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.35	**0.425**	Drinking water	**YES**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.10	**0.10**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**YES**						
A10	*Calcium (Ca^{2+})*	mg/l	80	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^+)	mg/l	13	**106.5**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	Drinking water	-
	Potassium (K^+)	mg/l	4.5	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment	Substance	Unit	BL	TV	Receptor	Use in GWB status assessment
	Magnesium (Mg^{2+})	mg/l	32	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	18	**134**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	390	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	30	**140**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.45	**0.475**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.19	**0.19**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	3.8	**3.8**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						
P	*Calcium (Ca^{2+})*	mg/l	80	-	-	-	*Nitrates (NO_3^-) (aerobic)*	mg/l	4	**27**	Drinking water	**NO**
	Sodium (Na^+)	mg/l	62	**131**	Drinking water	**NO**	*Phosphates (PO_4^{3-})*	µg/l	30	-	Drinking water	-
	Potassium (K^+)	mg/l	8.7	-	-	-	*Fluorides (F^-)*	mg/l	0.54	**1.00**	Drinking water	**NO**
	Magnesium (Mg^{2+})	mg/l	29	-	-	-	*Lead (Pb)*	µg/l	1.65	**5.83**	Drinking water	**NO**
	Chlorides (Cl^-)	mg/l	130	**190**	Drinking water	**NO**	*Arsenic (As)*	µg/l	4.9	**7.45**	Drinking water	**NO**
	Bicarbonate (HCO_3^-)	mg/l	360	-	-	-	*Mercury (Hg)*	µg/l	0.16	**0.85**	Drinking water	**NO**
	Sulphates (SO_4^{2-})	mg/l	30	**140**	Drinking water	**NO**	*Cadmium (Cd)*	µg/l	0.29	**2.65**	Drinking water	**NO**
	Ammonium (NH_4^+)	mg/l	0.350	**0.425**	Drinking water	**NO**	*Nickel (Ni)*	µg/l	2.2	**11.1**	Drinking water	**NO**
	Manganese (Mn)	mg/l	0.12	**0.12**	Drinking water	**NO**	*Chromium (Cr)*	µg/l	4	**27**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (anaerobic)	mg/l	2.3	**2.3**	Drinking water	**NO**	*Copper (Cu)*	µg/l	10	**10**	Drinking water	**NO**
	Iron (total) (Fe_{tot}) (aerobic)	mg/l	0.17	**0.19**	Drinking water	**NO**	*Zinc (Zn)*	µg/l	50	-	-	-
	Nitrates (NO_3^-) (anaerobic)	mg/l	0.4	**25.2**	Drinking water	**NO**						

Abbreviations:

TV - threshold value

BL - background level

- identified TGWBs (according to results from WP2)

Annex 3

Background levels and threshold values of Latvian groundwater bodies at risk

Groundwater body at risk Q2 (LVĢMC, 2019)

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment
Q2	*Chlorides (Cl^-)*	mg/l	152	**152**	Seawater intrusion	**YES**

Groundwater body at risk F5 (Retiķe and Bikše, 2018)

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment
F5	*Chlorides (Cl^-)*	mg/l	13.2	**131.6**	Seawater intrusion	**YES**
	Sodium (Na^+)	mg/l	22.3	**111.2**	Seawater intrusion	**YES**
	Sulphates (SO_4^{2-})	mg/l	42.5	**146.3**	Seawater intrusion	**YES**

Groundwater body at risk A11 (LVĢMC, 2019)

GWB	Substance	Unit	BL	TV	Receptor	Used in GWB status assessment
A11 (Quaternary aquifer)	*Chemical oxygen demand (COD)*	mg/l	35.5	**35.5**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	8.2	**129.1**	Drinking water	**YES**
	Synthetic surfactants	mg/l	0	**0.1**	Drinking water	**YES**
	Electrical conductivity	$\mu S/cm^{-1}$	190	**190**	Drinking water	**YES**
	Sum of trichloroethylene and tetrachloroethylene (TCE+PCE)	mg/l	0	**0.005**	Drinking water	**YES**
	Sum of monoaromatic hydrocarbons: benzene, ethylbenzene, toluene and xylenes (BTEX)	mg/l	0	**0.005**	Drinking water	**YES**
	Arsenic (As)	µg/l	4.9	**7.45**	Drinking water	**YES**
	Cadmium (Cd)	µg/l	0.29	**2.65**	Drinking water	**YES**
	Lead (Pb)	µg/l	1.65	**5.83**	Drinking water	**YES**
A11 (Upper Gauja (D_3gj_2) aquifer)	*Chemical oxygen demand (COD)*	mg/l	45	**45**	Drinking water	**YES**
	Sulphates (SO_4^{2-})	mg/l	25	**137.5**	Drinking water	**YES**
	Synthetic surfactants	mg/l	0	**0.1**	Drinking water	**YES**
	Electrical conductivity	$\mu S/cm^{-1}$	580	**580**	Drinking water	**YES**
	Sum of trichloroethylene and tetrachloroethylene (TCE+PCE	mg/l	0	**0.005**	Drinking water	**YES**
	Sum of monoaromatic hydrocarbons: benzene, ethylbenzene, toluene and xylenes (BTEX)	mg/l	0	**0.005**	Drinking water	**YES**
	Arsenic (As)	µg/l	4.9	**7.45**	Drinking water	**YES**

Annex 4

Structure of Estonian groundwater body conceptual models

GWB code	RBD	GWB group	Aquifer system	Admin. unit (e.g., county)	Area (km^2)

		Additional visual materials
Hydrogeological characteristics	Lithology	YES (Conceptual cross-section; map with groundwater levels and flow direction)
	Thickness	
	Overlying aquitard	
	Underlying aquitard	
	Groundwater level	
Hydrodynamics	Flow direction	YES (Map with groundwater levels and flow directions)
	Filtration coefficient and flow velocity	
	Recharge and regime	
Chemical composition	Chemical composition	YES (Maps and Piper diagrams)
	Conceptual model of the chemical composition formation	
GDTEs and GAAEs	Groundwater associated river waterbodies	-
	Groundwater associated standing water bodies and karst features	
	GDTEs	
Status assessment	Chemical status	-
	Quantitative status	
	Overall status	
Groundwater resources (m^3/d)	Natural resources (NR)	-
	Approved groundwater resources (AGR)	
	Groundwater abstraction (GA)	
	Available resources (AGR-GA)	
	Minimal available natural resources (NR-AGR)	
	Minimal available natural resources for abstraction (NR-GA)	

Annex 5

Structure of Latvian groundwater body conceptual models

<table>
<tr><td colspan="6">GWB code,
RBD</td><td>Additional visual materials</td></tr>
<tr><td colspan="6">Area (km²)</td><td rowspan="2">-</td></tr>
<tr><td colspan="6">Physico-geographical characteristics</td></tr>
<tr><td rowspan="3">Characterization of aquifers</td><td colspan="5">Type of aquifers, dominant lithology</td><td rowspan="4">YES
(Multiple cross-sections)</td></tr>
<tr><td colspan="5">The main characteristics of aquifers</td></tr>
<tr><td colspan="5">Thickness of aquifers</td></tr>
<tr><td>Overlying sediments</td><td colspan="5">Lithology and thickness</td></tr>
<tr><td colspan="6">Vulnerability of Quaternary aquifer</td><td rowspan="2">-</td></tr>
<tr><td colspan="6">Vulnerability of confined aquifers</td></tr>
<tr><td colspan="2">Land use (CORINE Land Cover)</td><td colspan="2">Most common land use types</td><td colspan="2">Distribution, %</td><td>-</td></tr>
<tr><td colspan="6">Nitrate vulnerable zone</td><td>YES
(Map with distribution)</td></tr>
<tr><td colspan="6">GDTEs</td><td>-</td></tr>
<tr><td rowspan="3">Groundwater recharge</td><td colspan="5">Main recharge mechanisms</td><td rowspan="3">-</td></tr>
<tr><td colspan="5">Average annual precipitation</td></tr>
<tr><td colspan="5">Recharge and discharge areas</td></tr>
<tr><td rowspan="2">Monitoring</td><td colspan="5">Number of monitoring stations, number of wells</td><td rowspan="2">YES
(Map with monitoring stations and springs)</td></tr>
<tr><td colspan="5">Types and frequency of observations</td></tr>
<tr><td rowspan="4">Groundwater resources</td><td colspan="5">Groundwater well fields</td><td rowspan="4">-</td></tr>
<tr><td colspan="5">Groundwater abstraction in well fields</td></tr>
<tr><td colspan="5">Calculated (approved) resources in well fields</td></tr>
<tr><td colspan="5">Recharge amount</td></tr>
<tr><td colspan="2">NBLs and TVs</td><td>Parameter</td><td>NBL</td><td>TV</td><td>Unit of measurement</td><td>-</td></tr>
</table>

Annex 6

Comparison between Estonian and Latvian groundwater body conceptual models

Section of the conceptual model		The situation in each country		Visual materials (maps, diagrams)		Suggestions for harmonization
		Estonia	**Latvia**	**Estonia**	**Latvia**	
GWB code		Provided	Provided	No visual materials provided for this section		**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (excluding fields *Groundwater body group*, *Aquifer system* and *Administrative unit*).
RBD		Provided	Provided			
GWB group		Provided	Not provided as separate field, but information is available			
Aquifer system		Provided				
Administrative unit (e.g. county)		Provided				
Area (km²)		Provided	Provided			
Physiographic characteristics		Not provided as separate field, but information is available	Provided	No visual materials provided for this section		**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure.
Hydrogeological characteristics	*Lithology*	Provided	Conceptual model structure differs, but information is available	Conceptual cross-section provided	Multiple cross-sections provided	**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (excluding field *Groundwater flow velocity* - such information is not available in the case of Latvia); 2) adopt the Estonian approach for the development of visual materials
	GWB thickness					
	Overlying aquitard					
	Underlying aquitard					
	Groundwater level		Not provided as separate field, but information is available	Map with groundwater levels and flow directions	No visual materials provided for this section	
Hydrodynamics	*Flow direction*	Provided	Conceptual model structure differs, but information is available			
	Filtration coefficient and groundwater flow velocity			No visual materials provided for this section		
	Recharge and regime					
Groundwater chemical composition	*Chemical composition*	Provided	Not provided as separate field, but information is available	Multiple maps and Piper diagrams (depending on overall situation of the GWB)	No visual materials provided for this section	**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (in the case of Latvia it will not be entirely possible to adopt the field *Conceptual model of the formation of chemical composition* - information will be provided according to its availability); 2) adopt the Estonian approach for the development of visual materials
	Conceptual model of the formation of chemical composition		Not developed due to lack of data and knowledge of the overall situation of the GWB			
Groundwater vulnerability	*Quaternary*	No data available	Provided	No visual materials provided for this section		**Recommendations:** 1) adopt the Latvian approach for the joint and

Section of the conceptual model		The situation in each country		Visual materials (maps, diagrams)		Suggestions for harmonization
		Estonia	Latvia	Estonia	Latvia	
	Pre-quaternary	Not provided as separate field, but information is available	Provided			harmonized conceptual model structure (in the case of Estonia Quaternary groundwater vulnerability map has not been developed - the field will remain blank).
Corine LandCover 2018		Not provided as separate field, but information is available	Provided	No visual materials provided for this section		**Recommendations:** 1) adopt the Latvian approach for the joint and harmonized conceptual model structure.
Nitrate vulnerable zone		Not provided as separate field, but information is available	Provided	No visual materials provided for this section	Map with Nitrate vulnerable zone distribution	**Recommendations:** 1) adopt the Latvian approach for the joint and harmonized conceptual model structure; 2) provide the map (not as a separate map but within previous visual materials) with Nitrate vulnerable zone distribution (for the relevant GWBs).
Monitoring	*Number of monitoring stations and wells (springs)*	Not provided as separate field, but information is available	Provided	Map with location and types of MPs		**Recommendations:** 1) adopt the Latvian approach for the joint and harmonized conceptual model structure; 2) provide the map with MPs distribution (not as a separate map but within previous visual materials).
	Types and frequency of observations		Provided			
GDTEs and GAAEs	*Groundwater associated river water bodies*	Provided	Regarding GAAEs - information is not provided as the results of identification and assessment of GDEs at the level of Latvian GWBs were available at the beginning of 2022; regarding GDTEs - information is provided only for the Gauja River basin (results of the GroundEco project). Information is currently available on GAAEs for all GWBs in Latvia; on GDTEs it is available for Daugava, Lielupe and Venta RBDs as the results from previously mentioned project, but in the Gauja and Salaca river basins GDTEs were identified during the WaterAct project.	No visual materials provided for this section		**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (a map with identified GDTEs and GAAEs will not be included in the conceptual model as such information is available as a separate chapter in WP2 joint report); 2) in the case of Latvia collect results from the project "Identification and assessment of groundwater dependent ecosystems at the level of Latvian groundwater bodies" regarding GAAEs in TGWBs.
	Groundwater associated standing water body ecosystems and karst features					
	GDTEs					

Section of the conceptual model		The situation in each country		Visual materials (maps, diagrams)		Suggestions for harmonization
		Estonia	Latvia	Estonia	Latvia	
Status assessment	*Quantitative status*	Provided	Not provided as separate field, but information is available	No visual materials provided for this section		**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (excluding fields *Overall status*).
	Chemical status					
	Overall status					
Groundwater resources (m^3/d)	*Natural resources (NR)*	Provided	No data available (no dynamic hydrogeological model has been developed)	No visual materials provided for this section		**Recommendations:** 1) adopt the Estonian approach for the joint and harmonized conceptual model structure (In the case of Latvia, by filling in information about those parameters for which information is available) 2) In the case of Latvia, it is necessary to consider the idea of development of a dynamic hydrogeological model (outside the WaterAct project) in order to be able to provide and calculate adequate information on groundwater resources.
	Approved groundwater resources (AGR)		Provided			
	Groundwater abstraction (GA)		Provided			
	Available groundwater resources (AGR-GA)		Not provided, but parameter can be calculated based on available information			
	Minimal available natural resource (NR-AGR)		No data available (no dynamic hydrogeological model has been developed)			
	Minimal available natural resource of groundwater for abstraction (NR-GA)					
NBLs and TVs		Not provided as separate field, but information is available	Provided	No visual materials provided for this section		**Recommendations:** 1) adopt the Latvian approach for the joint and harmonized conceptual model structure.

Note: To compare the structure of conceptual models, as a base Estonian conceptual model structure was chosen. For each conceptual model section information was provided whether such a section is provided in the case of each country. Conceptual model structure was supplemented with additional sections (**violet color**) if such a section was provided in the case of Latvia, but not in the case of Estonia

Annex 7

Joint and harmonized structure of conceptual models for Estonian-Latvian transboundary groundwater bodies

GWB code		**Additional visual material**
RBD		-
Area (km²)		-
Physiographic characteristics		-
Hydrogeological characteristics	*Lithology*	+
	GWB thickness	
	Overlying aquitard	
	Underlying aquitard	
	Groundwater level	
Hydrodynamics	*Flow direction*	+
	Filtration coefficient	
	Recharge and regime	
Groundwater chemical composition	*Chemical composition*	+
	Conceptual model of the chemical composition	
Groundwater vulnerability	*Quaternary*	-
	Pre-Quaternary	
CORINE Land Cover 2018		-
Nitrate vulnerable zone		+
Monitoring network	*Number of monitoring stations and points*	+
	Type and frequency of observations	
GDTEs and GAAEs	*Groundwater associated river water bodies*	-
	Groundwater associated standing water bodies and karst features	
	GDTEs	
Status assessment results	*Quantitative status*	-
	Chemical status	
Groundwater resources (m³/d)	*Natural resources (NR)*	-
	Approved groundwater resources (AGR)	
	Groundwater abstraction (GA)	
	Available groundwater resources (AGR-GA)	
	Minimal available natural resources (NR-AGR)	
	Minimal available natural resources for groundwater abstraction (NR-GA)	
NBLs and TVs	**Indicator** / **NBL** / **TV**	-

Annex 8

Comparison between Estonian and Latvian natural background levels and threshold values derivation techniques

Step and its description		Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. Dataset			
Time period	**Estonia:** Chemical data from 2004-2017 was used to represent present conditions and work with the dataset at the GWB level. For macro components (e.g. Cl^-, SO_4^{2-}, NO_3^-) data from earlier periods (1980s) was also considered. **Latvia:** Chemical data from 1994-2019 was used. In 1994, groundwater sampling procedure changed. Before the samples were taken without proper pumping that can influence the representativity of some analyzed parameters. Also, in 1994 almost all Na^+ and K^+ values were already analyzed separately (previously reported as a sum Na^++K^+).	Even though there are differences in chosen time periods, it is not considered to have a major impact on the outcome.	**Recommendations:** 1) although in case of Latvia extra data could be added from earlier time periods for parameters which cannot be affected by water pumping and are considered as conservatives (e.g. Cl^-), that would highlight the issue with Na^++K^+ values (which were often calculated) - no harmonization needed
Data sources	**Estonia:** Monitoring wells and water supply wells. **Latvia:** Monitoring wells and springs, water supply wells	The data source can be considered as similar. The only difference is that Estonia did not use spring data, but in Latvia those were only 30 extra points.	No harmonization needed
Removal of incomplete records	**Estonia:** Samples with missing supporting information (e.g. well number, representative aquifer) and missing at least one of 7 major elements (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-) were removed. **Latvia:** Samples with missing supporting information (e.g. well number, representative aquifer) and missing at least one of 7 major elements (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-) and duplicates were removed. As well, samples which do not represent any GWB were removed (not all groundwater in Latvia is a part of some GWB).	No difference	No harmonization needed
Na^++K^+ treatment	**Estonia:** Did not have this issue as the chosen time period for the data set was mainly 2004. **Latvia:** Samples with Na^+ and K^+ reported as a sum of Na^++K^+ removed as they mostly are calculated from ionic charge balance.	No difference	No harmonization needed
Ionic charge balance	**Both countries:** Used ±10% rule and the same formula (Lenntech, 2020) to remove suspicious samples:	The only difference is that Estonia used additional NH_4^+ values, while all other parameters such as major ions and NO_3^- were the same.	**Recommendations:** 1) as NH_4^+ is also often present in Latvian groundwater due to natural occurrence, it would be suggested to use NH_4^+ values in ionic charge balance calculations as well;

	Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
	$= 100 \cdot \left(\frac{\sum cations - \sum anions}{\sum cations + \sum anions} \right)$ The equivalent weight (g/eq or mg/meq) of a compound is defined as: Equivalent weight= M/Z where: M=molecular weight, g Z=charge		but before an analysis of how much adding of NH_4^+ to the calculation of ionic charge balance changes the results should be carried out.
Samples under detection limit (DL) treatment	**Estonia:** For values under DL, the values of DL were used. Most datasets had information about DLs. **Latvia:** For values under DL, the ½ of DL was used. Historical data did not have information about DLs and based on known laboratory techniques sometimes expert judgment was used to identify such samples.	Both techniques are the most common ones to deal with values under DL. The chosen methodological approach could become significant for the cases where there are lots of values under DLs (e.g. for trace elements).	**Recommendations:** 1) the suggested approach at EU level is to use ½ of DL to treat values under DLs (Wendland et al., 2006), but before an analysis of how many values under DL were present in the Estonian dataset should be carried out to understand if harmonization will bring much difference
Treatment of time series	**Estonia:** For the same well average values were used. **Latvia:** For the same well median values were used.	Both techniques are commonly used in treatment of time series, but median values are less impacted by possible outliers; the chosen methodological approach could become significant for the cases where a lot of wells have time series with significant trends.	**Recommendations:** 1) The suggested approach at EU level is to use median values (Wendland et al., 2006), but before an analysis of how many wells in Estonia have more than one record should be carried out to understand if harmonization will bring much difference.
2. Anthropogenic influence			
Treatment of saline intrusion	**Estonia:** Did not consider salinity constraints. **Latvia:** Removed samples with NaCl > 1000 mg/l, according to BRIDGE methodology (Wendland et al., 2006).	Not taking or taking into account salinity constraint might have a significant influence in areas where seawater/saltwater intrusion is present.	**Recommendations:** 1) the suggested approach at EU level is to remove samples with NaCl sum higher than 1000 mg/l (Wendland et al., 2006) as they are considered to not represent natural or freshwater conditions (only potable freshwater are considered to be delineated as GWB according to WFD 2000/60/EC; but before an analysis of how many samples fall out of further analysis if NaCl constraint is used should be carried out to understand if harmonization is necessary.
Treatment of agricultural influence	**Estonia:** Did not consider any constraint. **Latvia:** Removed sampling sites having median nitrate levels higher than 10 mg/l which are considered anthropogenically impacted; removing samples with values above DL for synthetic substances (e.g. pesticides) as suggested by BRIDGE methodology (Wendland et al., 2006).	Not taking or taking into account agricultural impact constraints might have a significant influence in areas where intensive agricultural activities are present (e.g. nitrate vulnerable zone).	**Recommendations:** 1) the minimum suggested approach at EU level is to remove samples with NO_3^- > 10 mg/l, but also eliminating samples with known presence of synthetic compounds is recommended (Wendland et al., 2006); 2) it would be suggested to use NO_3^- constraint at least in nitrates vulnerable zones. But before an analysis of

Step and its description		Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
			how many samples fall out using above mentioned constraints should be carried out to understand if harmonization is necessary.
3. Redox conditions			
Redox conditions	**Estonia:** Did not consider redox conditions, still somehow used them to eliminate suspicious samples (e.g. when NO_3^- and a lot of Fe_{tot} is present). **Latvia:** In some cases took into account redox conditions, but was not able to use the full scheme proposed by BRIDGE as Mn and O_2 were often missing. Samples with Fe_{tot} < 0.2 mg/l were considered as oxic and this was used to derive different NBLs for oxic and anoxic conditions for Fe_{tot} and NO_3^-.	Redox conditions might strongly influence the outcome as many elements are redox sensitive, and redox conditions can be used as forecasts for possible exceedances.	**Recommendations:** 1) it is recommended by BRIDGE methodology (Wendland et al., 2006) to use redox constraint: O_2 > 1 mg/l aerobic conditions and O_2 < 1 mg/l anaerobic, if such data is missing also Fe(II) and Mn(II) constraints can be used: aerobic samples (Fe < 0.2 mg/l and Mn < 0.05 mg/l) and anaerobic samples (Fe ≥ 0.2 mg/l and Mn ≥ 0.5 mg/l); 2) for redox conditions it is believed that most necessary data might be missing to correctly categorize samples into aerobic and aerobic, so harmonization is not suggested. It is suggested to highlight the importance of monitoring Fe, Mn, O_2 in monitoring programmes and hydrogeological studies.
4. *Derivation of NBLs*			
Chosen parameters	**Estonia:** This was the 3rd cycle in TV delineation, but for the first time NBLs were calculated at GWB level and taken into account. Parameters known and already identified as representing pressures and posing the risk for GWBs to not meet WFD objectives in Estonia were assessed: Cl^-, SO_4^{2-}, phenols, benzene, petroleum products, PAHs. NBLs were derived for all GWBs. Also synthetic substances have NBLs which are set as detection limits. For N_{tot} and P_{tot}, which were considered for surface water/GDEs receptors, NBLs were calculated, but further TVs were not derived (more research needed to support such values). **Latvia:** NBLs were derived for all parameters in all GWBs which can occur in groundwater naturally and where the dataset is enough to do that (also parameters which are not considered harmful and have no criteria values, e.g. Ca^{2+}, K^+ etc.). For synthetic substances (e.g. pesticides) NBL according to BRIDGE is derived as zero.	There are differences in how to choose parameters for whom to calculate NBLs. In Latvia, all naturally occurring substances were analyzed and NBLs were derived for all GWBs and all parameters for which it is statistically reasonable (enough data). The idea was to do this for precaution (e.g. if a new risk will be identified, there will already be NBLs) and there was no risk assessment carried out (unknown pressures). After the NBLs can be derived only for those GBWs and for those parameters which pose a risk to not meet objectives of WFD. In Estonia, NBLs were derived for specific substances based on identified major pressures and previous studies. The major difference however is in the fact that Estonia used DLs as NBLs for some synthetic substances. Latvia sets NBLs as zero for all substances which cannot occur naturally as they should not be present.	**Recommendations:** 1) list of chosen parameters might be harmonized only in TGWBs, otherwise it depends on the chosen approach of each MS; 2) however, it would be encouraged to use zero as NBLs for all synthetic substances as recommended by BRIDGE methodology (Müller et al., 2006, Wendland et al., 2006).
Calculation of	**Estonia:** 90th percentile	No difference	No harmonization needed

	Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
NBLs	**Latvia:** 90th percentile		
Grouping	**Estonia:** Not used in Estonia	Grouping was used only in Latvia to ease the further application process.	No harmonization needed
	Latvia: Baseline levels that are determined for a substance for each GWB can be combined in more general groups in order to reduce the number of different baseline levels, to promote more rounded baseline level numbers and to ease further groundwater management work.		
5. *Derivation of TVs*			
Chosen parameters	**Estonia:** Those which are considered to make a risk to not meet WFD objectives. Receptors are considered: saltwater intrusion, drinking water. TVs set only for GWBs at risk and adopted in legislation (Minister of Environment Regulation No.48/2019).	Both approaches are based on risk assessment.	No harmonization needed
	Latvia: Calculated for all parameters which have environmental criteria (drinking water standards), but TVs are set in legislation only for GWBs at risk.		
Calculation of TVs	**Estonia:** When comparing the criteria values with the established NBLs, two outcomes are possible for any substance or an indicator: (1) **NBL < criteria value**: in that case the MS will define the TV according to national strategies and a risk assessment (enabling a TV to be established above the BL providing it can be clearly justified). (2) **NBL > criteria value**: in this case, the TV should be equal to the NBL.	No difference	No harmonization needed
	Latvia: Two most common approaches for threshold detection were selected according to the experience of other European countries and BRIDGE methodology: (1) if the reference value is higher than the baseline level, then TV is calculated as the mid-point between baseline level and reference value, (2) if the reference value is lower than baseline level, then TV is equal to baseline level.		

Annex 9

Comparison between Estonian and Latvian approaches of pressure assessment in GWBs

Step and its description		Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. List of pressures			
Preparation of the list	**Estonia:** The joint list of all pressure types sources (point, diffuse and groundwater abstraction) was created based on *WFD Reporting Guidance 2016, Annex 1a: List of Pressure Types*, also taking into account the list of GWBs at risk or in bad status. **Latvia:** The list based on *WFD Reporting Guidance 2016, Annex 1a: List of Pressure Types* was prepared **only for point-source pressures**; in the process of creating the list the status of GWB was not taken into account.	Although both countries have used the same guidelines for preparing the list of pressures, only in the case of point pressures the lists between the two countries are comparable. In the case of assessment of diffuse and groundwater abstraction pressures, the approaches in both countries are significantly different (due to differences in available data sources (e.g. hydrogeological model) and knowledge base).	**Recommendations:** 1) due to differences of available data sources in each country and differently chosen approaches of list preparation, creation of a harmonized approach would be too complicated and time consuming, therefore, no harmonization is recommended during the WaterAct project; 2) harmonization should preferably be carried out within the framework of a separate project.
Target GWBs	**Estonia:** All pressure types affect only GWBs that are exposed on the ground surface, except groundwater abstraction. **Latvia:** All pressure types affect only GWBs that are exposed on the ground surface, except groundwater abstraction.	No difference	No harmonization needed
2. Point pressures			
Assessment procedure	**Estonia:** Using the previously mentioned list, assessment was performed using GIS analysis. Assumption was made that the point pressure source's impacted area is related only to the sub-catchment areas (SWB)) where the point pressure source is situated. The areas of geometric intersection between the GWB and each SWB were calculated. The spatial query was performed to find the relation between points and areas. Percentage of selected SWBs in the GWB was calculated. The analysis was repeated for each point pressure type separately. The result of the GIS analysis shows the percentage of the GWB area that may be affected by a particular pressure type. Based on GIS analysis, the impact of pressure sources to GWB was assessed qualitatively in the three categories: 1) ***no impact*** - pressure type affects less than 25% of GWB area; 2) ***minor impact*** - pressure type affects 25-50% of GWB area; 3) ***major impact*** - pressure type affects more than 50% of GWB area.	Although both countries have used the approach of assessing the impact of point pressures at the level of SWBs, in the case of Latvia this has only been the first step, which has been followed by a much more detailed and manual assessment by an expert, taking into account the individual geological and hydrogeological conditions of each place, where the specific pressure point is located.	**Recommendations:** 1) due to differences of available data sources in each country and the chosen level of detail of point pressure assessment level, creation of harmonized approach (for example, adopting the more detailed approach used in the case of Latvia) would be too complicated and time consuming, therefore no harmonization is recommended during the WaterAct project; 2) harmonization should preferably be carried out within the framework of a separate project.

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
Latvia: Using the previously developed point pressure list, the assessment was performed with a multi-step procedure using GIS analysis (initial assessment) and expert judgment (in-depth assessment). The analysis for all point pressure types were done jointly. Significance of pressure on GWB was initially classified into 4 significance classes: *insignificant, light, significant and very significant*, which at the last step for RBMP needs were reduced to only 2 significance classes - **insignificant** (previously used first 3 classes: *insignificant, light and significa*nt) and **significant** (previously used class *very significant*). **1.Initial assessment at the level of SWBs** Initial assessment was done at the scale of SWBs, identifying SWBs where at least 3-point pressure sites were located. Dispersion of these sites was also assessed - if the sites were scattered throughout SWB, impact was considered insignificant. Significant impact was considered in SWBs, where (1) pollution has reached confined aquifers, and/or (2) at least 1 historically contaminated site have been identified, and/or (3) at least 3-point pressure sites are concentrated together. The SWBs were selected for further assessment. **2. Assessment at the level of GWBs** Two pressure classes were already identified at the beginning: pressure was considered ***insignificant*** if GWB was not exposed on the ground surface, and pressure was considered ***light*** if GWB was partially or completely exposed on ground surface but no SWBs were identified in the previous assessment stage. For all the other GWBs additional assessment was performed. Pressure was considered ***significant*** if at least 1 pollution site (in previously selected SWBs) was located in area where (at least one of options): 1) protection of Quaternary aquifers are low; 2) karst processes are common; 3) groundwater abstractions were identified. Pressure was considered ***very significant*** (according to expert judgment) where point pollution can cause a significant impact on groundwater quality (degree of confined aquifer protection, groundwater abstraction and distribution of groundwater flows were assessed). **At the final stage** (for the need of RBMP and for better understanding to the general public), classes **were reduced to only 2 categories**: **insignificant** (including previously identified insignificant, light and significant classes) and **significant** (previously as very significant).		

Step and its description		Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
3. Diffuse pressures			
Assessment procedure	**Estonia:** Using the previously mentioned list, assessment was performed using GIS analysis. Assumption was made that the point pressure source's impacted area is related only to the sub-catchment areas (SWBs)) where the point pressure source is situated. The areas of geometric intersection between the GWB and each SWB were calculated. The spatial query was performed to find the relation between points and areas. Percentage of selected SWBs in the GWB was calculated. The analysis was repeated for each point pressure type separately. The result of the GIS analysis shows the percentage of the GWB area that may be affected by a particular pressure type. Based on GIS analysis, the impact of pressure sources to GWB was assessed qualitatively in the three categories: 1) ***no impact*** - pressure type affects less than 25% of GWB area; 2) ***minor impact*** - pressure type affects 25-50% of GWB area; 3) ***major impact*** - pressure type affects more than 50% of GWB area.	The methods applied in both countries are currently not comparable due to their significant differences - while in the case of Estonia, the same approach is used in the assessment of diffuse pressures as in the case of point pressures assessment (assessment is done at the level of SWBs), in the case of Latvia, the assessment of diffuse pressures is carried out in a multiple step procedure, using the assessment at the level of SWBs as well as at the level of GWB itself.	**Recommendations:** 1) due to differences of available data sources in each country and the chosen level of detail of diffuse pressure assessment level, creation of harmonized approach (for example, adopting the more detailed approach used in the case of Latvia) would be too complicated and time consuming, therefore no harmonization is recommended during the WaterAct project; 2) harmonization should preferably be carried out within the framework of a separate project.
	Latvia: As diffuse pressure sites were not included in the list of pressures, a separate assessment procedure was developed for this assessment. Procedure consists of 5 stages: 1) land use data assessment; 2) livestock pressure analysis; 3) diffuse pressure assessment on the level SWBs; 4) distribution of nitrate vulnerable zone 5) final assessment. **1. Land use data analysis** The area of agricultural land class (based on Corine Land Cover 2018 data) in each GWB was calculated, expressed as a percentage. After that, significance criterion was calculated by summing the occupied area within all GWBs (expressed as a percentage) and calculating its average value and standard deviation, additionally subtracting/adding the standard deviation to the average value. The significance criterion was divided **into four classes**: 1) ***insignificant*** (does not cause a pressure on GWB); 2) ***light*** (minimum pressure on GWB); 3) ***significant*** (causes pressure on GWB); 4) **very significant** (causes significant pressure on GWB) **2. Livestock pressure assessment** The allowable number of animal units (based on Agricultural Data Center data on the total number of livestock expressed in animal units) was calculated in each		

Step and its description		Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
	GWB, according to national legislation. To do that, also the area of agricultural land required for manure application (ha), was calculated in each GWB around each livestock farm by determining an individual 5 km buffer zone and ultimately from these buffer zones by calculating the total area of agricultural land in each GWB. ***Very significant pressure*** was applied to GWB if the permissible number of livestock units (DVp) per hectare was exceeded (according to national legislation, the permissible number of livestock units per hectare of agricultural land is 1.7). If this number was not exceeded, the pressure on GWB was considered ***insignificant***. **3. Diffuse pressure assessment on the level SWBs** All SWBs with poor and very poor-quality status due to diffuse agricultural pressure were identified. In SWBs, the diffuse agricultural pressures for which a significant or very significant impact was identified in the previous step, were taken into account. All poor and very poor quality SWBs affected by other diffuse loads, such as forestry and households not connected to the central sewerage systems, were also identified. For identified SWBs, the specific area was calculated in relation to the GWB area, expressed as a percentage. For the determination of diffuse pollution pressures in SWBs, a significance criterion limit of more than 20% of the GWB area was adopted. ***Very significant*** pressure on the GWB was attributed to the case where more than 20% of SWBs within the GWB were identified as having poor or very poor-quality status due to diffuse agricultural pressure (as well as pressures from other processes) in relation to the total GWB area; if the 20% limit was not exceeded, the pressure was considered as ***insignificant***. **4. Distribution of nitrate vulnerable zone** If the area of the nitrate vulnerable zone occupied more than 20% of the GWB, the pressure was considered to be ***very significant***; if the area occupied did not exceed 20% of the GWB, the pressure was considered ***insignificant***. **5. Final assessment** The final assessment was performed by summarizing the results obtained in the previous stages; the worst-case scenario was taken into account in the assessment of the diffuse pressure. **At the final stage** for the need of RBMP and for better understanding to the general public, **only 2 significance categories were defined**: **insignificant** (if no *very significant pressure* was identified in any of the previous steps) and **significant** (if *very significant pressure* was identified in at least one of the steps before).		
4. Groundwater abstraction			
Assessment procedure	**Estonia:** Groundwater abstraction was not included in the GIS analysis, but was assessed separately, using a hydrodynamical model. The total amount of groundwater	The methods applied in both countries are currently not comparable due to their significant differences - while in the case of Estonia, a hydrodynamical model	**Recommendations:** 1) due to significant differences of groundwater abstraction pressure assessment procedures in both

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
abstraction was compared with natural water balance, which was calculated for each GWB. **Latvia:** As the dynamic hydrodynamic model is still not developed for all GWBs in Latvia, groundwater abstraction pressure was assessed manually in five steps. **1. Gathering of groundwater abstraction data** Information on groundwater abstraction from the State Statistical Reports was collected. The abstraction was linked to GWBs and the average abstraction rate (m^3/d) was calculated for each abstraction point (groundwater well field or individual water well). **2. Compilation of information by administrative territorial units** The information was extrapolated to administrative territorial units and categorized into four groups: (1) areas without abstraction, (2) areas with abstraction up to 100 m^3/d, (3) areas with abstraction from 100 m^3/d to 1000 m^3/d and (4) areas with abstraction >1000 m^3/d. **3. Data validation** To avoid potential errors, it was examined whether the groundwater abstraction point belonging to a specific administrative territorial unit falls within a specific GWB or is located outside its territory. In cases when a specific administrative territorial division unit belonged to several GWBs at the same time, manual connection of groundwater abstraction volumes with the corresponding GWBs was performed. **4. Determination of specific abstraction indicator** The specific water abstraction indicator was introduced in order to objectively assess groundwater abstraction at the level of GWBs and to characterize significant abstraction pressure. It was calculated by dividing the amount of water abstraction by the total area of GWB in each GWB. From these indicators, the average specific water abstraction indicator was calculated - 1.43. **5. Assessment of significance** If more than 20% of the area at GWB level was occupied by administrative units with significant (100-1000 m^3/d) and very significant (>1000 m^3/d) water abstraction pressure obtained in Step 2, additional criterion was considered - whether the specific water abstraction indicator (1.43) was exceeded at the GWB level. If this indicator was exceeded together with significant and very significant groundwater abstraction, then the overall groundwater abstraction pressure was considered to be **significant** at the level of the whole GWB. If these conditions were not exceeded, the pressure was considered to be **insignificant**.	has been used (comparing groundwater abstraction volumes with the model information on natural groundwater balance of the GWB), in the case of Latvia, hydrodynamical model still has not been developed, therefore, groundwater abstraction pressure at the level of the GWB was evaluated in the context of its intensity and distribution.	countries (hydrodynamical model in the case of Estonia and assessment of pressure distribution in the case of Latvia), creation of harmonized approach (development of a new hydrodynamic model in the case of Latvia) would be too time and resources consuming, therefore no harmonization is recommended during the WaterAct project; 2) harmonization should preferably be carried out within the framework of a separate project, starting with development of a hydrodynamical model in Latvia, at first, at least for the identified TGWBs, but ideally - for the entire territory of Latvia; only after development of mutually comparable hydrodynamical models in both countries it will be possible to develop a harmonized approach of assessing the pressure of groundwater abstraction.

Annex 10

Comparison between Estonian and Latvian approaches of trend assessment

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. Data set		
Estonia: Data for the period 2014-2019 from all MPs for all relevant (with determined EQS, TVs and/or LVs) pollutants. **Latvia:** Data for the period 2000-2019 (if necessary, extending the period even more until the minimum number (6 samples) of samples required for analysis was reached) and only as one of the last and separate steps in chemical status assessment tests (for MPs and pollutants with exceedances sharing more than 20% of GWB area).	Major difference: 1) in the case of Latvia, longer time period was applied due to the lack of data and its quality – even with this longer data set and additional criterion trend assessment was possible only at some MPs; 2) in the case of Latvia, for the same reason the trend assessment is applied only as a separate step	Recommendations: 1) common time period must be chosen and applied for the trend assessment to ensure appropriate data comparability; 2) if an insufficient amount of data in the applied time period have been identified at any of the MPs, remark must be made that the trends assessment is not possible at this particular MP; 3) in the harmonized approach, trend assessment must be applied for all relevant pollutants (with determined EQS, TVs and/or LVs) and at all MPs (regardless of identified exceedances in the subsequent GWB condition assessment).
2. Trend plots		
Estonia: Trend plots generated in 2 levels: (1) for parameters with determined EQS,TVSs and/or LVs in all monitorings points; (2) for aggregated MPs for all GWBs - average concentration for every single year is calculated for parameters with determined GQS,TVSs and/or LVs from all MPs **Latvia:** Trend plots are generated for specific parameters in later steps for specific chemical status assessment tests; no trend plots are generated for aggregated MPs in GWBs.	Major differences: 1) while in the case of Estonia trend assessment is performed as a two-step procedure (aggregated data trend plots by GWB and single MP trend plots), in the case of Latvia it is performed only as a one-step procedure (single MP trend plots).	Recommendations: 1) in the case of Latvia, the use of aggregated data trend plots by whole GWB is not technically possible: it is related to the monitoring strategy implemented – the MPs sampled vary from year to year; as a result, the calculated average concentration of a parameter in each year for the whole GWB would not reflect the overall situation of the whole GWB, but rather the situation at various different MPs each year; 2) as suggested above, in the harmonized approach the trend assessment must be applied for all relevant pollutants (with determined EQS, TVs and/or LVs) and at all MPs. 3) in view of the above, it is recommended that each country maintain its current approach for the trend assessment during the WaterAct project (regarding single point and aggregated data trend plots); while planning the future cooperation and management of TGWBs and developing monitoring strategy and program, it should be anticipated and ensured that in the future also in the case of Latvia the use of aggregated data trend plots by GWB should be possible and could be harmonized with Estonia.
3. Software and procedure		

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
Estonia: The R software function lm() is used to generate p-values and calculate linear regression between year and the value of the chemical parameter. An average value from the period 2007-2009 is used as a baseline. The sustained upward trend is defined by positive R value.	**Major difference:** 1) both countries use different software for trend assessment; 2) in the case of Latvia, due to lack and quality of the data at some of the MPs, baselines are still not identified and calculated.	**Recommendations:** 1) taking into account that the joint R software training and development of appropriate scripts has been intended during the WP1 activity A.T1.5, in the harmonized approach both countries will be able to perform the trend assessment using R software and common scripts and functions; 2) in the case of Latvia, baseline must be identified and calculated (adopting the same time period as in the case of Estonia); in case of lack of data in the selected time period, extending it to the possibility of calculating the baseline
Latvia: Trend assessment is not performed in data pre-processing steps; however MS Excel Data analysis - Regression function is used to generate p-values and calculate linear regression between year and the value of the chemical parameter for specific parameters in later steps for specific tests. No starting point and baseline has been identified - the overall development of the situation at the specific MP since the beginning of the observations is observed. The sustained upward trend is defined by positive R value.		
4. *Trend significance*		
Estonia: *Statistically significant* trend is regarded in cases when the p-value is less than 0,05 (statistical confidence - 95%). *Environmentally significant* trend is regarded in cases when the trend line is above 75% of TV.	**Major difference:** 1) in the case of Latvia, only statistical significance have been applied and assessed during the trend assessment	**Recommendations:** 1) in the harmonized approach, also in the case of Latvia both – statistical and environmental – significance of the trend must be assessed to ensure joint and harmonized approach
Latvia: Trend significance assessment is not performed in data pre-processing steps; however only *statistically significant* trends are regarded in cases when the p-value is less than 0,05 (statistical confidence - 95%).		
5. *Use in chemical status assessment tests*		
Estonia: The occurrences of significant and sustained upward trend in MPs and in GWBs as whole are considered in such GWB chemical status assessment tests: “General quality assessment” and “Saline or other intrusions”.	**Major difference:** 1) in the case of Latvia, only trend assessment at single MPs and only as a separate step in chemical status assessments tests is performed	**Recommendations:** 1) as suggested above, in the harmonized approach the trend assessment must be applied for all relevant pollutants (with determined EQS, TVs and/or LVs) and at all MPs; 2) harmonized approach of the use of the trend assessment results should be achieved while harmonizing assessment procedures of “General quality assessment” and “Saline or other intrusions” tests.
Latvia: Trend assessment as separate step is performed in such GWB chemical status assessment tests: “General quality assessment” and “Saline or other intrusions”.		

Annex 11

Comparison between Estonian and Latvian approaches of the general quality assessment test (Test 1)

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. The background check		
Estonia: Aggregated data (calculated average concentrations of GWB-specific pollutants by each MP for period 2014-2019) were compared to EQS, TVs and/or LVs set in the national legislation (more detailed information available in Chapter 1.8.1.1). In case of exceedances, the assessment procedure was continued with the general quality assessment test (as well as other chemical quality assessment tests). If the average concentrations of all relevant pollutants at all MPs were below EQS, TVs and/or LVs, no further assessment was necessary during chemical status assessment and GWB was considered to be in good status (high confidence) with regard to chemical quality. No procedure was provided in case of non-existence of data.	Major differences: 1) in accordance with the CIS Guidance Document No.18, the background check should consider all parameters/pollutants that have been identified as the risk factor for particular GWB; considering this, in the case of Latvia, the intrusion pressure/risk should already be included in the background check step for these particular GWBs for which such pressure has been identified; in the case of Latvia, this improvement should also exclude the need for other tests in cases where no exceedances are identified in the background check step; 2) in the case of Estonia, no procedure have been provided in the cases when there are no monitoring data on GWB for the particular assessment period	Recommendations: 1) in the case of Latvia, parameters characterizing intrusion (Cl^- and SO_4^{2-}) for corresponding GWBs should be included in the background check step - such action will eliminate necessity of performing other assessment tests if no exceedances have been identified during the background check step; 2) considering identified Estonia-Latvian TGWBs, the problem of lack of data was not identified, therefore inclusion of this step in the assessment of TGWBs is not necessary.
Latvia: Aggregated data (calculated average concentrations of GWB-specific pollutants by each MP for period 2014-109) were compared to EQS, TVs and/or LVs set in the national legislation (more detailed information available in Chapter 1.8.1.2). General quality assessment test in Latvia was **divided into 3 parts**: 1) for all GWBs with pesticides and NO_3 (limits set by WFD); 2) for GWBs with identified significant diffuse pressure additionally with NO_2^-, NO_3^- and NH_4^+ (GWB-specific TVs and/or LVs), as well as with stricter quality standard for pesticides (½ of LVs set in national legislation); 3) for GWBs with identified significant point pressure additionally with NO_2^-, NO_3^- and NH_4^+, Cl^-, SO_4^{2-}, P_{tot}, N_{tot}, Cd, Pb, Hg, As, Ni, COD_{Mn}, BTEX, TCE and PCE (GWB-specific TVs + LVs set in national legislation). In case of exceedances, the assessment procedure was continued with the general quality assessment test (as well as other chemical quality assessment tests). If the average concentrations of all relevant pollutants at all MPs were below EQS, TVs and LVs, no further assessment was necessary in the general quality assessment tests and GWB in this test was considered to be in good status (high or average confidence), but further appropriate chemical quality assessment tests were necessary. In case of non-existence of data, GWB is in good status (low confidence).		
2. Treatment of exceedances		
Estonia:	Major differences:	Recommendations:

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
Assessment was performed whether the exceedances (separately for each parameter) affect more than 20% of GWB's total area (using Thiessen polygon method for defining the share of the importance of MPs of GWB). If exceedances did not affect more than 20% of GWB's total area, GWB was considered to be in good status (high confidence), but further assessment tests were necessary. If exceedances affected more than 20% of GWB's total area, assessment was continued with trend assessment (for parameters that affected more than 20% of GWB's total area).	1) while in the case of Estonia the assessment of exceedances was performed separately for each identified parameter in the background check step, in the case of Latvia this assessment was performed for all parameters together	1) In the case of Latvia, each parameter should be assessed separately the same way it was done in the case of Estonia
Latvia: Assessment was performed whether the exceedances (for all parameters together) affect more than 20% of GWB's total area (using Thiessen polygon method for defining the share of the importance of MPs of GWB). If exceedances did not affect more than 20% of GWB's total area, GWB was considered to be in good status (high or average confidence), but further assessment tests were necessary. If exceedances affected more than 20% of GWB's total area, assessment was continued with trend assessment (for parameters that affected more than 20% of GWB's total area).		
3. Trend assessment		
Estonia: Trend assessment results were used as two-step procedure: (1) firstly, aggregated data trend plots by whole GWB were used for determining whether the trend lines for parameters identified in previous step were over 75% mark of EQS, TVs and/or LVs; (2) secondly, (if aggregated data trend plot lines were not over 75% mark of EQS, TVs and/or LVs), trend plots by single MPs were used for determining statistically significant upward trends for these parameters. If aggregated data trend lines for any parameter were over 75% mark of EQS, TVs and/or LVs, assessment was followed with the next step (confidence level of status assessment). If aggregated data trend lines for any parameter were not over 75% mark of EQS, TVs and/or LVs, and also trend lines of single MPs did not indicate statistically significant upward trend, GWB was considered to be in good status (low confidence).	Major differences: 1) while in the case of Estonia trend assessment was performed as a two-step procedure (aggregated data trend plots by GWB and single MP trend plots), in the case of Latvia only as a one-step procedure (single MP trend plots); 2) in the case of Latvia, additional scenario was provided in cases when there was not enough data to perform trend assessment at single MP.	**Recommendations:** 1) in the case of Latvia, the use of aggregated data trend plots by whole GWB is not technically possible: it is related to the monitoring strategy implemented so far in Latvia that the MPs sampled vary from year to year; as a result, the calculated average concentration of a parameter in each year for the whole GWB would not reflect the overall situation of the whole GWB, but rather the situation at various different MPs each year; 2) in view of the above, it is recommended that each country maintain its current approach to the use of trend assessment results during the WaterAct project; while planning the future cooperation and management of TGWBs and developing monitoring strategy and program, it should be anticipated and ensured that in the future also in the case of Latvia the use of aggregated data trend plots by GWB should be possible and could be harmonized with Estonia; 3) with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data was insufficient to perform trend assessment - this step should be included in the harmonized approach for both countries
Latvia: Trend assessment was performed as a one-step procedure: trend plots by single MPs were used to determine statistically significant upward trends for previously identified parameters. If no statistically significant upward trend was identified at any MP, GWB was considered to be in good status (high or average confidence). If a statistically significant upward trend was identified in any MP, additional investigation was done whether the upward trend is the result of anthropogenic influence and whether it poses significant risk to GWB. If the upward trend was connected with anthropogenic impact which also could cause		

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
significant risk to GWB, GWB was considered to be in poor status (high confidence). If there was not enough monitoring data for the trend assessment, GWB was considered to be in good status (potentially at risk, average confidence).		
4. *Confidence level*		
Estonia: Confidence level of the general quality assessment test was evaluated as the last step during the test. If the number of MPs were sufficient for the assessment and it was possible to prove that human impact is causing the problem, GWB was considered to be in poor status (high confidence). If the number of MPs were not sufficient and it was not possible to prove that human impact is causing the problem, GWB was considered to be in good status (at risk; low confidence).	**Major difference:** 1) while in the case of Estonia confidence level was evaluated as the last step after trend assessment results, in the case of Latvia it was evaluated after the step in which assessment test was concluded; 2) furthermore, while in the case of the Estonia confidence level assessment incorporated both data sufficiency and anthropogenic impact, in the case of Latvia only the data sufficiency was tackled	**Recommendations:** 1) confidence level of the general quality assessment test in harmonized approach should be incorporated as a separate step, addressing available data sufficiency and quality, as well as anthropogenic impact
Latvia: Confidence level of the general quality assessment test was evaluated in the assessment step in which the test for each individual GWB was completed. If the number of MPs and groundwater samples taken were sufficient for the assessment, confidence level of the result of the general quality assessment was considered to be high. If the number of MPs and groundwater samples taken were not sufficient for the assessment, confidence level of the result of the general quality assessment was considered to be average.		

Annex 12

Comparison between Estonian and Latvian approaches of saline or other intrusions test - chemical status (Test 2)

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. Selection of GWBs and use of background check results (+ use of trend assessment results (Estonia))		
Estonia: The test was performed for GWBs for which individual Cl^- and/or SO_4^{2-} ion TVs have been set. Aggregated data (background check results) in each MP were compared to individual TVs, as well as trend plots by single MPs were used for identifying statistically significant upward trends of Cl^- and/or SO_4^{2-} ion concentrations. In case of any exceedance and statistically significant upward trend at any MP, assessment procedure was continued with the next step (trend assessment by aggregated data trend plots by whole GWB). If calculated average concentrations at all MPs were below individual TVs and no statistically significant trends were identified at any MP, GWB was considered to be in good status (high confidence). No procedure was provided in case of non-existence of data. **Latvia:** The test was performed for GWBs for which individual Cl^- and/or SO_4^{2-} ion TVs have been set. Saline or other intrusion test in Latvia was **divided into 2 parts**: (1) Seawater intrusion - GWBs that are bordering the sea and are substantially exposed on the surface **and** in which significant groundwater abstraction pressure is identified that may cause intrusion of seawaters (Cl^- only); (2) Saline water intrusion - GWBs that are located above, below or next to the high mineralization zone **and** in which significant groundwater abstraction pressure is identified that may activate the mixing of freshwaters with high mineralization waters (Cl^- and SO_4^{2-}). Aggregated data (background check results) in each MP were compared to individual TVs. In case of any exceedance, assessment procedure was continued with the next step (treatment of exceedances); no trend assessment included in this step. If calculated average concentrations at all MPs were below individual TVs, GWB was considered to be in good status (high or average confidence). In case of non-existence of data, GWB was considered to be in good status (low confidence).	Major differences: 1) in the case of Latvia, the use of trend assessment results by single MPs have not been incorporated in the first step of the test; 2) in the case of Latvia, the test is divided into two separate parts treating seawater and saline water intrusions separately; 3) in the case of Estonia, no procedure has been provided in the cases when there is no monitoring data for the selected time period.	Recommendations: 1) in the case of Latvia, trend assessment by single MPs should be moved up from the next steps and incorporated in the first step to ensure harmonized approach in both countries; with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment – this step should also be incorporated in the harmonized approach; 2) the problem of lack of data for calculating average concentrations for the selected time period was not observed for the identified TGWBs, therefore inclusion of this step in the harmonized approach is not necessary; 3) In the case of Latvia, the division of the assessment test into two separate parts should be prevented in the harmonized approach.

2. Usage of trend assessment results (aggregated data trend plots by GWB (Estonia))

Estonia:

Aggregated data trend plots by GWB were used to determine whether Cl^- and/or SO_4^{2-} ion trend lines exceeded 75% of individual TVs.

If aggregated data trend lines for Cl^- and/or SO_4^{2-} ions did not exceed 75% of individual TVs, GWB was considered to be in good status (potentially at risk).

If aggregated data trend lines for Cl^- and/or SO_4^{2-} ions did exceed 75% of individual TVs, assessment was followed with the next step (treatment of exceedances).

Latvia:

In the case of Latvia, aggregated data trend plots by GWB were not used in saline or other intrusions test (it is not technically possible as described in Chapter 3.4.).

Trend assessment in the case of Latvia was performed as a one-step procedure as a last step during the test (after treatment of exceedances).

Trend plots by single MPs were used for determining statistically significant upward trends for SO_4^{2-} and/or Cl^- concentrations.

If no statistically significant upward trends were identified at any MP, GWB was considered to be in good status (high or average confidence).

If statistically significant upwards trends were identified at any MP, GWB was considered to be in poor status (high confidence).

If there was not enough monitoring data for the trend assessment, GWB was considered to be in good status (potentially at risk, average confidence).

Major differences:

1) while in the case of Estonia trend assessment is performed as a two-step procedure (aggregated data trend plots by the whole GWB in this step and single MP trend plots in previous step), in the case of Latvia the trend assessment is performed only as a one-step procedure (by single MP trend plots);

2) while in the case of Estonia the trend assessment results by single MPs are used in the first step of the test, in the case of Latvia these results are used only in the last step of the test;

3) in the case of Latvia, an additional scenario is provided in cases when data amount is insufficient to trend assessment by single MPs.

Recommendations:

1) in the case of Latvia, the use of aggregated data trend plots by whole GWB is not technically possible (as described in Chapter 3.4.), therefore it is recommended that each country maintain its current approach in the use of trend assessment results in the harmonized approach;

2) in the case of Latvia, trend assessment by single MPs should be moved up from the next steps and incorporated in the first step to ensure harmonized approach in both countries;

3) with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment - this step should also be incorporated in the harmonized approach.

3. Treatment of exceedances

Estonia:

Assessment was performed whether the exceedances and/or statistically significant upward trends (separately for Cl^- and SO_4^{2-} ions) by single MPs represent more than 20% of the total area of GWB (using Thiessen polygon method for defining the share of the importance of MPs of GWB).

If the assessment showed that more than 20% of the total area of GWB is affected, GWB was considered to be in poor status.

If the assessment showed that less than 20% of the total area of GWB is affected, GWB is in good status (potentially at risk).

Latvia:

Treatment of exceedances was performed before trend assessment results interpretation (as the penultimate step).

Assessment was performed whether the exceedances (separately for Cl^- and SO_4^{2-} ions) by single MPs represent more than 20% of the total area of GWB (using Thiessen polygon method for defining the share of the importance of MPs of GWB).

If the assessment showed that less than 20% of the total area of GWB is affected, GWB was considered to be in poor status (high or average confidence).

If the assessment showed that more than 20% of the total area of GWB is affected,

Major differences:

1) in the case of Latvia, treatment of exceedances is performed before usage of trend assessment results.

Recommendations:

1) in the case of Latvia, trend assessment by single MPs should be moved up and incorporated in the first step to ensure harmonized approach in both countries;

2) with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment - this step should also be incorporated in the harmonized approach.

assessment was continued with the trend assessment.

4. *Confidence level*

Estonia: Evaluation of the confidence level was incorporated in the test only as an alternative step at the end of the test. If the number of MPs were sufficient for the assessment and good quality data is available for the assessment, GWB is in poor status. If the number of MPs are not sufficient and statistics are biased by low quality data, GWB is in good status (low confidence; human impact must be confirmed).	**Major difference:** 1) while in the case of Estonia confidence level is evaluated as the last step after trend assessment results and only used as an alternative, in the case of Latvia it was evaluated after the step in which assessment test was concluded	**Recommendations:** 1) confidence level of the saline or other intrusions test in harmonized approach should be incorporated as a separate and mandatory step, addressing available data sufficiency and quality
Latvia: Confidence level was evaluated in the assessment step in which the test for each individual GWB was completed. If the number of MPs and groundwater samples taken are sufficient for the assessment, confidence level of the result of chemical status assessment is high. If the number of MPs and groundwater samples taken are not sufficient for the assessment, confidence level of the result of chemical status assessment is medium.		

Annex 13

Comparison between Estonian and Latvian approaches of saline or other intrusions test - quantitative status (Test 7)

Step and its description	Description of main differences (green - none, blue - minor, orange - major)	Suggestions for harmonization
1. Selection of GWBs and initial use of trend assessment results		
Estonia: The test is performed for those GWBs for which SO_4^{2-} and/or Cl^- TVs have been set (GWB-specific). Aggregated data (calculated average concentrations) in MPs are compared to GWB-specific TVs; as well as trend plots by single MPs are used for identifying statistically significant upward trends of SO_4^{2-} and/or Cl^-. If calculated average concentrations are below TVs and/or no statistically significant upward trends are identified, GWB is in good status. In case of exceedances and/or statistically significant upward trends, assessment is continued with the next step (trend assessment). **Latvia:** The test is performed for GWBs with significant groundwater abstraction pressure + only for those GWBs for which intrusion test were performed during chemical status assessment. No trends assessment of SO_4^{2-} and/or Cl^- concentration was done during quantitative assessment as they were analyzed during chemical status assessment. The results of the respective tests from chemical status assessment of GWBs were used as a starting point for the tests - if a poor chemical status of GWB was not identified in the relevant test within the chemical status assessment, then a good quantitative status (average confidence) was marked in the appropriate test within the quantitative test. In case a poor status of GWB was identified in the relevant intrusion test as part of the chemical status assessment, an in-depth intrusion test was performed on these GWBs by performing a trend analysis of groundwater levels.	**Major differences:** 1) in the case of Latvia, the use of trend assessment results by single MPs have not been incorporated in the first step of the test	**Recommendations:** 1) in the case of Latvia, trend assessment by single MPs should be moved up from the next steps and incorporated in the first step to ensure harmonized approach in both countries; with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment – this step should also be incorporated in the harmonized approach; 2) with regard to the other actions performed in this step of the test, the harmonized approach needs to adopt the approach used in Estonia
2. Trend assessment of groundwater levels		
Estonia: Trend plots of groundwater levels by single MPs are used for identifying statistically significant downward trends. If the trend line at any MP shows a statistically significant downward trend, assessment is continued with the next step (local assessment). If the trend line at any MP does not show statistically significant downward trends, GWB is in good status (high confidence). **Latvia:** Trend plots of groundwater levels by single MPs are used for identifying statistically significant downward trends.	Minor difference	**Recommendations:** 1) with regard to the additional step used in the case of Latvia in cases when the amount of monitoring data is insufficient to perform trend assessment of groundwater levels – this step should not be incorporated in the harmonized approach as no problem of data insufficiency concerning groundwater level data was not identified

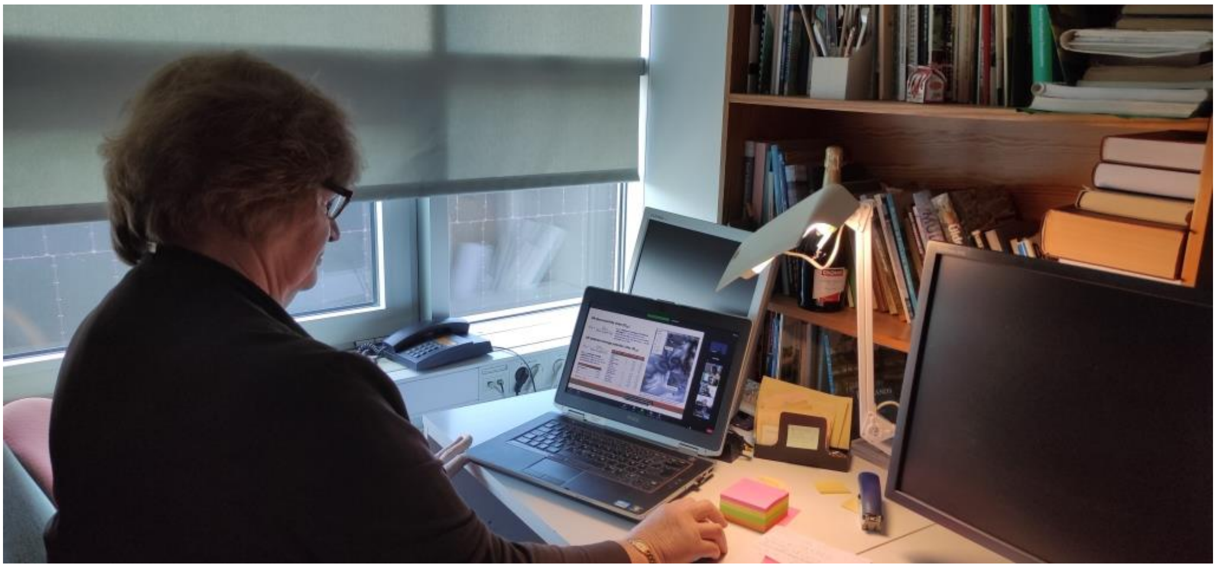
If the trend line at any MP shows a statistically significant downward trend, assessment is continued with the next step (local assessment). If the trend line at any MP does not show statistically significant downward trends, GWB is in good status (high confidence). If there is not enough data (or no data at all) to perform trend assessment of groundwater levels, GWB is also in good status, but with low confidence.		
3. Local assessment		
Estonia: Assessment is performed whether statistically significant upward trends of Cl^- and/or SO_4^{2-} coincide with statistically significant downward trends of groundwater levels (by single MPs). If both factors coincide with each other, the assessment is continued with the next step (treatment of exceedances). If both factors do not coincide with each other, GWB is in good status (at risk; the reason for groundwater level decrease must be explained in the future).	Minor difference	**Recommendations:** 1) for this harmonized approach, methodology used in the case of Estonia should be adopted
Latvia: Assessment is performed whether statistically significant upward trends of Cl^- and/or SO_4^{2} coincide with statistically significant downward trends of groundwater levels (by single MPs). If both factors coincide with each other, the assessment is continued with the next step (treatment of exceedances). If both factors do not coincide with each other, GWB is in good status (high confidence, but the reason for groundwater level decrease must be explained in the future).		
4. *Treatment of exceedances*		
Estonia: Assessment is performed whether the areas with statistically significant upward trends of Cl^- and/or SO_4^{2-}, and statistically significant downward trends of groundwater level take up more than 20% of GWB (using Thiessen polygon method for defining the share of the importance of MPs of GWB). If such areas affect more that 20% of GWB, assessment is continued with the next step (human impact). If such areas do not affect more than 20% of GWB, GWB is in good status (at risk).	Minor difference	**Recommendations:** 1) for this harmonized approach, methodology used in the case of Estonia should be adopted
Latvia: Assessment is performed whether the areas with statistically significant upward trends of Cl- and/or SO42-, and statistically significant downward trends of groundwater level take up more than 20% of GWB (using Thiessen polygon method for defining the share of the importance of MPs of GWB). If such areas affect more that 20% of GWB, assessment is continued with the next step (human impact). If such areas do not affect more than 20% of GWB, GWB is in good status (high confidence).		
5. *Human impact assessment*		

Estonia: Assessment is performed whether the statistically significant downward trends of groundwater level are caused by human activities. If human impact is responsible for the statistically significant downward trend of groundwater level, GWB is in poor status. If human impact is not responsible for the statistically significant downward trends of groundwater level, GWB is in good status (at risk).	Minor difference	**Recommendations:** 1) for this harmonized approach, methodology used in the case of Estonia should be adopted
Latvia: Assessment is performed whether the statistically significant downward trends of groundwater level are caused by human activities. If human impact is responsible for the statistically significant downward trend of groundwater level, GWB is in poor status (high confidence). If human impact is not responsible for the statistically significant downward trends of groundwater level, GWB is in good status (potentially at risk; more data needed).		

Annex 14

Experience exchange and trainings at EGU General Assembly 2021

Part 1 – Report prepared by Elve Lode (Tallinn University)



Disciplinary sessions

Important!

*Due to area of expertise The Hydrological Sciences (HS) session of vEGU21 was chosen for participation.
**Abstracts of all keynote speakers are provided in this report
***Titles of the Sub-sessions what were chosen are marked in color. Only the most interesting presentation abstracts of those sub-sessions are provided in this report.

Conclusions:

*All key presentations were useful in the sense to get an updated overview of different parts of HS session.
**It must be recognized that the modern hydrology research is a part of interdisciplinarity. A modern key word seems to be the Social-Hydrology, i.e., joined social science with hydrological water management science for example.

***Any kind of modelling approach is the main tool for description and prediction of hydrological processes. Remote sensing has been developed and supplemented the data production, by this improving significantly the modelling results both in Hydrology and in Hydrogeology.

Presentations in HS

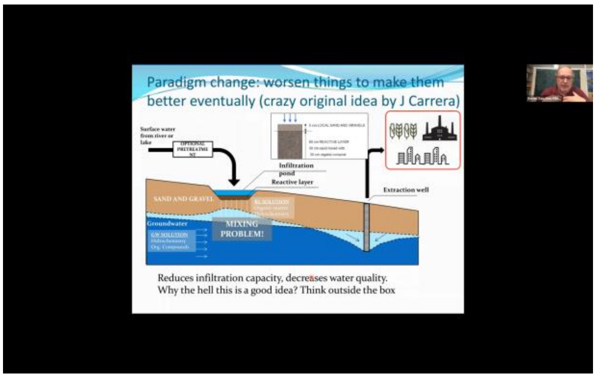
Tuesday, 20th April

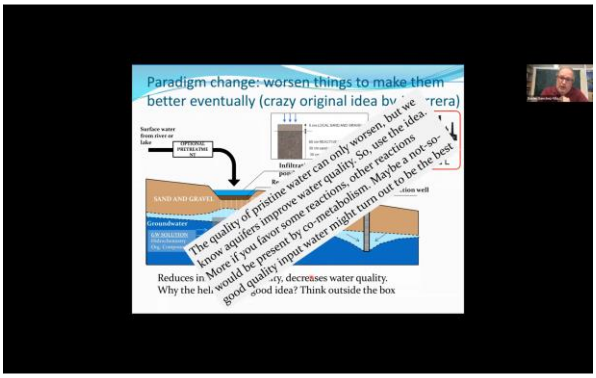
Porous media as a canvas for hydro-bio-geo-chemical processes: Facing the challenge

Xavier Sanchez-Vila

The more we study flow and transport processes in porous media, the larger the number of questions that arise. Heterogeneity, uncertainty, multi-disciplinarity, and interdisciplinarity are key words that make our live as researchers miserable… and interesting. There are many ways of facing complexity; this is equivalent as deciding what colors and textures to consider when being placed in front of a fresh canvas, or what are the sounds to include and combine in a music production. You can try to get as much as you can from one discipline, using very sophisticated state-of-the-art models. On the other hand, you can choose to bring to any given problem a number of disciplines, maybe having to sacrifice deepness in exchange of the better good of yet still sophisticated multifaceted solutions. There are quite a number of examples of the latter approach. In this talk, I will present a few of those, eventually concentrating in managed aquifer recharge (MAR) practices. This technology involves water resources from a myriad of perspectives, covering from climate change to legislation, from social awareness to reactive transport, from toxicological issues to biofilm formation, from circular economy to emerging compounds, from research to pure technological developments, and more. All of these elements deserve our attention as researchers, and we cannot pretend to master all of them. Integration, development of large research groups, open science are words that will appear in this talk. So does mathematics, and physics, and geochemistry, and organic chemistry, and biology. In any given hydrogeological problem you might need to combine equations, statistics, experiments, field work, and modeling; expect all of them in this talk. As groundwater complexity keeps amazing and mesmerizing me, do not expect solutions being provided, just anticipate more and more challenging research questions being asked.

How to cite: Sanchez-Vila, X.: Porous media as a canvas for hydro-bio-geo-chemical processes: Facing the challenges, EGU General Assembly 2021, online, 19-30 Apr 2021, EGU21-15490, https://doi.org/10.5194/egusphere-egu21-15490, 2021.





Landscape perspectives in hydrological understanding and modelling for water management

Berit Arheimer

The Darcy medal acknowledges water-resources research, engineering and management. In my medal lecture I will embrace these aspects by telling the story of how my team merges numerical models and observations with landscape information to learn about hydrological processes and provide decision-support to society. We predict spatial and temporal variability of water fluxes and resources at local, regional and global scales to estimate hydrological variables in the past, present and future. We also explore "what if" scenarios for societal planning. Such predictions provide useful knowledge to maintain water resources at suitable quantities and qualities, despite on-going global warming, urbanization and environmental change. Water is the basis for all life and most societal sectors; hence, it must be managed properly for sustainable development. I will demonstrate how our scientific findings from the model applications have influenced water resources engineering and management policy.

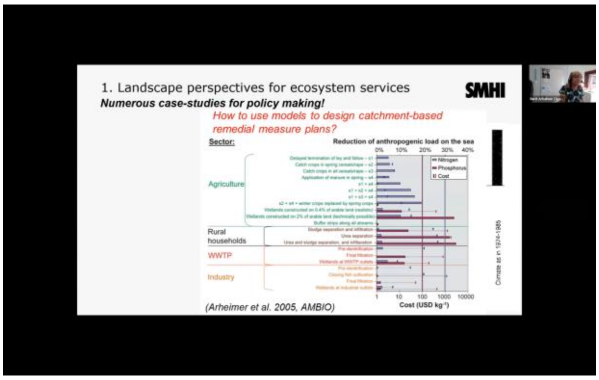
Water management is always local but wider landscape information, such as knowledge about upstream/downstream conditions and residence-time, is needed when designing management measures. Water resources are normally shared by many stakeholders often with opposing objectives. Here, we found that models can have added value for science communication, participatory processes and conflict resolution to reach environmental goals.

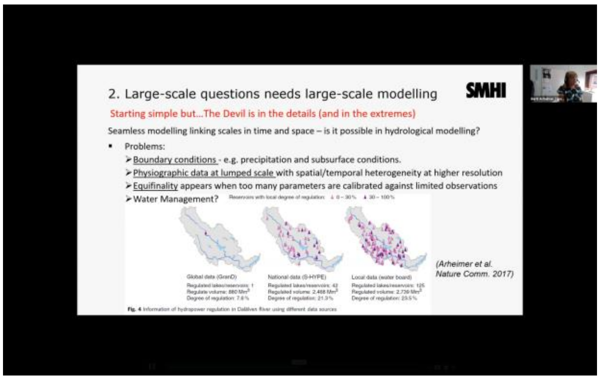
It is well known that numerical models are more or less wrong and linked with uncertainties, but nevertheless, models combined with multiple sources of observations can be very helpful to aggregate information, quantify influence from various processes and describe outcome of complex phenomena. From modelling experiments, I will show how we reached deeper understanding of hydrological process when using the landscape perspective and large-sample empirical data across different physiographical conditions. Linking the model to landscape characteristics also gave us the possibility to make water predictions with some confidence even in data sparse regions and for ungauged catchments.

Large-scale modelling of water resources should be accompanied with site-specific data and local knowledge to be applicable for water resources engineering and management. Therefore, we share our model and I will exemplify how we reach a better understanding and make use of new science in collaborative efforts across the globe. Recently, the modelled data was also aggregated into societal-relevant indicators and provided through web-based climate and water services. During co-development of such on-line tools with practitioners, however, we encountered a large knowledge gap between data producers and data users, which calls for mutual engagement to reach understanding.

To sum up, my team uses and provides open data, open science and community building world-wide to accelerate water research by sharing local insights and collective intelligence in addressing multiple landscapes. Yet, scientific knowledge is always preliminary and needs to be challenged by peers and explored by users to be practically beneficial. I therefore advocate for science communication as an emerging field to engage more with. Hydrological scientists have a lot to contribute and learn in dialogues to find hope and solutions under global change, which will help in sustaining the water resources and the Planet as we know it.

How to cite: Arheimer, B.: Landscape perspectives in hydrological understanding and modelling for water management, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12778, https://doi.org/10.5194/egusphere-egu21-12778, 2021.



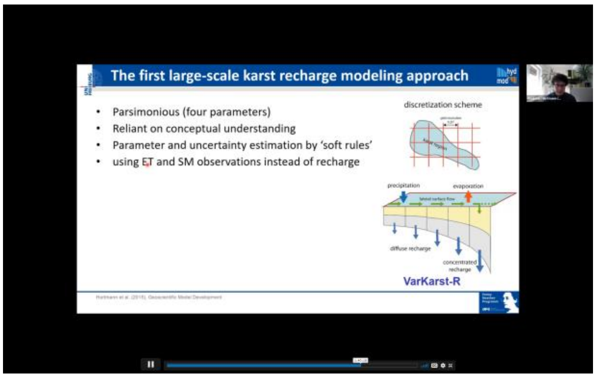


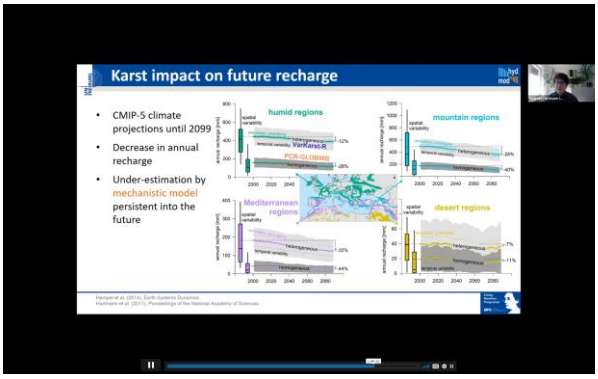
The karst and the furious – ways to keep calm when dealing with karst hydrology

Andreas Hartmann

The dissolution of carbonate rock 'karstification' creates pronounced surface and subsurface heterogeneity and results in complex flow and transport dynamics. Consequently, water resources managers face significant challenges keeping calm when dealing with karst water resources especially in times of environmental change. My lecture not only will provide an overview of the peculiarities of karst hydrology but it will also offer some approaches that facilitate the assessment of environmental changes on karst water resources. Using two case studies, one at the plot scale and the other at the scale of an entire continent, I will contrast the opportunities and challenges of dealing with karst across different scales and climatic regions. Along these case studies, I will elaborate (1) how understanding on dominant karst processes can be obtained, (2) how this understanding can be incorporated into karst specific modelling approaches, and (3) how karst models developed at different scales can be used for water management. The presentation will conclude with some thoughts to facilitate less furious implementations of karst approaches for everyone.

How to cite: Hartmann, A.: The karst and the furious – ways to keep calm when dealing with karst hydrology, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-1353, https://doi.org/10.5194/egusphere-egu21-1353, 2021.





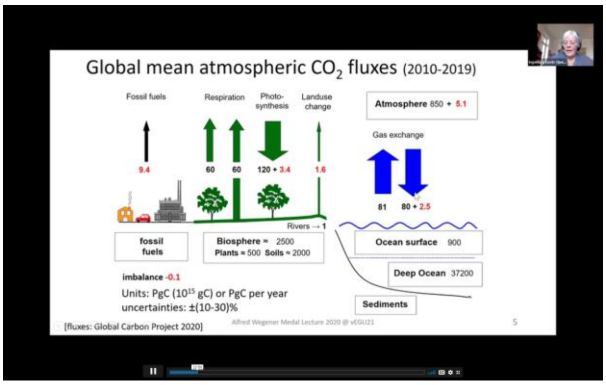
Wednesday, 21st April

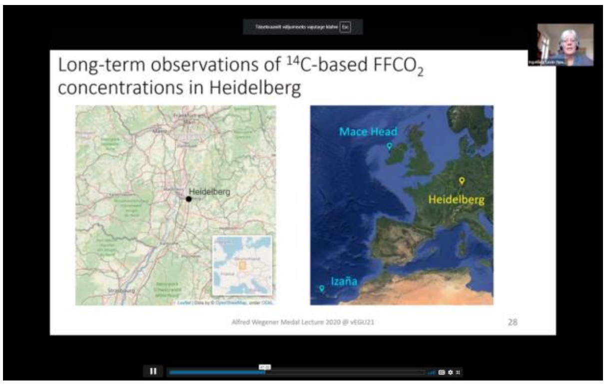
Radiocarbon in modern carbon cycle research

Ingeborg Levin

Atmospheric nuclear weapon testing in the 1950s and 1960s has been worrying, however, in many aspects it was extremely beneficial for environmental sciences. The artificial production of more than 6 x 10^{28} atoms or about 0.6 tons of radiocarbon (^{14}C), leading to a doubling of the $^{14}C/C$ ratio in tropospheric CO_2 of the Northern Hemisphere, has generated a prominent spike in 1963. This "bomb-spike" has been used as transient tracer in all compartments of the carbon cycle, but also to study atmospheric dynamics, such as inter-hemispheric and stratosphere-troposphere air mass exchange. Moreover, our attempt to accurately determine total bomb produced ^{14}C led to improved estimates of the atmosphere-ocean gas exchange rate and to a new constraint of the residence time of carbon in the terrestrial biosphere. Today, the transient bomb-radiocarbon signal has levelled off, and the anthropogenic input of radiocarbon-free fossil fuel CO_2 into the atmosphere has become the dominant driver of the $^{14}C/C$ ratio in global atmospheric CO_2. The observed decreasing $^{14}C/C$ trend in atmospheric CO_2 may thus help scrutinizing the total global release of fossil fuel CO_2 into the atmosphere. On the local and regional scale, atmospheric $^{14}C/C$ measurements are already routinely conducted to separate fossil fuel from biogenic CO_2 signals and to estimate trends of regional fossil fuel CO_2 emissions. Some prominent examples where the bomb $^{14}CO_2$ disturbance has been successfully used to study dynamic processes in the carbon cycle are discussed as well as our current activities applying this unique isotope tracer for continental scale carbon cycle budgeting.

How to cite: Levin, I.: Radiocarbon in modern carbon cycle research, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-4268, https://doi.org/10.5194/egusphere-egu21-4268, 2021.





Plants and river morpho-dynamics

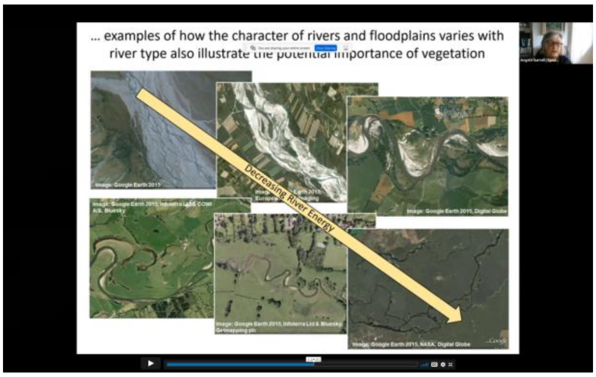
Angela Gurnell

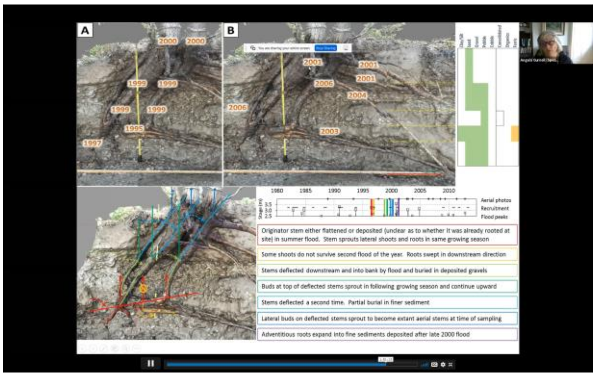
Research within the field of fluvial bio-geomorphology focuses on the impact of organisms, particularly plants, on physical processes and landform development within river environments. This research field has evolved and matured over 50 years such that strong links between plants and river morpho-dynamics are now established and are increasingly becoming embedded in river management practices.

In this presentation, I provide a personal perspective on the evolution of fluvial bio-geomorphology, emphasizing five parallel research themes that were initiated in different decades. Research within these themes continues and combines to underpin our current state of knowledge:

- The 1970s – Natural vegetation colonizes areas according to the degree of river disturbance such that certain plant communities are associated with particular river landforms.
- The 1980s – Dead wood pieces influence river morpho-dynamics and support the development of particular assemblages of physical habitats.
- The 1990s – Some large wood sprouts: dead and living trees drive a geomorphological continuum.
- The 2000s – River and riparian forest dynamics are linked: field observations, laboratory experiments and numerical models converge.
- The 2010s – Many riparian and aquatic plant species can act as river engineers: local engineer species reflect the environmental setting.
- 2020 onwards – Increasing integration: understanding how interactions between plants and rivers adjust with changes in the biogeographical setting, plant species pool and river energy.

How to cite: Gurnell, A.: Plants and river morpho-dynamics, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2793, https://doi.org/10.5194/egusphere-egu21-2793, 2021.





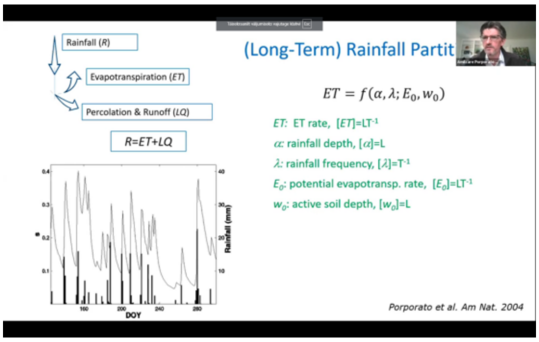
Thursday, 22nd April

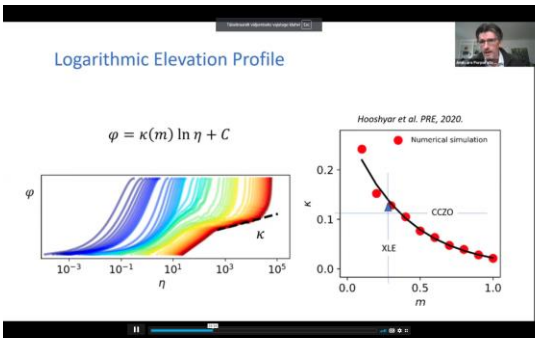
Hydrology without Dimensions

Amilcare Porporato

Dimensional analysis offers an ideal playground to tackle complex hydrological problems. The powerful dimension reduction, in terms of governing dimensionless groups, afforded by the PI-theorem and the related self-similarity arguments is especially fruitful in case of nonlinear models and complex datasets. After briefly reviewing these main concepts, in this lecture I will present several applications ranging from hydrologic partitioning (Budyko's curve) and stochastic ecohydrology, to global weathering rates and soil formation, as well as landscape evolution and channelization. Since Copernicus-dot-org asks me to add at least 25 words to the abstract, I would like to thank the colleagues who supported my nomination for the Dalton medal and my many collaborators.

How to cite: Porporato, A.: Hydrology without Dimensions, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8542, https://doi.org/10.5194/egusphere-egu21-8542, 2021.



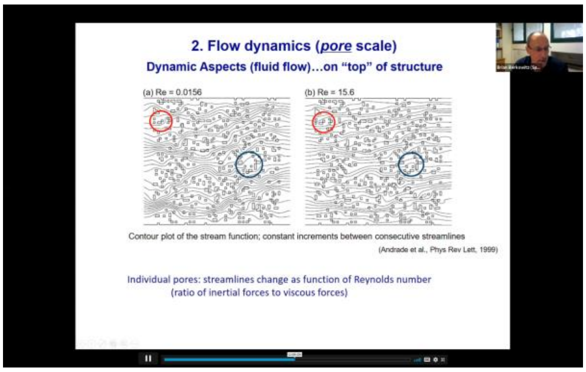


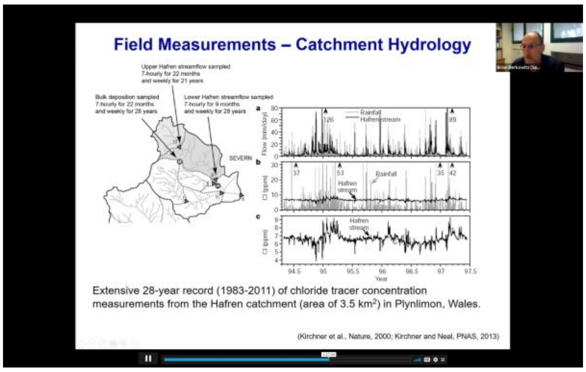
A (not so) random walk-through hydrological space and time

Brian Berkowitz

A key philosophical perspective in science is that nature obeys general laws. Identification of these laws involves integration of system conceptualization, observation, experimentation and quantification. This perspective was a guiding principle of John Dalton's research as he searched for patterns and common behaviors; he performed a broad range of experiments in chemistry and physics, and he entered over 200,000 observations in his meteorological diary during a period of 57 years. In this spirit, we examine general concepts based largely on statistical physics – universality, criticality, self-organization, and the relationship between spatial and temporal measures – and demonstrate how they meaningfully describe patterns and processes of fluid flow and chemical transport in hydrological systems. We discuss examples that incorporate random walks, percolation theory, fractals, and thermodynamics in analyses of hydrological systems – aquifers, soil environments and catchments – to quantify what appear to be universal dynamic behaviors and characterizations.

How to cite: Berkowitz, B.: A (not so) random walk-through hydrological space and time, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-428, https://doi.org/10.5194/egusphere-egu21-428, 2021.





Putting humans in the loop: coupling behavioral modeling with natural systems' models

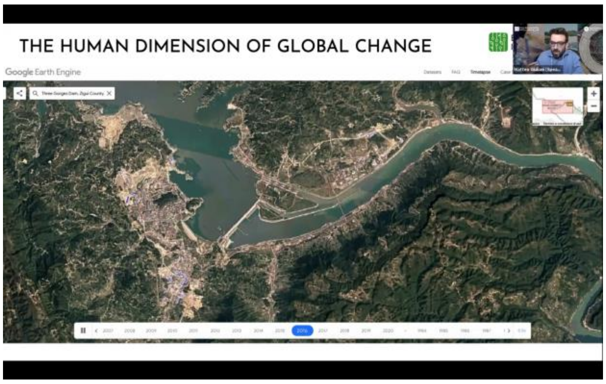
Matteo Giuliani

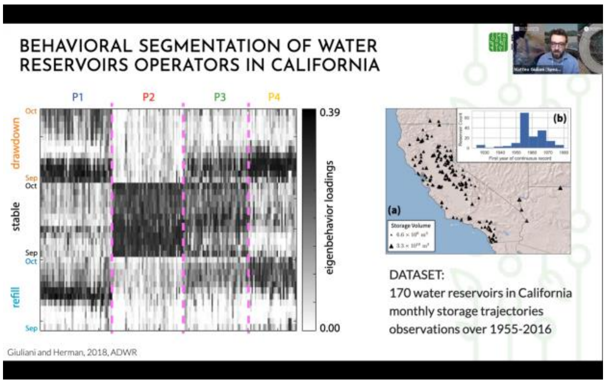
Natural systems' models have done tremendous progress in accurately reproducing a large variety of physical processes both in space and time. Conversely, despite human footprint is increasingly recognized as a major driver of undergoing global change, human behaviors and their interactions with natural processes still remain oversimplified in many models supporting strategic policy design. Recent years have seen an increasing interest and effort by scientists in quantitatively characterizing the co-evolution of nature and society. Nevertheless, state-of-the-art models often relies on behavioral rules empirically defined or derived by general social science or economic studies, which lack proper formalization for the specific case study as well as validation against observational data.

In this talk I will discuss my experiences in modeling human behaviors by taking advantage of the unprecedented amount of information and data nowadays available and of the improvements in machine learning and optimization algorithms. The resulting decision-analytic behavioral models flexibly blend descriptive models, which derive if-then behavioral rules specifying human actions in response to external stimuli, and normative models, which assume fully rational behaviors and provide optimal decisions maximizing a given utility function, where the ultimate goal is not to support optimal decisions but, rather, to understand and model human decisions and behaviors at different spatial and temporal scales.

A number of real world examples in the water domain will be used to provide a synthesis of recent advances in behavioral modeling and to stimulate discussion on key challenges, such as the role of individual behavioral factors in modeling decisions under uncertainty, the scalability of the models for capturing heterogenous behaviors, the definition of model's boundaries, the identification of behavioral preferences in terms of tradeoff among multiple competing objectives and the dynamic evolution of this tradeoff driven by extreme hydroclimatic events.

How to cite: Giuliani, M.: Putting humans in the loop: coupling behavioral modeling with natural systems' models, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9208, https://doi.org/10.5194/egusphere-egu21-9208, 2021.





Friday, 23rd April

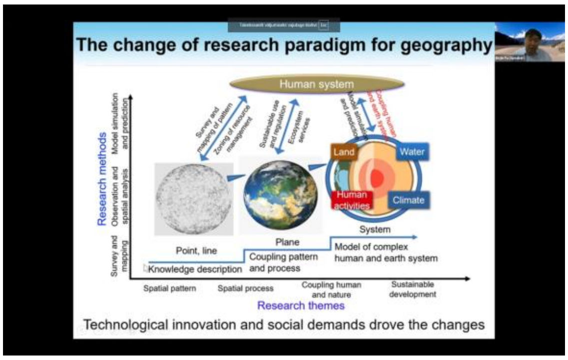
Coupling Human - Earth Systems for Sustainability

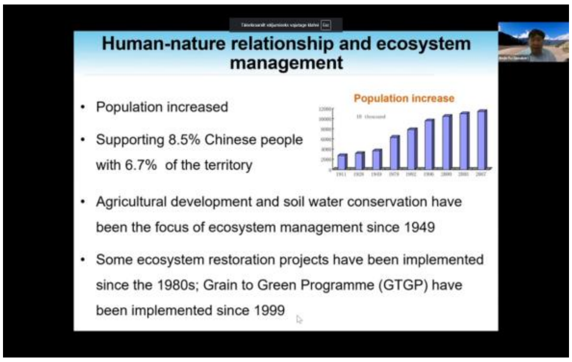
Bojie Fu

State Key Lab of Urban and Regional Ecology, Research Centre for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

Human influence on the natural environment has intensified, and the earth has entered the stage of Anthropocene. Earth surface processes are gradually dominated by human behavior, resulting in numerous resources, disasters and ecological problems. The ecosystem services of 60% are degradation in the world. The one of major challenges facing the world's people are meeting the needs of people today and in the future, and sustaining atmosphere, water, soil and biological products which provided by ecosystems. We will present how to coupling human-earth system and propose the research priorities. They are: (1) Integrating research on multiple processes of water, soil, air and ecosystem; (2) Cascades of ecosystem structure, functions and services; (3) Feedback mechanisms of natural and social systems; (4) Data, models and simulation of sustainable development;(5) Mechanism, approach and policy of sustainable development. Finally, a case study in the Loess plateau of China, an area suffered from severe soil erosion in the world was taken. The changes in four key ecosystem services including water regulation, soil conservation, carbon sequestration, and grain production were assessed and the tradeoff among the ecosystem services were analyzed under the changing landscapes due to the Chinese government's implementation of the Grain to Green Program (GTGP). We found that ecosystem services convert significantly. The adaptive management strategy was discussed aiming on restoring and improving the sustainable capability of ecosystems providing services, based on the understanding of structure, function and dynamics of ecosystem.

How to cite: Fu, B.: Coupling Human - Earth Systems for Sustainability, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9071, https://doi.org/10.5194/egusphere-egu21-9071, 2021.





Alexander von Humboldt's legacy in Earth System Science

Manfred R. Strecker

In this lecture I will first review some of Alexander von Humboldt's studies on the importance of vertical and latitudinal temperature gradients and surface processes in the context of mountain building and thereby highlight his seminal contributions to Earth System Science. In a second step I will briefly comment on his influence beyond science, including public outreach and the general public's Earth science literacy – in the face of fake news and distrust in scientific method and discourse, an issue timelier than ever.

The past decades have witnessed a radical shift in human perception of Earth and nature; climate change and increased competition for natural resources combined with human vulnerability to natural hazards have moved environmentalism from the fringes of public awareness to governmental policies. This shift in awareness was presaged by paradigmatic shifts in Earth Science leading to the modern view of Earth as a dynamic system of interactive physical, chemical and biological processes, and ultimately to establishment of the integrative field of Earth System Science. To a certain extent, this point of view and the realization that research across disciplinary boundaries is important and necessary to understand geoprocesses at a variety of time and length scales and in the context of linkages between the different spheres was already the fundament of Humboldt's thinking and research philosophy during the first half of the 19th century: "The principal impulse by which I was directed was the earnest endeavor to comprehend the phenomena of physical objects in their general connection, and to represent nature as one great whole." Alexander von Humboldt, Kosmos, I, Ch. VII, 1845. Although Humboldt wrote this sentence 176 years ago, it reveals his early recognition of the importance of interdisciplinary and transdisciplinary approaches in science. In this regard Humboldt clearly was ahead of his time and most research areas of modern Earth System Science had already been touched upon by him. From mineralogy, geology, volcanology, stratigraphy and paleontology to climatology, biogeography and geobotany, and oceanography he had addressed many aspects research in an integrative, non-isolationist approach. Although Humboldt published his work very early on in disciplinary journals, he followed a holistic approach in science, where inherent processes, their connections across spheres, and feedbacks between them were addressed.

Consequently, he also analyzed the influence of humans on the environment, particularly with regards to changes in microclimate, erosion, and biodiversity. By recognizing these relationships he truly followed an early Earth System Science approach, thus linking the geosphere and the anthroposphere. Interestingly, during his career Humboldt devoted himself increasingly to the transfer of knowledge to the general public, which not only resulted in regular public lectures, but also had a far-reaching influence in the art world. Taken together, Humboldt therefore paved the way for an integrative approach to the exploration of the Earth's systems beyond disciplinary boundaries, and with a strong commitment to share knowledge and educate the public.

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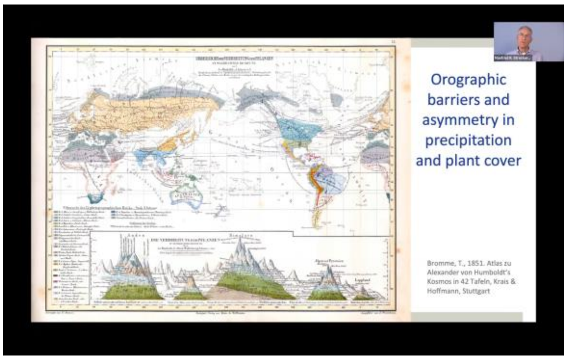

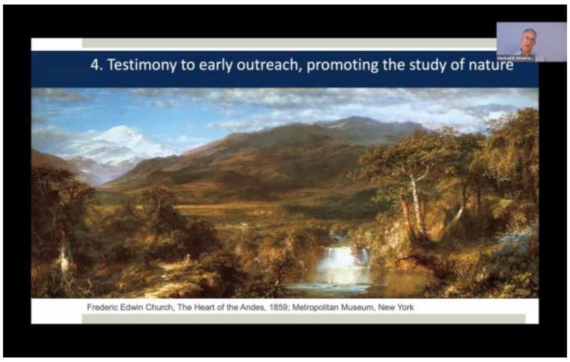

Monday, 26th April

POSTER THEMES

HS2.1.4

Hydrological processes in agricultural lands under changing environments

Convener: Jun Niu | Co-conveners: Noel Aloysius, Bellie Sivakumar

HS2.5.2

Recent advancement in estimating global, continental and regional scale water balance components

Convener: Hannes Müller Schmied[ECS] | Co-conveners: Stephanie Eisner[ECS], Lukas Gudmundsson, Rohini Kumar, Robert Reinecke[ECS]

HS5.4.2

Green infrastructure for sustainable urban hazard management

Co-organized by GM12/NH9

Convener: Daniel Green | Co-conveners: Jorge Isidoro, Lei Li[ECS], Louise Slater[ECS]

HS9.2

Transfer of sediments and contaminants in catchments, rivers systems and lakes

Co-organized by GM3

Convener: Núria Martínez-Carreras | Co-conveners: Patrick Byrne, Marcel van der Perk, Ottavia Zoboli[ECS]

HS10.6

Stable isotopes to study water and nutrient dynamics in the soil-plant-atmosphere continuum

Co-organized by BG2/SSS11

Convener: Natalie Orlowski[ECS] | Co-conveners: Adrià Barbeta[ECS], Josie Geris[ECS], Jana von Freyberg[ECS]

CL2.5

Predictions of climate from seasonal to (multi)decadal timescales (S2D) and their applications

Co-organized by AS4/HS13/NH1/NP5

Convener: André Düsterhus | Co-conveners: Panos Athanasiadis, Leonard Borchert[ECS], Leon Hermanson, Deborah Verfaillie[ECS]

AS1.31

Precipitation: Measurement, Climatology, Remote Sensing, and Modelling

Co-organized by HS13

Convener: Silas Michaelides | Co-conveners: Gail Skofronick-Jackson, Vincenzo Levizzani, Ehsan Sharifi[ECS], Yukari Takayabu

SC5.16

CoSMoS R-package: Simulating random fields and univariate or multivariate timeseries in hydro-climatology and beyond

Co-organized by HS11/NH11

Convener: Simon Michael Papalexiou[ECS] | Co-conveners: Nilay Dogulu, Yannis Markonis[ECS], Kevin Shook

HS1.2.4

Panta Rhei (hydrology, society, environmental change) and Unsolved Problems in Hydrology (UPH)

Co-sponsored by IAHS

Convener: Fuqiang Tian | Co-conveners: Berit Arheimer, Günter Blöschl, Christophe Cudennec, Giuliano Di Baldassarre, Heidi Kreibich, Elena Toth, Jing Wei[ECS]

HS9.1

Techniques for quantifying the sources and the dynamics of sediment in river catchments across a range of spatial and temporal scales

Co-organized by GM4

Convener: Olivier Evrard | Co-conveners: Gema Guzmán, Hugh Smith

HS10.9

Groundwater-surface water interactions: physical, biogeochemical and ecological processes

Convener: Jen Drummond[ECS] | Co-conveners: Jan Fleckenstein, Julia Knapp[ECS], Stefan Krause, Jörg Lewandowski

G3.4

Advances in satellite altimetry for the observation of the Earth's system

Co-organized by CR2/HS6/OS4

Convener: Eva Boergens[ECS] | Co-conveners: Stefan Hendricks, Karina Nielsen, Louise Sandberg Sørensen, Bernd Uebbing[ECS]

ITS2.5/OS4.8

Global plastic contamination: a journey towards scientifically informed policies and solutions

Co-organized by BG1/HS12/SSS12

Convener: Stefanie Rynders[ECS] | Co-conveners: Yevgeny Aksenov, Karin Kvale[ECS], Ilka Peeken, Anna Rubio, Tim van Emmerik[ECS], Beverly Waller

NET16

HS & GI ECS-networking event

Conveners: Caitlyn Hall[ECS], Tim van EmmerikECS | Co-conveners: Sina Khatami[ECS], Elena Cristiano[ECS]

HS1.2.1
Role of hydrology in policy, society and interdisciplinary collaborations: across disciplines and beyond scientists
Co-organized by EOS6
Convener: Maria-Helena Ramos | Co-conveners: Gemma Carr, Sharlene L. Gomes[ECS], Britta Höllermann[ECS], Thomas Thaler[ECS], Jutta Thielen-del Pozo

HS3.3
Advanced geostatistics for water, earth and environmental sciences & Spatio-temporal and/or (geo) statistical analysis of hydrological events, floods, extremes, and related hazards
Co-organized by ESSI1/GI2/SSS10
Convener: Emmanouil Varouchakis[ECS] | Co-conveners: Gerard Heuvelink, Dionissios Hristopulos, R. Murray Lark, Alessandra Menafoglio[ECS], Gerald A Corzo P, András Bárdossy, Panayiotis Dimitriadis[ECS]

HS6.8
Water level, storage and discharge from remote sensing and assimilation in hydrodynamic models
Convener: Jérôme Benveniste | Co-conveners: J.F. Crétaux, Fernando Jaramillo[ECS], Angelica Tarpanelli

HS7.6
Precipitation and urban hydrology
Co-organized by AS4/NH1
Convener: Nadav Peleg | Co-conveners: Lotte de Vos[ECS], Hannes Müller-Thomy[ECS], Susana Ochoa Rodriguez, Li-Pen Wang

HS10.2
From the source to the sea – rivers, estuaries, deltas, marshlands, and coastal seas under global change
Co-organized by BG4/NH1/OS2
Convener: Jana Friedrich | Co-conveners: Debora Bellafiore, Dietrich Borchardt, Andrea D'Alpaos, Holly Michael, Michael Rode, Christian Schwarz[ECS], Claudia Zoccarato[ECS]

BG2
Tropical ecosystems – biomes of global significance in transition
Co-organized by AS2/HS10/SSS8
Convener: Jošt Valentin Lavrič | Co-conveners: Alexander Knohl, Julia Drewer, Laynara F. Lugli[ECS], Carlos Alberto Quesada, Matthias Sörgel, Hans Verbeeck

HS1.1.1
The MacGyver session for innovative and/or self-made tools to observe the geosphere
Co-organized by BG2
Convener: Rolf Hut | Co-conveners: Theresa Blume, Marvin Reich[ECS], Andrew Wickert

HS4.3
Ensemble and probabilistic hydro-meteorological forecasts: predictive uncertainty, verification and decision making
Convener: Albrecht Weerts | Co-conveners: Trine Jahr Hegdahl, Schalk Jan van Andel, Fredrik Wetterhall

HS5.1.3
Impacts of land use and land cover changes on hydrological processes and water management
Convener: Giulio Castelli[ECS] | Co-conveners: Tommaso Pacetti[ECS], Sofie te Wierik[ECS]

CR2.4
Geophysical and in-situ methods for snow and ice studies
Co-organized by GI4/HS1.1/SM2
Convener: Franziska Koch[ECS] | Co-conveners: Polona Itkin, Kristina Keating, Mariusz Majdanski, Artur Marciniak, Emma C. Smith[ECS]

SESSION
HS10.9
Groundwater-surface water interactions: physical, biogeochemical and ecological processes
Convener: Jen Drummond[ECS] | Co-conveners: Jan Fleckenstein, Julia Knapp[ECS], Stefan Krause, Jörg Lewandowski

Residence Time in Hyporheic Bioactive Layers Explains Nutrient Uptake in Streams
***Eugènia Martí**, Angang Li, Susana Bernal, Brady Kohler, Steven A. Thomas, and Aaron I. Packman*

Controls of nitrogen cycling under gaining and losing conditions in a first order agricultural stream
***Oscar Jimenez-Fernandez**, Karsten Osenbrück, Marc Schwientek, Kay Knöller, and Jan Fleckenstein*

Spatial decoupling of in-stream nitrogen cycling observed in an open-air stream mesocosm
***Patricia Gallo Tavera** and Tobias Schuetz*

Seasonal variations in surface water groundwater interaction alter the relation of solute transport and biogeochemical processes in the hyporheic zone
***Lara-Maria Schmitgen** and Tobias Schuetz*

The hyporheic interstitial as interface between surface water and groundwater offers a unique environment for contaminant attenuation and nutrient cycling, with steep chemical gradients and high retention times. Disentangling the effect of seasonal dynamics in exchange flux intensities and directions, we carried out 19 measurement campaigns where we sampled the continuum surface water - hyporheic zone - groundwater and the climatic and hydraulic boundary conditions of a whole year. Groundwater, surface water and hyporheic zone pore water from four depths were sampled at two vertical profiles in a second order stream about 150 m downstream a municipal waste water treatment plant effluent. Samples were analyzed for physical water parameters, major anions, ammonium, iron, manganese, NPOC and five selected pharmaceuticals (diclofenac, carbamazepine, caffeine, ethinylestradiol and clofibric acid). Surface water and groundwater levels as well as river discharge were measured to quantify the hydraulic boundary conditions. In addition, three vertical profiles, each equipped with five newly developed probes (Truebner AG) allowed a parallel monitoring of continuous bulk water temperatures and bulk electrical conductivity dynamics over two years. Furthermore, continuous hyporheic exchange flux intensities and exchange depths were calculated using analytical and numerical model schemes to allow distinguishing between small scale transport and attenuation processes.

The typical behavior of the redox sensitive metals and nutrients with depth is visible in each single profile snapshot. The picture is not as clear for the examined pharmaceuticals, because dilution has a major effect on the observable low concentrations. However, a clear seasonal variation driven by hydraulic and climatic processes can be observed for all substances. We were able to trace the organic pollutants down to the groundwater. Furthermore, the influence of hyporheic exchange flux intensities and directions on nutrient and contaminant depth profiles is shown.

How to cite: Schmitgen, L.-M. and Schuetz, T.: Seasonal variations in surface water groundwater interaction alter the relation of solute transport and biogeochemical processes in the hyporheic zone, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2949, https://doi.org/10.5194/egusphere-egu21-2949, 2021.

The relevance of groundwater-lake interactions for the rapid eutrophication of Lake Stechlin
***Jörg Lewandowski**, Franziska Mehler, Himanshu Bhardwaj, and Anna Jäger*

Molecular insights into the unique degradation trajectory of natural dissolved organic matter from surface to groundwater
***Liza McDonough**, Megan Behnke, Robert Spencer, Christopher Marjo, Martin Andersen, Karina Meredith, Helen Rutlidge, Phetdala Oudone, Denis O'Carroll, Amy McKenna, and Andy Baker*

Relating biomolecular data to denitrification rates in infiltrating river water – insights from enzyme-based reactive transport modelling
***Anna Störiko**, Holger Pagel, Adrian Mellage, and Olaf A. Cirpka*

Reaction rates in the hyporheic zone explained by the lamellar theory of mixing
***Gauthier Rousseau**, Tanguy Le Borgne, and Joris Heyman*

A diffusive description of Vertical Mixing in the Benthic Biolayer
***Ahmed Monofy**, Fulvio Boano, Stanley B. Grant, and Megan A. Rippy*

Groundwater-surface water exchange: A New Graphical User Interface for temperature time-series analysis

Andrea Bertagnoli*, Matthijs van Berkel, Uwe Schneidewind, Ricky van Kampen, Stefan Krause, Andrew Tranmer, Charles Luce, and Daniele Tonina*

Riverine systems have a dynamic exchange of water with the hyporheic zone and groundwater. Exchange fluxes can be challenging to estimate because they vary spatially and temporally and depend on many geological and hydrological properties. Temperature as a tracer has become a low-cost and robust method to monitor such fluxes both at local and reach (several channel widths) scales. Here, we present the capabilities and functionality of a new graphical user interface (GUI) developed in Python which is operating system independent. The GUI integrates standard and state-of-the-art signal processing methods with data visualization and analysis techniques. The signal analysis library allows the user to select the important frequencies to improve result confidence while the advanced LPMLEn and window function in FFT to reduce leakage in the extraction process of the amplitude and phase of the signals. The GUI streamlines the entire analysis process, from evaluating the raw temperature data to obtaining end-user specified parameters such as flux and streambed thermal properties. It allows for the analysis of single-probe and multi-probe data from short to long-term data sets.

How to cite: Bertagnoli, A., van Berkel, M., Schneidewind, U., van Kampen, R., Krause, S., Tranmer, A., Luce, C., and Tonina, D.: Groundwater-surface water exchange: A New Graphical User Interface for temperature time-series analysis, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9311, https://doi.org/10.5194/egusphere-egu21-9311, 2021.

Effects of natural streambed sediment on the riverbed exchange flows and microbial respiration

Yunxiang Chen*, Jie Bao, Bing Li, Xiaofeng Liu, Roman DiBiase, and Timothy Scheibe*

Effect of precipitation and stream discharge on the source composition of stream water

Zhi-Yuan Zhang*, Christian Schmidt, and Jan Fleckenstein*

Exchange flows at the water-sediment interface control river water quality and carbon cycling through microbial respiration. However, accurate quantification of these exchange flows and microbial respiration is still challenging in field surveys due in part to the dynamic turbulence generated by streambed topography. Using a framework that combines Structure-from-Motion (SfM) photogrammetry with a fully-coupled surface-subsurface computational fluid dynamics (CFD) model, this work studies the effects of streambed sediment structure on riverbed turbulence and its impact on exchange flows and microbial respiration. Specifically, the SfM photogrammetry is first applied to obtain mm- to cm-scale resolution riverbed topography over a meter scale domain at four sites; these high-resolution riverbed topography data are then used to generate meshes for use in hyporheic Foam, a fully coupled surface-subsurface model developed in OpenFOAM. Simulated time series of water depth and average flow velocity from a previously-developed 30-kilometer scale CFD model will be used to set the water depth and mean flow velocity conditions for high-resolution CFD models of the SfM-characterized locations. The modeling results will be used to investigate the dependence of riverbed exchange flows, concentration gradients, and the concentration profile from the water surface to riverbed on water depth, mean velocity, roughness size, sediment distribution, bed porosity, and subsurface permeability. The relative importance of flow advection, turbulence dispersion, and microbial reaction in both streambed and surface water will also be evaluated.

How to cite: Chen, Y., Bao, J., Li, B., Liu, X., DiBiase, R., and Scheibe, T.: Effects of natural streambed sediment on the riverbed exchange flows and microbial respiration, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13878, https://doi.org/10.5194/egusphere-egu21-13878, 2021.

Operational prediction of river-groundwater exchange, groundwater levels and aquifer storage: The Wairau Plain Aquifer

Thomas Wöhling

The Remarkable Generality of the Transient Storage Model with Residence Time Dependence: Temporal Moments

Mohammad Aghababaei*, Timothy Ginn, Kenneth Carroll, Ricardo Gonzalez-Pinzon*

Use of helium as an artificial tracer to study surface water/groundwater exchange

Théo Blanc*, Morgan Peel, Matthias S. Brennwald, Rolf Kipfer, and Philip Brunner*

Analyzing surface water-groundwater interactions on selected sites of the River Moselle: Identifying transport processes along an important inland waterway in Germany

***Simon Mischel**, Michael Engel, Sabrina Quanz, Dirk Radny, Axel Schmidt, Michael Schlüsener, and Arne Wick*

Hydraulic engineering structures like locks affect the natural hydraulic conditions and have a relevant impact on surface water – groundwater interactions due to enlarging the hydraulic gradient. For this, these sites are excellent areas to study associated flow paths, mass transport and their spatial and temporal variability in higher detail. However, no large-scale study at an inland waterway is available in Germany until now.

Our work aims to close this gap by applying a multiparameter approach for analyzing surface water-groundwater-interactions by using pH, electrical conductivity, major ions in combination with various other tracers like stable water isotopes, 222-Rn, and tritium. In this context, we also investigate the usability of organic trace compounds and their associated transformation products as potential new tracers.

The main study approach is based on the hypothesis that i) gaining stream sections show relatively high 222-Rn concentrations originating from discharging groundwater and ii) losing stream sections which are characterized by low 222-Rn concentrations as well as lower tritium and organic trace compounds inventories compared to unaffected areas.

During different flow-scenarios of the river Moselle, we test these hypotheses by means of a high-resolution longitudinal sampling at 2 km intervals of the main stream (along 242 km) and its major tributaries in combination with groundwater sampling at numerous wells.

Here, we present the first results of the longitudinal sampling campaign of the river Moselle in October 2020, which took place during intermediate flow conditions (Q = 200 m^3/s). We used on-site and in-situ 222-Rn measurements and electrical conductivity as a tracer to immediately identify zones along the Moselle with increased groundwater inflow.

With the use of these tracers, we will deepen the conceptual process understanding of surface water – groundwater interactions occurring at larger streams and during different flow conditions, which may lead to a general river characterization of losing and gaining stream reaches. Moreover, understanding the sources of water compounds and the processes involved during transportation and transformation is crucial for maintaining a good quality of the water body, which is key for proper water management. The findings obtained in the region of the Moselle river might be further transferred to other waterways and support decision making.

How to cite: Mischel, S., Engel, M., Quanz, S., Radny, D., Schmidt, A., Schlüsener, M., and Wick, A.: Analyzing surface water-groundwater interactions on selected sites of the River Moselle: Identifying transport processes along an important inland waterway in Germany, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11973, https://doi.org/10.5194/egusphere-egu21-11973, 2021.

Quantifying spatial and seasonal variations of groundwater-surface water interaction for the prediction of hydrological turnover on the catchment scale

***Lars Bäthke**, Sven Ulrich, and Tobias Schuetz*

Targeting hyporheic exchange as well as gains and losses as the means of interaction between ground- and surface water in a stream leads forward to the consideration of both influencing the apparent hydrological turnover at the catchment scale i.e. the cumulative effect of gains and losses on physical water composition along a stream. The variability in hydrological turnover across a catchment is governed by the spatially varying connectivity between groundwater and the streambed. Especially under low flow conditions, expansion of turnover relative to stream flow is prominent and its spatial variability is intensified.

Studying the scaling behavior of hydrological turnover processes, we measured hydrological turnover along two representative stream segments of about 500-600m length at a second order tributary to the river Mosel in Trier, western Germany by applying differential sault dilution gauging over 10 campaigns in summer and 7 in winter. Each stream reach represents a typical geomorphological setting in the catchment. The upstream reach is characterized by steep sloping terrain towards the stream with pastures and forest at higher elevations as the dominant land use. At the downstream reach the terrain is flatter with the stream meandering. The land use is diverse with meadow, pastures and forest as well as settlements. Each respective reach was split into two equidistant parts, resulting in three measurements of hydrological turnover, first and second section as well as the whole reach. Thus, acquiring data accounting for the spatial variability in each reach as well as between reaches. The measurements were carried out weekly, at the two stream reaches from August to September with stream flow ranging from ca. 2 l/s to 94 l/s and at the downstream reach from November to February with stream flow ranging from 200 l/s to over 1000 l/s.

The results show clearly the positive relationship between discharge and the relative volume of water exchanged between stream, hypohreic zone and groundwater as gains and losses at the reach scale. In addition to that, exchange processes vary independently at both investigated reaches. However, the dataset suggests a distinctive relationship between turnovers of an entire reach compared to the sum of the two sub-reach sections. The slope of this relationship may be a first step for the upscaling of observed exchange and turnover processes from the reach to the network scale.

How to cite: Bäthke, L., Ulrich, S., and Schuetz, T.: Quantifying spatial and seasonal variations of groundwater-surface water interaction for the prediction of hydrological turnover on the catchment scale, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12616, https://doi.org/10.5194/egusphere-egu21-12616, 2021.

Investigating the hydrogeological controls of an ephemeral stream's flow regime on an alluvial fan in an ecologically important setting in North West England

__Joel Blackburn__, Jean-Christophe Comte, Gez Foster, and Christopher Gibbins

Groundwater dynamics and groundwater surface-water exchange in the near-stream zone across the hydrologic year

__Enrico Bonanno__, Günter Blöschl, and Julian Klaus

Groundwater dynamics and flow directions in the near-stream zone depend on groundwater gradients, are highly dynamic in space and time, and reflect the flow paths between stream channel and groundwater. A wide variety of studies have addressed groundwater flow and changes of flow direction in the near-stream domain which, however, have obtained contrasting results on the drivers and hydrologic conditions of water exchange between stream channel and near-stream groundwater. Here, we investigate groundwater dynamics and flow direction in the stream corridor through a spatially dense groundwater monitoring network over a period of 18 months, addressing the following research questions:

- How and why does groundwater table response vary between precipitation events across different hydrological states in the near-stream domain?
- How and why does groundwater flow direction in the near-stream domain change across different hydrological conditions?

Our results show a large spatio-temporal variability in groundwater table dynamics. During the progression from dry to wet hydrologic conditions, we observe an increase in precipitation depths required to trigger groundwater response and an increase in the timing of groundwater response (i.e. the lag-time between the onset of a precipitation event and groundwater rise). This behavior can be explained by the subsurface structure with solum, subsolum, and fractured bedrock showing decreasing storage capacity with depth. A Spearman rank (rs) correlation analysis reveals a lack of significant correlation between the observed minimum precipitation depth needed to trigger groundwater response with the local thickness of the subsurface layer, as well as with the distance from and the elevation above the stream channel. However, both the increase in groundwater level and the timing of the groundwater response are positively correlated with the thickness of the solum and subsolum layers and with the distance and the elevation from the stream channel, but only during wet conditions. These results suggest that during wet conditions the spatial differences in the groundwater dynamics are mostly controlled by the regolith depth above the fractured bedrock. However, during dry conditions, local changes in the storage capacities of the fractured bedrock or the presence of preferential flow paths in the fractured schist matrix could control the spatially heterogeneous timing of groundwater response. In the winter months, the groundwater flow direction points mostly toward the stream channel also many days after an event, suggesting that the groundwater flow from upslope locations controls the near-stream groundwater movement toward the stream channel during wet hydrologic conditions. However, during dry-out or long recessions, the groundwater table at the foot slopes decreases to the stream level or below. In these conditions, the groundwater fall lines point toward the foot slopes both in the summer and in the winter and in different sections of the stream reach. This study highlights the effect of different initial conditions, precipitation characteristics, streamflow, and potential water inflow from hillslopes on groundwater dynamics and groundwater surface-water exchange in the near stream domain.

How to cite: Bonanno, E., Blöschl, G., and Klaus, J.: Groundwater dynamics and groundwater surface-water exchange in the near-stream zone across the hydrologic year, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9576, https://doi.org/10.5194/egusphere-egu21-9576, 2021.

Quantifying vertical streambed fluxes around woody structures using high-resolution streambed temperature measurements
***Uwe Schneidewind**, Silvia Folegot, Matthijs van Berkel, Andrea Bertagnoli, Ricky van Kampen, Charles Luce, Daniele Tonina, and Stefan Krause*

The contribution of instream wood to streambed organic matter controls on microbial metabolic activity
***Ben Howard**, Sami Ullah, Nick Kettridge, Ian Baker, and Stefan Krause*

Effect of sediment-organism interactions on hyporheic exchange in streams: role of sediment reworking time
***Shivansh Shrivastava**, Michael Stewardson, and Meenakshi Arora*

Periodic alterations of the hydrological exchange in hyporheic sediments: colmation, hyporheic fauna and abiotic parameters in a second order stream during one year
***Heide Stein** and Hans Jürgen Hahn*

HS1.2.1
Role of hydrology in policy, society and interdisciplinary collaborations: across disciplines and beyond scientists
Co-organized by EOS6
Convener: Maria-Helena Ramos | Co-conveners: Gemma Carr, Sharlene L. Gomes[ECS], Britta Höllermann[ECS], Thomas Thaler[ECS], Jutta Thielen-del Pozo

The construction of reference conditions under the EU Water Framework Directive
***Tobias Krueger** and James Linton*

With this contribution we connect to the 3rd theme of the session, 'hydrology as practiced within society'. Based on our recent article Linton & Krueger (2020), we demonstrate how the reference conditions and subsequent water quality targets under the EU Water Framework Directive (WFD) do not exist 'out there', waiting to be discovered, but are outcomes of complex negotiations between hydrological, ecological, technical and socio-political realities.

Treating reference conditions and targets as naturally given, as WFD implementation does at least implicitly, upholds a false sense of authority that obscures the manifold choices in the creation of the reference conditions while denying the people charged with implementing the targets or having to live with the resulting water quality an influence over those choices.

We argue that the concept of reference conditions must be abandoned in a world where water everywhere bears the traces of human presence. Instead, water quality targets should be set openly, location-specific and involving those for whom water quality is a matter of concern. We will give examples from other jurisdictions where such an approach is established practice.

Reference: Linton, J. and Krueger, T. (2020), The Ontological Fallacy of the Water Framework Directive: Implications and Alternatives. Water Alternatives, 13(3): 513-533.

How to cite: Krueger, T. and Linton, J.: The construction of reference conditions under the EU Water Framework Directive, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-227, https://doi.org/10.5194/egusphere-egu21-227, 2021.

Structuring the water quality policy problem: Applying Q-methodology to explore perspectives in hydrology, government, and community
***Schuyler Houser**, Reza Pramana, and Maurits Ertsen*

Proposed methodology for the assessment of groundwater chemical and quantitative status in the Republic of Belarus (in accordance with the principles of the EU Water Framework Directive)
***Olga Vasniova**, Olga Biarozka, Andreas Scheidleder, and Franko Humer*

Is scientific research on water-tourism nexus responding to the challenges identified by stakeholders and policy-makers? The case of Benidorm, Spain
***Rubén A. Villar-Navascués**, Sandra Ricart, Antonio M. Rico-Amorós, and María Hernández-Hernández*

Stakeholders, users, participatory approaches

The transition toward resilient water management regimes: where are we now?

Matteo Mannocchi

The HydroSocial Cycle approach to deepen on socio-ecological systems analysis and water management

Sandra Ricart *and Andrea Castelletti*

Balancing socio-ecological systems among competing water demands is a difficult and complex task. Traditional approaches based on limited, linear growth optimization strategies overseen by command/control have partially failed to account for the inherent unpredictability and irreducible uncertainty affecting most water systems due to climate change. Governments and managers are increasingly faced with understanding driving-factors of major change processes affecting multifunctional systems. In the last decades, the shift to address the integrated management of water resources from a technocratic ''top-down'' to a more integrated ''bottom-up'' and participatory approach was motivated by the awareness that water challenges require integrated solutions and a socially legitimate planning process. Assuming water flows as physical, social, political, and symbolic matters, it is necessary to entwining these domains in specific configurations, in which key stakeholders and decision-makers could directly interact through social-learning. The literature on integrated water resources management highlights two important factors to achieve this goal: to deepen stakeholders' perception and to ensure their participation as a mechanism of co-production of knowledge. Stakeholder Analysis and Governance Modelling approaches are providing useful knowledge about how to integrate social-learning in water management, making the invisible, visible. The first one aims to identify and categorize stakeholders according to competing water demands, while the second one determines interactions, synergies, overlapping discourses, expectations, and influences between stakeholders, including power-relationships. The HydroSocial Cycle (HSC) analysis combines both approaches as a framework to reinforce integrated water management by focusing on stakeholder analysis and collaborative governance. This method considers that water and society are (re)making each other so the nature and competing objectives of stakeholders involved in complex water systems may affect its sustainability and management. Using data collected from a qualitative questionnaire and applying descriptive statistics and matrices, the HSC deepens on interests, expectations, and power-influence relationships between stakeholders by addressing six main issues affecting decision-making processes: relevance, representativeness, recognition, performance, knowledge, and collaboration. The aim of this contribution is to outline this method from both theory and practice perspective by highlighting the benefits of including social sciences approaches in transdisciplinary research collaborations when testing water management strategies affecting competing and dynamic water systems.

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From co-production of knowledge to a participatory governance concept: a research design focusing on knowledge practices in flood risk management and disaster risk reduction

Ida Wallin*i*

Stakeholder Participation in Flood-Related Disaster Risk Management in Ghana

Fafali Roy Ziga-Abortta*, Sylvia Kruse, Britta Höllermann, and Joshua Ntajal*

Systematic User Feedback to Co-develop a Flood Early Warning System in West Africa

Martijn Kuller*, Jafet Andersson, and Judit Lienertl*

Transdisciplinary Design of Adaptation Pathways in Peri-urban India: Planning for Water Needs in a Sustainable Urban Transition

Sharlene L. Gomes*, Sarah Luft, Shreya Chakraborty, Leon M. Hermans, and Carsten Butschl*

How scale matters in joint knowledge production for nature-based solutions. Dynamic proximity among stakeholders in climate adaptive water management for brook catchment Aa, the Netherlands

Ermy Brok*, Judith Floor, Frank van Lamoen, and Angelique Lansul*

The question 'how scale matters' from experienced policy makers in adaptive water management motivated us to explore the issue. In search for climate resilience of brook catchments stakeholders collaborate. Those collaborations involve dynamic proximity, giving rise to innovative, creative solutions using natural hydrological and landscape processes. Dynamic proximity is known from innovation research in the field of high-tech regional economic development. The question is whether dynamic proximity among stakeholders influences success of joint knowledge production (JKP) processes as well. We focus on a more nature-tech context of regional economic development: creating nature-based solutions (NbS) to support climate resilience. The conceptual model to study the creative process of JKP combines the four dimensions of JKP with four forms of dynamic proximity. Along this matrix quotes of stakeholders were analyzed from seven semi-structured interviews. At least one stakeholder in the process for the brook-restoration of the Aa (the Netherlands) was selected from industry, academia, government and non-profit organizations (following the 'quadruple helix model'). Findings show that stakeholders who are versatile in using various forms of social, cognitive, institutional and geographical dynamic proximity in the process of JKP experience the process as more successful. Moreover, stakeholders overdoing the institutional or geographical aspects of proximity run into adverse effects, a mechanism recognized in economic geography as the proximity paradox. Furthermore, stakeholders are better supported when they use knowledge instruments, but only when keeping in mind the balance of forms of dynamic proximity. Findings were validated against two stakeholders' experiences in another process for the Aa of Weerijs (the Netherlands). We suggest refining the model by adding two forms of dynamic proximity relating to interests and to resources, enabling a sharper focus on knowledge production under the heading of cognitive proximity. So, scale matters in such rural, natural processes. The perspective on proximity helps innovation, if proximity among stakeholders does not become too proximate. We have summarized findings in the form of a proximity tool, which is useful for optimizing the science-policy interface in regional adaptive water management.

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Hydrology across disciplines: the experience of a Public Hydrological Service in Italy

Giuseppe Ricciardi, *Alessandro Allodi, Fabio Bordini, Monica Branchi, Francesco Cogliandro, Elisa Comune, Valentina dell'Aquila, Mauro Del Longo, Giuseppe Nicolosi, Mauro Noberini, Filippo Pizzera, Fabrizio Tonelli, and Franca Tugnoli*

How are guaranties of quality forged and assessed in flood risk modelling?

Remi Barbier *and Isabelle Charpentieri*

Development of interactive diagnostic tools and metrics for the socio-economic consequences of floods

Annie-Claude Parent, *Frédéric Fournier, François Anctil, Brian Morse, Jean-Philippe Baril-Boyer, and Pascal Marceau*

Building the tools to speed up the policy design cycle: letting policy makers work with hydrologic models themselves through eWaterCycle

Nick van de Giesen, *Rolf Hut, and Niels Drost and the Netherlands eScience Centre*

Building the tools to speed up the policy design cycle: letting policy makers work with hydrologic models themselves through eWaterCycle

Hydrologists are important experts that policy makers rely on when making water related decisions. Through policy briefs, often including scenario simulations, policy makers are informed about the consequences their (intended) policies (or lack thereof) will have.

In drafting policy briefs, or choosing which scenario to run, scientists inevitably make political decisions, from obvious ones (how to weigh the importance of one land use type over another) to more hidden ones (using Kling-Gupta efficiency, which focuses more on low flow, to calibrate a model instead of Nash-sutcliffe efficiency, which focuses more on high flows). Ideally one wants to design the policymaker - scientist interaction such that most political decisions are made by the policymaker, without requiring her/him to become an expert hydrologist in the process. Any remaining (inevitable) decisions made by the hydrologist should be as transparent as possible.

The eWaterCycle hydrologic research platform facilitates this type of policy maker - hydrologists interaction. Within the platform experiments such as scenario runs are Jupyter notebooks that a governmental data-scientist can construct without having to be an expert in the hydrological models used: these are stored in (OPEN and FAIR) containers. Interactive web applications can be easily built on top of these notebooks using widgets, to allow the ultimate political decision maker to explore a broader range of policy options, instead of having to choose from a view of pre-run scenarios.

We will present a few examples of how the eWaterCycle hydrological research platform can be used to support water-relevant policy decision making.

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Coproducing a water quality dashboard: Data communication for decision support in the Brantas River basin, Indonesia

Christa Nooy*, Schuyler Houser, Reza Pramana, Astria Nugrahany, Daru Rini, and Maurits Ertsen*

Living Labs towards sustainable groundwater management: case study in Malia, Crete, Greece

George Karatzas*, Anthi-Eirini Vozinaki, Ioannis Trichakis, Ioanna Anyfanti, Christina Stylianoydaki, Emmanouil Varouchakis, Christos Goumas, Pier Paolo Roggero, Thuraya Mellah, Hanene Akrout, and Seifeddine Jomaa*

Tuesday, 27th April

HS2.4.4 EDI

Hydrological extremes: from droughts to floods

Convener: Louise SlaterECS | Co-conveners: Gregor Laaha, Ilaria Prosdocimi, Lena M. Tallaksen, Anne Van Loon

HS5.2.2

Groundwater resources management: reconciling demand, high quality resources and sustainability

Convener: Maurizio Polemio | Co-convener: Konstantinos (Kostas) Voudouris

HS6.10 EDI

The Third Pole Environment (TPE) under global changes

Convener: Yaoming Ma | Co-conveners: Franco Salerno, Bob Su, Fan Zhang

HS7.3 EDI

Water, climate, food and health

Co-organized by CL3.2/NH10/NP8

Convener: George Christakos | Co-conveners: Alin Andrei Carsteanu, Elena CristianoECS, Andreas Langousis, Hwa-Lung Yu

HS10.1

General ecohydrology

Convener: Giulia Vico | Co-conveners: Miriam Coenders-Gerrits, Fabrice Vinatier, Julian Klaus, Christoph Hinz

ITS2.14/HS12.2 EDI

Nature-Based Solutions for Global Environmental Challenges and SDG nexus research

Co-organized by BG1/CL3.2/NH1/SSS12

Convener: Zahra Kalantari | Co-conveners: Carla FerreiraECS, Haozhi PanECS, Suzanne JacobsECS, Alicia CorreaECS, Paulo Pereira

NH1.7

Extreme meteorological and hydrological events induced by severe weather and climate change

Co-organized by AS1/HS2.4

Convener: Athanasios Loukas | Co-conveners: Maria-Carmen Llasat, Uwe Ulbrich

CR3.6

Hydrology of ice shelves, ice sheets and glaciers - from the surface to the base

Co-organized by HS13

Convener: Sammie BuzzardECS | Co-conveners: Ian Hewitt, Amber Leeson, Martin WearingECS

SSS11.4 EDI
Field and laboratory experiments, measurements and modelling of soil detachment and transport in Soil Science, Geomorphology and Hydrology research
Co-organized by EOS2/GM3/HS13
Convener: Thomas Iserloh^ECS | Co-conveners: Steffen Seitz, Miriam Marzen^ECS, Jorge Isidoro, Petr Kavka, Kazuki Nanko

BG4.4 EDI
Aquatic biogeochemical cycles of carbon, nitrogen and phosphorus. From measurements to understanding hydrochemical patterns and processes
Co-organized by HS13
Convener: Magdalena Bieroza | Co-conveners: Andrea Butturini, Diane McKnight

CL4.17 EDI
Land-atmosphere interactions and climate extremes
Co-organized by AS2/BG3/HS13
Convener: Ryan Teuling | Co-conveners: Gianpaolo Balsamo, Diego G. Miralles, Sonia Seneviratne, Wim Thiery^ECS

HS1.1.2
Advances in river monitoring and modelling for a climate emergency: data-scarce environments, real-time approaches, inter-comparison of innovative and classical frameworks, uncertainties, harmonization of methods and good practices
Co-organized by GI4/GM2/NH1
Convener: Nick Everard | Co-conveners: Silvano F. Dal Sasso, Alexandre Hauet, Alonso Pizarro^ECS

HS8.1.1 EDI
Modern challenges and approaches to modeling subsurface flow and transport across multiple scales
Convener: Monica Riva | Co-conveners: Daniel Fernandez-Garcia, Alberto Guadagnini, Xavier Sanchez-Vila

HS5.4.1 EDI
Water resources policy and management: digital water and interconnected urban infrastructure
Convener: Andrea Cominola^ECS | Co-conveners: Newsha Ajami, Ana Mijic, David Steffelbauer^ECS, Riccardo Taormina^ECS

HS6.2
Remote sensing of soil moisture
Convener: Clément Albergel | Co-conveners: Luca Brocca, Patricia de Rosnay, Jian Peng, Nemesio Rodriguez-Fernandez

HS8.1.3 EDI
Innovative methods for the quantification of subsurface processes
Convener: Maria Klepikova | Co-conveners: Pietro De Anna, Clement Roques

HS9.3
Measurement and monitoring techniques for sedimentary and hydro-morphological processes in open-water environments
Co-organized by GM2
Convener: Stefan Achleitner | Co-conveners: Mário J Franca, Kordula Schwarzwälder, Axel Winterscheid

BG3.17 EDI
Complex case studies for ecosystem responses to climate and hydrological extremes
Co-organized by HS10/NH8
Convener: Adrienn Horváth^ECS | Co-conveners: Zoltán Gribovszki, Péter Kalicz, Dejan Stojanovic, Jan Szolgay

GM5.2 EDI
Advancing theory and modelling of river systems and erosion mechanics
Co-organized by HS13, co-sponsored by IAG
Convener: Shawn Chartrand | Co-conveners: He Qing Huang, Paul Carling, Ian D. Rutherfurd, Alexander Beer^ECS, Claire Masteller^ECS, Matteo Saletti^ECS

SC5.15 EDI
An introduction in processing and evaluation of X-ray images with SoilJ
Co-organized by HS11/SSS11
Convener: John Koestel | Co-conveners: Wiebke Mareile Heinze^ECS^, Katharina Meurer

HS5.2.3 EDI
Water resources policy and management - systems solutions in an uncertain world
Convener: Jazmin Zatarain Salazar^ECS^ | Co-conveners: Julien Harou, Jan Kwakkel, Manuel Pulido-Velazquez, Amaury Tilmant

HS7.5 EDI
An introduction in processing and evaluation of X-ray images with SoilJ
Co-organized by NH1
Convener: Francesco Marra | Co-conveners: Elena Cristiano^ECS^, Efthymios Nikolopoulos, Nadav Peleg, Konrad Schoeck

HS8.2.3 EDI
Groundwater and water scarcity in dry regions: causes, processes, regional solutions
Co-organized by CL2
Convener: Martin Sauter | Co-conveners: Irina Engelhardt, Noam Weisbrod, J.C. Maréchal, Xavier Sanchez-Vila, Zhilin Guo^ECS^, Taher Kahil, Ting Tang^ECS^

HS9.4 EDI
Numerical modelling of hydro-morphological processes in open water environments
Co-organized by GM3
Convener: Bernhard Vowinckel | Co-conveners: Sándor Baranya, Katharina Baumgartner, Gabriele Harb, Nils Rüther

EOS5.3 EDI
The evolving open-science landscape in geosciences: open data, software, publications and community initiatives
Co-organized by HS1.2
Convener: Remko C. Nijzink^ECS^ | Co-conveners: Niels Drost, James Farquharson, Alexandra Kushnir^ECS^, Francesca Pianosi, Stan Schymanski, Leonardo Uieda^ECS^, Fabian Wadsworth^ECS^

NH3.12
From landslide hydrology towards reliable landslide early warning systems
Co-organized by HS9
Convener: Luca Piciullo | Co-conveners: Thom Bogaard, Raymond Cheung, Katy Freeborough, Stefano Luigi Gariano, Roberto Greco, Dominika Krzeminska^ECS^, Samuele Segoni

NH3.12
From landslide hydrology towards reliable landslide early warning systems
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HS10.1
General ecohydrology
Convener: Giulia Vico | Co-conveners: Miriam Coenders-Gerrits, Fabrice Vinatier, Julian Klaus, Christoph Hinz

Chairpersons: Giulia Vico, Miriam Coenders-Gerrits, Christoph Hinz

Natural terrestrial ecosystems

Soil-Moss-Relations: The path of water from dripping to infiltration
***Sonja M. Thielen**, Corinna Gall, Martin Nebel, Thomas Scholten, and Steffen Seitz*

Hot or not? The effect of stemflow on infiltration and soil properties
***Johanna Clara Metzger**, Janett Filipzik, Beate Michalzik, and Anke Hildebrandt*

How do spatial throughfall patterns reflect in soil moisture patterns?

***Christine Fischer**, Murray Lark, Johanna C. Metzger, Thomas Wutzler, and Anke Hildebrandt*

Net precipitation assessment in a grassland and soil moisture response at plot scale in a temperate climate

***Gökben Demir**, Johanna Clara Metzger, Janett Filipzik, Christine Fischer, Beate Michalzik, Jan Friesen, and Anke Hildebrandt*

Whole-tree rainfall interception measured directly by gravimetry and its relationship with plant traits

***Stefanie Pflug**, Bernard R. Voortman, and Jan-Philip M. Witte*

Comparative analysis of throughfall event response for 6 different forest stands

***Theresa Blume**, Lisa Schneider, Janek Dreibrodt, and Andreas Güntner*

Climate change effects on forest floor interception in woody Cerrado ecosystem

***Livia Rosalem**, Miriam Gerrits-Coenders, Jamil A. A. Anache, Julian S. Sone, Dimaghi Schwamback, Alessandra Campos, and Edson Wendland*

Response of stemflow as a function of various characteristics of the precipitation event

***Katarina Zabret** and Mojca Šraj*

The amount of rainfall intercepted by vegetation is usually estimated by considering the amounts of precipitation, throughfall and stemflow. As stemflow values most often present only a minor fraction of the partitioned rainfall, they are frequently neglected. In addition, stemflow development during the event and under different conditions is also rarely analyzed. At the study plot in Ljubljana, Slovenia, rainfall partitioning components and rainfall event characteristics have been measured since 2014. This database with high frequency measured data was used to analyze how different rainfall event properties influence the development of stemflow measured under the birch tree (*Betula pendula* Roth.).

156 rainfall events with observed stemflow were selected. For each event a figure showing increase of rainfall and stemflow during the event was prepared. The figures were grouped according to their similarity using a hierarchical clustering approach. For each group the significant event characteristics were analyzed. Certain influence on the response of the stemflow was observed for rainfall amount and its intensity, duration of dry period before the event, as well as for average air temperature and air humidity during the event. The figures showing the situation for rainfall events with the smallest rainfall amounts and the lowest intensities were grouped in the cluster 1. The cluster 2 combined stemflow events with negligible response to rainfall development. These events delivered less than 20 mm of rainfall, while their duration was on average 5 hours, which is significantly less than duration of the events, grouped in the clusters 3 and 4. The average air temperature for events, grouped in cluster 2, was quite high as 65% of the events were observed during leafed phenophase. These events were also characterized with generally quite long dry periods before the event. The events merged in the cluster 3 showed noticeable response to rainfall development as the stemflow dynamics followed the increase of the rainfall. These events were characterized by an average of 30 mm of rainfall, reaching up to 102 mm per event. Also rainfall intensity was quite high and similar to rainfall intensities, significant for events grouped in cluster 4. It consisted of events with the strongest stemflow response, which coincide also with the largest amounts of rainfall on average per event. However, air temperature was the lowest and air humidity was the highest during the events, grouped in the cluster 4, which corresponds to mainly leafless phenophase.

How to cite: Zabret, K. and Šraj, M.: Response of stemflow as a function of various characteristics of the precipitation event, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8171, https://doi.org/10.5194/egusphere-egu21-8171, 2021.

Impact of soil hydraulic properties on water-soil-plant relations

***Mathieu Javaux** and Andrea Carminati*

Linking soil water and solutes fluxes to soil properties and vegetation types: insights from a case-study in the high tropical Andes of Ecuador

***Sebastián Páez-Bimos**, Veerle Vanacker, Marcos Villacis, Marlon Calispa, Oscar Morales, Armando Molina, Pierre Delmelle, Braulio Lahuatte, Bert De Bievre, and Teresa Muñoz*

Effects of the Turbulent Schmidt Number on the Mass Exchange of a Vegetated Lateral Cavity

***Luiz Oliveira**, Filipe Queiroz, Taís Yamasaki, Johannes Janzen, and Carlo Gualtieri*

A model of stomatal closure driven by nonlinearities in soil-plant hydraulics

***Fabian Wankmüller**, Mohsen Zarebanadkouki, and Andrea Carminati*

Modeling root water uptake depth driven by climate and soil texture using a simple bucket model approach

***Ruth Adamczewski**, Sven Westermann, and Anke Hildebrandt*

Near stream groundwater table fluctuations impact transpiration rates of riparian plants: a field study with stomatal conductance and dendrometry measurements

***Stefano Martinetti**, Simone Fatichi, Marius Floriancic, Paolo Burlando, and Peter Molnar*

Vegetation establishment, growth, and succession in riparian ecosystems are linked to river and groundwater dynamics. This is especially true in Alpine gravel-bed rivers with wide floodplains and a strong river-aquifer exchange. Here we provide data evidence of riparian plant response to short-term groundwater table fluctuations in a braided gravel-bed river (Maggia). We used indirect physiological variables for photosynthesis and transpiration – stomatal conductance g_s and daily variation in stem diameter ΔD_d – which we measured at six mature riparian trees of the Salicaceae family, one *Populus nigra* and one *Alnus incana* specimen at two sites during two growing seasons. The site where g_s measurements were conducted showed a greater depth to groundwater with higher variability compared to the site were dendrometers were placed.

We analyzed the data by means of two different random forest regression algorithms for the two study sites. One with the transpiration-induced daily tree diameter drop during the growing season 2017 as the dependent variable, and one with the raw gs measurement sequence, obtained on 10 days throughout the growing season 2019, as the dependent variable. In both algorithms the independent variables consisted of meteorological measures (locally measured and at valley scale) and of groundwater and river stages near the individual plants. We also separated the gs measurements into low and high groundwater stage conditions observed during the gs field campaign and applied traditional regression analysis of gs on vapor pressure deficit VPD and global radiation r_g for the 2 groundwater stage conditions separately.

The data analyses demonstrate that:

a) short-term variation of the groundwater table affects riparian vegetation: at the site with deeper groundwater, the water table depth was the best predictor of g_s variability, while at the site with shallower groundwater, temperature and vapor pressure deficit were the best predictors of ΔD_d variability;
b) (b) instantaneous stomatal conductance is related to vapor pressure deficit (VPD), but conditioned by groundwater levels, with higher stomatal conductance for the same radiative input and VPD when the water table was higher.
c) (c) local micro-climate measured at tree locations had a stronger predictive power for gs than valley scale climate, suggesting local climate may be an important control on vegetated stands on gravel bars.

Even though the considered plants are located in close proximity to the river and could be considered to be unaffected by water stress, our analysis provides evidence of riparian trees undertaking physiological adjustments to transpiration in response to groundwater stage, depending on their riparian floodplain settings. In the heavily regulated Maggia river this has implications on the minimum flow release by dams, as prolonged periods of low water stage in the river will lead to a decrease in groundwater stage, and subsequently in reduced growth of phreatophytic riparian plants on the floodplain. We argue such plant-scale measurements should be helpful for the optimization of flow release levels in regulated riparian systems.

How to cite: Martinetti, S., Fatichi, S., Floriancic, M., Burlando, P., and Molnar, P.: Near stream groundwater table fluctuations impact transpiration rates of riparian plants: a field study with stomatal conductance and dendrometry measurements, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9899, https://doi.org/10.5194/egusphere-egu21-9899, 2021.

Climate and land use influences on changing spatiotemporal patterns of mountain vegetation cover in southwest China

***Shanshan Jiang**, Xi Chen, Keith Smettem, and Tiejun Wang*

WATZON: the Italian network of ecohydrology and critical zone observatories

__Marco Borga__, Daniele Penna, Nasta Paolo, Comiti Francesco, Stefano Ferraris, Riccardo Rigon, Carolina Allocca, Anam Amin, Giacomo Bertoldi, Stefano Brighenti, Davide Canone, Giorgio Cassiani, Matteo Censini, Concetta D'Amato, Ginevra Fabiani, Alessio Gentile, Chiara Marchina, Nunzio Romano, Stellato Luisa, and Zuecco Giulia

Managed ecosystems

Hydrological effects of combining Italian alder and blackberry in an agroforestry system in South Africa

__Svenja Hoffmeister__, Rafael Bohn Reckziegel, Florian Kestel, Rebekka Maier, Jonathan P. Sheppard, and Sibylle K. Hassler

Transpiration rates of pine (Pinus brutia) and cypress (Cupressus sempervirens) trees in a Mediterranean mixed plantation forest

__Hakan Djuma__, Adriana Bruggeman, Marinos Eliades, Panagiota Venetsanou, Christos Zoumides, and Melpomeni Siakou

Influence of trees and topography on soil water content in semi-arid region, the case of an agro-silvo-pastoral ecosystem dominated by Faidherbia albida (Senegal)

__Djim Diongue__, Didier Orange, Waly Faye, Olivier Roupsard, Frederic Do, Christophe Jourdan, Christine Stumpp, Awa Niang Fall, and Serigne Faye

Impact of combined nitrogen loading and long-term drought on a semi-natural temperate grassland – achieving a process-based understanding across scales

__Maren Dubbert__, Angelika Kübert, Arndt Piayda, Christiane Werner, and Youri Rothfuss

The influence of landscape spatial arrangement on nitrogen and phosphorus export in agricultural catchments

__Rémi Dupas__, Antoine Casquin, Sen Gu, Gérard Gruau, and Patrick Durand

Dimensioning of riparian buffer zones in agricultural catchments at national level

__Evelyn Uuemaa__, Ain Kull, Kiira Mõisja, Hanna-Ingrid Nurm, and Alexander Kmoch

Aquatic ecosystems

Improving understanding of hydrological and biogeochemical processes controlling the effectiveness of two-stage ditches in reducing eutrophication

__Lukas Hallberg__ and Magdalena Bieroza

Ecosystem services provided by groundwater dependent wetlands in Irish karst

__Fabio Massimo Delle Grazie__ and Laurence Gill

Turloughs, the focus of this study, are ephemeral lakes and they are mostly groundwater dependent. They are present mostly in Ireland and have been compared hydrologically to polje for the period inundation and lacustrine deposits. They are flooded for some periods across the year (typically in the winter) but usually dry up in summer months. Turloughs are protected under the Water Framework Directive (WFD, Directive 2000/60/EC) and the EU Habitats Directive (92/43/EEC). Ecosystem services can be defined as the conditions and processes through which natural ecosystems sustain and fulfil human life. These can be classified as provisioning, regulating, and cultural and examples of them are water and raw materials production, flood risk attenuation, carbon sequestration. The determination of the ecosystem services can help analyze different scenarios linked to pressures like road drainage schemes, water supply and wastewater disposal.

Seven turloughs (Blackrock, Lough Coy, Lough Aleenaun, Lough Gealain, Caranavoodaun, Skealoghan, Coolcam) have been selected from a previous study and samples of waters were collected monthly to determine carbon and nutrients. Carbon and nutrients were also determined on soil samples taken from the turlough catchment. The overwhelming majority of wetlands act as long-term sinks for CO2. To determine whether this is the case for some of the turloughs in the study, greenhouse gases from soils and water were monitored and balances were worked out. Ecosystem services were quantified through various models which had to be adapted to the special conditions present in the turloughs.

The seven turloughs have different hydrological characteristics. Hydrology is the main driver of vegetation distribution therefore communities are distributed in zones arranged along the flooding gradient. Aquatic invertebrates also show a succession of communities through the hydroperiod.

The seven turloughs studied provide a variety of hydrological characteristics, habitat, soil and vegetation and offer different ecosystem services. Each ecosystem service was quantified using appropriate models. Almost all the turloughs are at risk from anthropic activities and potentially from climate change. Important ecosystem services for these turloughs are flood mitigation, nutrient retention, carbon sequestration, habitat preservation and recreational activities.

How to cite: Delle Grazie, F. M. and Gill, L.: Ecosystem services provided by groundwater dependent wetlands in Irish karst , EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-4082, https://doi.org/10.5194/egusphere-egu21-4082, 2021.

Mediterranean Temporary Ponds: using isotope hydrology tools to describe and understand their behavior

Alexandra Mattei, *Laurent Sorba, Emilie Garel, Sebastien Santoni, Sophie Orsini, and Frédéric Huneau*

Streamflow change induced by climate change and vegetation recover in a karst region of southwest China

Lianbin Cai, *Xi Chen, and Zhicai Zhang*

An operational method for the ecohydrological classification of temporary rivers and streams

Francesc Gallart, *Núria Cid, Pilar Llorens, Jérôme Latron, Núria Bonada, Maria Soria, and Narcís Prat*

Water courses that recurrently cease to flow represent a large part of drainage networks, and are expected to expand with global warming and increased exploitation of water resources. Common classifications of the regime of these temporary streams are based on the statistics of zero flow events. This is partly practical because these statistics can be obtained from flow records or model simulations and the results can be used for some environmental regulations or management purposes.

Nevertheless, it is well known that the main hydrological control on riverine aquatic life is the presence-absence of water rather than its flow regime. Disconnected pools that frequently remain in temporary streams after flow cessation provide valuable refuges for aquatic life, which can last up to all year round. An operational characterization of the hydrological regime of temporary streams useful for ecological purposes must therefore take into account at least the three main aquatic phases that they undergo: flow, disconnected pools and dry stream bed. However, gauging stations and the derived hydrological models may only marginally inform about the possible occurrence of disconnected pools after the cessation of flow.

In order to facilitate the implementation of the European Water Framework Directive to the temporary streams, an operational approach has been developed to describe and classify the regime of temporary streams and to assess their degree of hydrologic alteration, relevant to aquatic life. This approach is encapsulated in the freely available TREHS software. The first step of this approach is the gathering of information on the frequency of the three aquatic phases using diverse sources of information, such as flow records and simulations, in situ observations, interpretation of aerial or terrestrial series of photographs, and interviews with local inhabitants or technicians familiar with the riverine systems. Up to six metrics describing these frequencies and their temporal patterns of occurrence are used to determine the natural and observed stream regime, and to assess the degree of hydrological alteration.

The combination of the complementary frequencies of the three main aquatic phases allows the description of the regime of every stream as a point in a ternary plot, where the three vertices of the triangle represent the perennial streams, the perennial pools and the terrestrial systems, respectively. This ternary plot assists the classification of the regime of any stream that takes into account the statistics of the main proxies of the occurrence of aquatic habitats. The TREHS software also provides a classification of the regimes in the ternary plot that groups the regimes of assumed ecological significance and uses terms that are conflict-free from the current classifications. Furthermore, TREHS users can easily define new regime classes in this plot according to the ecohydrological characteristics of their streams.

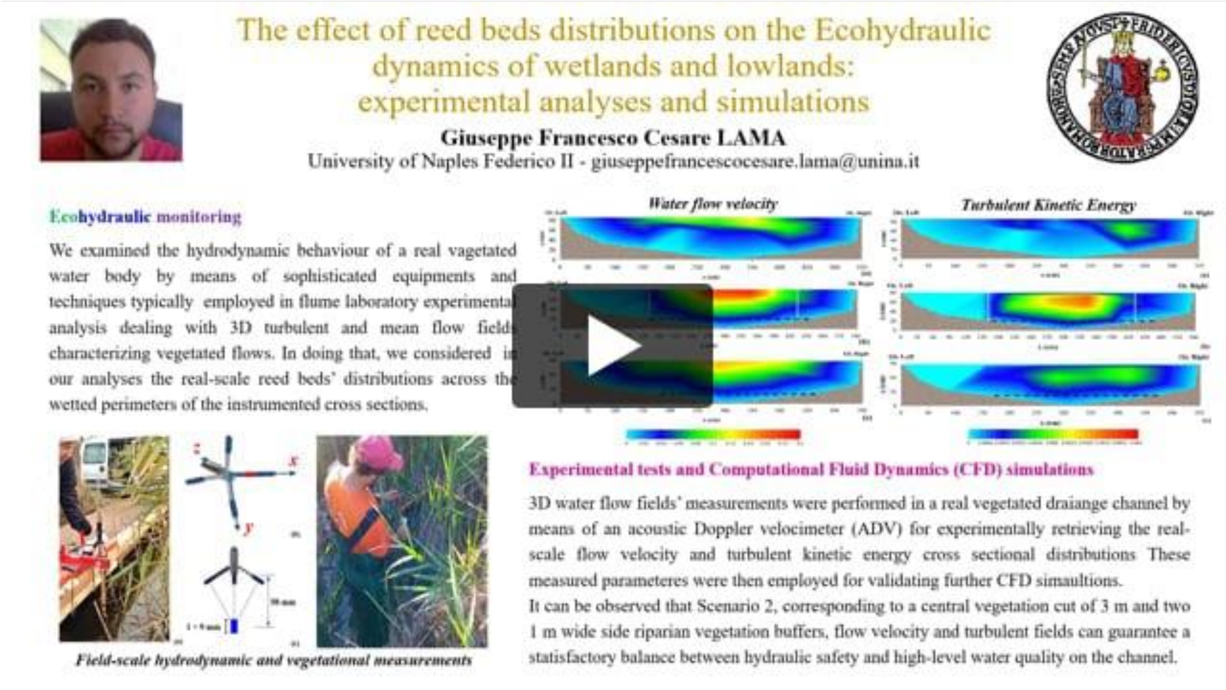
How to cite: Gallart, F., Cid, N., Llorens, P., Latron, J., Bonada, N., Soria, M., and Prat, N.: An operational method for the ecohydrological classification of temporary rivers and streams, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-4360, https://doi.org/10.5194/egusphere-egu21-4360, 2021.

The salt route through time and space: Following horizontal and lateral intrusion of brackish surface water into a natural floating root mat and its plant community

***Milou Huizinga**, Rien Aerts, Richard S.P. van Logtestijn, Sjoerd E.A.T.M. van der Zee, and Jan-Philip M. Witte*

The effect of reed beds distributions on the Ecohydraulic dynamics of wetlands and lowlands: experimental analyses and simulations

Giuseppe Francesco Cesare Lama



Insights into fish-anthropogenic pressures relationships using machine learning techniques: the case of Castilla-La Mancha (Spain)

***Carlotta Valerio**, Graciela Gómez Nicola, Rocío Aránzazu Baquero Noriega, Alberto Garrido, and Lucia De Stefano*

Influence of morphometric parameters and meteorological conditions on ephemeral pool hydrology in the Canadian Shield forest

***Marjolaine Roux**, Marie Larocque, Philippe Nolet, and Sylvain Gagné*

HS5.2.3 EDI

Water resources policy and management - systems solutions in an uncertain world

Convener: Jazmin Zatarain Salazar[ECS] | Co-conveners: Julien Harou, Jan Kwakkel, Manuel Pulido-Velazquez, Amaury Tilmant

Combining hydroeconomic modelling and bottom-up approaches for climate change adaptation. Application to the Jucar river basin (Spain)

***Manuel Pulido-Velazquez**, Patricia Marcos-Garcia, Antonio Lopez-Nicolas, Hector Macian-Sorribes, and Adria Rubio-Martin*

Co-evolutionary macro-economy and river system modeling framework

***Mohammed Basheer**, Victor Nechifor, Alvaro Calzadilla, and Julien Harou*

Using a socio-hydrology stance to address the paradox between global decarbonization, lithium fever, and sustainability in the Atacama Salt Deposit

***Marcos Canales**, Juan Castilla-Rho, Sebastian Vicuña, James Ball*

Bayesian Belief Networks for the metamodeling of simulation-optimization model to identify optimum water allocation scenario, Application in Miyandoab plain, Urmia Lake basin, Iran

***Amirhossein Dehghanipour**, Gerrit Schoups, Hossein Babazadeh, Majid Ehtiat, and Bagher Zahabiyoun*

Communicating water-related climate change hazards to local stakeholders

Laura Müller *and Petra Döll*

Revisiting the storage-reliability-yield concept in hydroelectricity

Andreas Efstratiadis*, Ioannis Tsoukalas, and Demetris Koutsoyiannis*

OpenHiGis: A national geographic database for inland waters of Greece based on the INSPIRE Directive Hydrology Theme

Ino Papageorgaki*, Antonis Koukouvinos, and Nikos Mamassis*

Testing the environmental flow allocation requirements in Colombia through the HeCCA 1.0 tool

Maria Camila Fernandez Berbeo*, Nicolas Cortes Torres, Karen Ortega Tenjo, Martin Perez Pedraza, Laura Laverde Mesa, Carlos Cubillos Peña, and Sergio Salazar Galan*

The influence of floating spheres on evaporation suppression under different climatic conditions

Maram M. Shalaby*, Ibrahim N. Nassar, and Ahmed M. Abdallah*

Evaluation of methods for calculating potential evapotranspiration in climate change scenarios

Maria-Carmen Vicente-Torres *and Miguel Angel Perez Martin*

Despite uncertainties involved by future scenarios, the acknowledgement of climate change problem (WMO 2019/1248 reinforces the past five years as the warmest in industrial records, part of the warmest decade on record 2010-2019, and the need for urgent mitigation and adaptation actions have only grown in recent years. In the European Territory (EEA 1/2017), a significant decrease in summer soil moisture content in the Mediterranean region, while increases in north-eastern countries are projected for the coming decades. The current temperature increase derived from the emission of gases to the atmosphere, in the range of 0.1-0.3 ºC per decade by the IPCC experts Special Report 2018, obliges a deep review of the agricultural productivity factors, according to the FAO-56 /2006.

Soil moisture content is thus approached as a dynamic variable, with changes in temperature as well as precipitation constantly affecting evapotranspiration and infiltration rates. In this paper, five computing methods for crop water evapotranspiration (Penman-Monteith proposed by FAO-56, Thornwaite, and three temperature-based methods: Hargreaves 1975, Hargreaves-Samani 1985, Samani 2000) are not only scientifically compared but also applied to a Spanish Study Case at Valencian Community in the Mediterranean Basin. Results are affected by local single crops coefficient (also proposed by FAO-56) for citrus trees in upper Palancia River catchment, representative of intensive agriculture in the area, and calculated under four future scenarios (from +1ºC to 4ºC of unitary temperature increase).

Analyzed results by percentual comparison with Penman-Monteith estimation, demonstrate a similar application range (from -1% of variation in +1ºC scenario to -4% of variation in 4ºC scenario) for scarcer data-based methods (Hargreaves 1975, Hargreaves-Samani 1985 and Samani 2000) except Thornthwaite. Allowing to conclude that Thornthwaite projections in the Mediterranean Climate overestimate up to 3% (+1ºC scenario), 6% (+2ºC scenario), 11% (+3ºC scenario) and 16% (+4ºC scenario) the monthly values of crop evapotranspiration.

How to cite: Vicente-Torres, M.-C. and Perez Martin, M. A.: Evaluation of methods for calculating potential evapotranspiration in climate change scenarios, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-1785, https://doi.org/10.5194/egusphere-egu21-1785, 2021.

Transboundary subparts of groundwater bodies (GWB) and transboundary monitoring network of the Republic of Belarus and the Ukraine – developed under the European Water Initiative Plus for Eastern Partnership Countries (EUWI+)

Nataliia Lyuta*, Iryna Sanina, Olga Biarozka, Olga Vasniova, Andreas Scheidleder, and Franko Humer*

A policy tree optimization approach to dynamic adaptation under climate uncertainty

Jonathan Herman *and Jonathan Cohen*

Disentangling uncertainties in risk-based planning of water resources in the UK

Francesca Pianosi*, Andres Penuela-Fernandez, and Christopher Hutton*

Proper consideration of uncertainty has become a cornerstone of model-informed planning of water resource systems. In the UK Government's 2020 Water Resources Planning Guidelines, the word "uncertainty" appears 48 times in 82 pages. This emphasis on uncertainty aligns with the increasing adoption by UK water companies of a "risk-based" approach to their long-term decision-making, in order to handle uncertainties in supply-demand estimation, climate change, population growth, etc. The term "risk-based" covers a range of methods - such as "info-gap", "robust decision-making" or "system sensitivity analysis" - that come under different names but largely share a common rationale, essentially based on the use of Monte Carlo simulation. This shift in thinking from previous (deterministic) "worst-case" approach to a "risk-based" one is important and has the potential to significantly improve water resources planning practice. However its implementation is diminished by a certain lack of clarity about the terminology in use and about the concrete differences (and similarities) among methods. On top of these difficulties, in the next planning-cycle (2021-2026) two further step changes are introduced: (1) water companies are requested to move from a cost-efficiency approach focused on achieving the supply-demand balance, towards a fully multi-criteria approach that more explicitly encompasses other objectives including environmental sustainability; (2) as a further way to handle long-term uncertainties, they are required to embrace an "adaptive planning" approach. These changes will introduce two new sets of uncertainties around the robust quantification of criteria, particularly environmental ones, and around the attribution of weights to different criteria. This urgently calls for establishing structured approaches to quantify not only the uncertainty in model outputs, but also the sensitivity of those outputs to different forms of uncertainty in the modelling chain that mostly control the variability of the final outcome – the "best value" plan. Without this understanding of critical uncertainties, the risk is that huge efforts are invested on characterizing and/or reducing uncertainties that later turn out to have little impact on the final outcome; or that water managers fall back to using oversimplified representation of those uncertainties as a way to escape the huge modelling burden. In this work, we aim at starting to establish a common rationale to "risk-based" methods within the context of a fully multi-criteria approach. We use a proof-of-concept example of a reservoir system in the South-West of England to demonstrate the use of global (i.e. Monte Carlo based) sensitivity analysis to simultaneously quantify output uncertainty and sensitivity, and identify robust decisions. We also discuss the potential of this approach to inform the construction of a "decision tree" for adaptive planning.

How to cite: Pianosi, F., Penuela-Fernandez, A., and Hutton, C.: Disentangling uncertainties in risk-based planning of water resources in the UK, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-10225, https://doi.org/10.5194/egusphere-egu21-10225, 2021.

Equitable adaptation planning under deep uncertainty for the upper Vietnam Mekong Delta
Bramka Arga Jafino *and Jan Kwakkel*

Robust technology and policy pathways to urban water security
Marta Zaniolo*, Sarah Fletcher, and Meagan Mauterl*

Many-objective risk assessment framework for guiding operational decisions on multiple reservoirs
Quan Dau*, David Dorchies, and Jean-Claude Bader*

Water Decision Support System for Urban Water Security under Uncertain Future: A Case Study of Upper Yamuna River Basin, India
Dinesh Kumar*, Chandrika Thulaseedharan Dhanya, and Ashvani Gosain*

Wednesday, 28th April

HS9.5
Ecohydraulic processes in rivers, lakes and reservoirs: restoration and mitigation approaches
Co-organized by BG4/GM3
Convener: Stefan Haun | Co-conveners: Roser Casas-Mulet, Markus Noack, Lennart Schönfelder[ECS]

Chairpersons: Roser Casas-Mulet, Markus Noack, Lennart Schönfelder

Effects of riparian woody vegetation on EPT functional connectivity in Western Germany
Andrés Peredo Arce*, Martin Palt, Martin Schletterer, and Jochem Kail*

The effects of large wood (LW) on water and sediment connectivity in river systems: a new LW dis-connectivity index and its application in sediment management contexts
Ronald E. Pöppl*, Hannah Fergg, Maria T. Wurster, Anne Schuchardt, and David Morche*

It is well known that in-stream large wood (LW) can have significant effects on channel hydraulics and thus water and sediment connectivity, i.e. by creating hydraulic resistance that decreases flow velocity and transport capacity. The relationship between an in-stream LW structure and its hydraulic function (incl. the related effects on water and sediment connectivity) is generally quantified through drag force. Drag analyses, however, are data-demanding and often not straightforward - especially in complex debris jam settings where LW accumulations consist of wood pieces of widely variable sizes. Here, we introduce a simple LW dis-connectivity index (calculated based on visually estimated, field-derived LW parameters such as the degree of channel blockage), which has been applied in different sediment management contexts in medium-sized mixed-load streams in Austria.

How to cite: Pöppl, R. E., Fergg, H., Wurster, M. T., Schuchardt, A., and Morche, D.: The effects of large wood (LW) on water and sediment connectivity in river systems: a new LW dis-connectivity index and its application in sediment management contexts, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14342, https://doi.org/10.5194/egusphere-egu21-14342, 2021.

Influences of channel morphology and large wood on bed sediment grain size characteristics along a headwater stream, southern Brazil

***Karla Campagnolo**, Danrlei de Menezes, and Masato Kobiyama*

Drag coefficients of large instream wood – mystery or science?

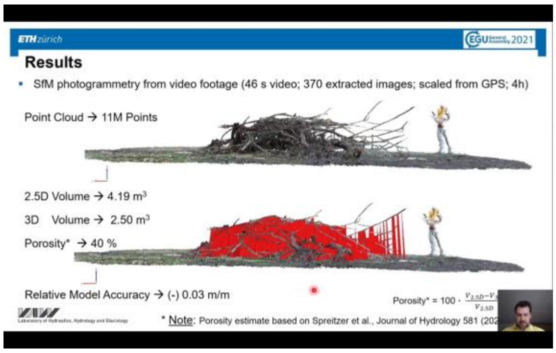
Ingo Schnauder

Impact of morpho- and vegetation-dynamics on flood, erosion and ecology in large lowland rivers

***Kshitiz Gautam**, Sanjay Giri, Biswa Bhattacharya, and Gennadii Donchyts*

Video footage from drones for Structure-from-Motion photogrammetry – A practical and rapid assessment method for large wood accumulations in rivers?

***Gabriel Spreitzer**, Isabella Schalko, Robert M. Boes, and Volker Weitbrecht*



UAV monitoring of urban stream restoration sustainability

Jakub Langhammer

Towards a better understanding of river dynamics in semi-urbanized areas: a machine learning analysis on time-series satellite images

***Alessio Cislaghi**, Paolo Fogliata, Emanuele Morlotti, and Gian Battista Bischetti*

Seasonal variation in water and sediment fluxes of the Yangtze River under precipitation change and human interference

***Yao Yue**, Yuanfang Chai, Shitian Xu, and Xiaofeng Zhang*

Achieving Flood Reduction with Natural Water Retention Measures in Agricultural Catchments in Ireland

***Pia Laue**, Paul Quinn, Mary Bourke, Darragh Murphy, Mark Wilkinson, Simon Harrison, and John Weatherill*

A cost-efficient riverscape methodology for GIS characterization and planning of river restoration in Scandinavia

***Jo Halvard Halleraker**, Janos Steiner, Ulrich Pulg, Johan Kling, and Knut Alfredsen*

A novel multi-parameter approach to assess the effects of river restoration measures on the sediment matrix

***Alcides Aybar Galdos**, Stefan Haun, Sebastian Schwindt, Ruslan Biserov, Beatriz Negreiros, Maximilian Kunz, and Noack Markus*

The HydroEcoSedimentary Tool: an integrated approach to characterize interstitial processes in freshwater systems

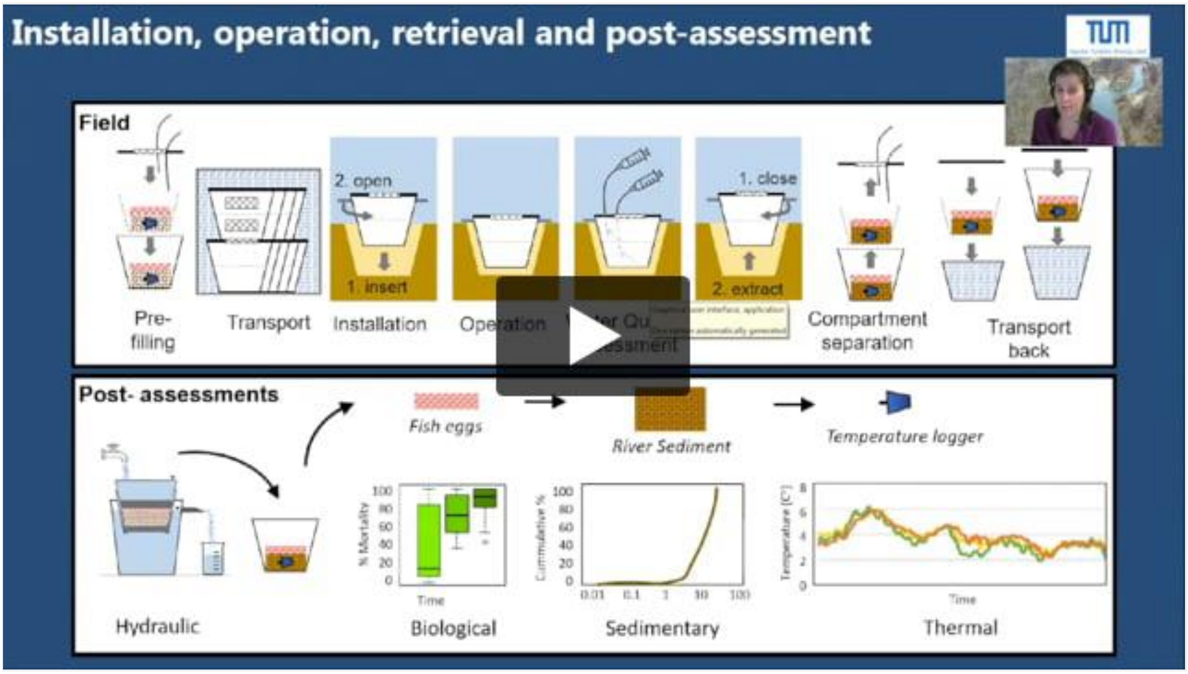
***Roser Casas-Mulet**, Joachim Pander, Maximilian Prietzel, and Juergen Geist*

Increased deposition of fine sediments in streams affects a range of key ecosystem processes across the sediment-water interface, and it is a critical aspect of river habitat degradation and restoration. Understanding the mechanisms leading to fine sediment accumulation along and across streambeds, and their affectation to ecological processes is therefore essential for comprehending human impacts on river ecosystems and inform river restoration. Here, we introduce the HydroEcoSedimentary Tool (HEST) as an integrated approach to assess hydro-sedimentary and ecologically relevant processes together. The HEST integrates the estimation of a range of processes occurring in the interstitial zone, including sedimentary (fine sediment accumulation and fine sediment loss upon retrieval), hydraulic (hydraulic conductivity), geochemical (water quality and temperature) and ecological (with a focus on brown trout early life stages).

We tested the HEST application in two rivers with different degrees of morphological degradation in Germany. The HEST was successful in recording the set of key hydro-sedimentary and ecologically relevant factors, and in providing a mechanistic linkage between and biological effect in a site-specific context. The HEST data confirmed that salmonid embryo mortality could be linked to high fine deposition in gravel beds. In addition, the HEST illustrated that such mortality could be linked explicitly to interstitial depths and to different infiltration pathways for fines (e.g. vertical vs. horizontal). Although interstitial water quality and temperature were within ecological thresholds and did not show significant differences with surface water, it was still useful to monitor such variables and to rule out any effect on mortality. Water temperature, for example, could be extremely important to detect local groundwater inputs, which has been demonstrated to have a significant effect on embryo salmonids elsewhere. The HEST also allowed accounting for the loss of fines during retrieval failure and estimating hydrological factors with the HEST illustrates its additional usefulness and reliability.

Compared to other methods, the HEST expands the possibilities to monitor and quantify fine sediment deposition in streambeds by differentiating between vertical, lateral and longitudinal infiltration pathways, and distinguishing between the depth (upper vs. lower layers) at which interstitial processes occur along the streambed column.

How to cite: Casas-Mulet, R., Pander, J., Prietzel, M., and Geist, J.: The HydroEcoSedimentary Tool: an integrated approach to characterize interstitial processes in freshwater systems, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-345, https://doi.org/10.5194/egusphere-egu21-345, 2021.



Knowledge sharing on fish-friendly hydropower: the FIThydro wiki

***Bendik Hansen** and Lennart Schönfelder*

Locomotion of juvenile silver carp (Hypophthalmichthys molitrix) near the separation zone at the channel confluence

***Lei Xu**, Saiyu Yuan, Yuchen Zheng, and Yihong Chen*

Analysis of fishways in the Middle and Lower Jinsha River Basin (China)

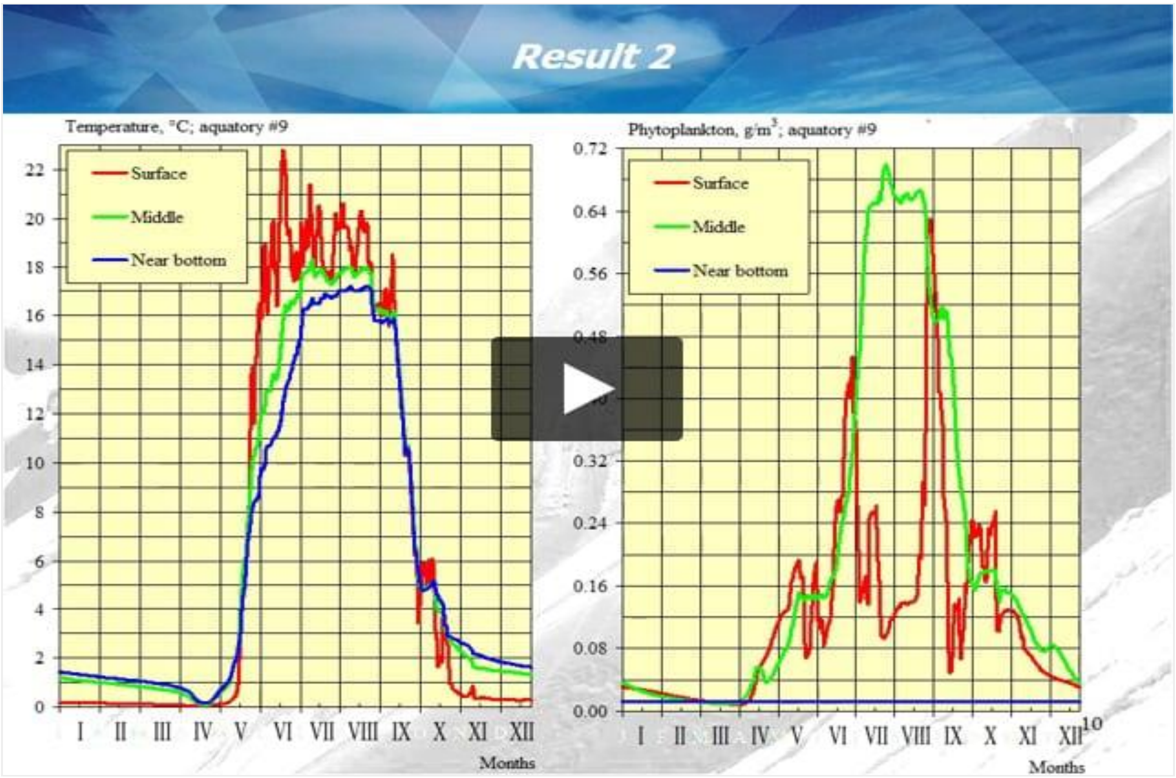
***Siqi Tong**, Silke Wieprecht, and Martin Schletterer*

Ecological effects of flow disturbance on phytobenthos communities in natural and regulated alpine streams

***Luca Bonacina**, Riccardo Fornaroli, Valeria Mezzanotte, and Francesca Marazzi*

Hydrological paradoxes of phytoplankton distribution in the Novosibirsk reservoir

***Aleksandr Tskhai,** Vladislav Ageikov, and Aleksandr Semchukov*

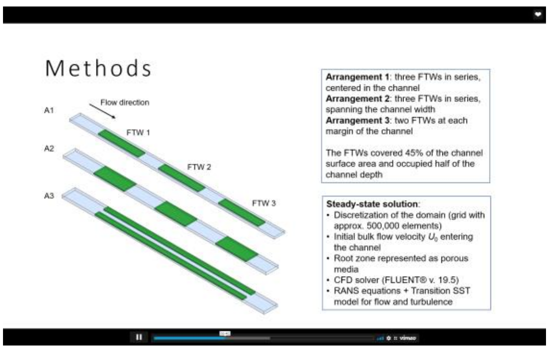


Long term research and monitoring along the brown-water river Tudovka (Tver Region, Russia)

***Rick Lotzkes**, Vyacheslav V. Kuzovlev, Yuri N. Zhenikov, Kyrill Y. Zhenikov, Silke Wieprecht, and Martin Schletterer*

Effects of three floating treatment wetland arrangements on the flow field of a channel

***Taís Yamasaki** and Johannes Janzen*



HS5.1.2
Advances in sociohydrology
Convener: Giuliano Di Baldassarre | Co-conveners: Mohammad Ghoreishi[ECS], Britta Höllermann[ECS], Melanie Rohse, Murugesu Sivapalan

Chairpersons: Giuliano Di Baldassarre, Britta Höllermann, Melanie Rohse

Modeling

Integrating institutions into a socio-hydrological model: an example for water quality management in Burkina Faso
Gemma Carr*, Marlies Barendrecht, Liza Debevec, and Bedru Balana*

Model Informed Data Collection in Coupled Human-Water Systems: An Exploratory Application of a Hydrological and Agent-Based Model
Behshad Mohajer*, David Yu, Marco Janssen, and Margaret Garcia*

Augmenting a Sociohydrological Flood Risk Model for Companies with Process-oriented Loss Estimation
Lukas Schoppa*, Marlies Barendrecht, Tobias Sieg, Nivedita Sairam, and Heidi Kreibich*

Representing ancient southern Mesopotamia irrigated landscapes in an agent-based model
Dengxiao Lang *and Maurits W. Ertsen*

Dynamic Coupling of SWAT+ with System Dynamics Models using Tinamït and a Socket Based Protocol
Joel Z. Harms*, Julien J. Malard, and Jan F. Adamowski*

Application of the theory of planned behavior with agent-based modeling for sustainable management of vegetative filter strips
Prajna Kasargodu Anebagilu*, Jörg Dietrich, Lisette Prado Stuardo, Bruno Morales, Etti Winter, and Jose Luis Arumi*

Hierarchical Bayesian inference and spatial validation of socio-ecological system dynamics models: participatory modelling for Indigenous smallholder agriculture and food security in Guatemala
Julien Malard*, Jan Adamowski, Héctor Tuy, and Hugo Melgar-Quiñonez*

Development of scenarios for future emissions of chemicals from agricultural, industrial and urban systems
Poornima Nagesh*, Hugo J. de boer, Stefan C. Dekker, and Detlef P. van Vuuren*

A Budyko-like framework for exploring the controls of long-term flood risk in coupled human-flood systems
Marlies H Barendrecht*, Alberto Viglione, Heidi Kreibich, and Günter Blöschl*

Case studies

Increased Socio-economic Vulnerability in the Floodplains of Brahmaputra Basin, India
Sukrati Gautam*, Apoorva Singh, and Chandrika Thulaseedharan Dhanya*

A multiple streams analysis of drought policies in Ceará state, Brazil
Louise Cavalcante*, Germano Ribeiro Neto, Art Dewulf, Pieter van Oel, and Francisco Souza Filho*

A meta-analysis of the drivers of irrigation in the West African Sudan Savanna
Silvia Schrötter*, Jed Kaplan, Matthias Schmidt, and Peter Fiener*

Longitudinal Survey Data Call For Diversifying Temporal Dynamics In Modelling Human-Water Systems
lena Mondino*, Anna Scolobig, Marco Borga, and Giuliano Di Baldassarre*

Payment for Ecosystem Services policies in Peru: assessing the social and ecological dimensions of water services in the upper Santa River basin

***Rosa María Dextre**, María Luisa Eschenhagen, Mirtha Camacho, Sally Rangecroft, Laurence Couldrick, Caroline Clason, and Sergio Morera*

The interaction between society changes and hydrological extremes: the case of Yangtze River Basin, before and after the 1931 flood

***Chang Liu**, Akiyuki Kawasaki, and Tomoko Shiroyama*

Assessing Water Security in Central Asia through a Delphi Approach

***Aliya Assubayeva**, Stefanos Xenarios, Albina Li, and Siamac Fazli*

Perspectives

Socio-Hydrogeology: uncovering the hidden connections within the Human-Groundwater Cycle

***Viviana Re**, Paul Hynds, Theresa Frommen, and Shrikant Limaye*

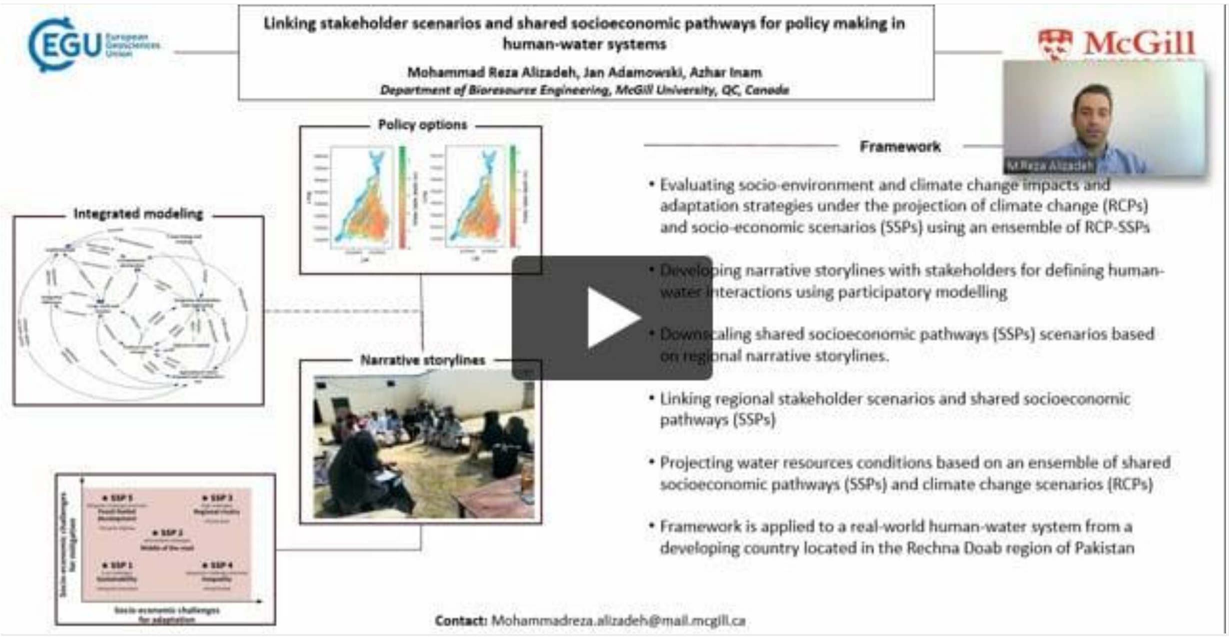
Socio-hydrogeology has been recently proposed as a new approach in the field of human-water research, focusing on the assessment of the reciprocity between people and groundwater. Notwithstanding some obvious similarities with socio-hydrology, there are notable, and indeed important differences; while socio-hydrology aims to investigate and understand the dynamic interactions and feedbacks between (surface)water and people, due to the more private and local nature of groundwater in many instances, socio-hydrogeology seeks to understand individuals and communities as a primary source, pathway and receptor for potable groundwater supplies, including the role of (local) knowledge, beliefs, risk perception, tradition/history, and consumption. In essence, the "socio" in socio-hydrology might be said to represent society, while its counterpart within socio-hydrogeology embodies sociology, including social, cognitive, behavioral and socio-epidemiological science. Moreover, while socio-hydrology tends towards examination of human-water interactions at relatively larges scales via coupled modelling, socio-hydrogeology is often focused at a significantly smaller scale (e.g. individual household or community supplies), and as such, employs a wide range of mixed methods, including modelling, albeit to a lesser degree. Being at its early development stage, the discipline is still being defined and formalized. Nevertheless, several researchers are currently implementing this approach worldwide.

By presenting a comparative analysis of the approaches and outcomes from several socio-hydrogeological studies undertaken across a range of socio-demographic and climatic regions including Canada, Italy, India, Ireland, Myanmar and Tunisia, this presentation will highlight the benefits and shortcomings of going beyond classical hydrogeological and hydrogeochemical investigations targeted to assess the impact of human activities on groundwater quality and quantity, and indeed, the effects of these impacts on associated individuals and communities (i.e. humans frequently represent the issue, the receptor and the solution). By shedding light on the added value of understanding the cause-effect relations between people and the hidden component of the water cycle (e.g. to jointly assess how scarce and polluted groundwater affect human/social wellbeing), socio-hydrogeology can provide evidence-based solutions to regionally bespoke problems. Similarly, otherwise neglected local or regional information can add value to scientific outcomes and contribute to foster new groundwater management actions tailored on the needs of local populations as well as on the overall achievement of long-term sustainability. Socio-hydrogeology can therefore provide new insights useful for socio-hydrological modelling, and, together, they can effectively underpin successful Integrated Water Resources Management plans at local and regional scale. Perhaps most importantly, it is hoped that by initiating discussion between practitioners of both sub-disciplines, experiences, expertise and perspectives can be shared and employed (e.g. more “technical” modelling within socio-hydrogeology, increased integration of “non-expert” knowledge within socio-hydrology) in order to bolster both areas of study, with an overarching objective of protecting the entire hydrological cycle, and the people supplied and impacted by it.

How to cite: Re, V., Hynds, P., Frommen, T., and Limaye, S.: Socio-Hydrogeology: uncovering the hidden connections within the Human-Groundwater Cycle, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-493, https://doi.org/10.5194/egusphere-egu21-493, 2021.

Linking stakeholder scenarios and shared socioeconomic pathways for policy making in human-water systems

***Mohammadreza Alizadeh**, Jan Adamowski, and Azhar Inam*



Losing faith

***Richard Grünwald**, Wenling Wang, and Yan Feng*

Potential of sociohydrology for studying natural disasters

***Franciele Maria Vanelli** and Masato Kobiyama*

HS8.3.2

Vadose zone processes: advances and future perspectives in soil hydrology

Co-organized by BG3/SSS6

Convener: Roland Baatz[ECS] | Co-conveners: Stefano Ferraris, Teamrat Ghezzehei, Martine van der Ploeg, Harry Vereecken

euptfv2: updated hydraulic pedotransfer functions for Europe

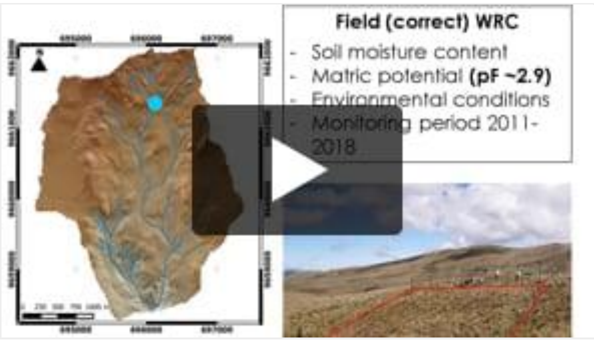
***Brigitta Szabó**, Melanie Weynants, and Tobias Weber*

Wet-range physical realism in a model of soil water retention

John R. Nimmo

How well do standard laboratory methods represent the field water retention curve of volcanic ash soils (Andosols)?

***Giovanny Mosquera**, Franklin Marín, Jan Feyen, Rolando Célleri, Lutz Breur, David Windhorst, and Patricio Crespo*



A simple model to predict hydraulic conductivity in medium to dry soil from the water retention curve

***Andre Peters**, Tobias L. Hohenbrink, Sascha C. Iden, and Wolfgang Durner*

Extending established soil hydraulic property models by non-capillary water: A comprehensive model performance test

***Tobias L. Hohenbrink**, Andre Peters, Sascha C. Iden, and Wolfgang Durner*

Functional role of earthworms to control the hydraulic conductivity of constructed wetlands

***Océane Gilibert**, Dan Tam Costa, Sabine Sauvage, Didier Orange, Yvan Capowiez, Frédéric Julien, and Magali Gerino*

Water content and metal pollution dynamics in the surface layer of urban soils: first results of the PROFILES project

***Martina Siena** and Marco Peli*

On the identifiability of soil hydraulic parameters in lysimeter experiments: a Bayesian perspective

***Marleen Schübl**, Giuseppe Brunetti, and Christine Stumpp*

A modelling framework to predict transpiration reductions during drought based on soil hydraulics

***Andrea Carminati** and Mathieu Javaux*

Coupled water, vapor and heat flow in evaporation experiments under different boundary conditions

***Sascha Iden**, Johanna Blöcher, Efstathios Diamantopoulos, and Wolfgang Durner*

Actual evaporation from bare soils - A comparison of numerical modelling and field lysimeter data

***Deep Chandra Joshi**, Andre Peters, Sascha C. Iden, Beate Zimmermann, and Wolfgang Durner*

A physically-based soil surface model and its combination with numerical models for predicting bare-soil evaporation rates

***Xiaocheng Liu**, Chenming Zhang, Yue Liu, David Lockington, and Ling Li*

Grassland dynamics of soil moisture and temperature

***Stefano Ferraris**, Mesmer N'Sassila, Alessio Gentile, Marta Galvagno, Herve Stevenin, Davide Canone, Maurizio Previati, Ivan Bevilacqua, Davide Gisolo, and Kevin Painter*

Improving the representation of cropland sites in the Community Land Model (CLM) version 5.0

***Theresa Boas**, Heye Bogena, Thomas Grünwald, Bernard Heinesch, Dongryeol Ryu, Marius Schmidt, Harry Vereecken, Andrew Western, and Harrie-Jan Hendricks-Franssen*

How soil hydrology reacts during strong precipitation events?

***Antoine Sobaga**, Florence Habets, Bertrand Decharme, and Noële Enjelvin*

Modeling groundwater table and runoff in self-organizing hydrologically sensitive areas

***Naaran Brindt**, Steven Pacenka, Brian K. Richards, and Tammo S. Steenhuis*

A hysteretic model for rainfall-runoff of a simplified catchment
Denis Flynn *and Warren Roche*

Thursday, 29th April

HS2.1.7
Snow and ice accumulation, melt, and runoff generation in catchment hydrology: monitoring and modelling
Co-organized by CR7
Convener: Guillaume Thirel | Co-conveners: Francesco Avanzi ECS, Doris Duethmann ECS, Abror Gafurov, Juraj Parajka

HS2.5.1
Large scale hydrology
Convener: Inge de Graaf ECS | Co-conveners: David Hannah, Oldrich Rakovec ECS, Shannon Sterling, Ruud van der Ent

HS4.4
Operational forecasting and warning systems for natural hazards: challenges and innovations
Co-organized by NH9
Convener: Céline Cattoën-Gilbert | Co-conveners: Michael Cranston, Femke Davids, Ilias Pechlivanidis

HS8.1.8
Emerging particles and biocolloids in terrestrial and aquatic systems
Convener: Constantinos Chrysikopoulos | Co-conveners: Thomas Baumann, Markus Flury, Meiping Tong, Christophe Darnault

HS8.3.3
Soil-Plant Interaction
Co-organized by SSS9
Convener: Mohsen Zarebanadkouki | Co-conveners: Martin Bouda ECS, Valentin Couvreur ECS, John Koestel, Naftali Lazarovitch

HS10.8
Peatland hydrology
Co-organized by BG3
Convener: Michel Bechtold | Co-conveners: Ullrich Dettmann ECS, Joseph Holden, Björn Klöve, Marie Larocque

NP4.2
Analysis of complex geoscientific time series: linear, nonlinear, and computer science perspectives
Co-organized by BG2/CL5.2/ESSI1/GI2/HS3/SM3/ST2
Convener: Reik Donner | Co-conveners: Tommaso Alberti ECS, Giorgia Di Capua ECS, Federica Gugole ECS, Andrea Toreti

NH6.4
Using satellite soil moisture and rainfall data for the monitoring and the prediction of natural hazards
Co-organized by GM3/HS6
Convener: Massimiliano Bordoni ECS | Co-conveners: Luca Ciabatta ECS, Anne Felsberg ECS, Gabriella Petaccia, Lu Zhuo ECS

The challenges of irrigation in the COVID19 scenario
Co-organized by HS13/NH8
Convener: Leonor Rodriguez-Sinobas | Co-conveners: Daniele Masseroni ECS, María Fátima Moreno Pérez, Giuseppe Provenzano, Alejandro Pérez-Pastor

SC4.14
An interdisciplinary approach to Forecasting and Early Warning Systems
Co-organized by CR8/HS11/NH11

Convener: Adele Young[ECS] | Co-conveners: Erika Meléndez-Landaverde[ECS], Nikolaos Mastrantonas[ECS], Santiago Gómez-Dueñas[ECS], Linda Speight

HS4.5
Reducing the impacts of natural hazards through forecast-based action: from early warning to early action
Convener: Marc van den Homberg | Co-conveners: Andrea Ficchi, Gabriela Guimarães Nobre, David MacLeod, Annegien Tijssen

HS6.1
Remotely-sensed evapotranspiration
Co-organized by BG3/GI4
Convener: Hamideh Nouri | Co-convener: Pamela Nagler

NP3.3
Scaling, Multifractals from Urban to Climate scales, from Theories to Big Data Analysis and Simulations
Co-organized by AS5/HS13
Convener: Ioulia Tchiguirinskaia | Co-conveners: Igor Paz, Arun Ramanathan[ECS]

GM4.16
(Dis)connectivity in hydro-geomorphic systems: emerging concepts and their applications
Co-organized by HS13, co-sponsored by IAG
Convener: Ronald Pöppl[ECS] | Co-conveners: Lina Polvi Sjöberg[ECS], Laura Turnbull-Lloyd, Anthony Parsons

HS2.1.3
Zero flow: hydrology and biogeochemistry of intermittent and ephemeral streams
Co-organized by BG4
Convener: E. Sauquet | Co-conveners: Anna Maria De Girolamo, Catherine Sefton

HS6.5
Remote sensing for flood dynamics monitoring and flood mapping
Co-organized by NH6
Convener: Guy J.-P. Schumann | Co-conveners: Alessio Domeneghetti, Nick Everard, Ben Jarihani, Angelica Tarpanelli

HS7.4
Hydroclimatic change and unchange: exploring the mysteries of variability, nature and human impact
Co-sponsored by IAHS and WMO
Convener: Serena Ceola[ECS] | Co-conveners: Christophe Cudennec, Theano Iliopoulou[ECS], Harry Lins, Alberto Montanari

HS8.1.9
Thermal energy applications and associated processes in porous and fractured aquifers
Co-organized by ERE6
Convener: Martin Bloemendal[ECS] | Co-conveners: Peter Bayer, Olivier Bour, Kathrin Menberg

HS10.4
Estimates of evapotranspiration from in-situ measurements: bridging scales and addressing uncertainties
Co-organized by AS2/BG3
Convener: Sibylle K. Hassler | Co-conveners: Harrie-Jan Hendricks Franssen, Corinna Rebmann

HS10.4
Estimates of evapotranspiration from in-situ measurements: bridging scales and addressing uncertainties
Co-organized by AS2/BG3
Convener: Sibylle K. Hassler | Co-conveners: Harrie-Jan Hendricks Franssen, Corinna Rebmann

ITS4.3/NH1
Data Science and Machine Learning for Geohazard
Co-organized by GM2/HS12/SM1
Convener: Hui Tang[ECS] | Co-conveners: Jonathan Bedford[ECS], Fabio Corbi, Michaela Wenner[ECS]

OS4.1
Tides in the past, present and future
Co-organized by G3/HS13/NH5
Convener: Sophie-Berenice Wilmes[ECS] | Co-conveners: Michael Schindelegger[ECS], Stefan Talke, Joanne Williams

HS2.1.2
Advances in African hydrology and climate: modelling, water management, environmental and food security
Convener: Fiachra O'Loughlin | Co-conveners: Peter Burek, Feyera Hirpa

HS3.5
Clustering in hydrology: methods, applications and challenges
Co-organized by ESSI1/NP4
Convener: Nilay Dogulu | Co-conveners: Svenja Fischer[ECS], Wouter Knoben[ECS]

HS5.2.1
Improving hydroclimatic services for water sectors: from forecasts to management and policy
Convener: Matteo Giuliani[ECS] | Co-conveners: Louise Arnal[ECS], Tim aus der Beek, Louise Crochemore[ECS], Stefano Galelli, Charles Rougé[ECS], Andrew Schepen[ECS], Christopher White

HS6.3
Remote sensing of seasonal snow
Co-organized by CR2
Convener: Rafael Pimentel[ECS] | Co-conveners: Claudia Notarnicola, Alexander Kokhanovsky

HS7.7
Hydrometeorologic stochastics for hydrologic applications: extremes, scales, probabilities
Co-organized by NH1, co-sponsored by IAHS-ICSH
Convener: Hannes Müller-Thomy[ECS] | Co-conveners: Marco Borga, Auguste Gires, Jose Luis Salinas Illarena[ECS], Alberto Viglione

HS8.3.1
Subsurface structures and complex dynamics in heterogeneous soils, fractured-porous media, and at rock–soil interfaces: from laboratory experiments and field recognition to numerical representation
Convener: Jannes Kordilla[ECS] | Co-conveners: Edoardo Martini[ECS], Hannes H. Bauser[ECS], Anna Botto[ECS], Marco Dentz, John R. Nimmo, Noam Weisbrod

NH9.1
Natural hazards and vulnerable societies – perspectives on natural hazard risk methods, data, interactions, and practice from global to local scales
Co-organized by GM12/HS2.5
Convener: Philip Ward | Co-conveners: Johanna Mård[ECS], Korbinian Breinl[ECS], James Daniell[ECS], John K. Hillier[ECS], Giuliano Di Baldassarre, Hessel Winsemius, Michael Hagenlocher[ECS]

ITS2.7/ESSI2
Detecting and Monitoring Plastic Pollution in Rivers, Lakes, and Oceans
Co-organized by EOS7/GI4/HS12/OS4
Convener: Lauren Biermann[ECS] | Co-conveners: Katerina Kikaki[ECS], Cecilia Martin[ECS], Irene Ruiz[ECS], Tim van Emmerik[ECS]

HS2.1.5
Advances in forest hydrology
Convener: Alicia Correa[ECS] | Co-conveners: Christian Birkel, Luisa Hopp, Rodolfo Nóbrega[ECS], Daniele Penna

HS6.6
Application of remotely sensed water cycle components in hydrological modelling
Convener: Zheng Duan | Co-conveners: Hongkai Gao, Shanhu Jiang, Junzhi Liu, Jian Peng

HS7.8

Spatial extremes in the hydro- and atmosphere: understanding and modelling

Co-organized by AS4/NH1

Convener: Manuela Irene Brunner[ECS] | Co-conveners: András Bárdossy, Philippe Naveau, Simon Michael Papalexiou[ECS], Elena Volpi

HS8.2.8

Field and modelling approaches to assess natural processes and engineering problems in the complex karst environment

Convener: Hervé Jourde | Co-conveners: Joanna Doummar, Mario Parise, Natasa Ravbar, Xiaoguang Wang[ECS], Georg Kaufmann

HS10.3

General organizing principles and optimality in ecohydrological systems

Co-organized by BG1

Convener: Stan Schymanski | Co-conveners: Oskar Franklin, Remko C. Nijzink[ECS], Iain Colin Prentice, Han Wang[ECS]

AS4.5

Clouds, moisture, and precipitation in the Polar Regions: Sources, processes and impacts

Co-organized by CR7/HS13

Convener: Irina V. Gorodetskaya | Co-conveners: Susanne Crewell, Tom Lachlan-Cope, Penny Rowe, Manfred Wendisch

HS1.2.7

Bridging physical, analytical and information-theoretic approaches to system dynamics and predictability in Hydrology and Earth System Sciences

Co-organized by NP5

Convener: Rui A. P. Perdigão | Co-conveners: Julia Hall[ECS], Cristina Prieto[ECS], Maria Kireeva[ECS], Shaun Harrigan[ECS], Grey Nearing, Benjamin L. Ruddell, Steven Weijs

HS2.3.4

Plastic in freshwater environments

Convener: Daniel González-Fernández | Co-conveners: Freija Mendrik[ECS], Merel Kooi[ECS], Marcel Liedermann, Tim van Emmerik[ECS]

HS2.4.6

Flash drought: definition, dynamics, detection, and prediction

Convener: Mike Hobbins | Co-conveners: Celine Bonfils, Andrew Hoell, David Hoffmann[ECS], Matthew Wheeler

HS3.4

Deep learning in hydrological science

Co-organized by ESSI1/NP4

Convener: Frederik Kratzert[ECS] | Co-conveners: Claire Brenner[ECS], Pierre Gentine, Daniel Klotz[ECS], Grey Nearing

HS5.3.3

Innovation in hydropower operations and planning to integrate renewable energy sources and optimize the Water-Energy Nexus

Convener: Benoit Hingray | Co-conveners: David C. Finger, Baptiste François, Elena Pummer, Nathalie Voisin

GM4.13

Denudation, land cover dynamics and sedimentary source-to-sink fluxes under changing climate and anthropogenic impacts

Co-organized by HS13, co-sponsored by IAG

Convener: Achim A. Beylich | Co-conveners: Alessio Cislaghi[ECS], Katja Laute, Ana Navas, Olimpiu Pop, Elmar Schmaltz[ECS], Stefan Steger[ECS], Zbigniew Zwoliński

PGM3

Subdivision meeting HS10 Ecohydrology, wetlands and estuaries

Convener: Anke Hildebrandt

HS10.8
Peatland hydrology
Co-organized by BG3
Convener: Michel Bechtold | Co-conveners: Ullrich Dettmann[ECS], Joseph Holden, Björn Klöve, Marie Larocque

Hydrological modeling and hydraulic characterization

General considerations for modeling water table dynamics in peatlands
Alex Cobb *and Charles Harvey*

The quantification of water storage capacity of peatlands across different hydroclimatic settings using a simple rainfall event to water-table response ratio method
Marc-André Bourgault*, Michel Bechtold, Joseph Holden, Antony Blundell, Ullrich Dettman, Michelle Garneau, Tim Howson, Sylvain Jutras, Bjørn Kløve, Marie Larocque, Hannu Marttila, Kathryn McKendrick-Smith, Meseret Memburu, Anna-Kaisa Ronkanen, Nigel Roulet, and Bärbel Tiemeyer*

Long-term rewetting of fen peatlands alters the response of water tables to rainfall and temperature
Sate Ahmad*, Haojie Liu, Shajratul Alam, Anke Günther, Gerald Jurasinski, and Bernd Lennartz*

Characterization of nested water supplies in a mid-latitude/altitude peatland using long-term monitoring data before and after restoration. The case study of the Frasne peatland (Jura Mountains, France)
Alexandre Lhosmot*, Louis Collin, Geneviève Magnon, Marc Steinmann, Catherine Bertrand, Vanessa Stefani, Philippe Binet, Marie-Laure Toussaint, Anne Boetch, and Guillaume Bertrand*

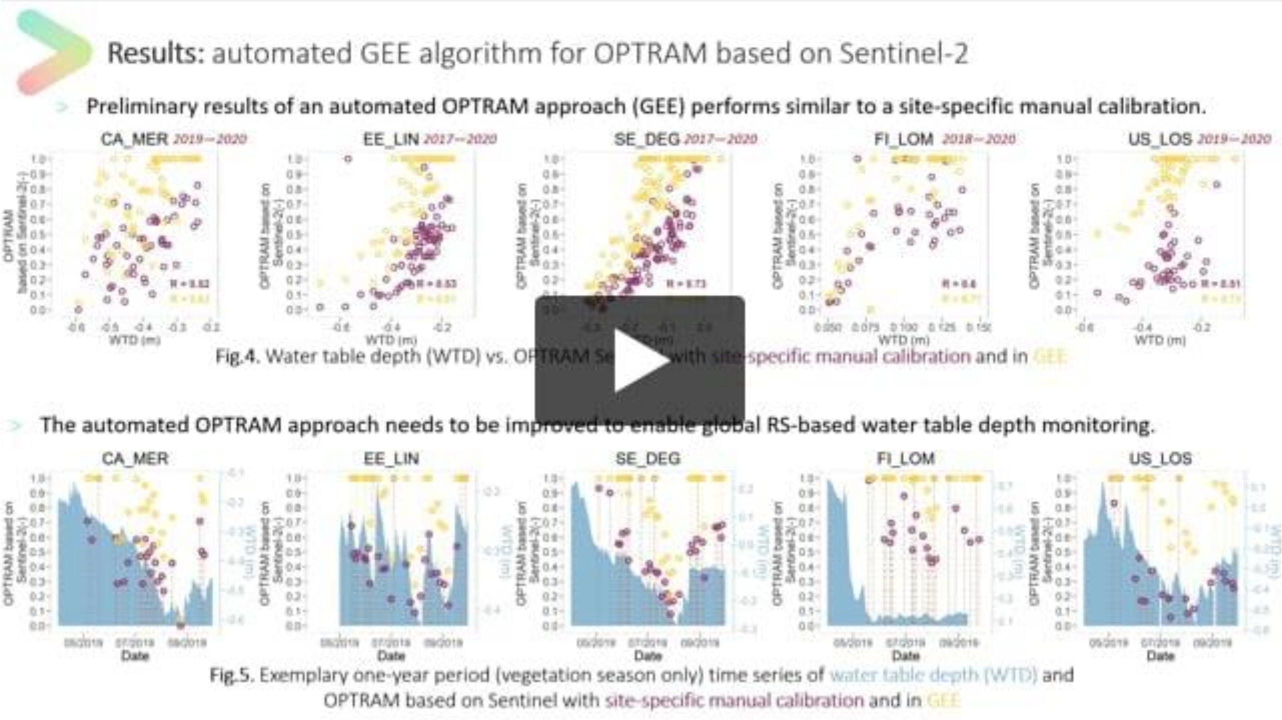
Effect of Macroporosity on Physical Property Estimates for Peat Soils
Miaorun Wang*, Haojie Liu, and Bernd Lennartz*

Remote sensing of peatlands

Thermal UAS Imaging to Monitor Restored Peatlands
Lauri Ikkala*, Hannu Marttila, Anna-Kaisa Ronkanen, Jari Ilmonen, Sakari Rehell, Timo Kumpula, and Björn Klöve*

Monitoring of water table dynamics in peatlands with OPTRAM: Towards globally applicable algorithms in Google Earth Engine using Landsat and Sentinel-2

***Iuliia Burdun**, Michel Bechtold, Viacheslav Komisarenko, Annalea Lohila, Elyn Humphreys, Ankur R. Desai, Mats B. Nilsson, Valentina Sagris, Ülo Mander, and Gabrielle De Lannoy*



Characterization of Alpine peatlands based on remote sensing of vegetation and water content

***Sonia Silvestri** and Alessandra Borgia*

Deriving SAR Soil Moisture Retrieval Algorithms and Soil Drainage Classification for Boreal Peatlands

***Laura Bourgeau-Chavez**, Jeremy Graham, Andrew Poley, Dorthea Leisman, and Michael Battaglia*

InSAR time series over rewetted bogs highlight spatially heterogeneous surface deformation

***Verena Huber García**, Janina Klatt, Martina Schlaipfer, Francesco De Zan, Ralf Ludwig, and Philip Marzahn*

Runoff and other discharge pathways

Impairing pipe-to-stream connectivity in a heavily degraded blanket bog: the results of a pipe outlet blocking trial

***Taco Regensburg**, Pippa Chapman, Michael Pilkington, David Chandler, Martin Evans, and Joseph Holden*

Hydrological contrast between peatlands and forests: Implications on extreme flow in the boreal landscape

***Shirin Karimi**, Jan Seibert, Eliza Maher Hasselquist, Kevin Bishop, Reinert Huseby Karlsen, and Hjalmar Laudon*

Storm-runoff processes in a mainly waterlogged low mountain range catchment in the national park Hunsrück-Hochwald, SW-Germany

Julian Zemke

Submarine groundwater discharge from coastal peatlands of northeast Germany

***Erwin Don Racasa**, Bernd Lennartz, Miriam Ibenthal, and Manon Janssen*

Ecological and water quality impacts, and other topics

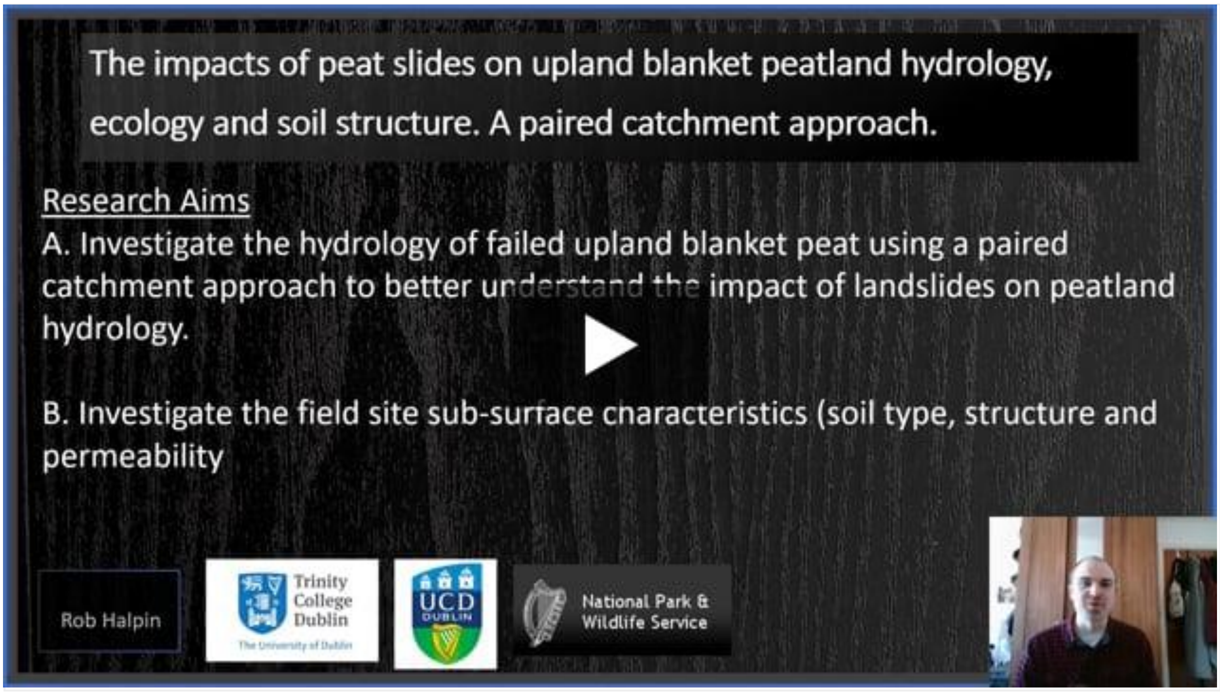
Ecological Impact of Plantation Forestry on Blanket Bog on a Low Order Stream

***Raymond Flynn**, Cormac McConigley, Gary O'Connell, Francis Mackin, and Florence Renou Wilson*

Nordic Bioeconomic Pathways - catchment scale water quality impacts of various scenarios and projections
***Joy Bhattacharjee**, Hannu Marttila, Artti Juutinen, Anne Tolvanen, Arto Haara, Jouni Karhu, and Björn Klöve*

Quantifying fluvial carbon losses from lowland peatland ecosystems across a drainage-impact spectrum
***Peter Cox**, Laurence Gill, Shane Regan, and Matthew Saunders*

The impacts of peat slides on upland blanket peatland hydrology, ecology and soil structure. A paired catchment approach
***Rob Halpin**, Mary Bourke, Mike Long, and Andrew Trafford*



Quantifying the contribution of wetlands drying to aerosol generation across Iran
***Majid Bayati**, Nooshdokht Bayat-Afshary, and Mohammad Danesh-Yazdi*

HS6.1
Remotely-sensed evapotranspiration
Co-organized by BG3/GI4
Convener: Hamideh Nouri | Co-convener: Pamela Nagler

Chairpersons: Hamideh Nouri, Pamela Nagler

Agriculture

Application of SVEN model to estimate evapotranspiration on a coffee plantation using MODIS and Sentinel products
***Ana María Durán-Quesada**, Ioanna Pateromichelaki, Mónica García, Sheng Wang, Yolande Serra, Marco Gutiérrez, and Cristina Chinchilla*

CubeSats deliver daily crop water use at 3 m resolution
***Bruno Jose Luis Aragon Solorio**, Matteo G. Ziliani, and Matthew F. McCabe*

Inter-comparison of remotely-sensed actual evapotranspiration products in the Zayandehrud river basin, Iran
***Neda Abbasi**, Hamideh Nouri, Sattar Chavoshi Borujeni, Pamela Nagler, Christian Opp, Armando Barreto Munez, Kamel Didan, and Stefan Siebert*

Rice water requirements: local assessment based on remote sensing data in the Lower Mondego (Portugal)
***Isabel P. de Lima**, Romeu G. Jorge, and João L.M.P. de Lima*

Scale analysis of evapotranspiration estimates from an energy-water balance model and remotely sensed LST
***Nicola Paciolla**, Chiara Corbari, Giuseppe Ciraolo, Antonino Maltese, and Marco Mancini*

Non-agriculture (urban, riparian, forest, etc.)

The role of aerodynamic resistance in thermal remote sensing-based evapotranspiration models
***Ivonne Trebs**, Kaniska Mallick, Nishan Bhattarai, Mauro Sulis, James Cleverly, Will Woodgate, Richard Silberstein, Nina Hinko-Najera, Jason Beringer, Zhongbo Su, and Gilles Boulet*

Estimating land-surface evapotranspiration based on a first-principles primary productivity model
***Shen Tan**, Han Wang, and Colin Prentice

Changes in Water Use on the Lower Colorado River in the USA from 2000-2020
***Pamela Nagler**, Armando Barreto-Muñoz, Sattar Chavoshi Borujeni, Hamideh Nouri, Christopher Jarchow, and Kamel Didan*

Spatio-temporal changes in water demand of urban greenery
***Sattar Chavoshi Borujeni**, Hamideh Nouri, Pamela Nagler, Armando Barreto-Muñoz, and Kamel Didan*

A correction factor for evapotranspiration prediction in urban environments using physical-based models
***Alby Duarte Rocha**, Stenka Vulova, Christiaan van der Tol, Michael Förster, and Birgit Kleinschmit*

A data-driven approach to quantifying urban evapotranspiration using remote sensing, footprint modeling, and deep learning
***Stenka Vulova**, Fred Meier, Alby Duarte Rocha, Justus Quanz, Hamideh Nouri, and Birgit Kleinschmit*

Development of a Three-Source Remote Sensing Model for Estimation of Urban Evapotranspiration (TRU)
***Han Chen**, Jinhui Jeanne Huang, Edward McBean, Zhiqing Lan, Junjie Gao, Han Li, and Jiawei Zhang*

Comparison of seasonal evapotranspiration of temperate coniferous forests with Copernicus Sentinel-1 time series
***Marlin Markus Mueller**, Clémence Dubois, Thomas Jagdhuber, Carsten Pathe, and Christiane Schmullius*

Estimating evapotranspiration from thermal infrared data : extension of the two source SPARSE model to a four-source representation in order to account for the sun-earth-sensor configuration
***Samuel Mwangi**, Gilles Boulet, and Albert Olioso*

Part 2 – Report prepared by Aiga Krauze (Latvian, Environment, Geology and Meteorology Center)

On 19.04.2021. project manager Aiga Krauze attended EGU Plenary meeting via Zoom platform. In the beginning of the meeting we were introduced to the organization team. Then the statistics of the attendance was communicated – about 800 attendees were participating in the plenary meeting. Participants then were asked to approve the agenda by answering poll questions - yes or no.

Next thing on the agenda was the report by the EGU president. He said that over 14 thousand participants have registered this year from 126 countries. Half of the participants are regular members and the other half are early career scientists.

This year EGU has introduced a new virtual center where participants can access all of the conference events.

The EGU president also talked about equality, diversity and inclusivity (EDI), he mentioned awards and the interesting fact is that greater % of awards were received by women in the year 2021.

Patric Jacobs explained the EGU family structure, finances and how Covid has affected finances and salaries. He also showed a slide about the total income in 2021 that is mainly made of registration fees and all the expenditures.

Finally all of the participants were asked if they are in favor to discharge the current Executive and next auditors were elected. Then the inauguration of the new officers and the new president was happening.

DAY 1

April 26th, attending session "Groundwater-surface water interactions: physical, biochemical and ecological processes"

Quantifying spatial and seasonal variations of groundwater- surface water interaction for the prediction of hydrological turnover on the catchment scale

Lars Bäthke, *Sven Ulrich, and Tobias Schuetz*

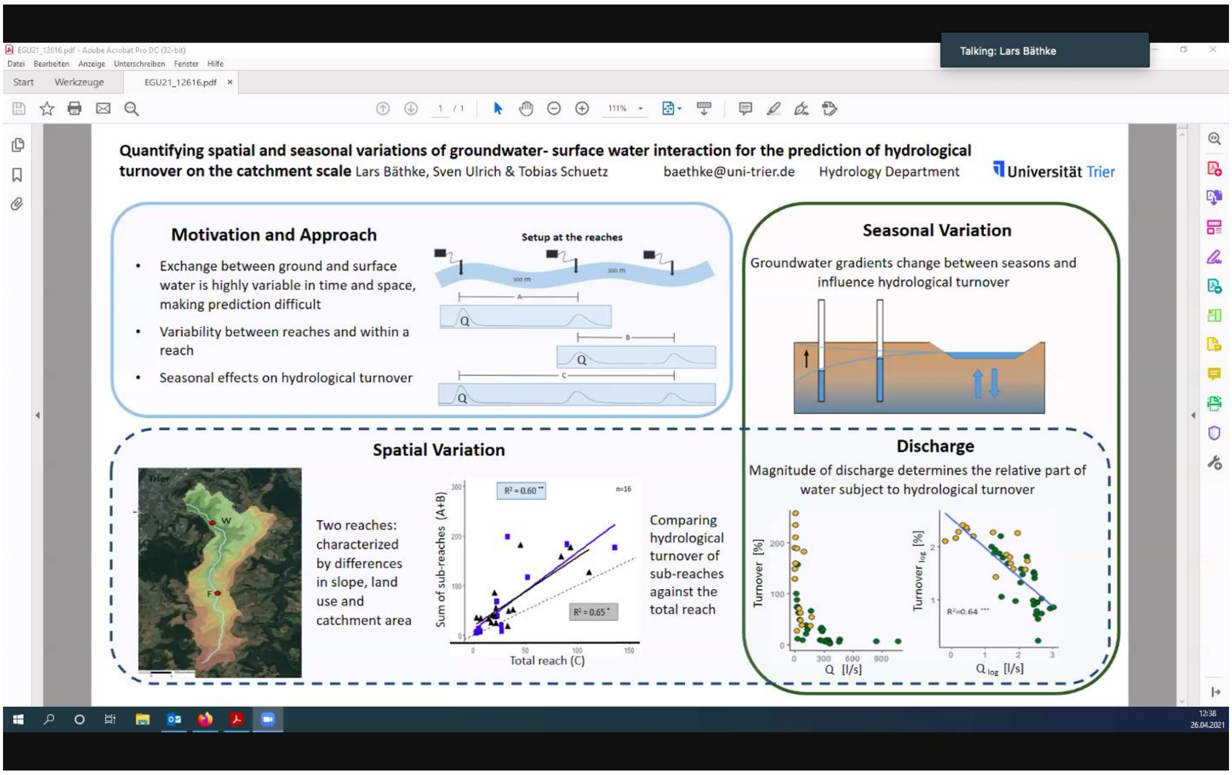
University of Trier, Department of Hydrology, Trier, Germany (baethke@uni-trier.de)

Targeting hyporheic exchange as well as gains and losses as the means of interaction between ground- and surface water in a stream leads forward to the consideration of both influencing the apparent hydrological turnover at the catchment scale i.e. the cumulative effect of gains and losses on physical water composition along a stream. The variability in hydrological turnover across a catchment is governed by the spatially varying connectivity between groundwater and the streambed. Especially under low flow conditions, expansion of turnover relative to stream flow is prominent and its spatial variability is intensified.

Studying the scaling behavior of hydrological turnover processes, we measured hydrological turnover along two representative stream segments of about 500-600m length at a second order tributary to the river Mosel in Trier, western Germany by applying differential sault dilution gauging over 10 campaigns in summer and 7 in winter. Each stream reach represents a typical geomorphological setting in the catchment. The upstream reach is characterized by steep sloping terrain towards the stream with pastures and forest at higher elevations as the dominant land use. At the downstream reach the terrain is flatter with the stream meandering. The land use is diverse with meadow, pastures and forest as well as settlements. Each respective reach was split into two equidistant parts, resulting in three measurements of hydrological turnover, first and second section as well as the whole reach. Thus, acquiring data accounting for the spatial variability in each reach as well as between reaches. The measurements were carried out weekly, at the two stream reaches from August to September with stream flow ranging from ca. 2 l/s to 94 l/s and at the downstream reach from November to February with stream flow ranging from 200 l/s to over 1000 l/s.

The results show clearly the positive relationship between discharge and the relative volume of water exchanged between stream, hyporheic zone and groundwater as gains and losses at the reach scale. In addition to that, exchange processes vary independently at both investigated reaches. However, the dataset suggests a distinctive relationship between turnovers of an entire reach compared to the sum of the two sub-reach sections. The slope of this relationship may be a first step for the upscaling of observed exchange and turnover processes from the reach to the network scale.

How to cite: Bäthke, L., Ulrich, S., and Schuetz, T.: Quantifying spatial and seasonal variations of groundwater-surface water interaction for the prediction of hydrological turnover on the catchment scale, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12616, https://doi.org/10.5194/egusphere-egu21-12616, 2021.



Groundwater dynamics and groundwater surface-water exchange in the near-stream zone across the hydrologic year

Enrico Bonanno[1,2]*, Günter Blöschl*[2]*, and Julian Klaus*[1]

[1]Catchment and Eco-Hydrology Group, Luxembourg Institute of Science and Technology, Belvaux, Luxembourg
[2]Institute of Hydraulic and Water Resources Engineering, Vienna University of Technology, Vienna, Austria

Groundwater dynamics and flow directions in the near-stream zone depend on groundwater gradients, are highly dynamic in space and time, and reflect the flow paths between stream channel and groundwater. A wide variety of studies have addressed groundwater flow and changes of flow direction in the near-stream domain which, however, have obtained contrasting results on the drivers and hydrologic conditions of water exchange between stream channel and near-stream groundwater. Here, we investigate groundwater dynamics and flow direction in the stream corridor through a spatially dense groundwater monitoring network over a period of 18 months, addressing the following research questions:

- How and why does groundwater table response vary between precipitation events across different hydrological states in the near-stream domain?
- How and why does groundwater flow direction in the near-stream domain change across different hydrological conditions?

Our results show a large spatio-temporal variability in groundwater table dynamics. During the progression from dry to wet hydrologic conditions, we observe an increase in precipitation depths required to trigger groundwater response and an increase in the timing of groundwater response (i.e. the lag-time between the onset of a precipitation event and groundwater rise). This behavior can be explained by the subsurface structure with solum, subsolum, and fractured bedrock showing decreasing storage capacity with depth. A Spearman rank (rs) correlation analysis reveals a lack of significant correlation between the observed minimum precipitation depth needed to trigger groundwater response with the local thickness of the subsurface layer, as well as with the distance from and the elevation above the stream channel. However, both the increase in groundwater level and the timing of the groundwater response are positively correlated with the thickness of the solum and subsolum layers and with the distance and the elevation from the stream channel, but only during wet conditions. These results suggest that during wet conditions the spatial differences in the groundwater dynamics are mostly controlled by the regolith depth above the fractured bedrock. However, during dry conditions, local changes in the storage capacities of the fractured bedrock or the presence of preferential flow paths in the fractured schist matrix could control the spatially heterogeneous timing of groundwater response. In the winter months, the groundwater flow direction points mostly toward the stream channel also many days after an event, suggesting that the groundwater flow from upslope locations controls the near-stream groundwater movement toward the stream channel during wet hydrologic conditions. However, during dry-out or long recessions, the groundwater table at the foot slopes decreases to the stream level or below. In these conditions, the groundwater fall lines point toward the foot slopes both in the summer and in the winter and in different sections of the stream reach. This study highlights the effect of different initial conditions, precipitation characteristics, streamflow, and potential water inflow from hillslopes on groundwater dynamics and groundwater surface-water exchange in the near stream domain.

How to cite: Bonanno, E., Blöschl, G., and Klaus, J.: Groundwater dynamics and groundwater surface-water exchange in the near-stream zone across the hydrologic year, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9576, https://doi.org/10.5194/egusphere-egu21-9576, 2021.

Seasonal variations in surface water groundwater interaction alter the relation of solute transport and biogeochemical processes in the hyporheic zone

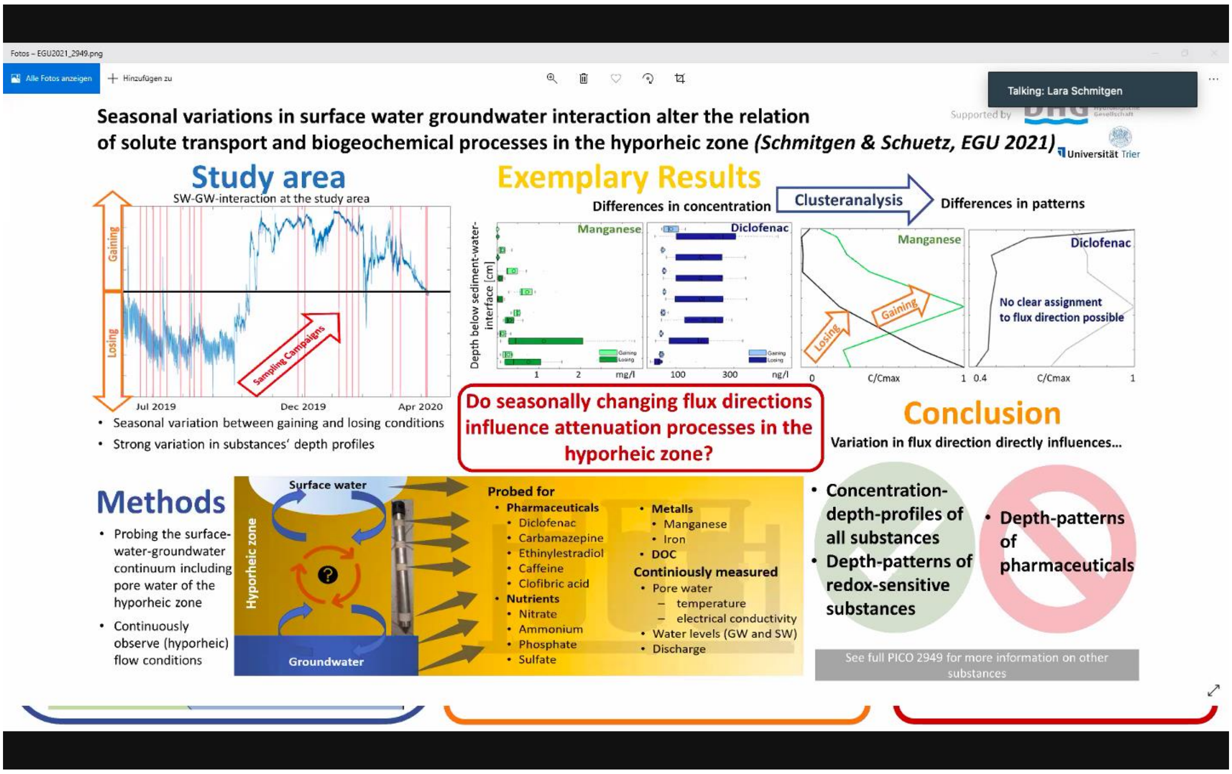
Lara-Maria Schmitgen *and Tobias Schuetz*

University Trier, Hydrology, Trier, Germany (schmitgen@uni-trier.de)

The hyporheic interstitial as interface between surface water and groundwater offers a unique environment for contaminant attenuation and nutrient cycling, with steep chemical gradients and high retention times. Disentangling the effect of seasonal dynamics in exchange flux intensities and directions, we carried out 19 measurement campaigns where we sampled the continuum surface water - hyporheic zone - groundwater and the climatic and hydraulic boundary conditions of a whole year. Groundwater, surface water and hyporheic zone pore water from four depths were sampled at two vertical profiles in a second order stream about 150 m downstream a municipal waste water treatment plant effluent. Samples were analyzed for physical water parameters, major anions, ammonium, iron, manganese, NPOC and five selected pharmaceuticals (diclofenac, carbamazepine, caffeine, ethinylestradiol and clofibric acid). Surface water and groundwater levels as well as river discharge were measured to quantify the hydraulic boundary conditions. In addition, three vertical profiles, each equipped with five newly developed probes (Truebner AG) allowed a parallel monitoring of continuous bulk water temperatures and bulk electrical conductivity dynamics over two years. Furthermore, continuous hyporheic exchange flux intensities and exchange depths were calculated using analytical and numerical model schemes to allow distinguishing between small scale transport and attenuation processes.

The typical behavior of the redox sensitive metals and nutrients with depth is visible in each single profile snapshot. The picture is not as clear for the examined pharmaceuticals, because dilution has a major effect on the observable low concentrations. However, a clear seasonal variation driven by hydraulic and climatic processes can be observed for all substances. We were able to trace the organic pollutants down to the groundwater. Furthermore, the influence of hyporheic exchange flux intensities and directions on nutrient and contaminant depth profiles is shown.

How to cite: Schmitgen, L.-M. and Schuetz, T.: Seasonal variations in surface water groundwater interaction alter the relation of solute transport and biogeochemical processes in the hyporheic zone, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2949, https://doi.org/10.5194/egusphere-egu21-2949, 2021.



The relevance of groundwater-lake interactions for the rapid eutrophication of Lake Stechlin

***Jörg Lewandowski* [1,2]**, *Franziska Mehler[1,3], Himanshu Bhardwaj[1,4] and Anna Jäger[1]*

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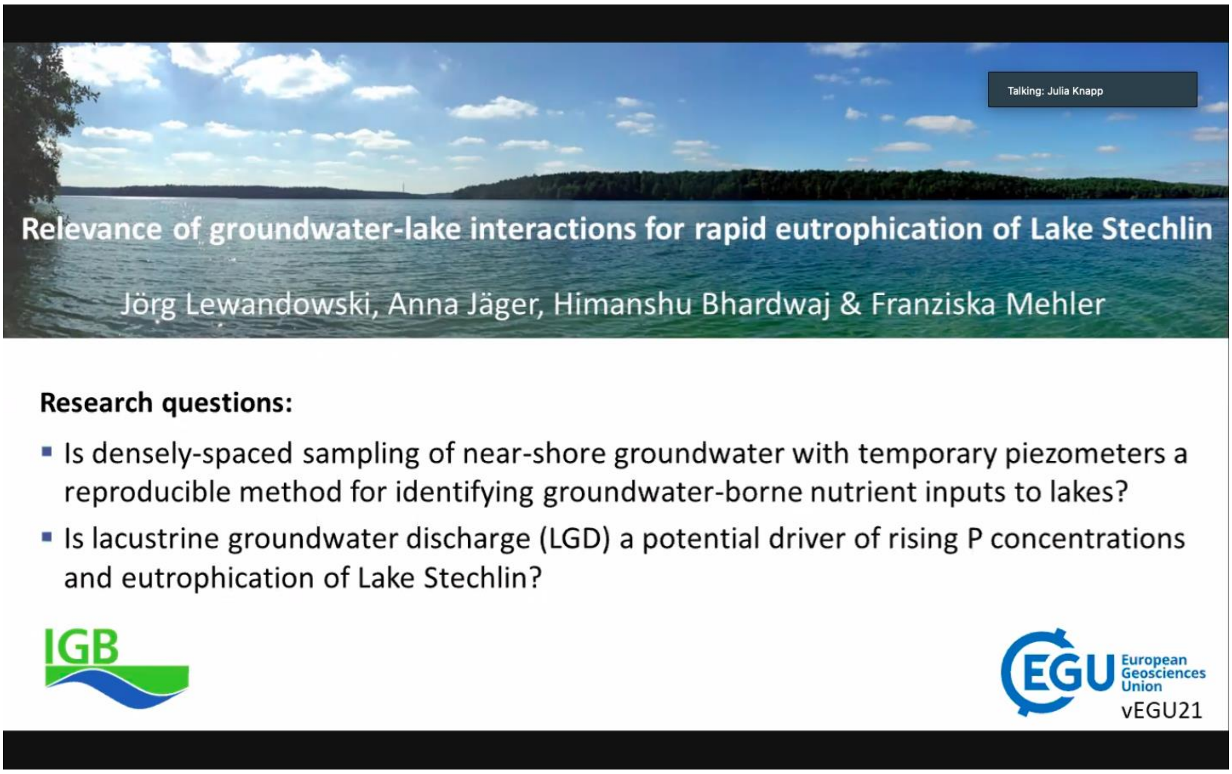
Lake Stechlin is located in a nature reserve and its catchment is nearly completely forested, there is no agriculture and only one small settlement. About 10 years ago there were the first indications in the lake's hypolimnion for changes of the trophy. In the last 3 years the lake is experiencing a rapid eutrophication and phosphorus (P) concentrations quadrupled compared to the concentrations 10 years ago. It is generally agreed that the origin of this P is internal P cycling which is a self-reinforcing process. However, the trigger that started the intense internal P cycling is still unknown. There are several different hypotheses and we focused on investigating the role of groundwater for the eutrophication of Lake Stechlin. Groundwater is a crucial component of the water balance of Lake Stechlin because there are basically no surface inflows and outflows, i.e. besides precipitation and evaporation, both lacustrine groundwater discharge and infiltration of lake water into the aquifer are the only other relevant terms of the water balance. Anthropogenic and climate change-induced alterations in groundwater inflow and outflow might have triggered the rapid eutrophication by different processes and we present a conceptual model of the involved processes. Main findings are (1) At a few locations we measured P concentration in the aquifer which were up to two orders of magnitude above the P concentrations of the lake water. (2) Due to several years of low precipitation in a row, the volume of lacustrine groundwater discharge decreased and with that the input of important P binding agents decreased, thus influencing the lake's internal P cycling. (3) Warmer average annual temperatures increase evaporation and simultaneously lead to a concentration of phosphorus in the lake. Local reversals of groundwater flow directions could also prevent lake water and with-it P from leaving the lake. Thus, groundwater might be an important factor for the degradation of Lake Stechlin.

How to cite: Lewandowski, J., Mehler, F., Bhardwaj, H., and Jäger, A.: The relevance of groundwater-lake interactions for the rapid eutrophication of Lake Stechlin, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2152, https://doi.org/10.5194/egusphere-egu21-2152, 2021.



Groundwater-surface water exchange: A New Graphical User Interface for temperature time-series analysis

Andrea Bertagnoli[(1)]***,*** *Matthijs van Berkel*[(2)]*, Uwe Schneidewind*[(3)]*, Ricky van Kampen*[(2,4)]*, Stefan Krause*[(3)]*, Andrew Tranmer*[(1)]*, Charles Luce*[(5)]*, and Daniele Tonina*[(1)]

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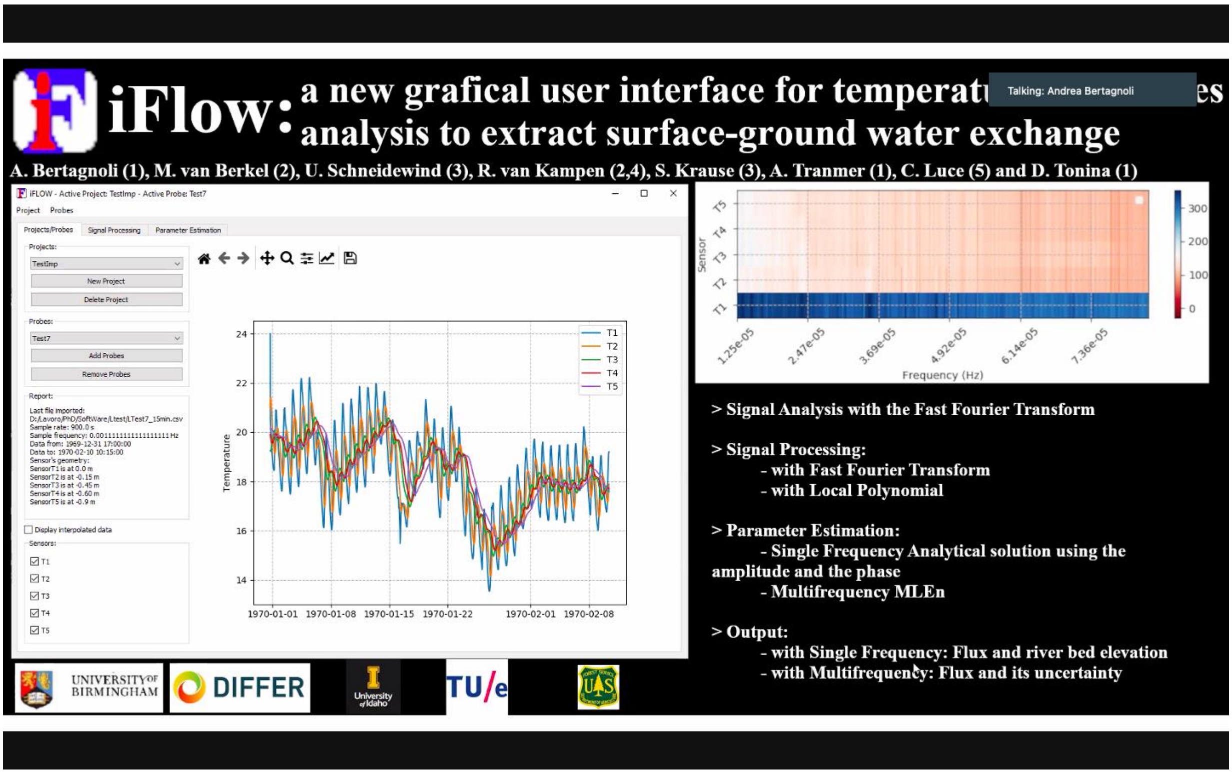
Riverine systems have a dynamic exchange of water with the hyporheic zone and groundwater. Exchange fluxes can be challenging to estimate because they vary spatially and temporally and depend on many geological and hydrological properties. Temperature as a tracer has become a low-cost and robust method to monitor such fluxes both at local and reach (several channel widths) scales. Here, we present the capabilities and functionality of a new graphical user interface (GUI) developed in Python which is operating system independent. The GUI integrates standard and state-of-the-art signal processing methods with data visualization and analysis techniques. The signal analysis library allows the user to select the important frequencies to improve result confidence while the advanced LPMLEn and window function in FFT to reduce leakage in the extraction process of the amplitude and phase of the signals. The GUI streamlines the entire analysis process, from evaluating the raw temperature data to obtaining end-user specified parameters such as flux and streambed thermal properties. It allows for the analysis of single-probe and multi-probe data from short to long-term data sets.

How to cite: Bertagnoli, A., van Berkel, M., Schneidewind, U., van Kampen, R., Krause, S., Tranmer, A., Luce, C., and Tonina, D.: Groundwater-surface water exchange: A New Graphical User Interface for temperature time-series analysis, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9311, https://doi.org/10.5194/egusphere-egu21-9311, 2021.



Effect of precipitation and stream discharge on the source composition of stream water

***Zhi-Yuan Zhang*[1]**, *Christian Schmidt*[1,2], *and Jan Fleckenstein*[1]

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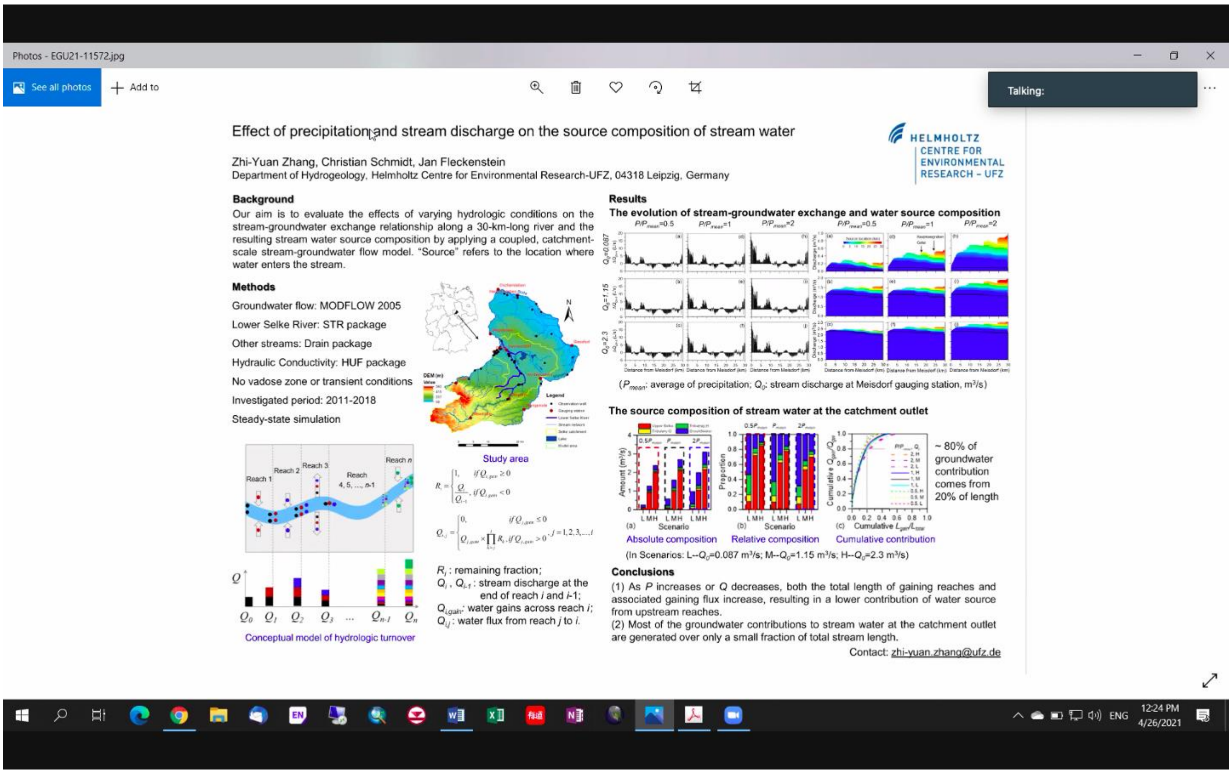
The exchange of water between streams and groundwater plays an important role for hydrologic and biogeochemical processes. Along a stream the composition of stream water is modified by sequential losses of stream water with the current in-stream chemical signature to the subsurface and gains of water with another signature from the subsurface. This process has been termed hydrologic turnover. To date, most studies on hydrologic turnover have been focused on small stream networks. Moreover, the influence of hydrologic conditions on hydrologic turnover has not been systematically investigated. Taking the lower Selke River in central Germany as an example, we evaluated the evolution of stream-groundwater exchange and the source composition of stream water under different precipitation and stream discharge conditions, based on a coupled stream-groundwater model built in MODFLOW using the Streamflow-routing (SFR1) package. The results show that the stream reaches could be classified into three types: permanently gaining reaches, permanently losing reaches, and transitional reaches. Transitional reaches range from losing condition at higher stream discharge or lower precipitation to gaining condition at lower stream discharge or higher precipitation. In the lower Selke River with a length of 30 km, transitional reaches account for nearly 30% of the total river length in the studied period from 2011 to 2018. Regardless of dry or wet hydrologic condition, nearly 80% of the total groundwater contribution to stream discharge at the catchment outlet were generated over 20% of the total river length. This indicates diffuse groundwater pollution such as from agricultural nitrate may enter the stream network predominantly at a few distinct reaches. Our analysis can help to prioritize areas in a catchment where reduction of diffuse groundwater pollution would have the highest impact on improving stream water quality.

How to cite: Zhang, Z.-Y., Schmidt, C., and Fleckenstein, J.: Effect of precipitation and stream discharge on the source composition of stream water, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11572, https://doi.org/10.5194/egusphere-egu21-11572, 2021.



Analyzing surface water-groundwater interactions on selected sites of the River Moselle: Identifying transport processes along an important inland waterway in Germany

Simon Mischel, *Michael Engel, Sabrina Quanz, Dirk Radny, Axel Schmidt, Michael Schlüsener, and Arne Wick*

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Hydraulic engineering structures like locks affect the natural hydraulic conditions and have a relevant impact on surface water – groundwater interactions due to enlarging the hydraulic gradient. For this, these sites are excellent areas to study associated flow paths, mass transport and their spatial and temporal variability in higher detail. However, no large-scale study at an inland waterway is available in Germany until now.

Our work aims to close this gap by applying a multiparameter approach for analyzing surface water-groundwater-interactions by using pH, electrical conductivity, major ions in combination with various other tracers like stable water isotopes, 222-Rn, and tritium. In this context, we also investigate the usability of organic trace compounds and their associated transformation products as potential new tracers.

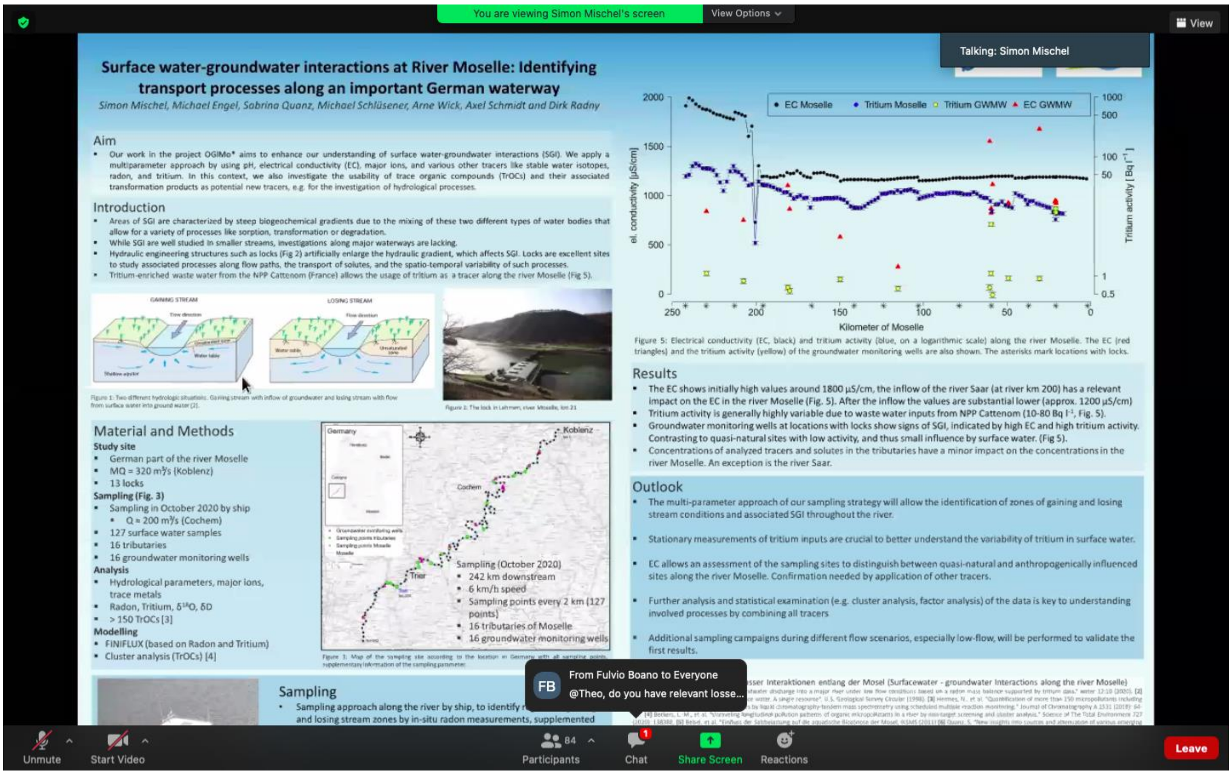
The main study approach is based on the hypothesis that i) gaining stream sections show relatively high 222-Rn concentrations originating from discharging groundwater and ii) losing stream sections which are characterized by low 222-Rn concentrations as well as lower tritium and organic trace compounds inventories compared to unaffected areas.

During different flow-scenarios of the river Moselle, we test these hypotheses by means of a high-resolution longitudinal sampling at 2 km intervals of the main stream (along 242 km) and its major tributaries in combination with groundwater sampling at numerous wells.

Here, we present the first results of the longitudinal sampling campaign of the river Moselle in October 2020, which took place during intermediate flow conditions (Q=200 m^3/s). We used on-site and in-situ 222-Rn measurements and electrical conductivity as a tracer to immediately identify zones along the Moselle with increased groundwater inflow.

With the use of these tracers, we will deepen the conceptual process understanding of surface water – groundwater interactions occurring at larger streams and during different flow conditions, which may lead to a general river characterization of losing and gaining stream reaches. Moreover, understanding the sources of water compounds and the processes involved during transportation and transformation is crucial for maintaining a good quality of the water body, which is key for proper water management. The findings obtained in the region of the Moselle river might be further transferred to other waterways and support decision making.

How to cite: Mischel, S., Engel, M., Quanz, S., Radny, D., Schmidt, A., Schlüsener, M., and Wick, A.: Analyzing surface water-groundwater interactions on selected sites of the River Moselle: Identifying transport processes along an important inland waterway in Germany, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11973, https://doi.org/10.5194/egusphere-egu21-11973, 2021.



DAY 2

April 27th, attending session "Groundwater resources management: reconciling demand, high quality resources and sustainability"

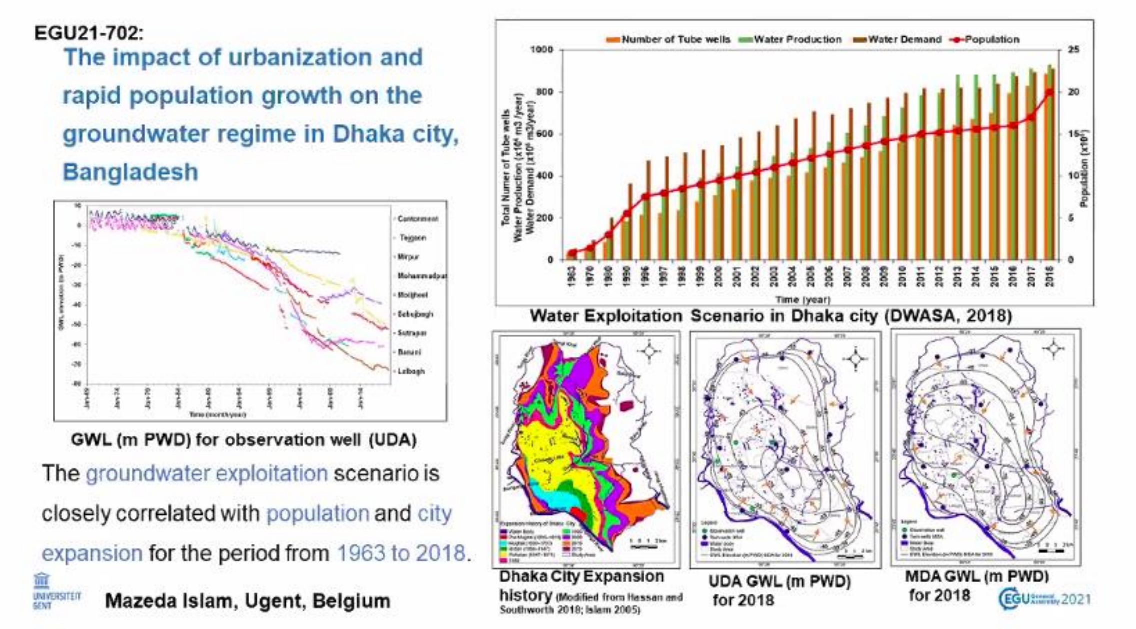
The impact of urbanization and rapid population growth on the groundwater regime in Dhaka city, Bangladesh

Mazeda Islam, *Marc Van Camp, Delwar Hossain, Md. Mizanur Rahman Sarker, Shahina Khatun, and Kristine Walraevens*

Dhaka city with an area of about 306 Km2 and a population of more than 20 million is located in the central part of Bangladesh. Immense and prolonged groundwater abstraction due to rapid unplanned urbanization and population blast in this city have led to significant decline in groundwater level in the last three decades. 78% of the supplied water comprises groundwater from the Dupi Tila Sandstone aquifer system. Hydrogeological and geophysical data aided to the delineation of three different aquifers (based on lithology): Upper Dupi Tila aquifer (UDA), Middle Dupi Tila aquifer (MDA) and Lower Dupi Tila aquifer (LDA). The evaluation of long-term hydrographs, piezometric maps and synthetic graphical overviews of piezometric trends in both the UDA and MDA depicts that the rate of dropping of groundwater level (GWL) is very substantial. Massive pumping in the city has altered its natural hydrologic system. The groundwater level has dropped on average 2.25 m/year and 2.8 m/year in UDA and MDA, respectively, in the whole city in 2018, whereas the average rate of decline in the center of the depression cone during this time was 4.0 m/year and 5.74 m/year respectively. Presently, the groundwater level elevation has declined to levels lower than -85 and -65 m PWD in UDA and MDA, respectively. The changes in pattern and magnitude of depression cones in UDA and MDA are directly associated with the city expansion and number of deep tube wells installed over a certain period in particular parts of the city. The depletion of GWL from 1980 to 2018 is very notable. There is only limited vertical recharge possible in the UDA and MDA as they are semi-confined aquifers, and only lateral flow mostly in the UDA and MDA from the surroundings is to be expected. In this regard the long-term management of groundwater resources in Dhaka city is urgently needed, otherwise the condition may go beyond control.

Key words: Groundwater abstraction, city expansion, hydrographs, piezometric maps, GWL decline, depression cone

How to cite: Islam, M., Van Camp, M., Hossain, D., Sarker, Md. M. R., Khatun, S., and Walraevens, K.: The impact of urbanization and rapid population growth on the groundwater regime in Dhaka city, Bangladesh, EGU General Assembly 2021, online, 19-30 Apr 2021, EGU21-702, https://doi.org/10.5194/egusphere-egu21-702, 2021.



From the hydrogeological and geochemical conceptualization to the groundwater management: the Gioia Tauro Plain (Southern Italy)

Giuseppe Cianflone, Giovanni Vespasiano, Rosanna De Rosa, Carmine Apollaro, Rocco Dominici, and Maurizio Polemio

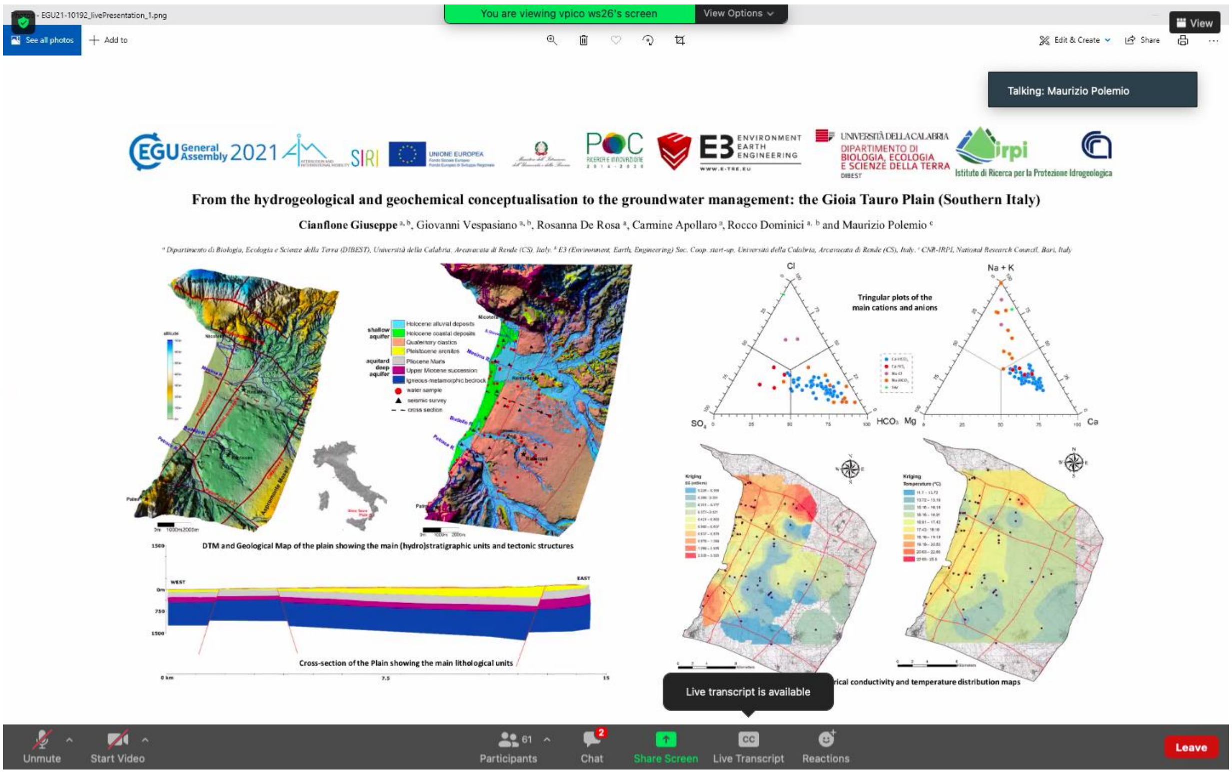
The Gioia Tauro plain (GTP) is an industrialized and agricultural coastal area of about 500 km2 in the Tyrrhenian side of Calabria. Its harbor is one of the most important container traffic hubs in the Mediterranean basin. The GTP groundwater resources are constantly at risk of depletion and quality degradation due to anthropic activities.

GTP is a half-graben bounded by two massifs. The boundaries are marked by three main fault systems: the Nicotera-Gioiosa fault zone, NW-SE striking and right lateral kinematics along the north boundary; the NNE-SSW Cittanova Fault, a high-angle normal and active fault along the eastern border; the Palmi-Locri fault zone with NW-SE trend and a mainly strike-slip kinematics along the south boundary. The GTP sedimentary infill is made by an upper Miocene siliciclastic and carbonate succession overlay by Pliocene marly-limestone rhytmites and Piacenzian-Calabrian sandstones and calcarenites with interbedded 20 m thick volcaniclastic deposits. Upward, the sedimentary infill continues with alluvial (in eastern and middle sector) and coastal (in the western sector) deposits.

Six geochemical facies of groundwater were distinguished, with different salinities and temperatures. The majority of samples is of cold shallow groundwater and shows Ca-HCO_3, Ca(Mg-Na)-HCO_3(Cl-SO_4) and Na-HCO_3 composition and overall low salinities (TDS < 1 g/l). Only few samples, with Na-SO_4 and Na-Cl composition, show high salinity (TDS < 3.5 g/l) and temperature (above 20°C). These latter occur in the northern portion of the plain, near the intersection of the Palmi-Gioia Tauro and Nicotera-Gioiosa faults systems, and in the southern sector, near Palmi town.

It was created a geodatabase using data of hundreds of boreholes, geotechnical and geophysical investigations. Furthermore, it is carrying out a geological and geophysical survey along the plain boundaries using passive seismic technique to infer the deep of discontinuities among the main geological units described above. The acquired data allowed to identify: i) the shallow aquifer, made by Pleistocene-Holocene deposits characterized by complex lateral variations; ii) at the bottom, the aquitard, represented by Pliocene marls; iii) the deep aquifer, consisting of the upper Miocene succession. The highest thickness of shallow aquifer (more than 200 m) is observed in the middle GTP sector. The thickness variation is strictly related to the NE-SW high angle normal faults which cross the GTP. The ongoing geological, geochemical, and geophysical surveys will allow: i) to identify the geometry of the hydrogeological units; ii) to define the hydrogeological features of the groundwater systems useful for modelling purposes, and iii) to improve the knowledge of water rock interactions processes (e.g., relations between deep and shallow waters, anthropogenic effects, seawater intrusion) for management purposes.

How to cite: Cianflone, G., Vespasiano, G., De Rosa, R., Apollaro, C., Dominici, R., and Polemio, M.: From the hydrogeological and geochemical conceptualization to the groundwater management: the Gioia Tauro Plain (Southern Italy), EGU General Assembly 2021, online, 19-30 Apr 2021, EGU21-10192, https://doi.org/10.5194/egusphere-egu21-10192, 2021.



Using an Extreme Gradient Boosting Learner for Mapping Hydrogeochemical Parameters in Germany

__Maximilian Nölscher__ and Stefan Broda

Information on the spatial distribution of hydrogeochemical parameters is crucial for decision making. Machine learning based methods for the mapping of hydrogeochemical parameter concentrations have been already studied for many years to evolve from deterministic and geostatistical interpolation methods. However, the reflection of all relevant processes that the target variable depends on is often difficult to achieve, because of the mostly insufficient determination and/or availability of features. This is especially true if you limit yourself to freely accessible data.

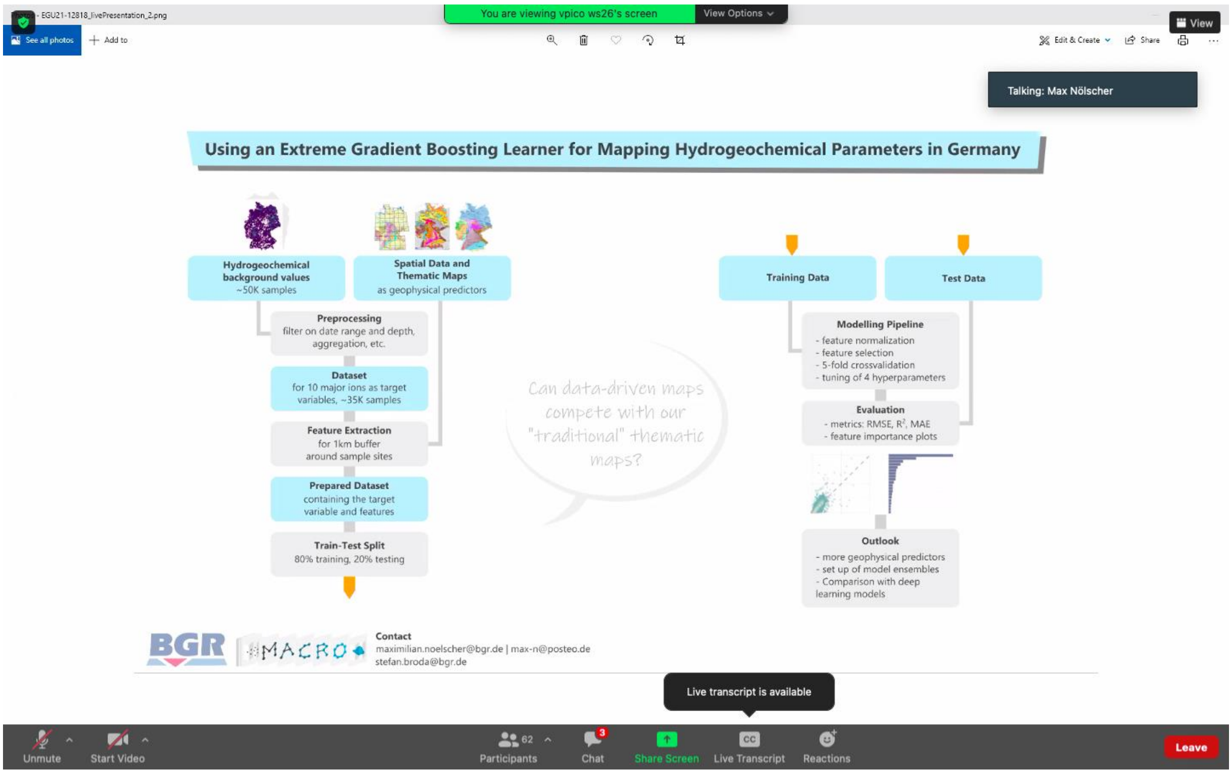
In this study, we apply an extreme gradient boosting learner (XGB) to map major ion concentrations across Germany. The training data consist of water samples from approximately 50K observation wells across Germany and a wide range of environmental data as predictors. The water samples were collected between the 1950s and 2005 at anthropogenically undisturbed locations.

The environmental data includes hydrogeological units and parameters, soil type, lithology, digital elevation model (DEM) and DEM derived parameters etc. The values of these features at the respective water sample location were extracted on the basis of a polygon, approximately representing the area that has an impact on the target variable (ion concentration). For a comparison, different polygon shapes are used.

The model was set up as chained multioutput regression, meaning that the prediction of the previous model in a linear sequence of single-output models is used as input for the subsequent model.

The results are planned to serve for a comparison with state-of-the-art deep learning architectures.

How to cite: Nölscher, M. and Broda, S.: Using an Extreme Gradient Boosting Learner for Mapping Hydrogeochemical Parameters in Germany, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12818, https://doi.org/10.5194/egusphere-egu21-12818, 2021.



Assessing groundwater management sustainability of coastal cities by utilizing the City Blueprint Approach

Khawon Lee, *Sun Woo Chang and Jeryang Park*

Groundwater is the largest freshwater resource available on Earth, and many coastal regions are depending on groundwater as a primary freshwater source. For example, in Busan and Incheon, two of the largest coastal cities in South Korea, 5.7% and 7.0% of freshwater uses are from groundwater while only 1.8% is from groundwater in Seoul, the capital of the country. Globally, groundwater availability is diminishing primarily by population increase, and especially in coastal regions, this problem is exacerbated by overexploitation and seawater intrusion, which causes groundwater contamination and further reduces its availability. Here, we view the groundwater system and its management for sustainability as a complex problem that is associated with various social, economic, and environmental factors. By adopting the City Blueprint Approach (CBA), which has been used extensively for assessing the sustainability of integrated water management of numerous cities on the globe, we identify water management factors that potentially have direct and indirect links and feedbacks with groundwater variables. We selected Busan and Incheon as case studies for coastal cities that are facing the risk of groundwater salinization by seawater intrusion. This study aims to 1) assess City Blueprint (CB) of selected coastal cities, 2) identify major factors for coastal groundwater management through correlation analysis, and 3) suggest management options regarding identified factors for sustainable groundwater management of the study areas. Our results on CB indicate that the groundwater quality and quantity of the selected cities are currently in 'good' status. Also, from the correlation analysis, we identified heat risk and freshwater scarcity as the major factors that potentially can affect groundwater quantity. For groundwater quality, the factors of voice and accountability, regulatory quality, and rule of law and control of corruption, most of which had not been explicitly considered for groundwater management, were identified as the major factors. Some of these factors were assessed from 'little concern' to 'very concern' for both cities. These results indicate that, regarding the linkages between groundwater variables and other factors in concern, more actions beyond environmental factors should be taken for sustainable groundwater management. This study helps to understand how non-conventional factors could contribute to coastal groundwater, and can provide extensive options for sustainable groundwater management.

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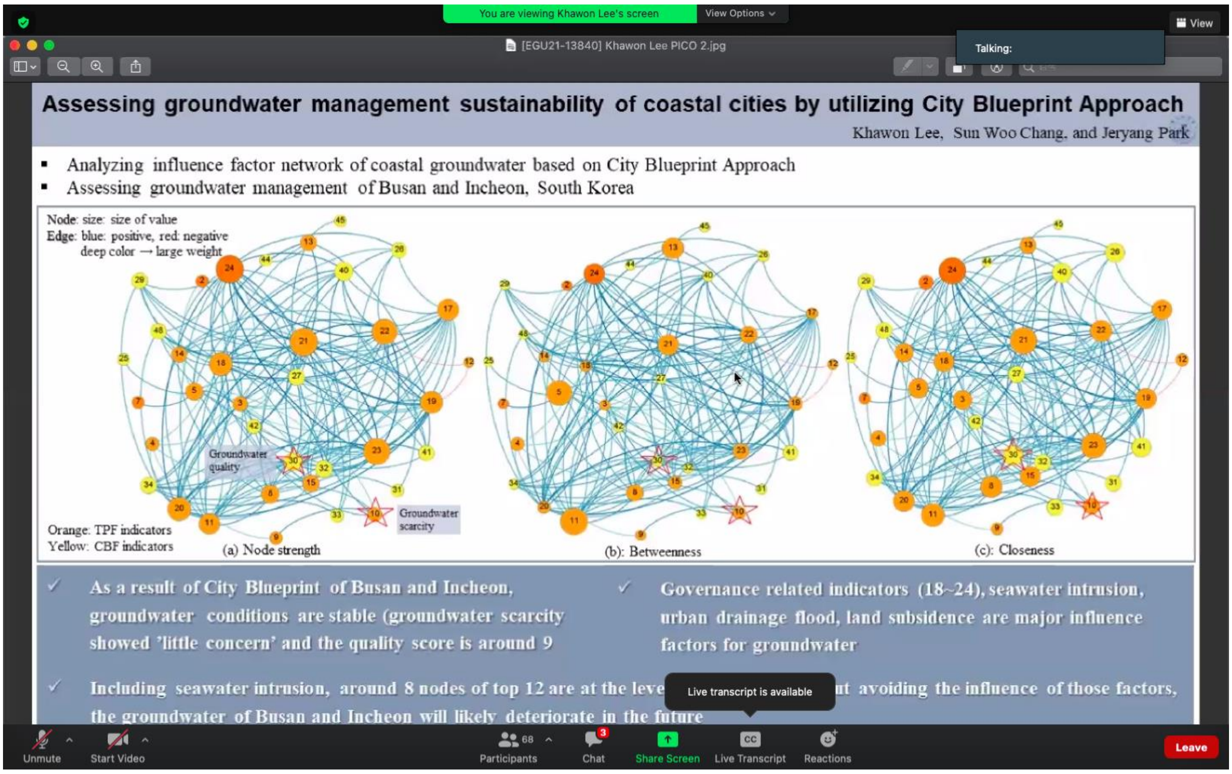


Hydrogeological characterization and groundwater quality assessment in an atoll island (Magoodhoo Island of Faafu Atoll - Maldives)

Chiara Zanotti, *Barbara Leoni, Veronica Nava, Luca Fallati, Marco Rotiroti, and Tullia Bonomi*

Although freshwater is a vital resource for domestic and productive purposes, it is a very limited and vulnerable resource on atoll islands. Besides precipitations, on coral atolls groundwater is the only source of fresh water, usually extending below sea level in the form of a thin fresh water lens. Several possible environmental hazard can affect the availability of the resource, ranging from salinization induced by overexploitation to deterioration induced by unsustainable land use. Therefore, it becomes important to understand and characterize atolls' islands aquifers and identify sustainable and hazardous practices to support a wise and farsighted resource management.

In this work a detailed characterization of the aquifer of Magoodhoo Island (Faafu Atoll – Maldives) is performed, through a hydrogeological mapping and groundwater quality characterization.

The Magoodhoo Island, with an area of 0.213 km2, is a typical and representative native inhabited island (c.a. 850 people) not affected by intense tourist traffic.

In order to collect topographic data, a drone survey was performed, with a fly altitude set at 80 m a.s.l. to reach a 4 cm ground pixel resolution obtaining a Digital Elevation Model (DEM), with a resolution of 10 cm.

Groundwater depth (m a.s.l.) was measured in 37 monitoring wells using a water level dipper to obtain a piezometric map of the aquifer. Furthermore, two CTD-diver were used to measure groundwater depth in a monitoring well and tidal oscillation of the sea level simultaneously with a time-resolution of 15 minutes for 5 days.

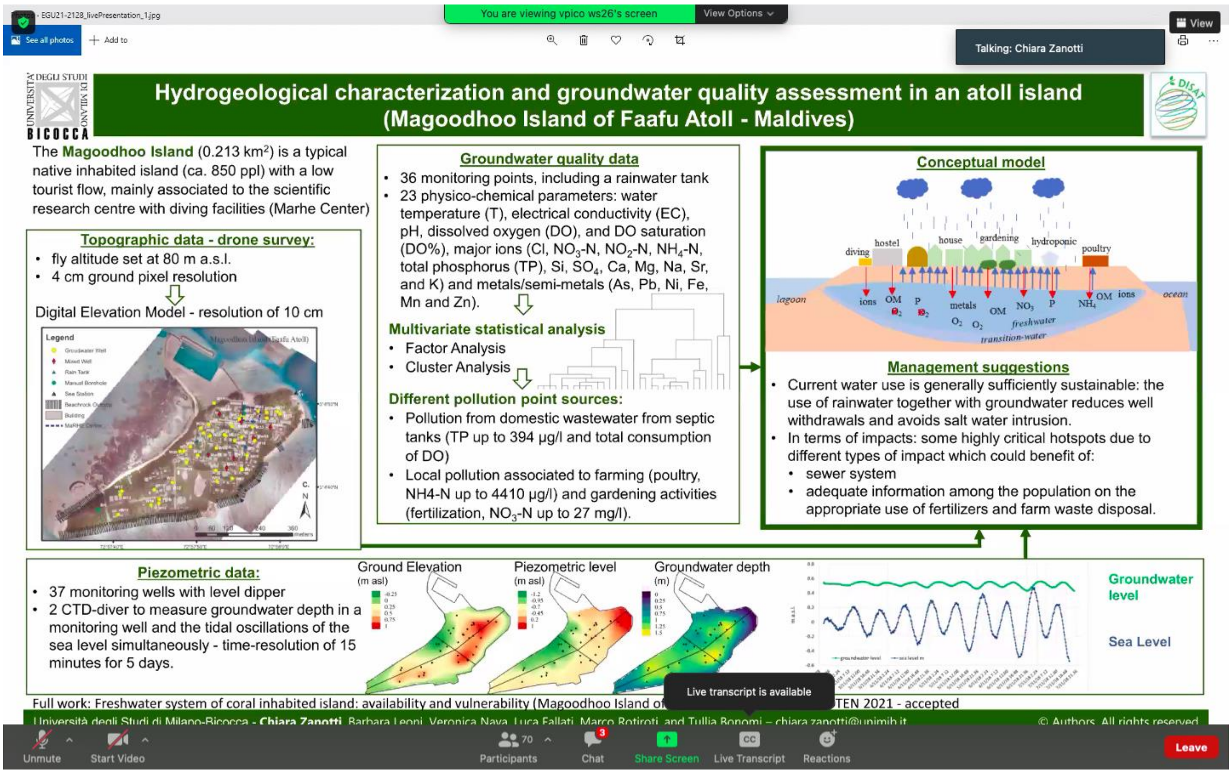
Groundwater quality data were collected in 36 monitoring points, including a rainwater tank and analyzed for physico-chemical parameters including water temperature (T), electrical conductivity (EC), pH, dissolved oxygen (DO), and DO saturation (DO%), major ions (Cl, NO_3-N, NO_2-N, NH_4-N, total phosphorus (TP), Si, SO_4, Ca, Mg, Na, Sr, and K) and metals/semi-metals (As, Pb, Ni, Fe, Mn and Zn).

Results show that groundwater depth varies spatially from around 1 m a.s.l. in the north-eastern part (ocean side) to -1.2 m a.s.l. in the central-western part. On the time scale, a good correlation between groundwater level and tidal fluctuations is observed and a tidal lag of about 3.5 hours was determined through a cross-correlation analysis.

Groundwater quality data highlighted different pollution point sources. The main impact on water quality was related to domestic activities producing a great amount of organic matter and wastewater. Other cases of local pollution were identified and associated to farm (poultry) and gardening activities (fertilization).

This study allowed for an in-depth knowledge of the Magoodhoo island aquifer system, which can be extended to other Maldivian and atoll islands constituting a valuable support for future water resource planning and management.

How to cite: Zanotti, C., Leoni, B., Nava, V., Fallati, L., Rotiroti, M., and Bonomi, T.: Hydrogeological characterization and groundwater quality assessment in an atoll island (Magoodhoo Island of Faafu Atoll - Maldives), EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2128, https://doi.org/10.5194/egusphere-egu21-2128, 2021.

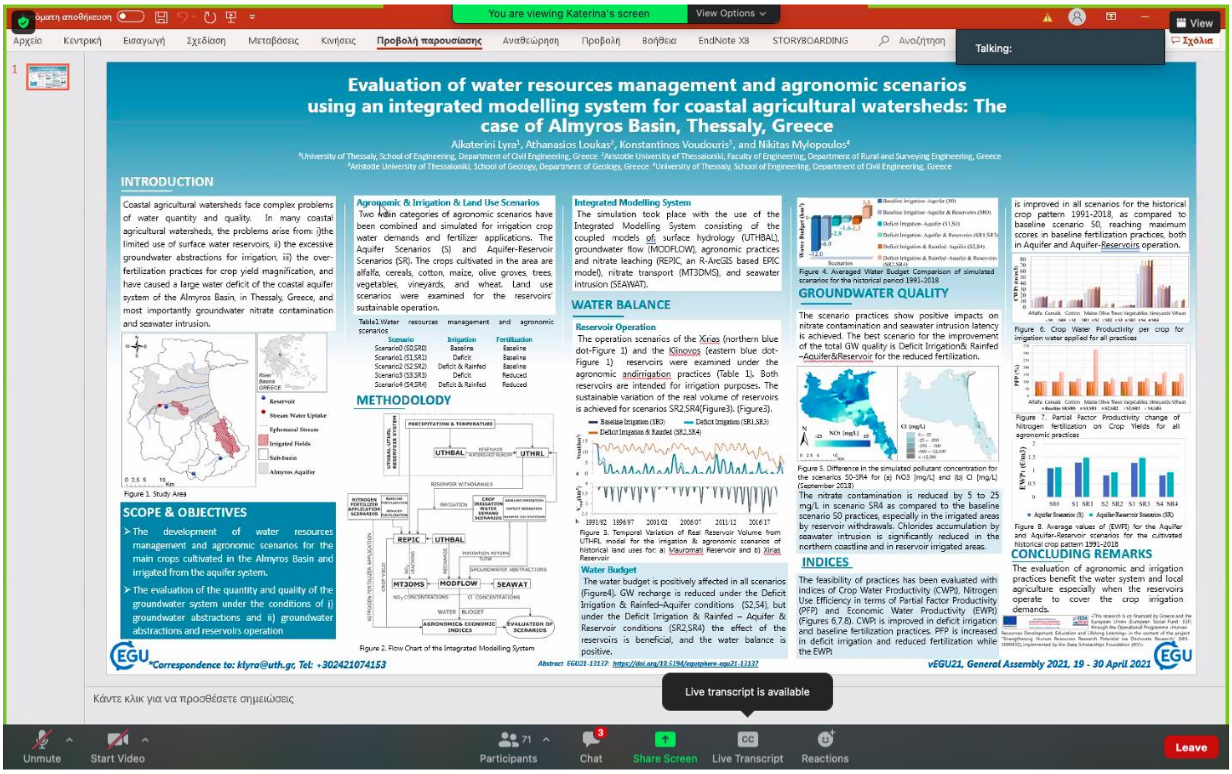


Evaluation of water resources management and agronomic scenarios using an integrated modelling system for coastal agricultural watersheds: The case of Almyros Basin, Thessaly, Greece

Aikaterini Lyra, *Athanasios Loukas, Konstantinos Voudouris, and Nikitas Mylopoulos*

Coastal agricultural watersheds face complex problems of water quantity and quality. In many coastal agricultural watersheds, the problems arise from: i) the limited use of surface water, ii) the excessive groundwater abstractions for irrigation, and iii) the over-fertilization practices for crop yield magnification. These complex and interrelated problems may be studied by using an integrated modelling system of surface water and groundwater able to simulate the processes regarding the quantity and quality of water. In this study, water resources management and agronomic scenarios are developed for the evaluation of the quantity and quality of the groundwater system of the semi-arid coastal agricultural Almyros Basin, in Thessaly, Greece. The historical and current unsustainable irrigation and fertilization practices, the groundwater abstractions, and the limited use of surface water reservoirs have caused a large water deficit of the aquifer system, groundwater nitrate contamination and seawater intrusion, resulting in severe degradation of water resources. Land use change and agronomic scenarios, as well as, reservoir operation scenarios, are combined and simulated using an integrated modelling system. The Integrated Modelling System consists of coupled models of: surface hydrology (UTHBAL), groundwater flow (MODFLOW), agronomic practices and nitrate leaching (REPIC, an R-ArcGIS based EPIC model), nitrate transport (MT3DMS), and seawater intrusion (SEAWAT). The models have been calibrated and validated against observations/measurements of various variables, e.g. groundwater table levels, crop yields, nitrate concentrations and chloride concentrations. The feasibility of the simulation of the various scenarios have been, also, evaluated with indices of Crop Water Productivity (CWP), Nitrogen Use Efficiency (NUE) and Economic Water Productivity (EWP).

How to cite: Lyra, A., Loukas, A., Voudouris, K., and Mylopoulos, N.: Evaluation of water resources management and agronomic scenarios using an integrated modelling system for coastal agricultural watersheds: The case of Almyros Basin, Thessaly, Greece, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13137, https://doi.org/10.5194/egusphere-egu21-13137, 2021.



Geochemical characterization of groundwater and saltwater intrusion processes along the Luy River, Binh Thuan, Vietnam

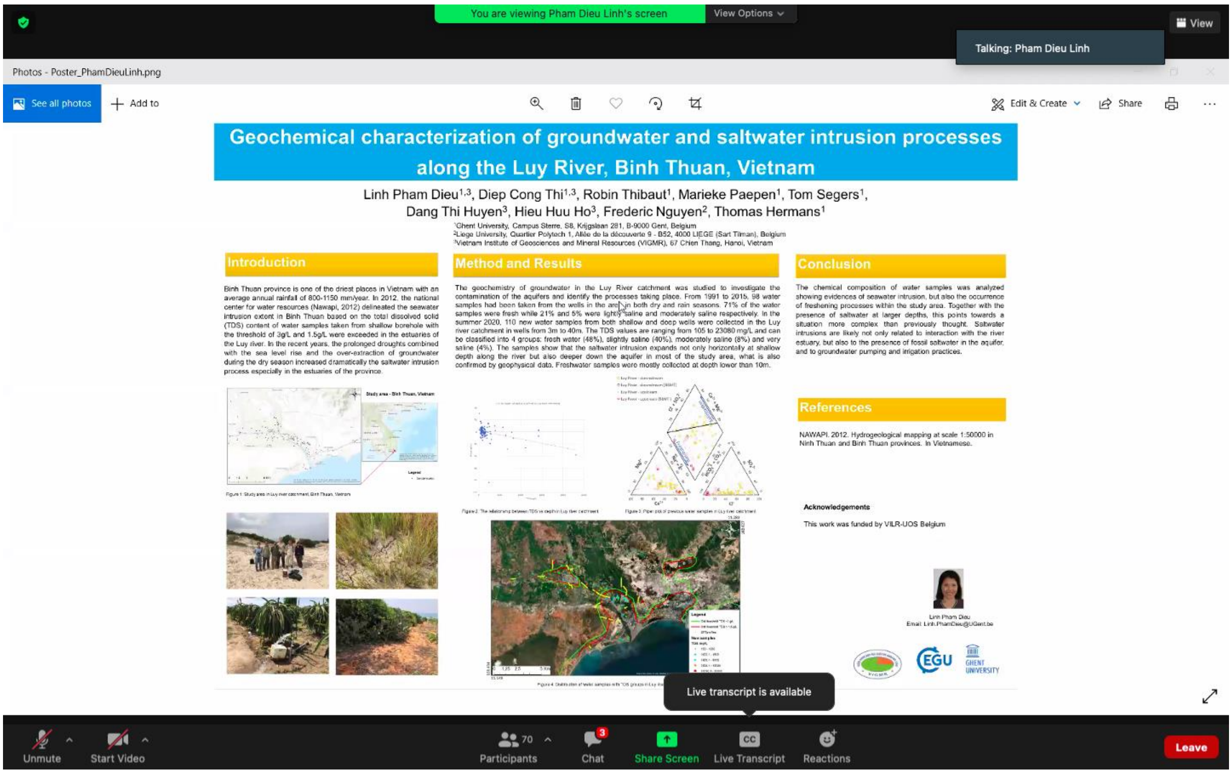
Linh PHAM Dieu, *Diep Cong Thi, Robin Thibaut, Marieke Paepen, Tom Segers, Huyen Dang Thi, Hieu Ho Huu, Frederic Nguyen, and Thomas Hermans*

With an average annual rainfall of 800-1150 mm/year, the Binh Thuan province is one of the driest places in Vietnam. The quantity and quality of groundwater play a significant role in the agriculture, aquaculture development and daily life of the local communities. In 2012, the national center for water resources delineated the seawater intrusion extent in Binh Thuan based on the total dissolved solids (TDS) content of water samples taken from shallow boreholes. The threshold of 3 g/L and 1.5 g/L were exceeded in the estuaries of the Luy, Long Song and Ca Ty rivers. In recent years, the prolonged droughts combined with the sea level rise and the over-extraction of groundwater during the dry season increased dramatically the seawater intrusion process especially in the estuaries of the province.

The geochemistry of groundwater in the Luy River catchment was studied to investigate the contamination of the aquifers and identify the processes taking place. From 1991 to 2015, 98 water samples had been taken from the wells in the area in both dry and rainy seasons. 71% of the water samples were fresh while 21% and 5% were lightly saline and moderately saline respectively. In summer 2020, 110 new water samples from both shallow and deep wells were collected in the Luy river catchment in wells from 3m to 40m. The TDS values are ranging from 105 to 23080 mg/L and can be classified into 4 groups: freshwater (48%), slightly saline (40%), moderately saline (8%) and very saline (4%). The samples show that the seawater intrusion expands not only horizontally at shallow depth along the river but also deeper down the aquifer in most of the study area, what is also confirmed by geophysical data. Freshwater samples were mostly collected at a depth lower than 10m. The chemical composition of water samples were analyzed showing evidence of seawater intrusion, but also the occurrence of freshening processes within the study area. Together with the presence of saltwater at larger depths, this points towards a situation more complex than previously thought. Saltwater intrusions are likely not only related to interaction with the river estuary, but also to the presence of fossil saltwater in the aquifer, and to groundwater pumping and irrigation practices.

KEYWORDS: Saltwater intrusion, Geochemistry, Groundwater extraction

How to cite: PHAM Dieu, L., Cong Thi, D., Thibaut, R., Paepen, M., Segers, T., Dang Thi, H., Ho Huu, H., Nguyen, F., and Hermans, T.: Geochemical characterization of groundwater and saltwater intrusion processes along the Luy River, Binh Thuan, Vietnam, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-906, https://doi.org/10.5194/egusphere-egu21-906, 2021.



DAY 3

Mapping, Monitoring, Forecasting and Assessing the Impact of Climate Change in Groundwater Systems in Ireland

Joan Campanyà i Llovet, *Ted McCormack, Damien Doherty, Philip Schuler, Monika Kabza, Ellen Mullarkey, and Owen Naughton*

In recent years Ireland has experienced significant and unprecedented flooding events, such as groundwater floods, that extended up to hundreds of hectares during the winter flood season, lasting for weeks to months, and affecting many rural communities in Ireland. In response to the serious flooding of winter 2015-2016, specifically related to groundwater, Geological Survey Ireland (GSI) initiated a project (GWFlood, 2016-2019), in collaboration with Trinity College Dublin (TCD) and Institute of Technology Carlow (ITC), to investigate the drivers, map and numerically model the extent of groundwater flooding in Ireland. Through this project, the use of remote sensing data, Sentinel-1 satellite imagery from the European Space Agency Copernicus program, was key to overcome the practical limitations of establishing and maintaining a national field-based monitoring network. The main outputs for this project included: 1) a national historic groundwater flood map, 2) a methodology for hydrograph generation using satellite images, and 3) predictive groundwater flood maps for Ireland.

Subsequently GSI started a new project (GWClimate, 2020-2022), in collaboration with ITC, to monitor floods in Ireland using remote sensing data, to enable short-term forecasting groundwater floods at a national scale, and to evaluate the potential that climate change may have on Irish groundwater resources, both in terms of flooding and drought issues. The GWClimate project is enhancing the tools developed by GWFlood in order to deliver: 1) seasonal flood maps for Ireland, 2) near-real time satellite-based hydrographs, 3) groundwater flood forecasting tools, and 4) maps evaluating the impact of climate change in groundwater systems in Ireland. The outputs of this project will contribute to monitor and quantify the impacts of flooding in Ireland at a national scale, improve the national capacity to understand how groundwater resources respond to climatic stresses, and improve the reliability of adaptation planning and predictions in the groundwater sector.

Data and maps from GWClimate and GWFlood projects are available at: 1) https://gwlevel.ie, and 2) https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/activities/groundwater-flooding/gwflood-project-2016-2019/Pages/default.aspx

How to cite: Campanyà i Llovet, J., McCormack, T., Doherty, D., Schuler, P., Kabza, M., Mullarkey, E., and Naughton, O.: Mapping, Monitoring, Forecasting and Assessing the Impact of Climate Change in Groundwater Systems in Ireland, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16012, https://doi.org/10.5194/egusphere-egu21-16012, 2021.

Towards a European denitrification concept for improved groundwater quality management and chemical status assessment

Laurence Gourcy, *Klaus Hinsby, Laerke Thorling, Stephanie Pinson, Matthew Ascott, Hans-Peter Broers, Eline Malcuit, and Christos Christophi*

Denitrification potential is an important parameter to know for adequate and efficient management and assessment of groundwater vulnerability and chemical status. Denitrification removes nitrate in groundwater, but the denitrification capacity is highly variable in space and time, and it may be used up with time. When linking pressure and impact the effect of partial or complete denitrification and denitrification capacity should be taken into account. In some areas, denitrification is seen as an advantage, allowing higher N release below soil without leading to a decrease of the groundwater quality and eventually concentrations in groundwater higher than the WFD and the GWD threshold values, which EU member states have to establish to protect drinking water and groundwater dependent terrestrial and associated aquatic ecosystems.

Within the GEOERA HOVER project, the aim was to assess the spatial extent and importance of denitrification. The studied cases permitted at a first step to highlight the heterogeneities of the approaches due to the variability of information obtained i.e. the likelihood of denitrification, depth and thickness of redox transition zone, complete denitrification status. The parameters used to define the denitrification vary also from one country to another based on a large set of redox sensitive ions (Eh, O_2, NO_3, NO_2, Fe, Mn, SO_4, CH_4, δ18O-NO_3 et δ15N-NO_3, H_2S or N_2). Some of these parameters can be accessed by standard methods in most laboratories, used for groundwater quality monitoring, while others require specialized analysis and interpretations.

Considering groundwater and hydrogeological data available in most of the EU countries, a simple method is proposed in order to classify the monitoring points into three classes: oxic, anoxic and mixed. After being tested in different well-known areas the method will be applied in various lithologies and hydrogeological contexts The proposed method will enable the development of European maps supporting groundwater quality management across Europe.

How to cite: Gourcy, L., Hinsby, K., Thorling, L., Pinson, S., Ascott, M., Broers, H.-P., Malcuit, E., and Christophi, C.: Towards a European denitrification concept for improved groundwater quality management and chemical status assessment, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14289, https://doi.org/10.5194/egusphere-egu21-14289, 2021.

Impact of climate change on groundwater: a global assessment with the CNRM climate models

Maya Costantini, *Bertrand Decharme, and Jeanne Colin*

Groundwaters found in aquifers play an important role in the hydrological cycle and are essential for human activities and for natural ecosystems. They account for approximately one third of the human fresh water withdrawals and sustain ecosystems by supplying soil moisture during dry periods. Climate change will impact every component of the climate system and aquifers are no exception. Precipitation is the main driver of groundwater recharge and relatively shallow aquifers respond rather quickly to changes in the precipitation rates. Thus, climate change should have an impact on water table depths and could lead to water scarcity and food insecurity in some regions. Therefore, knowing the response of the aquifers to climate change is important to improve the development of mitigation and adaptation plans in water management.

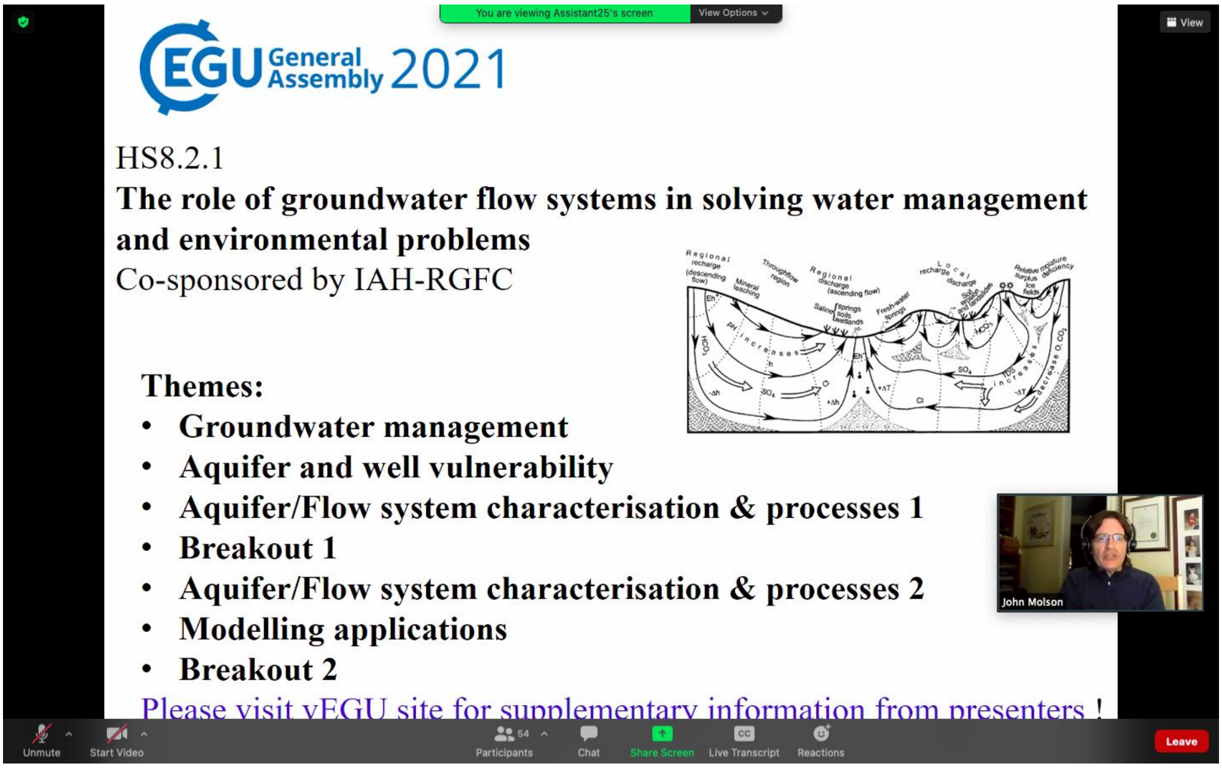
Here, the response of unconfined shallow aquifers to climate change is assessed at the global scale using the global climate model developed in our institute (CNRM): CNRM-CM6 and CNRM-ESM2. We analyze simulations conducted for the Coupled Model Intercomparison Project 6 (CMIP6) following four pathways of greenhouse gas concentrations until 2100. The CNRM models are the only global climate models representing the physicals processes involving aquifers. Results show that aquifers should replenish at the global scale on average, which is consistent with the projected global intensification of precipitation. However, the evolution of water table depths is not uniform and presents large regional disparities. Additionally to climate change, anthropogenic impacts like intensive groundwater withdrawals for agricultural, domestic and industrial purposes should exacerbate the depletion in some aquifers basins. In order to identify these regions, the evolution of the water table depths is compared with the population density. This analysis highlights the widening risk of water stress in some already aquifer-dependent regions.

How to cite: Costantini, M., Decharme, B., and Colin, J.: Impact of climate change on groundwater: a global assessment with the CNRM climate models, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9634, https://doi.org/10.5194/egusphere-egu21-9634, 2021.

DAY 4

On 30th of April Aiga Krauze participated in session HS8.2.1 "The role of groundwater flow systems in solving water management and environmental problems". She presented WaterAct project. Later she participated in a breakout chat room about groundwater management where questions were asked. There were four questions about WaterAct presentation:

1) There was a question about cross-boundary cooperation – how that works?
2) Also there was a question about public awareness – how that will be implemented?
3) Are stakeholders involved in spring monitoring guide development?
4) Also – what is taught in schools of Latvia about groundwaters?



Managing coastal aquifers in climate and socio-economic change: An indicator-based multi-criteria decision system approach

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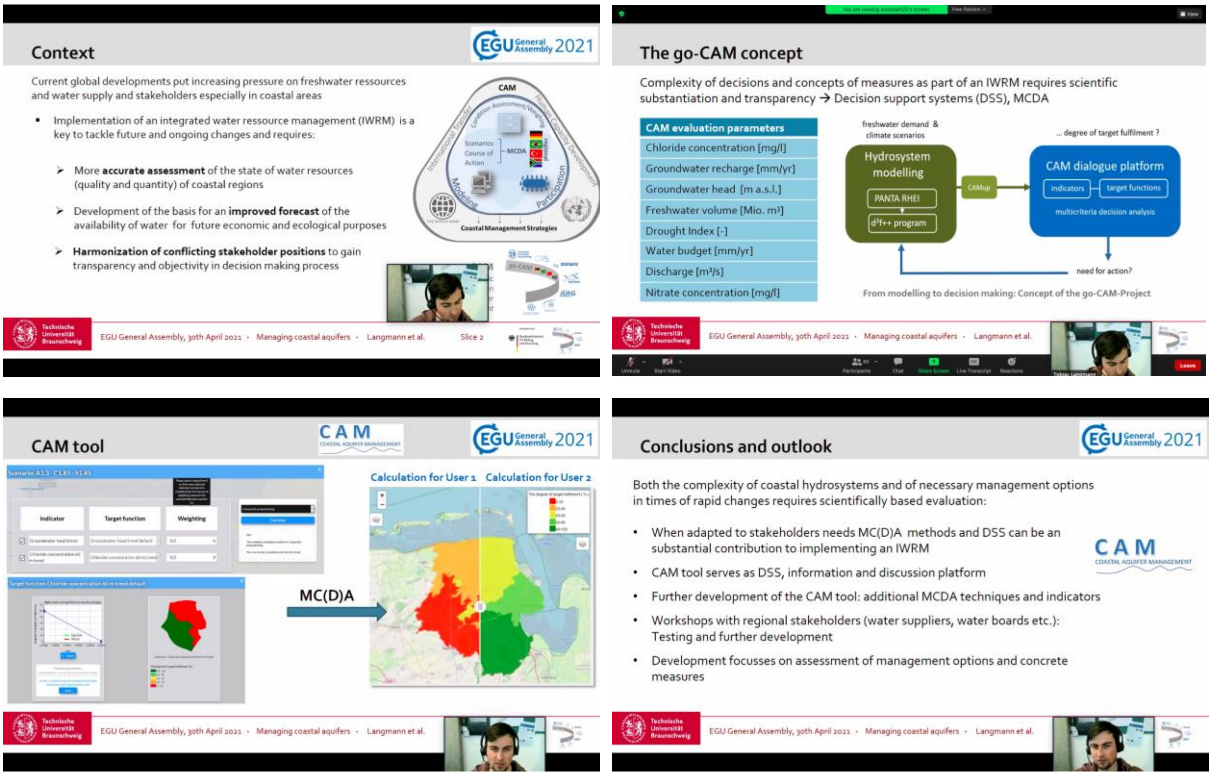
Worldwide, climate change as well as socio-economic changes are increasing pressure on water supply in coastal regions and lead to major changes in groundwater recharge as well as the regional water balance as parts of the hydrosystem. These changes are threatening water security and, thereby, impede the fulfillment of the SDG 6 targets, esp. SDG targets 6.2., 6.4. and 6.6 of the UN 2030 Agenda for Sustainable Development. Thus, a modern water management demands innovative and profound methods and tools that comprehensively cover these complex changes. To address this challenge, in the BMBF project "go-CAM" (Implementing strategic development goals in Coastal Aquifer Management) we took the methodological approach of developing new groundwater status indicators (e.g. chloride concentration in groundwater, position of saltwater/freshwater interface, freshwater volume) and corresponding target functions implemented in a new online-based management and evaluation tool called "CAM" (Coastal Aquifer Management). Both the physically based indicators as well as the target functions tackle economic as well as ecological issues. The groundwater status indicators are directly derived from the results of high-resolution, process-based (hydrological and hydrogeological) modeling of coastal hydrosystems. Due to their physical nature, the indicators are only applicable with appropriately designed climate and socio-economic scenarios for coastal water management if they are generated with models that also capture the system-relevant processes: Groundwater recharge, groundwater abstraction, discharge dynamics through drainage systems, sea level rise and groundwater discharge to the sea and saltwater intrusion.

The CAM platform is a tool that provides a way to make the results of the complex and extensive numerical modeling usable for a wider community and thus allow for a more efficient result exploitation. Building on the indicators and the selection of target functions and weighting factors the CAM tool uses Multi-Criteria Decision Analysis techniques (MCDA) to strengthen transparency and objectivity in decision-making processes and encourage communication between decision-makers in the water sector of coastal regions. In this way, the application of the CAM tool contributes to the establishment of an integrated water resources management and to derive and discuss future water management strategies as well as concrete measures.

Our methodological approach as well as the results are presented applied to a regional coastal groundwater study area in the northwestern part of Germany, the Sandelermöns region, which covers an area of about 1,000 km².

How to cite: Langmann, T., Schöniger, H. M., Schneider, A., and Sander, M.: Managing coastal aquifers in climate and socio-economic change: An indicator-based multi-criteria decision system approach, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12064, https://doi.org/10.5194/egusphere-egu21-12064, 2021.



How irrigation good practices can put under pressure the groundwater system of the Bacchiglione Basin (Italy)

***Mara Meggiorin*[1,2], *Giulia Passadore*[2], *Silvia Bertoldo*[1], *Andrea Sottani*[1], *and Andrea Rinaldo*[2,3]**

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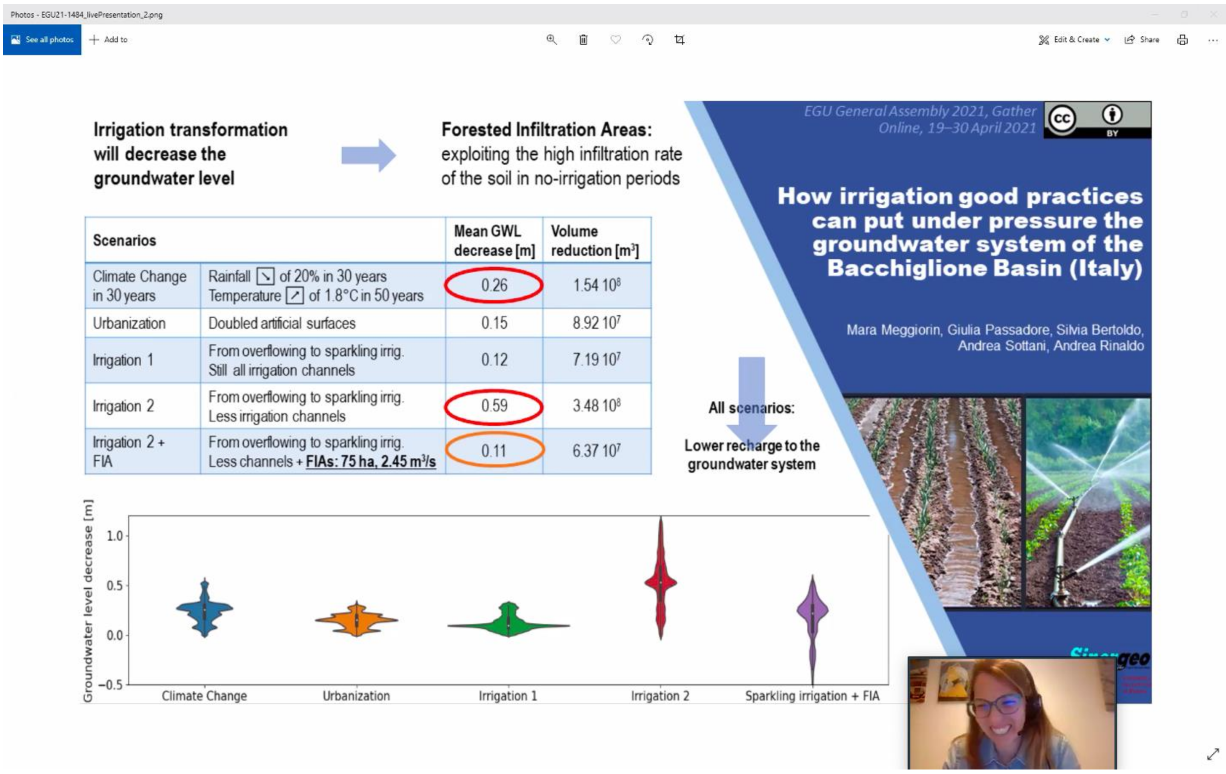
In the coming years, water resource management will become more and more important for satisfying competing water-related needs under the pressure of water scarcity and climate change. The choice of how to allocate water is difficult, uncertain, and context specific. This study aims to bring to the fore a significant example of sustainability of groundwater system management under specific requirements and dependence on irrigation activities. The groundwater system at hand is the Bacchiglione basin, near Vicenza (Veneto, Italy), an essential water asset for local ecosystems, human needs and economic activities. Its recharge mainly happens in the northern unconfined portion by three factors: river seepage, rain and irrigation infiltrations.

Historically, the contribution of irrigation practices has been fundamental for recharging the hydrogeological system. However, local irrigation authorities have begun to replace traditional irrigation techniques, such as the field overflow or draining channels, with more innovative techniques, such as piping grids with sprinkling devices. The shift towards more efficient methodologies, whose main goal is to save water, puts under pressure the local groundwater system because of the reduced artificial recharge.

Currently, the present irrigation network, techniques and activity schedule yields an overall annual irrigation contribution of approximately 5.4 m^3/s, about the 25% of the total inflow at the basin scale. This flow is expected to decrease in the future. By modelling the system (via FEFLOW), this study concerns possible scenarios by changing the irrigation technique. As an example, all currently overflowed fields are converted to sprinkling irrigation. This technical change leads to an estimated inflow decrease of 1.6 m^3/s during the irrigation period between May and August, without considering the consequent decreased dispersion by distribution channels. This scenario highlighted an area particularly affected by a piezometric drawdown which is of particular interest because in the district many wells for the public supply authorities are located.

Our study confirms irrigation as an important recharging factor within the Bacchiglione basin. The project of making agriculture more efficient with 'good practices' involves in this specific case a lowering groundwater level, comparable to climate change and land use change effects. To counteract such resource depletion, local irrigation authorities have already tested managed aquifer recharge measures, like e.g. forested infiltration areas. To be effective, however, such interventions should be planned at larger spatial scales to grant adequate long-term effects. Moreover, the present work suggests to keep active irrigation channels in winter months to increase seepage and also to sustain local habitats and ecosystems and maintain the rural landscape.

How to cite: Meggiorin, M., Passadore, G., Bertoldo, S., Sottani, A., and Rinaldo, A.: How irrigation good practices can put under pressure the groundwater system of the Bacchiglione Basin (Italy), EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-1484, https://doi.org/10.5194/egusphere-egu21-1484, 2021.



Water management in the Mucille area (NE Italy) through hydrologic balance estimation

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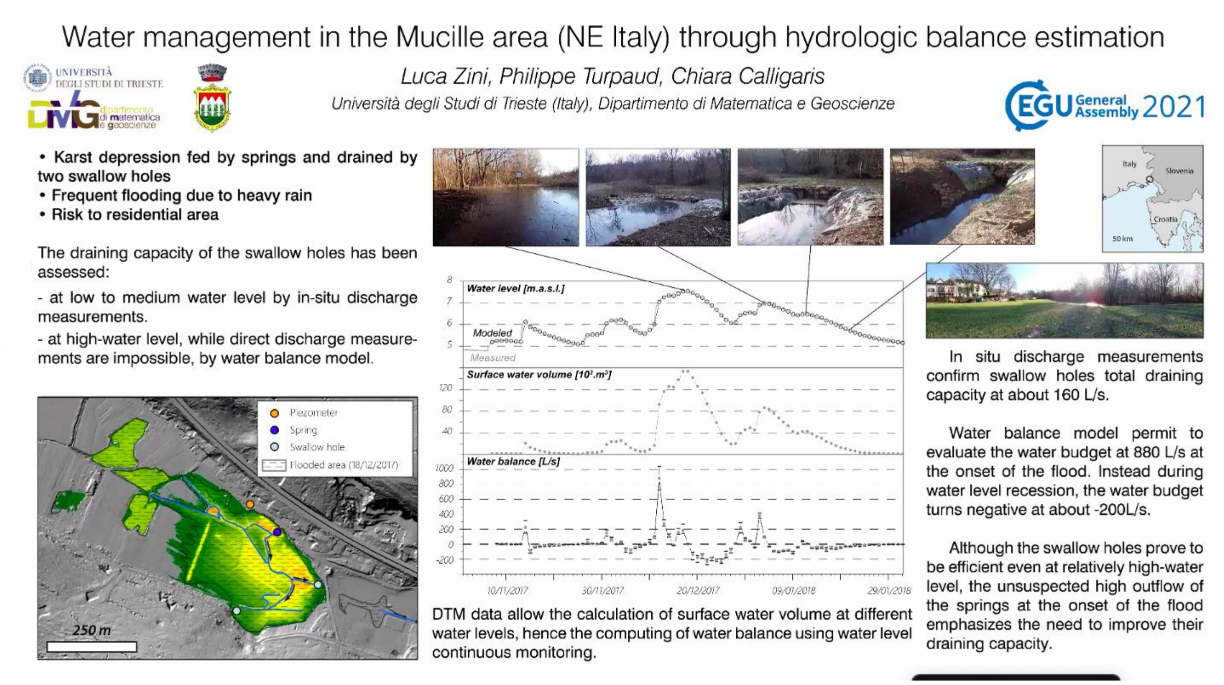
After abundant rainfalls, the Mucille area (Ronchi dei Legionari, Northeastern Italy) is subject to frequent flooding. Although this area has always been exposed to such hazard, these inundations become problematic since 2001 as they more frequently affect housing and recreational areas, leading the population to believe that the swallow holes draining the area stopped functioning. The increased frequency of intense rainfall events led the municipal technicians to involve the Department of Mathematics and Geosciences of the University of Trieste to assess the situation. The Mucille karstic depression is fed by a spring area and drained by two swallow holes one of which is permanently active while the other operates only during floods. The Mucille springs represent the westernmost drain of the Classical Karst aquifer. During floods, as in-situ discharge measurements are impossible, only a hydrologic balance model may assess the inflow or outflow discharges. The extension of the flooded areas has been mapped. The obtained flooded surface together with high resolution DEM coverage allows to calculate the volume of surface water. Combined with water table levels recorded in an adjacent piezometer, this volume can be computed over time. Thus, the hydrologic balance (inflow minus outflow) can be estimated. This model has been applied to several flood events among which, two were the most important in terms of flooded areas: one in December 2017 and the other in November 2019. During the event of December 2017, the water level reached 7,5 m a.s.l. and the difference between the inflow and the outflow was 880 l/s. The day following the peak, the discharge difference decreased to 273 l/sand the 5 subsequent days the water balance was close to equilibrium. From the eighth day on, the outflow became predominant resulting in a negative budget between -233 and -78 l/s. The flood event of November 2019 reached the maximum inundated area at a water level of 7,8 m a.s.l. with a difference between the inflow and the outflow of 750 l/s . Two days after the peak a negative balance of -200 l/s was recorded and remained negative for the next 5 days. A period of intermittent precipitations increased again the inflow up to 600 l/s. Following a period of ten days with a negative balance the water level returned to the initial values of 5 m a.s.l. This study provides evidences fundamental for the design of measures to mitigate the risk. It estimates the discharge of the swallow holes, confirming their efficiency. Nonetheless it also emphasizes the need to improve their draining capacity, especially considering the unsuspected high outflow of the springs at the onset of the flood.

How to cite: Zini, L., Turpaud, P., and Calligaris, C.: Water management in the Mucille area (NE Italy) through hydrologic balance estimation, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-12006, https://doi.org/10.5194/egusphere-egu21-12006, 2021.



Spatial variability and changes in storage-discharge relationships of crystalline catchments: implications for resilience and water resources management

***Ronan Abhervé*[(1)]*, Clément Roques[(1)], Laurent Longuevergne[(1)], Stéphane Louaisil[(2)], Jean-Raynald de Dreuzy[(1)], and Luc Aquilina[(1)]*

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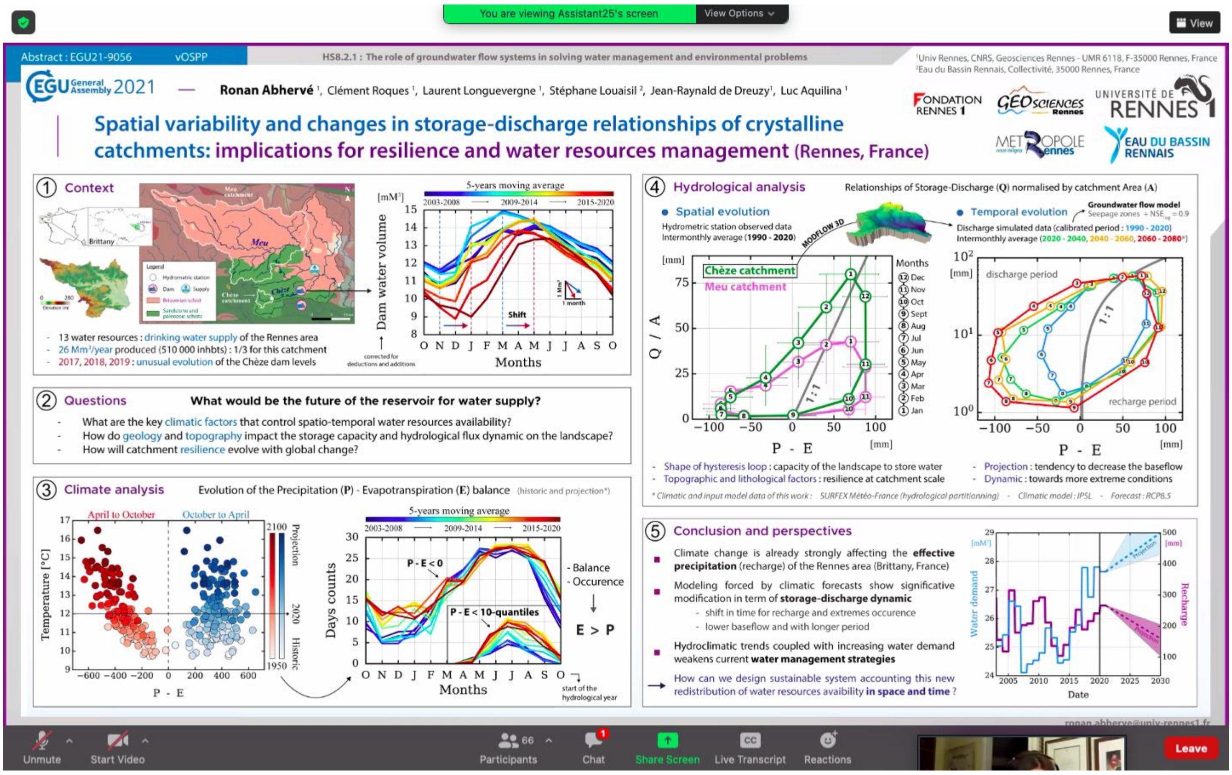
While it is well understood and accepted that climate change and growing water needs affect the availability of water resources, the identification of the main physical processes involved remains challenging. It notably requires to filter interannual to interdecadal fluctuations and extreme events to isolate the underlying trends. Metropolitan areas are specifically subject to growing pressures because of the significant and increasing demand, combined with the strong anthropization of land uses.

The Meu-Chèze-Canut catchment supplies the city of Rennes with drinking water (680 km² - 500 000 users, Brittany, France). In this field laboratory, we explore the dynamics of the water cycle and water resources availability. In this context, water supply is mostly coming from reservoir storage for which levels shows a medium-term vulnerability in response to frequent relatively dry years. Based on retrospective data analysis, we describe the relationship between climatic forcing (precipitation, temperature) and water availability (aquifer storage, river discharge and reservoir storage) in different parts of the catchment that are characterized by distinct lithological and topographical settings. We then evaluate the resilience of both surface and groundwater resources, their past evolution and their resilience to climate change and increasing societal needs.

Water resources availability in these catchments relies on two geological formations with distinct hydrodynamics properties: the Armorican sandstone and Brioverian schist. To assess the resilience of the system, we specifically analyzed the relationships between monthly effective precipitation and stream discharge within nine sub-catchments over the past 30 years. We observe annual hysteresis relationships - that is, a time lag between precipitation and discharge highlighting the capacity of the landscape to temporarily store water - with significant variability in shapes across the catchments. We argue that topographic and lithological factors play key roles in controlling this variability through their impacts on subsurface storage capacity and characteristic drainage timescales. We propose perspectives based on the complementary use of calibrated groundwater models to leverage these results and provide adaptive water management strategies.

How to cite: Abhervé, R., Roques, C., Longuevergne, L., Louaisil, S., de Dreuzy, J.-R., and Aquilina, L.: Spatial variability and changes in storage-discharge relationships of crystalline catchments: implications for resilience and water resources management, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-9056, https://doi.org/10.5194/egusphere-egu21-9056, 2021.



Management of groundwater salinization under a climate change scenario in an aridarea

Oussama Dhaoui, *Isabel Margarida Horta Ribeiro Antunes, Belgacem Agoubi, and Adel Kharroubi*

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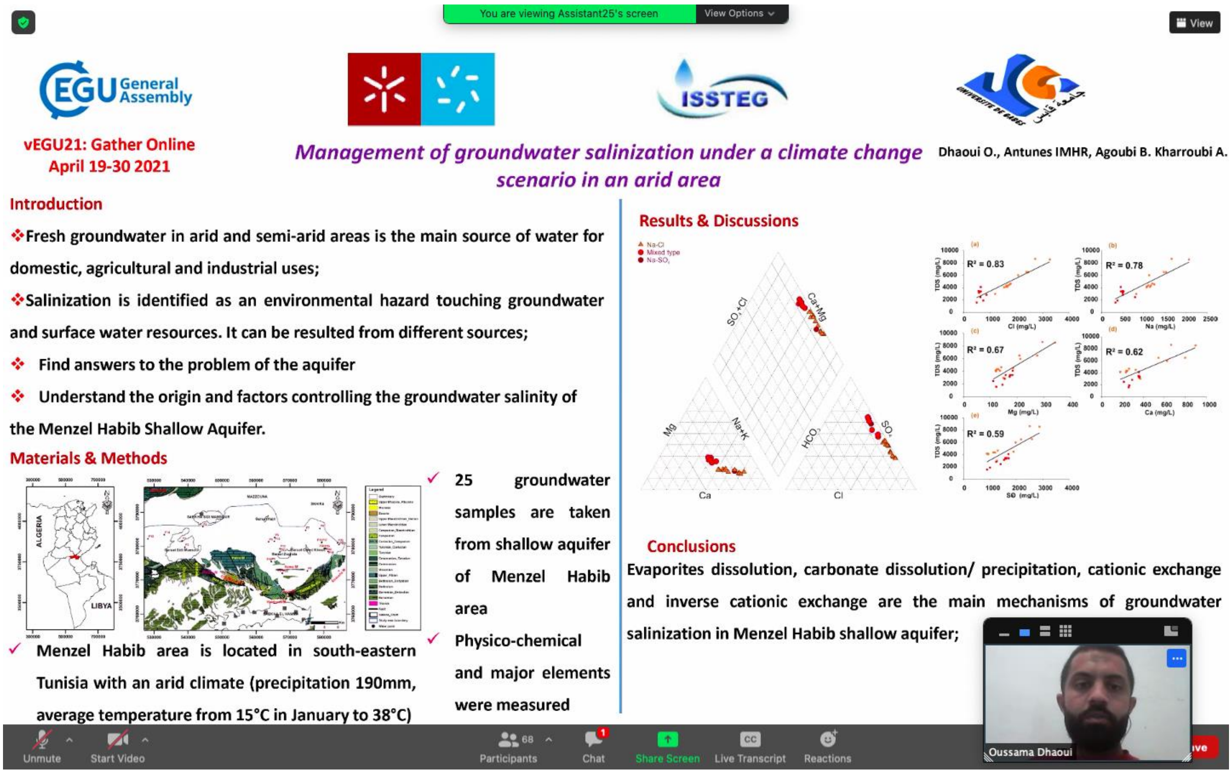
Most future scenarios for water resources are predicting water scarcity, with a decrease in the amount of precipitation and limitation on groundwater recharge for the next five decades. In arid and semi- arid areas, the water quality is a great problem and groundwater salinization is one of the principal causes of degradation of water resources worldwide. Menzel Habib aquifer is located in the northwest of Gabès region (southeastern Tunisia), included in the arid Mediterranean bioclimatic area, with dry hot summers and relatively warm winters. Groundwater geochemistry from the study area shows a Na-Cl and Ca-Mg-Cl-SO_4 dominant facies. The high groundwater mineralization and its correlation between total dissolved solids and major ions suggest a contribution of SO_4 , Cl, Na, Ca and Mg in groundwater salinization processes. The salinization of groundwater is mainly associated with the Triassic evaporites, with the dissolution of halite, anhydrite and gypsum, occurring in the area, and related to the tectonic context of the region. Additionally, other geochemical processes occurred, such is the cation exchange mechanisms. Changes in precipitation patterns and intensity, with water scarcity, low recharge and excessive pumping have affected groundwater quantity and quality. Nowadays, the occurrence of climate changes scenarios is a major drawback for water use for irrigation and drinking water supply in arid and semi-arid regions, such as Menzel Habib aquifer.

How to cite: Dhaoui, O., Horta Ribeiro Antunes, I. M., Agoubi, B., and Kharroubi, A.: Management of groundwater salinization under a climate change scenario in an aridarea, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-7783, https://doi.org/10.5194/egusphere-egu21-7783, 2021.



Impacts of Desalinated Irrigation Water in the Abu Dhabi surficial aquifer

Claudia Cherubini[(1)], *Sathish Sadhasivam[(1)], Nicola Pastore[(2)], and Monica Ghirotti[(1)]*

[(1)]University of Ferrara, Department of Physics & Earth Sciences, Ferrara, Italy (claudia.cherubini@unife.it)
[(2)]Polytechnical University of Bari, DICATECH

Abu Dhabi is one of the arid regions in the world having less than 100 mm of rainfall per annum. The renewability of freshwater occurs only in the eastern part. The groundwater resources under desirable quality are very concise due to limited dilution/rainfall and higher rate of evaporation. Hence, in recent decades, desalinated water has been introduced for agriculture activities and surplus desalinated water is injected into the aquifer as artificial recharge. This study is conducted to understand the impacts in the aquifer system caused by the introduction of desalinated water for agriculture activities and for aquifer recharge structures. The simulation was carried out from 2000 to 2050 using reported rate of groundwater pumping and of desalinated water with 0.1 g/l, 0.5 g/l, 1 g/l, 1.5 g/l and 2 g/l degrees of salinity. A wide range of decline in the groundwater table is noticed in the western part of the aquifer due to less rainfall recharge. The results confirm that this region demands either reduction in agricultural activities or additional usage of desalinated water by which the pumping of groundwater can be reduced further. The improvement in the groundwater quality is noticed in the aquifer due to the addition of less saline desalinated water into the aquifer. This study confirms the long-term suitability of existing aquifer recharge structure. Also, it expresses the need of further management practices in quantifying the desalinated water contribution for agriculture activities.

How to cite: Cherubini, C., Sadhasivam, S., Pastore, N., and Ghirotti, M.: Impacts of Desalinated Irrigation Water in the Abu Dhabi surficial aquifer, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13095, https://doi.org/10.5194/egusphere-egu21-13095, 2021.

Investigating the possible measure to protect groundwater from polluted streams in Arid and Semi-Arid Regions: the Eastern Nile Delta case study

Ismail Abd-Elaty, *Martina Zelenakova, Salvatore Straface, Zuzana Vranayová, Mohamed Abu-hashim, Abdelazim Negm, and Andrea Scozzari*

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Groundwater is the main source of drinking water in the Nile Delta. Unfortunately, it might be polluted by seepage from polluted streams. This study was carried out to investigate the possible measures to protect groundwater in the Nile delta aquifer using a numerical model (MT3DMS - Mass Transport 3-Dimension Multi-Species). The sources of groundwater contamination were identified and the total dissolved solids (TDS) was taken as an indicator for the contamination. Different strategies were investigated for mitigating the impact of polluted water: i) allocating polluted drains and canals in lower permeability layers; ii) installing cut-off walls in the polluted drains, and finally, iii) using lining materials in polluted drains and canals. Results indicated these measures effective to mitigate the groundwater pollution. In particular, the cut-off wall was effective for contamination reduction in shallow aquifers, whereas it had no effect in the deep aquifer, while lining materials in polluted drains and canals were able to prevent contamination and to protect the freshwater in the aquifers. It is worth mentioning that this study was partially supported by a bilateral project between ASRT (Egypt) and CNR (Italy).

How to cite: Abd-Elaty, I., Zelenakova, M., Straface, S., Vranayová, Z., Abu-hashim, M., Negm, A., and Scozzari, A.: Investigating the possible measure to protect groundwater from polluted streams in Arid and Semi-Arid Regions: the Eastern Nile Delta case study, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14734, https://doi.org/10.5194/egusphere-egu21-14734, 2021.

Management of groundwater sustainability and contamination - a Mozambique case study

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Groundwater is vulnerable to contamination from natural and anthropogenic activities. The agricultural and human activities associated with hydrological characteristics influence the quality of groundwater. The City of Tete is in the Nharthanda Valley (Zambezi River, Central Mozambique). The city faces a set of serious structural issues of access to water such as a precarious public water supply system, including a lack of network management, water rationing, and a poor sewerage system. Groundwater is collected from the aquifer for the public water supply system of the old city of Tete and a for a traditional agro-livestock farm, which is irrigated by artesian wells. Groundwater abstraction has increased in the last few decades, and it was identified as a risk for groundwater quality and quantity. Groundwater physic-chemical and microbiological parameters obtained from fifteen boreholes and eleven wells have been determined to assess water quality. The presence of potential contaminant activities throughout the Nhartanda Valley and adjacent areas associated with contamination of the Zambezi River contribute to the degradation of water quality. The high vulnerability index for most chemical and microbiological elements indicates that groundwater is easily reached by bacteria and viruses and other potentially toxic substances. Most of the water parameters, from wells and boreholes, exceed the water referenced values allowed for human consumption and agricultural use. The protection of the Nhartanda Valley aquifer system is necessary and urgent. The identification of the most vulnerable areas provides important information for groundwater management, such as the indication of protection measures in aquifer systems.

How to cite: Antunes, I. M. H. and Bande, A.: Management of groundwater sustainability and contamination - a Mozambique case study, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-910, https://doi.org/10.5194/egusphere-egu21-910, 2021.

Reducing the risk for contamination of river bank filtration systems using inverse modelling and anthropogenic traces

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Many drinking water systems worldwide are based on river bank filtration. From a quantitative point of view river bank filtration systems are highly reliable because of the high permeability of alluvial aquifers linked to high production rates. However, there might be an increased risk of contamination because of the short residence time between the river and the production well, especially during flood events.

Flood events change the river-aquifer hydraulic interactions and may increase infiltration rates (e.g., due to an increased hydraulic head, larger river infiltration widths, or erosion of a siltation layer). This leads to changes in groundwater flow paths and production wells might abstract water with a shorter residence time and lower quality. Groundwater quality may degrade during flood events due to the presence of undesirable chemicals (e.g., wastes water treatment plant overflow) and the occurrence of fecal indicator bacteria such as *E.Coli*.

Groundwater modelling can assist in developing strategies to protect river bank filtration from such undesired contamination by predicting optimal operation conditions. The key impediment of this approach is significant uncertainties in subsurface properties and the associated uncertainties of the groundwater flow paths. To reduce uncertainties in model predictions, anthropogenic tracers including the MRI contrast agent gadolinium and artificial sweeteners were used in this study. They revealed sources and flow patterns, and have been used to derive mixing ratios representing different temporal and spatial scales. Including anthropogenic tracers into the objective function of the calibration process also led to more accurate estimation of groundwater flow paths. This was critical to predict the best water works operation strategy during flood events.

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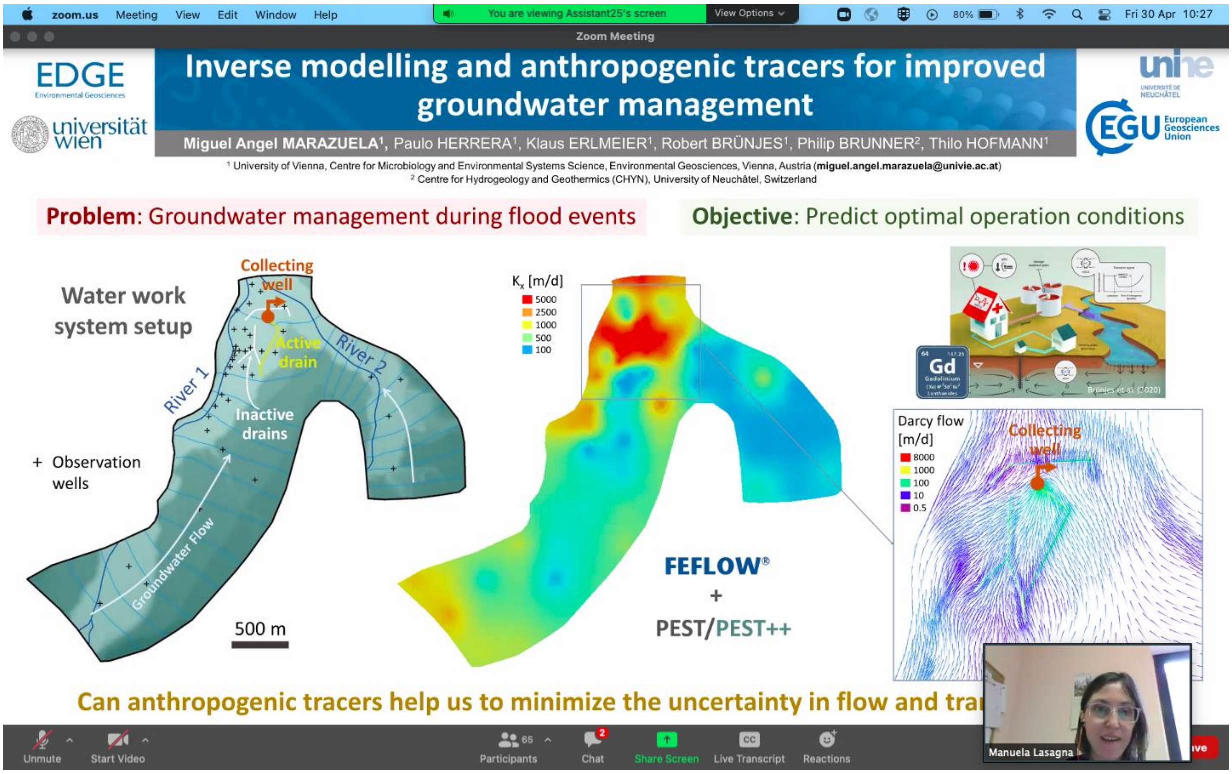

Hydrogeochemical and nitrate isotopic indicators of vulnerability in the Katari-Lago Menor basin-aquifer, Lake Titicaca-Bolivia

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In the semi-arid Bolivian Altiplano, the Katari and Lago Menor Basin, ranging between 6000 and 3800 m a.s.l. in altitude, hosts a major aquifer in Quaternary sediments of fluvioglacial and paleo lacustrine origin. This basin supports a population of over 1.2 million of inhabitants and the largest city in the Altiplano, El Alto, one of the Latin America's fastest growing cities in the 1980s. This rapid urban growth was accompanied by minimal land planning, and lack of basic infrastructure and environmental policies. In addition, the region is greatly affected by climate change, causing the glaciers to shrink. A multi-tracer approach was used to understand the main hydrogeochemical processes taking place along the groundwater flow, and to evaluate the impact of anthropogenic activities on groundwater quality and nitrate concentrations. In the upper part of the aquifer (above 4000m), in the Piedmont subsystem, siliciclastic and evaporitic rocks host groundwater of high quality. Here, groundwater chemistry is dominated by silicate weathering leading to a Ca(Mg)-HCO_3 facies, low nitrate concentrations (< 3.2 mgL^{-1}), and low mineralization. At lower altitude, the anthropogenic impact is revealed by the increase in NO3- concentrations, reaching up to 35.6 mgL^{-1}. Nitrate stable isotopes allowed discriminating three main nitrate contributions: leaching from areas influenced by manure piles, use of synthetic N fertilizers, and leakage from sewage collection pipes. Natural attenuation of nitrate occurs when fresh groundwater mixes with brackish groundwater of evaporitic origin. On the other hand, in the lacustrine plain (~3860 to 3810 m a.s.l), the groundwater geochemistry is dominated by evaporite dissolution and calcite precipitation, while nitrate originates from nitrification of synthetic fertilizers. This first hydrogeochemical study of one of the major groundwater systems in the Northern Altiplano is an important step towards a better management of this crucial water resource for the sustainable development of this region.

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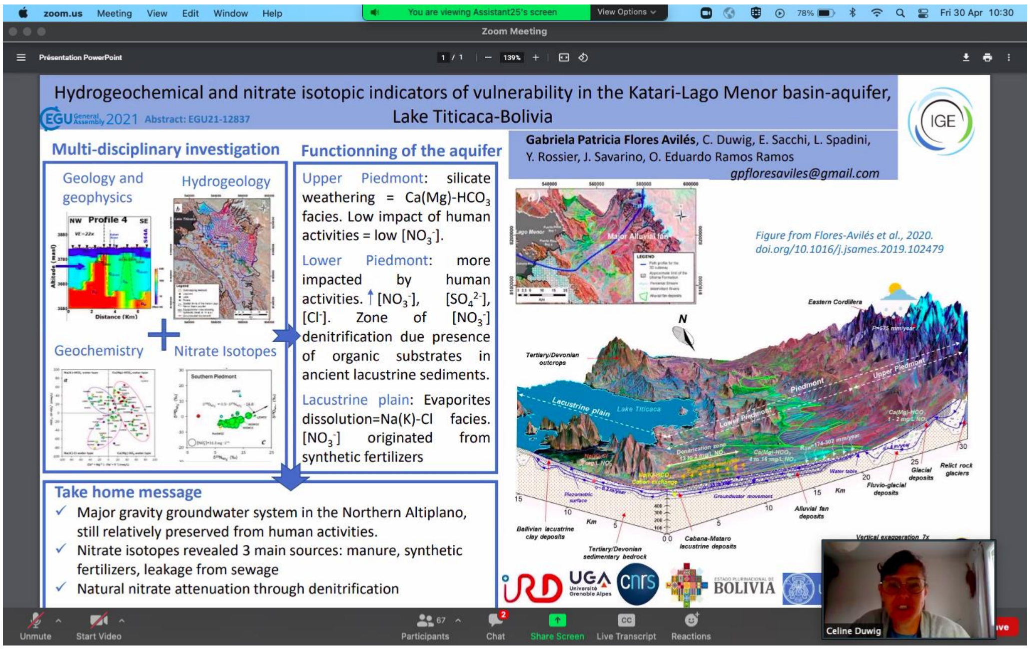

Vulnerability Assessment of Shallow Aquifers in Abuja using GIS and Hydrogeological Parameters

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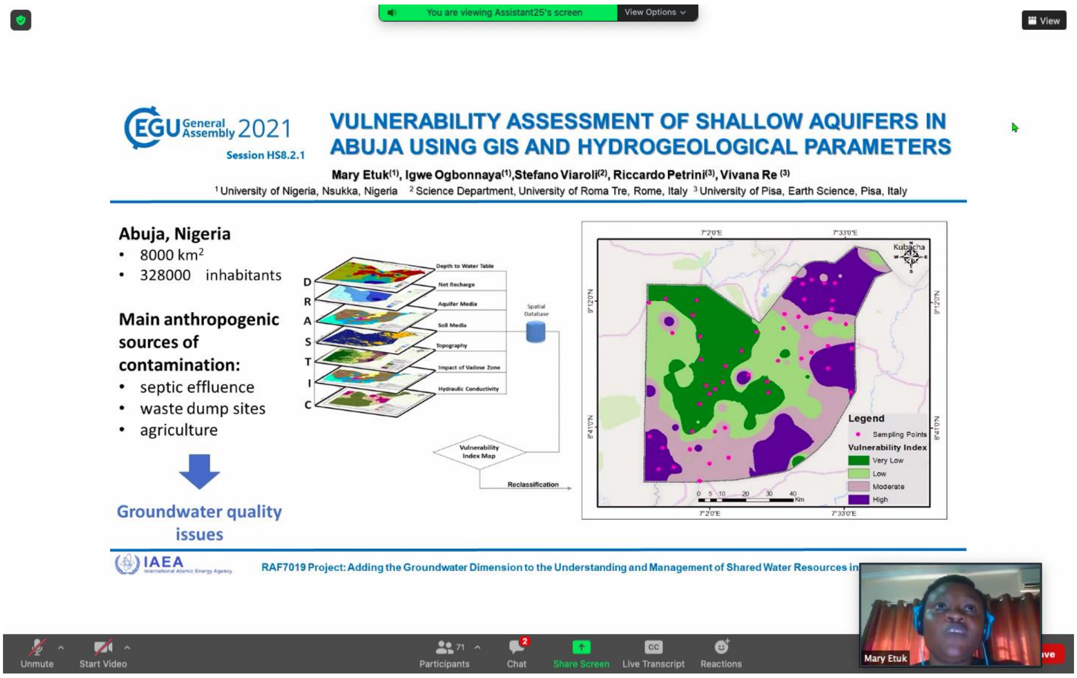
One of the major challenges for the sustainable development of the federal capital territory of Abuja (Nigeria) is related to the access to safe fresh water resources. This area lies within the drought prone parts of the Sahel region. As in many regions of the world there has been growing competing demands for fresh water as a result of population growth and groundwater quality degradation. In this context, the paucity of data and in-depth knowledge of aquifer features and groundwater flow makes groundwater management even more complex, with a severe impact on access to safe water resources for the local populations. To address this challenge, the purpose of the presented research is to generate information on aquifer settings and its vulnerability and on the qualitative and quantitative assessment of the available groundwater resources. Remote sensing and GIS were applied to improve the available information on groundwater resources of Abuja. Fundamental information such as recharge rate, availability and vulnerability of groundwater to pollution was determined. Aquifer vulnerability zones were delineated using the DRASTIC model by integrating layers of depth to groundwater, aquifer recharge, aquifer media, soil type, topography, impact of vadose zone and hydraulic conductivity. The study area covers about 8000km². The elevation ranges from 62 to 843m a.s.l. with the highest elevations at the North Eastern parts and the lowest elevations at the South Western parts of the study area. There are three soil types in the area, the silty clay, silt loam and clay with clay being the predominant soil type. The five major rock types in the area include migmatite gneiss, schist and metasediment, sandstone and river alluvium, granite and quartzite. The aquifer type is phreatic and the depth to groundwater ranges from 2.8 to 21.9 m. The high recharge areas occurred mostly in highly fractured areas covered with metasedimentary rocks, migmatite gneiss and sandstones. The groundwater vulnerability zones in the study area were grouped into four classes: High, moderate, low and very low. The highly vulnerable zones are the North Eastern parts of the study area covering most parts of Bwari and parts of the municipal council areas and also the Southern parts of the study area covering parts of Kuje and Abaji. They constitute the highly fractured areas covered with silt loam soil type. The very low vulnerable zones are the North Western and Central parts covering mostly Gwgwalada and Kwali areas. This study demonstrates that GIS and remote sensing techniques are efficient and cost-effective tool for delineation of groundwater vulnerability zones. The information obtained will be used as a basis for a geochemical characterization of groundwater quality in the region with the overall goal of supporting new groundwater management plans in the region.

How to cite: Etuk, M., Ogbonnaya, I., Viaroli, S., Petrini, R., and Re, V.: Vulnerability Assessment of Shallow Aquifers in Abuja using GIS and Hydrogeological Parameters, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8712, https://doi.org/10.5194/egusphere-egu21-8712, 2021.



Hydrogeological and hydrochemical characterization to assess wells vulnerability in the scope of Water Safety Plans, a case study in Northern Italy

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Groundwater is a key resource to fulfil human drinking needs worldwide. Therefore, guaranteeing a safe and constant supply of drinking water to the public has been an important focus at European level. Recently, the EU approach to drinking water monitoring radically changed, moving from the simple water quality monitoring, toward a more comprehensive risk assessment, involving the whole supply chain from collection to distribution. Particularly, EU Directives 2015/1787 and 2020/2184 endorsed the Water Safety Plan (WSP) system which requires a detailed assessment of every possible dangerous event.

Groundwater extraction constitutes the first step of the supply chain, and therefore the most vital. In this work, an approach to assess groundwater wells vulnerability in the scope of WSP is proposed, considering natural and anthropogenic hazards, through a hydrogeological, hydrochemical and hydrodynamical characterization. The study area is the Lake Iseo morainic amphitheater (ca. 180 km^2) in the Brescia province, Northern Italy. Particularly, 17 wells have been analyzed, serving 4 municipalities.

Two main dangerous events have been considered as possible hazard for the collected groundwater: a) anthropogenic impact from the surface, related to the land use, and b) natural contamination by reduced species consequent to the degradation of natural organic matter.

Groundwater extraction vulnerability to these two dangerous events has been assessed, considering several hydrogeological aspects: a) the kind of the exploited aquifer (shallow, confined, semiconfined), b) groundwater depth for the shallow aquifers, c) permeability of the vadose zone for the shallow aquifers and d) red-ox conditions of the collected groundwater.

To assess these parameters, lithostratigraphic, chemical and piezometric data were analyzed, reaching a deep understanding of the system by characterizing the different exploited groundwater bodies from a hydrogeological, hydrochemical and hydrodynamic point of view.

Hydrogeological sections were elaborated, covering the whole amphitheater, 7 in the N-S direction and 7 in the W-E direction. The interpretation of these sections allowed to identify the distribution of the main aquifer bodies and the relationships between the various hydrogeological units. To evaluate the red-ox conditions and perform groundwater quality characterization, chemical data were analyzed, including major ions and red-ox sensitive species, through boxplot and statistical analysis. Furthermore, piezometric levels were analyzed to identify groundwater depth, flow directions and watersheds. Of the 17 wells, one resulted to be confined with reducing conditions. Among the remaining, 7 are semiconfined while 9 are shallow, with oxidizing conditions in both cases. Concerning groundwater depth, 13 present values above 40 m, 2 between 20 m and 40 m, and 1 below 20 m. As regards the vadose zone permeability, 9 present high permeability, 7 mediums. Totally, in terms of vulnerability to anthropic impacts, one well has low vulnerability, 9 medium and 6 high, while in terms of vulnerability to natural contamination one well has high vulnerability and the remaining low.

This approach allowed a deep understanding of the system and constitutes a reproducible methodology to assess groundwater wells vulnerability to natural and anthropogenic contaminations.

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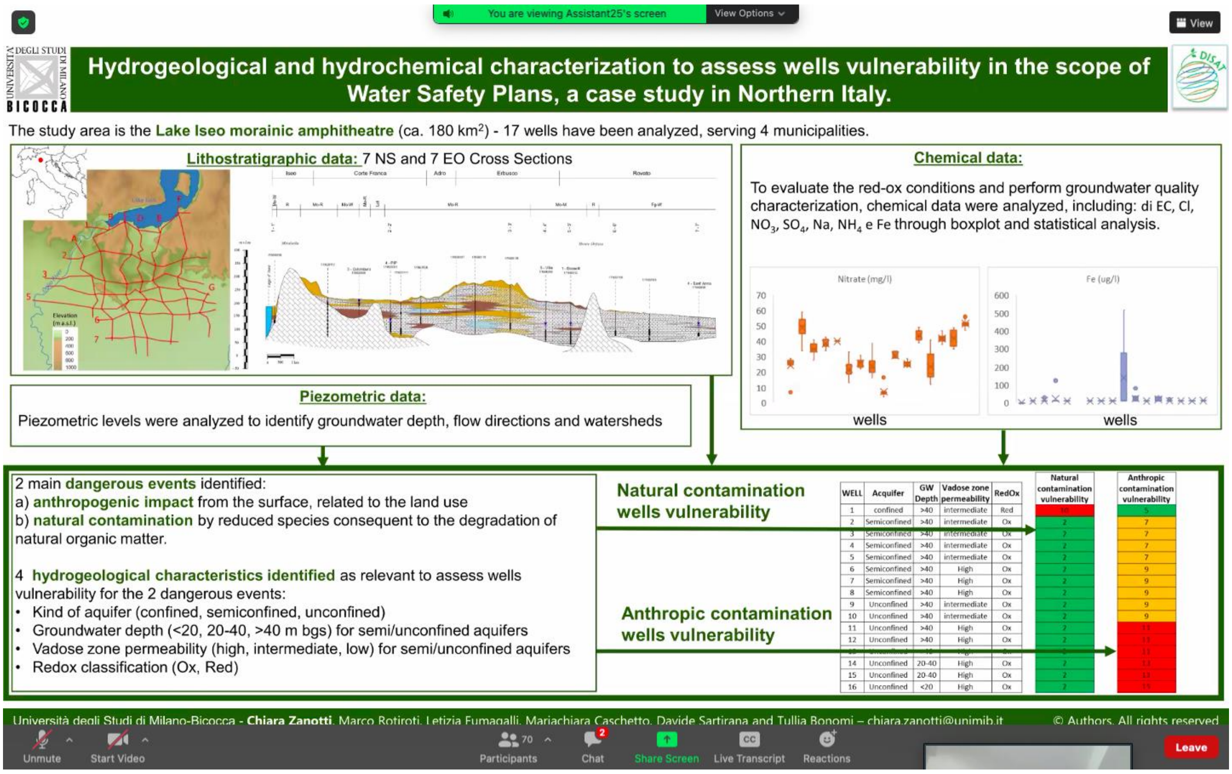

Multiple DNA-tracer transport approach for determining aquifer matrix properties in a laboratory 3D aquifer sand tank: a methodical perspective

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Use of environmental or artificial tracers has been an effective approach to characterize groundwater flow and solute transport, tracking pollutant migration and determine travel time. However, availability of a distinctive number of tracers, variability in interaction with the aquifer matrix, and analytical detection limits are namely few of the significant concerns to be addressed and which led us to focus on employing novel DNA tracers.

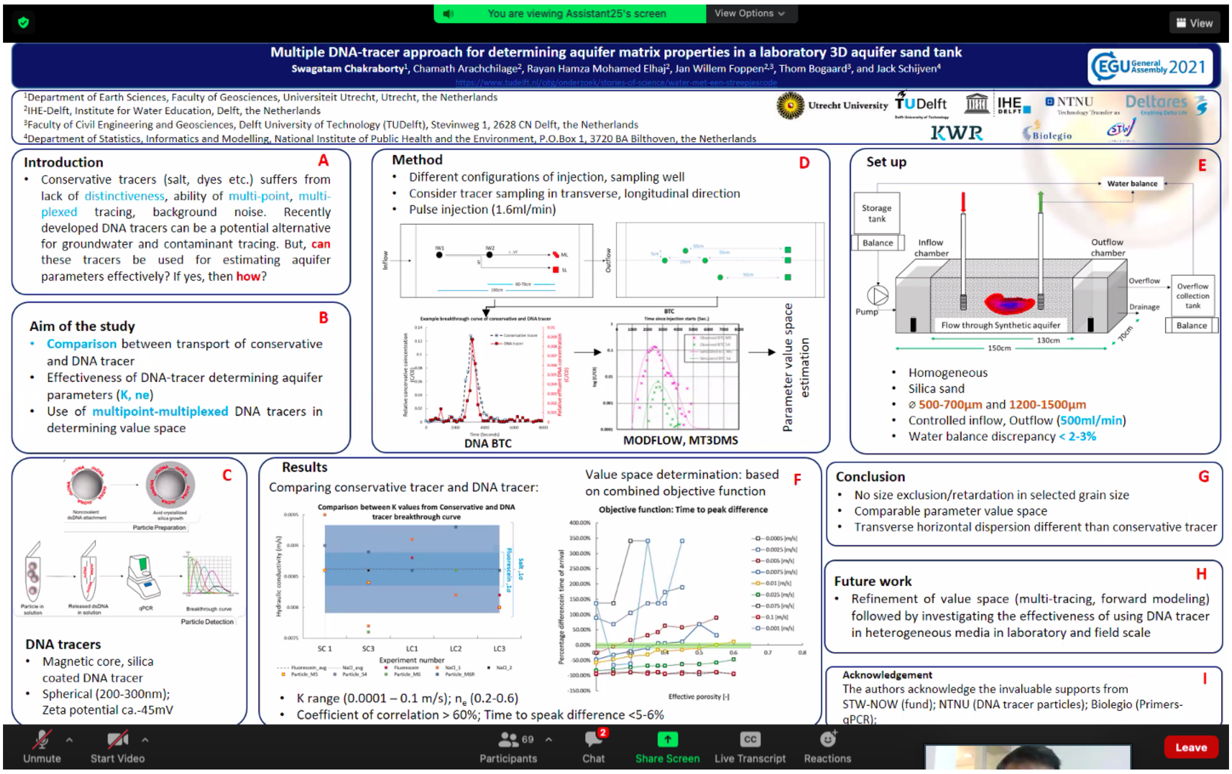
Besides the quality of being unique, improbably prevalent in nature and environmentally friendly, DNA tracers can be synthesized virtually in infinite numbers of distinct sequences, rendering them a potential candidate for multi-tracer applications for subsurface and groundwater flow characterization. Studies have already demonstrated the potential of DNA tracing in groundwater studies but a blueprint for methodical application and analysis is required.

In this study, we investigate the applicability of DNA tracers in determining hydraulic parameters of a natural aquifer, such as, hydraulic conductivity, effective porosity, dispersity, and travel time, the most significant characters of a matrix, influencing solute or pollutant transport. In addition, we aim to leverage the applicability of the tracers in terms of minimizing the uncertainty in estimating the parameters.

In order to capitalize on these advantages of DNA tracers with the aim of addressing the aforementioned objectives, this research focuses on employing multiple dsDNA (ds=double stranded) tracers in a 1.3 m long three-dimensional sand-filled aquifer tank. Under forced-gradient water flow conditions, distinctly sequenced, monodispersed dsDNA tracers are instantaneously injected through injection wells, taking into account different scenarios. The scenarios consider different configurations of injection and sampling strategies. Samples collected periodically were subjected to quantitative polymerase chain reaction (qPCR) for DNA concentration estimation. All the silica-encapsulated DNA particles were comparable in size and surface properties.

Individual breakthrough curves from each of the scenarios are carefully analyzed for determining water flow and hydraulic properties. In addition, the experiments producing multiple breakthrough curves are cumulatively analyzed for obtaining a minimal uncertainty for the parameter estimations.

How to cite: Chakraborty, S., Arachchilage, C., Elhaj, R. H. M., Foppen, J. W., Bogaard, T., and Schijven, J.: Multiple DNA-tracer transport approach for determining aquifer matrix properties in a laboratory 3D aquifer sand tank: a methodical perspective, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16366, https://doi.org/10.5194/egusphere-egu21-16366, 2021.



Heterogeneity of hydrogeological conceptual models in crystalline basement aquifers under equatorial climate: case study of French Guiana

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Crystalline rocks aquifers are usually represented with a low porosity and hydraulic conductivity giving low well yields. Over the world, more than 880 million people live on crystalline basement rocks. Thus, abilities to spot sufficient groundwater resource in these systems are crucial. Nevertheless, assessment of the sustainable reservoirs in crystalline basement aquifers is challenging. The well-admitted conceptual model presents a stratiform-weathered profile above a fractured zone showing a decreasing fracture density with depth. The interconnection between these two compartments defines the hydraulic parameters: the weathered profile is capacitive while the fractured zone is transmissive.

French Guiana is mostly composed of Paleoproterozoic rocks belonging to the Guiana Shield. It was formed during protracted periods of intense suprasubduction related magmatism, metamorphism and deformation, culminating with the Transamazonian orogeny, bracketed between 2.3 and 1.9 Ga. This peculiar geological history creates a large diversity of geological units from undeformed granitic units to ultramylonitized shears-zone related meta-volcano-sedimentary units and through brittle to ductile deformed units. Furthermore, over almost 200 Ma, the French Guiana recorded a deep weathering phase leading to heterogeneous and complex profiles up to 80-100 m deep. In such a context, hydrogeological exploration is thus puzzling, especially as French Guiana is covered by the Amazonian Forest, reducing direct observations.

We use a multi-disciplinary method from remote sensing to field observations through geophysical tomography to propose conceptual models of groundwater circulation helping us to localize precisely (meter scale) exploration borewells. After 15 years of hydrogeological surveys, the BRGM has studied plural units: (i) classical isotropic unit (Mahury Massif (MM)) and Granitic unit (Mana), (ii) ductile to brittle deformed units separated by strike-slip fault (Rosebel-Bonidoro unit (RBU) and Armina Unit (AU)), (iii) ultramylonitized unit (Paramaca Unit

(PU)). A large heterogeneity of hydrogeological conceptual models for each context arise from our results. Notwithstanding this diversity and thanks to these conceptualizations, we were able to propose successfully useable sustainable resources, confirming the robustness of the method.

The MM and Mana are classical isotropic units displaying a deep weathered profile. The confined aquifer is located into the fractured layer with yield reaching 15 $m^3.h^{-1}$. Crosscutting dolerite dyke is attested to be an interesting hydrogeological target with yield near 20 $m^3.h^{-1}$. The highest yields in French Guiana for crystalline basement rocks (30 $m^3.h^{-1}$) are found in confined aquifer in PU context. This record could be due to the ultra-mylonitic deformation giving a high permeable unit. Three different places were studied for the AU (Sparouine, Roura, Beauséjour). As for the PU, aquifers are all confined. Yields are systematically low (around 2-5 $m^3.h^{-1}$). The RBU is an interesting and contrasting unit because it does not show developed weathered profile. It seems that an unconfined aquifer must probably recharge surroundings units (i.e. PU and AU).

This work highlights the high potential of ductile to ultra-mylonitic shear zones for groundwater resource. Taking together, these conceptual models highlight that, in French Guiana and probably in entire Guiana Shield, Transamazonian tectonometamorphic structures as well as early Jurassic extensive faults correspond to sustainable useable groundwater resources.

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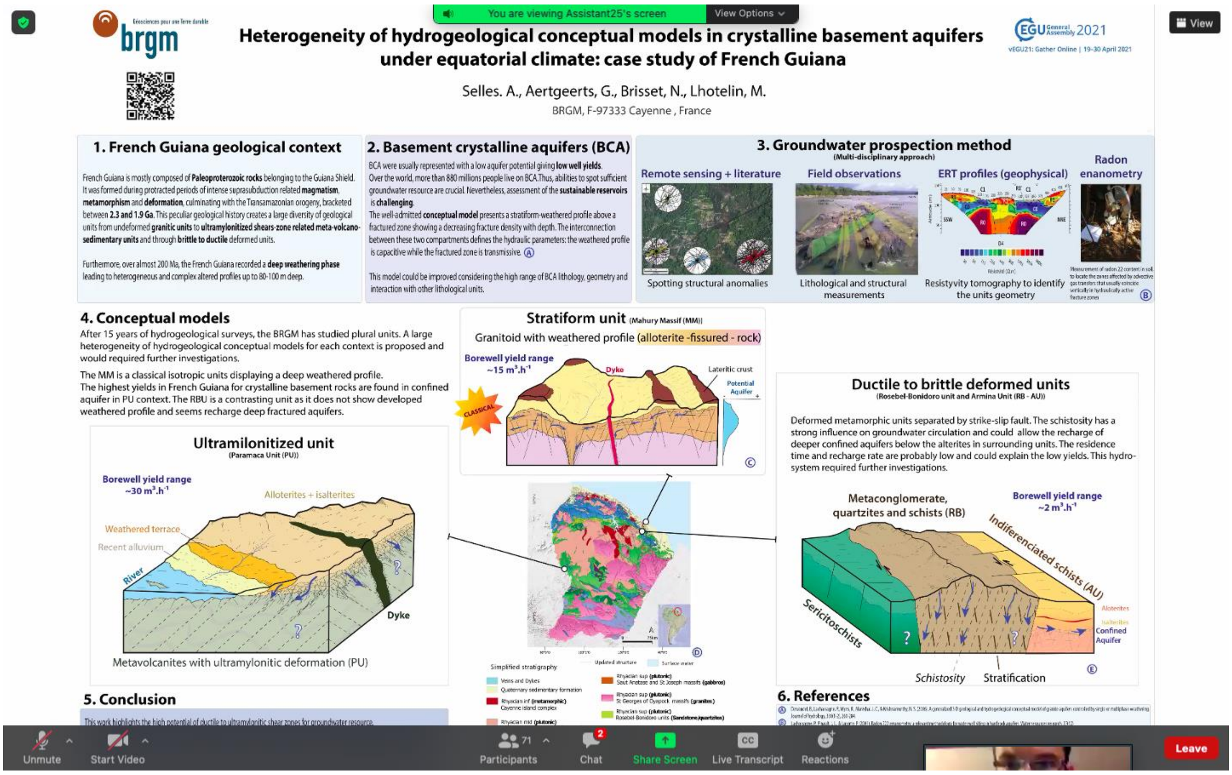

Remote sensing for assessment of groundwater resources, A case study of Stampriet Transboundary Aquifer

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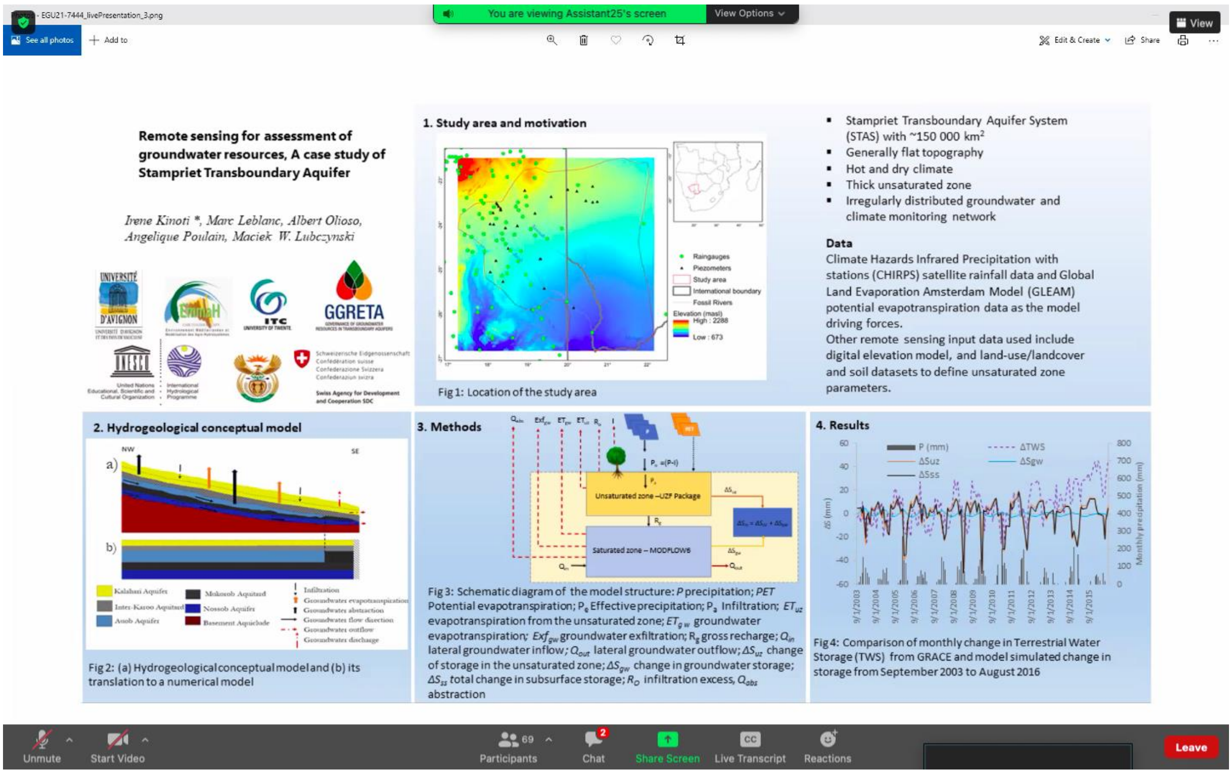
Distributed integrated hydrological models (IHMs) are the most effective tools for estimating groundwater recharge in arid and semi-arid areas characterized by thick unsaturated zone. It is also important to capture spatio-temporal aquifer dynamics by using real-time or near-real-time data, for sustainable water resources management. However, such data is often unavailable in developing countries where monitoring networks are scarce. In recent years, remote sensing has played an important role in providing spatio-temporal information for evaluation and management of water resources. Nevertheless, application of remote sensing in groundwater studies is still limited and has mainly focused on assessment of groundwater recharge and groundwater storage as well as to provide boundary conditions and driving forces for both standalone groundwater models and IHMs. This study entails application of remote sensing data in developing the distributed integrated hydrological model for Stampriet transboundary multi-layered aquifer system shared between Namibia, Botswana and South Africa. A numerical model has been set – up using MODFLOW 6 coupled with the Unsaturated Zone Flow (UZF) Package where Climate Hazards Infrared Precipitation with stations (CHIRPS) rainfall data and Global Land Evaporation Amsterdam Model (GLEAM) potential evapotranspiration data were implemented as the model driving forces. Other input data used include digital elevation model, and land-use/landcover and also soil datasets to define unsaturated zone parameters. The model has been calibrated with groundwater level measurements as the state variables in transient conditions at daily time step for a period of 16 years. The model-simulated unsaturated zone and groundwater storage was compared to GRACE-derived sub-surface storage anomaly, further also used to constrain the model. The calibrated model provides spatio-temporal water flux dynamics as well as water balances and hence an understanding of the groundwater-resource dynamics and replenishment. This information is shown useful for proper management of the transboundary water resource as well as for policy making.

How to cite: Kinoti, I., Leblanc, M., Olioso, A., Lubczynski, M., and Poulain, A.: Remote sensing for assessment of groundwater resources, A case study of Stampriet Transboundary Aquifer, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-7444, https://doi.org/10.5194/egusphere-egu21-7444, 2021.



Imaging the extent of saltwater intrusion in the Luy river coastal aquifer (Binh Thuan) using electrical resistivity tomography (ERT)

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Seawater intrusion has been one of the most concerning issues of the Vietnam South Central provinces in recent years, especially in the Binh Thuan province which is characterized by a hyper-arid climate. During the dry season extending from November to April, seawater intrudes through estuaries and threatens groundwater resources. The latter are under increasing pressure due to water extraction for agri- and aquaculture. To evaluate the current state of salinity in the shallow coastal aquifer, 21 electrical resistivity tomography (ERT) measurements were collected along the downstream part of the Luy river based on the previous saltwater intrusion boundary which was estimated from water samples collected from shallow boreholes. The data were inverted to get the resistivity distribution of the subsurface and interpreted in terms of salinity. Comparison with well data shows that resistivity values below 6.5 Ohm.m correspond to the presence of saltwater in the aquifers. On the right bank of the river, a higher elevation dune area contains a freshwater aquifer which limits the intrusion of saltwater. On the left bank dominated by lowland areas, saline water fills almost the entire thickness of the aquifer, except locally for small thin freshwater lenses. At larger distances from the sea, the aquifer displays a complex distribution of fresh and saline lenses. Those variations seem to be correlated with the presence of clay lenses, recharge sources and irrigation practices. ERT data also reveals the depth of the rock basement. The geophysical observations show that the extension of saltwater intrusion is much larger and more complex than expected from existing borehole data and is not limited to interaction with the river.

KEYWORDS: saltwater intrusion, groundwater, electrical resistivity tomography, Luy river

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Local natural background levels assessment through a groundwater redox zonation, the case of Lombardy Region

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Discretizing anthropogenic and natural contaminations represents a crucial step in groundwater management and regulation. Natural background levels (NBLs) have a huge impact on groundwater protections and remediation strategies, but it is still an issue on the ground in terms of reliability and accuracy, thus its derivation needs further scientific efforts.

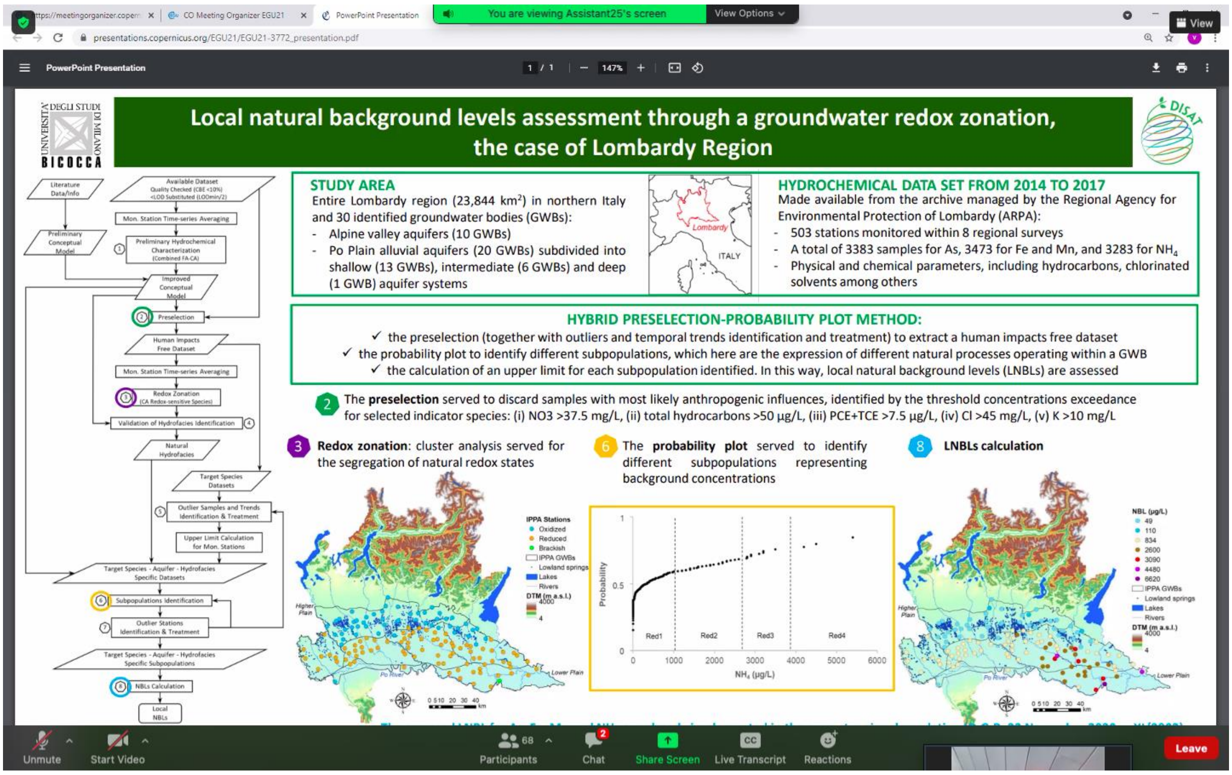
The derivation of local NBLs (LNBLs) is intended to overcome the limitation of considering a groundwater body (GWB) homogeneous, hence accounting hydrogeochemical heterogeneities within the aquifer system.

This work presents a statistical approach assessing LNBLs for sensitive redox species (As, Fe, Mn, NH_4) in 30 GWBs within the Lombardy Region. Under the monitoring network of the Regional Agency for Environmental Protection of Lombardy (ARPA), more than 500 wells were investigated, thus each GWBs were identified within 4 aquifer types: shallow, intermediate, deep Po Plain aquifers and Alpine valley aquifers. The initial dataset underwent preselection and multivariate analyses, appointing at each well a geogenic redox zonation. It leaded to discretize geochemically-homogeneous subgroups and characterize them as function of site-specific natural facies: oxidized (293 wells), reduced (199 wells) and saline (11 wells). Interquartile range criteria, validations' tests (Mann-Kendall and Shapiro-Wilk), probability density histograms and probability plots inferred temporally and spatially the datasets, one for each target species, discretized for aquifer and natural facies appurtenances. This resulted in the identification of the statistical distributions from redox-homogeneous sets of data from which the LNBLs were derived.

Considering the Po Plain aquifer (shallow, intermediate and deep), NBLs derivation for As revealed three subgroups within the oxidized facies, for which the NBLs values are of 2, 3 and 7 µg/L, four subgroups ascribe to the reduced facies with NBLs of 13, 49, 71 and 291 µg/L, and two subgroups for the saline facies with NBLs of 3 and 12 µg/L. According Fe, two are the subgroups within the oxidized facies, with NBLs of 40 and 94 µg/L, four subgroups fall in the reduced facies with NBLs of 653, 1430, 3200 and 6000 µg/L; within the saline facies, two subgroups are identified with NBLs of 1647 and 6000 µg/L. Two subgroups characterize the oxidized facies for NBLs of Mn with values of 8 and 27 µg/L, and NBLs of 34, 216, 485, 912 and 1514 µg/L refer to five subgroups in reduced facies, while within the saline facies fall two subgroups with NBLs of 381 and 921 µg/L. With regards to NH4, NBLs reach values of 49, 110 and 190 µg/L for the three subgroups within the oxidized facies, whereas values of 834, 2600, 3090, 4480 µg/L are derived for the four subgroups in the reduced facies; the two subgroups ascribed to the saline facies reveal NBLs of 1860 and 6620 µg/L.

Data demonstrate how an in depth understanding of aquifers' redox-zonation turned out to be functional for assessing LNBLs. Regional Legislation (D.G.R. 23novembre2020 n.3903) has been amended on the basis of the outcomes of this work, revealing site redox-specific LNBLs of practical significance.

Funding: this work was granted and carried out in collaboration with Lombardy Region How to cite: Rotiroti, M., Caschetto, M., Zanotti, C., Parini, M., Cipriano, G., Bonomi, T., and Fumagalli, L.: Local natural background levels assessment through a groundwater redox zonation, the case of Lombardy Region., EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-3772, https://doi.org/10.5194/egusphere-egu21-3772, 2021.



Establishment of groundwater baseline using end-member mixing analysis in the groundwater flow system approach

Susana Rodriguez Padilla*[1]*, *Selene Olea Olea*[2]*, and Oscar Escolero Fuentes*[3]

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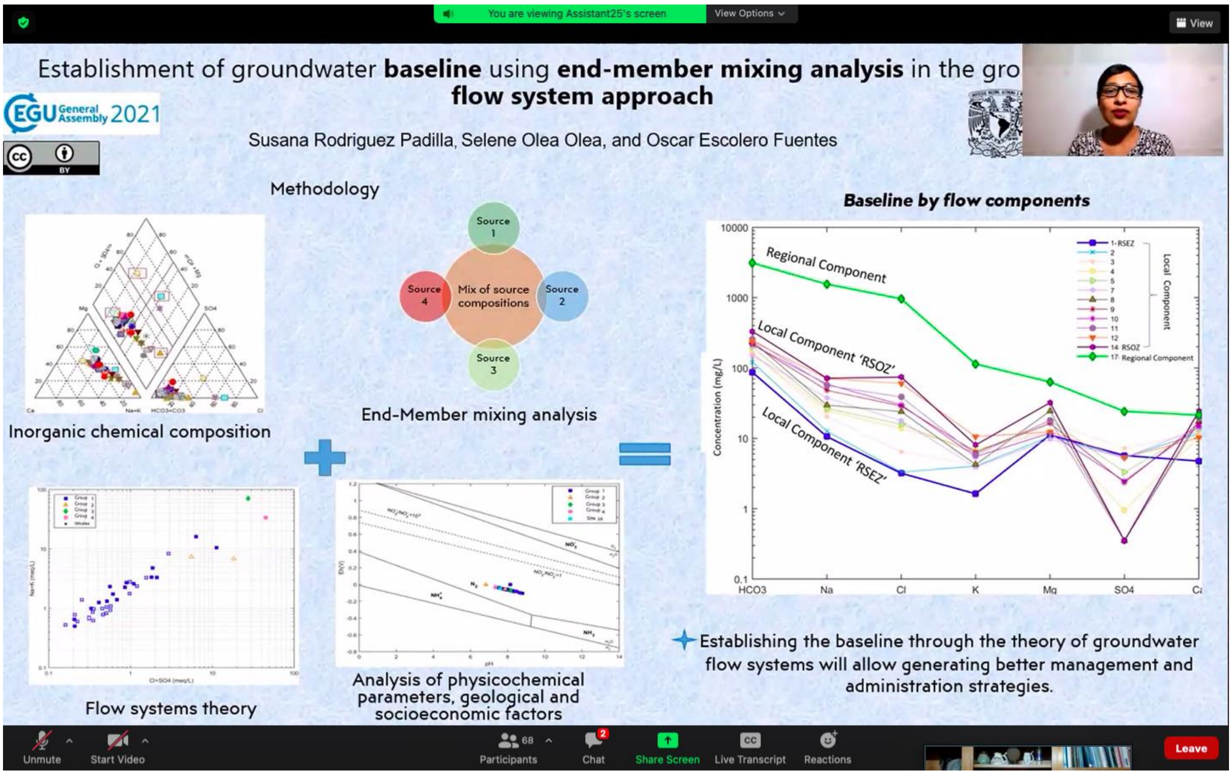
The aim of this research is to establish the groundwater baseline in a sub-basin located in the southwest of Mexico City, an area affected by anthropogenic activities.

The methodology consists of groundwater sampling in 40 sites to measure major ions and physicochemical parameters as temperature, pH, Eh, and total dissolved solids. The end-member mixing analysis was applied using the groundwater flow system approach. The groundwater baseline was established using flow components that were defined.

The main results are: to found four groundwater flow components: 1) local, 2) intermediate, 3) cold regional, and 4) hot regional; to established a groundwater baselines; to relate the anomalous concentrations of nitrate and sulfate due to anthropogenic activities in the area; to associate the fertilizer use, wastewater, and the canal leaching black waters as the principal sources of these concentrations.

The conclusions show the importance to use the groundwater flow system approach to differentiate natural processes as hydrochemical evolution due to water-rock interaction of the anthropogenic influence. In the context where groundwater is extracted without knowing its baseline and the anthropological implications, the groundwater flow system approach to permit generated best management and administration strategies.

How to cite: Rodriguez Padilla, S., Olea, S., and Escolero Fuentes, O.: Establishment of groundwater baseline using end-member mixing analysis in the groundwater flow system approach, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-6642, https://doi.org/10.5194/egusphere-egu21-6642, 2021.



Part 3 – Report prepared by Kersti Türk (Ministry of Environment, Estonia)

Sr isotope fractionation in a karst river: case study of Krka, Croatia

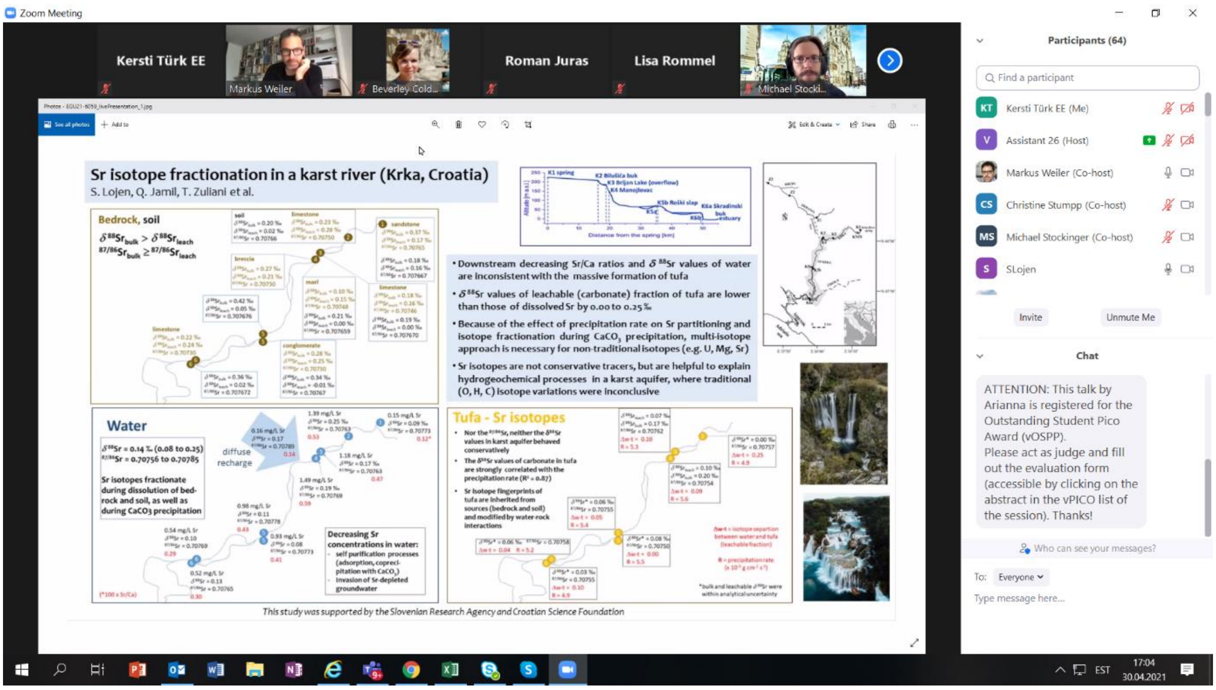
***Sonja Lojen,** Qasim Jamil, Tea Zuliani, Leja Rovan, Tjaša Kanduč, Polona Vreča, Marko Štrok, Elvira Bura Nakić, and Neven Cukrov*

Precipitation of calcite from water fractionates strontium (Sr) isotopes because of preferential incorporation of light (^{86}Sr) isotopes into the solid phase, making continental carbonates one of the most ^{88}Sr depleted reservoirs. It was suggested that carbonate precipitation is the most likely process controlling $\delta^{88/86}$Sr composition of karst water. Therefore, the ^{88}Sr enrichment of river water could be used for the estimation of Sr and carbonate precipitation at catchment scale.

In the present study, we report on trace element partitioning and Sr isotope fractionation between tufa and water in the groundwater fed karst river Krka (Croatia). Water and tufa along with samples of bedrock and soil as the main contributors of dissolved and particulate Sr at seven main waterfalls and cascades along a 33 km section of the river were analyzed for trace element and Sr isotope composition ($\delta^{88/86}$Sr).

The highest $\delta^{88/86}$Sr values were measured in soils and in siliciclastic rocks, while in limestone, the δ88/86Sr values were similar to those of old tufa precipitated in the period between 96 and 141 ky BP. Recent tufa, however, was considerably depleted in ^{88}Sr. The isotope fractionation between water and recent tufa varied a lot and was inversely correlated with Mg and Sr partitioning coefficients, while correlations with precipitation rates and temperature were rather weak. The $\delta^{88/86}$Sr of recent tufa was strongly correlated with the stable isotope composition of organic carbon, which indicates that apart from hydrochemical, hydraulic parameters and temperature, plants and microbial communities that knowingly stimulate the tufa formation also affect the isotope fractionation of Sr.

How to cite: Lojen, S., Jamil, Q., Zuliani, T., Rovan, L., Kanduč, T., Vreča, P., Štrok, M., Bura Nakić, E., and Cukrov, N.: Sr isotope fractionation in a karst river: case study of Krka, Croatia, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-6059, https://doi.org/10.5194/egusphere-egu21-6059, 2021

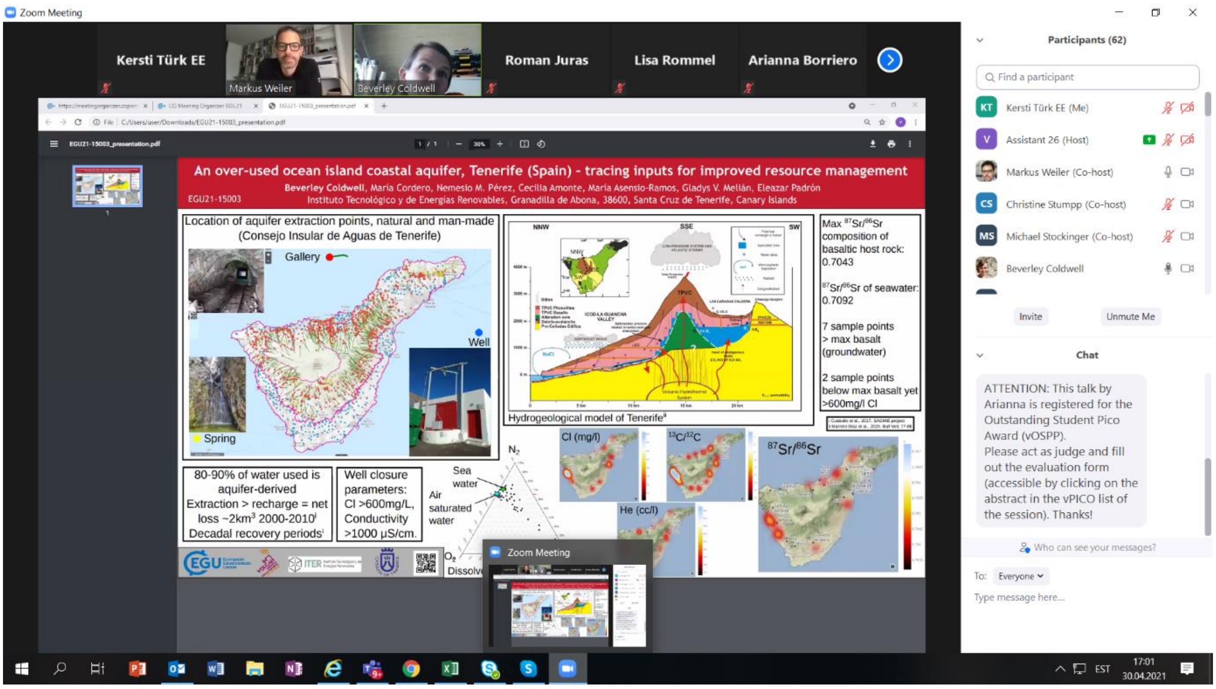


An over-used ocean island coastal aquifer, Tenerife (Spain) – tracing inputs for improved resource management

***Beverley Coldwell,** María Cordero, Nemesio M. Pérez, Cecilia Amonte, María Asensio-Ramos, Gladys Melián, and Eleazar Padrón*

The island of Tenerife (Canary Islands, Spain) relies on basalt-hosted aquifers to provide 90% of water for agriculture and human consumption. The island is characterized by a low-permeability core, overlain by permeable materials which are cut by impermeable dykes. The effect is a compartmentalized aquifer, which is exploited sequentially as each "pocket" of water is exhausted. The island is home to ~1 million people (with an additional 5 million visiting tourists per year), and although rain/snowfall can be heavy in winter storms, it is unpredictable from year to year, and rapid surface water run off occurs due to the steep geography. While net recharge into the upper zones of the Tenerife aquifer have been quantified (around 2 months between intense rainfall and water table fluctuations), water must then follow a tortuous path to recharge lower zones and aquifer "pockets". Water recharge to the coastal aquifers is also interrupted and extracted during its journey. Human and agricultural pressure is highest near the coast, and has led to intensive exploitation of existing wells and horizontal galleries. In response to the intensification of water extraction and slow recharge rates, marine intrusions into the coastal aquifers of Tenerife have occurred, traditionally recorded by rising chloride levels and resulting in well/gallery closures as well as increased pressure on other extraction sites. However, in a volcanic ocean island setting, natural processes can mimic the appearance of salinization in a coastal aquifer. Management of aquifer resources require careful consideration of seawater incursions vs. volcanic degassing contributions vs. ocean island rainfall. Full hydrochemical breakdown of 43 coastal aquifer extraction sites reveal seawater intrusion is affecting the western coastal aquifer, with the agreement of multiple parameters. The strontium isotopic signature of well samples was also measured, because it is not subject to the biological or physical fractionation processes of other isotopic systems, thereby forming distinct reservoirs for groundwater ($^{87}Sr/^{86}Sr$ of host rock), and seawater. $^{87}Sr/^{86}Sr$ signatures suggest the northern coastal aquifers are also subject to seawater incursions. This parameter may be a more sensitive indicator than chlorides and conductivity markers for salinisation, especially in an ocean island environment where coastal aquifers are subject to intensive land use practices, seawater spray, and affected by diffuse volcanic degassing.

How to cite: Coldwell, B., Cordero, M., Pérez, N. M., Amonte, C., Asensio-Ramos, M., Melián, G., and Padrón, E.: An over-used ocean island coastal aquifer, Tenerife (Spain) – tracing inputs for improved resource management, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-15003, https://doi.org/10.5194/egusphere-egu21-15003, 2021.

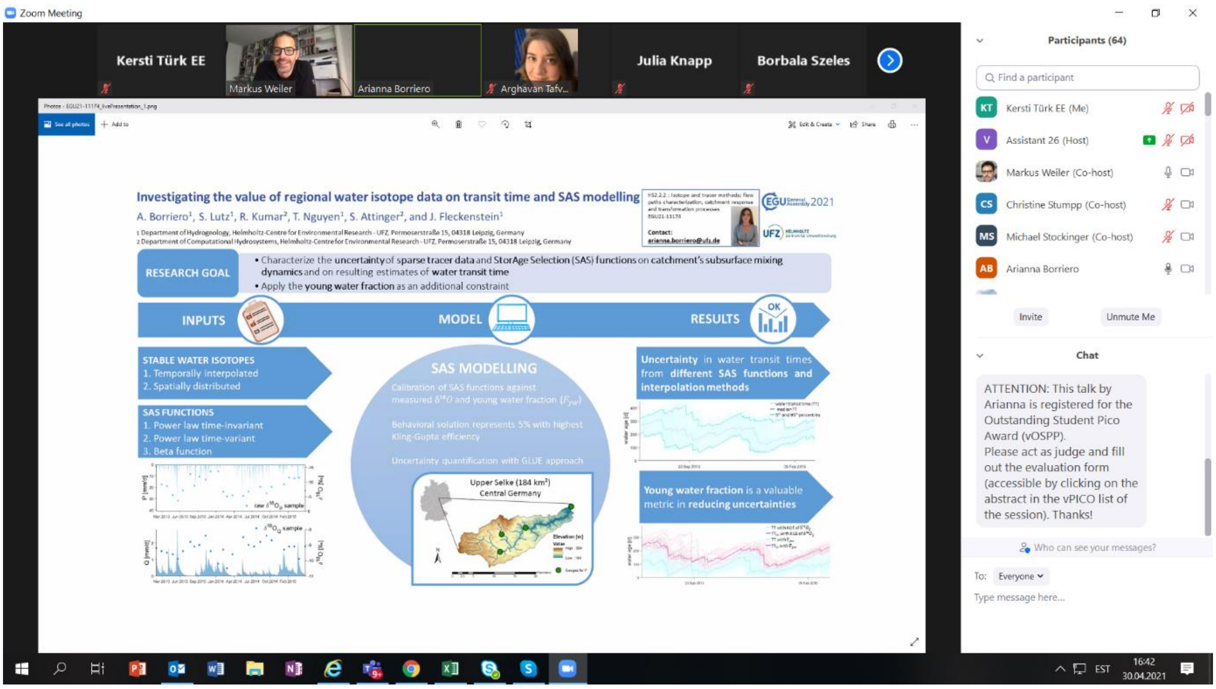


Investigating the value of regional water isotope data on transit time and SAS modelling

***Arianna Borriero**, Stefanie Lutz, Rohini Kumar, Tam Nguyen, Sabine Attinger, and Jan Fleckenstein*

High nutrient concentrations despite mitigation measures and reduced inputs are a common problem in anthropogenically impacted catchments. To investigate how water and solutes of different ages are mixed and released from catchment storage to the stream, catchment-scale models based on water transit time from StorAge Selection functions (SAS) are a promising tool. Tracking fluxes of environmental tracers, such as stable water isotopes, allows to calibrate and validate these models. However, this requires collection of water samples with an adequate temporal and spatial resolution, while sampling in catchments at the management scale is often limited by the high costs of the instruments, maintenance and chemical analysis. Therefore, temporal and spatial interpolation techniques are needed. This study demonstrates how to deal with sparse tracer data in space and time, and evaluates if these data are valuable to constrain the subsurface mixing dynamics and transit time with SAS modelling. We simulated water isotope data in diverse sub-basins of the Bode catchment (Germany) and calibrated the SAS function parameters against the measured streamflow isotope data. We tested four different combinations of spatial and temporal interpolation of the measured precipitation isotope data. In terms of temporal interpolation, monthly oxygen isotopes in precipitation (δ18OP) collected between 2012 and 2015 were converted to a daily time step with a step function and sinusoidal interpolation. In terms of spatial interpolation, the model was tested with raw values of δ18OP collected at a specific sampling point and with δ18OP interpolated using kriging to gain the spatial pattern of precipitation. The effect of the spatial and temporal interpolation techniques on the modeled SAS functions was analyzed using different parameterizations of the SAS function (i.e., power law time-invariant, power law time-variant and beta law). The results show how tracer input data with different distribution in time and space affect the SAS parameterization and water transit time. Moreover, they reveal preference of the sub-basins to mobilize either younger or older water, which has implications on how water flows through a catchment and on the fate of solutes.

How to cite: Borriero, A., Lutz, S., Kumar, R., Nguyen, T., Attinger, S., and Fleckenstein, J.: Investigating the value of regional water isotope data on transit time and SAS modelling, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11174, https://doi.org/10.5194/egusphere-egu21-11174, 2021.

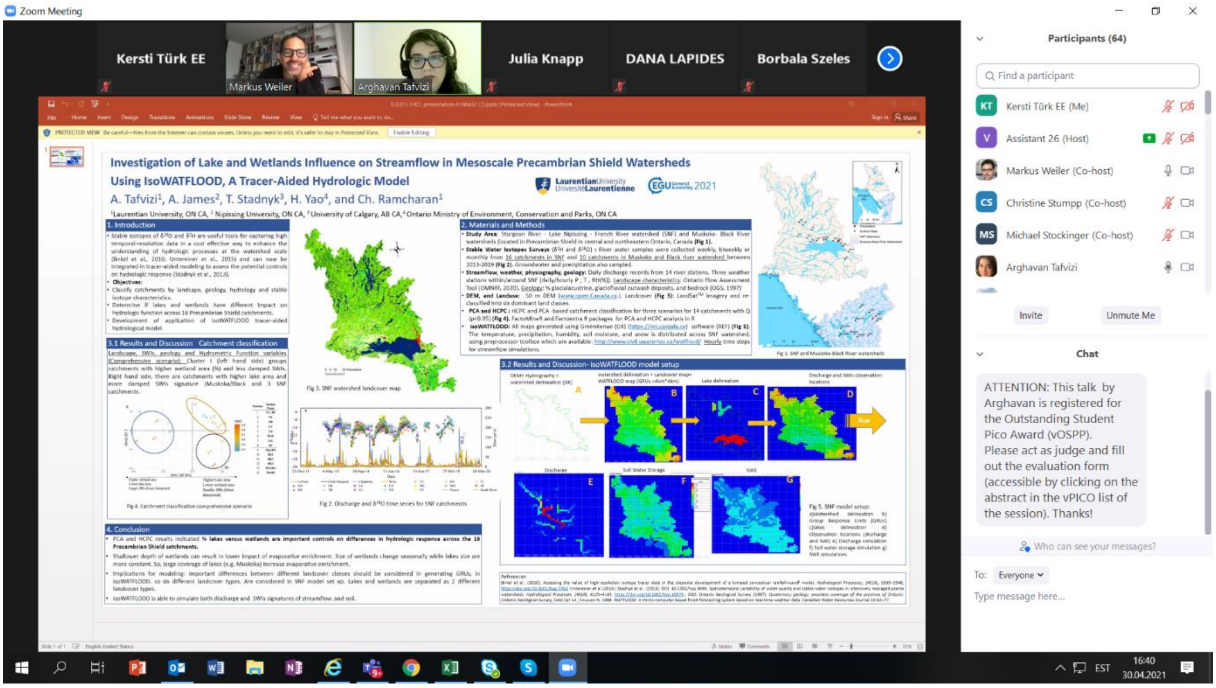


Investigation of Lake and Wetlands Influence on Streamflow in Mesoscale Precambrian Shield Watersheds Using IsoWATFLOOD, A Tracer-Aided Hydrologic Model

Arghavan Tafvizi, *April James, Tricia Stadnyk, Huaxia Yao, and Charles Ramcharan*

Hydrologists continue to be challenged in accurately predicting spatial variation in storage, runoff, and other hydrological processes in both natural and disturbed landscapes. Lakes and wetlands are important hydrologic stores in Precambrian shield watersheds. Identifying how they affect streamflow, independently and/or collectively is a challenge. Tracer-aided hydrologic modeling coupled with field-based stable isotope surveys offer a potentially powerful approach to investigation of mesoscale streamflow generation processes because the influence of evaporative enrichment generates a distinct signature of the surface water endmember, and continuous and distributed simulated streamflow can be tested against field observations under a range of flow conditions. The main objectives of this research are to investigate the influence of lakes and wetlands on streamflow generation by developing application of the tracer-aided hydrologic model isoWATFLOOD for the ~ 15 275 km^2 Sturgeon - Lake Nipissing - French River (SNF) basin located on the Precambrian Shield in Northeastern Ontario, Canada. Monthly surveys of $\delta^{18}O$ and δ^2H in river flow were collected between 2013 to 2019 (weekly to monthly) across eight sub-catchments, with supporting observations of volumes and stable isotopes in snow cores, snowmelt, precipitation and groundwater. Application of the hydrologic model isoWATFLOOD to the SNF Basin is developed for the first time, allowing for simulation of discharge and stable isotopes in streamflow and soil moisture across multiple sub-catchments. In model building, consideration of differences in quaternary geology, landcover, and sub catchment locations are considered. Landcover ranges from the boreal forests to impervious urban areas, while dominated by temperate forest, with some coverage of agriculture/disturbed impacted systems; several major sub-catchments having hydropower regulations. Previous statistical analysis has highlighted the importance of wetlands, lakes, and quaternary geology as influential on differences in hydrologic and isotope response in SNF watershed, as a result, model building is considering different landcover types as lakes and wetlands. Six different Landover are considered for generating Group Response Units (GRUs). The model is calibrated using discharge and stable water isotope. IsoWATFLOOD can represent variation in streamflow generation across the study area. Identifying the different impacts of lakes and wetlands on streamflow generation processes in study area by applying isoWATFLOOD for the SNF watershed will be the main achievement of this study.

How to cite: Tafvizi, A., James, A., Stadnyk, T., Yao, H., and Ramcharan, C.: Investigation of Lake and Wetlands Influence on Streamflow in Mesoscale Precambrian Shield Watersheds Using IsoWATFLOOD, A Tracer-Aided Hydrologic Model , EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-5907, https://doi.org/10.5194/egusphere-egu21-5907, 2021.



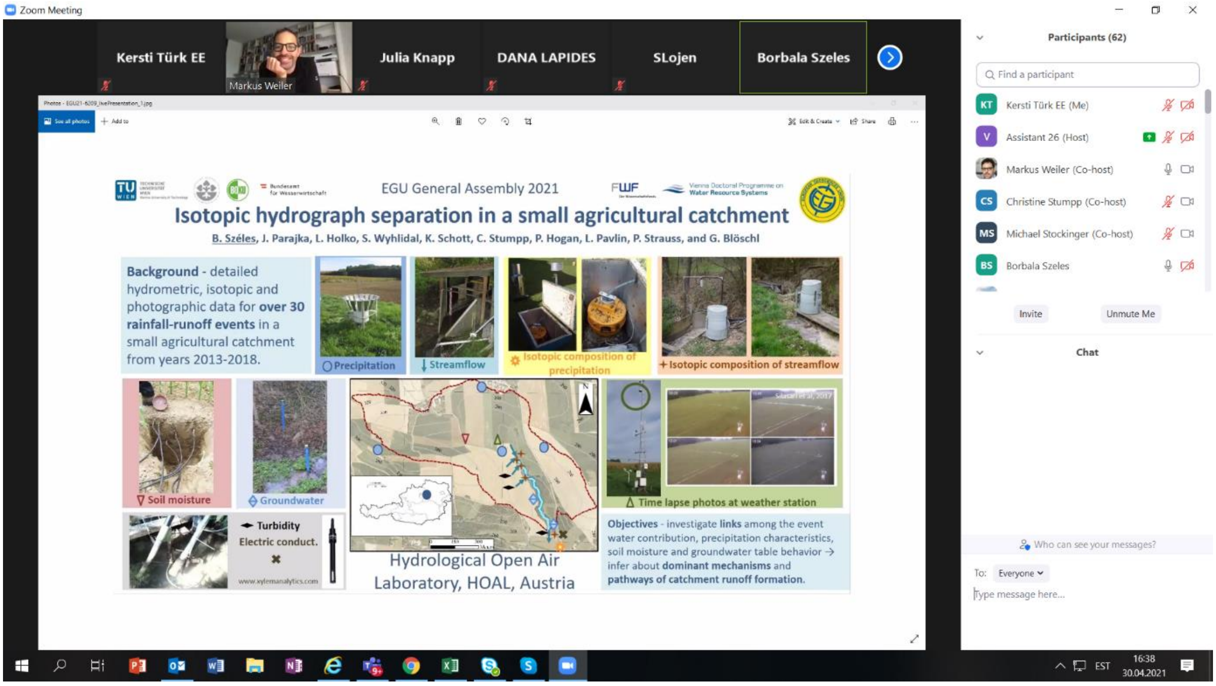
Isotopic hydrograph separation in a small agricultural catchment

***Borbála Széles,** Juraj Parajka, Ladislav Holko, Stefan Wyhlidal, Katharina Schott, Christine Stumpp, Patrick Hogan, Lovrenc Pavlin, Peter Strauss, and Günter Blöschl*

Exploring the isotopic composition of precipitation and streamflow in small catchments and the event and pre-event components of precipitation events using two-component isotopic hydrograph separation may better explain the overall catchment behavior, more specifically the sources of water origin. This study's main objective is to investigate the origin of water for different streamflow gauges in a small agricultural catchment, which represent different runoff generation mechanisms. The analysis will be performed in the Hydrological Open-Air Laboratory (HOAL) in Austria, a 66-ha experimental catchment dominated by agricultural land use (Blöschl et al., 2016). One of the main specialties of this research catchment is that several tributaries of the catchment representing different runoff generation mechanisms are gauged, such as tile drainage flow or saturation excess runoff from erosion gullies. Two-component isotopic hydrograph separation (for both ^{18}O and ^{2}H) will be conducted for five streamflow gauges (catchment inlet and outlet, two erosion gullies and a tile drainage system) for multiple events in the period 2013-2018. The results will be linked and interpreted using additional observations such as time-lapse images of overland flow, electric conductivity measurements, groundwater level changes, evapotranspiration measurements, etc. The aim is to explain and discuss the processes of rainfall-runoff generation in small agricultural catchments.

Reference: Blöschl, G., et al. (2016). The Hydrological Open-Air Laboratory (HOAL) in Petzenkirchen: A hypothesis-driven observatory. Hydrol. Earth Syst. Sci., 20(1), 227–255. doi: 10.5194/hess-20-227-2016.

How to cite: Széles, B., Parajka, J., Holko, L., Wyhlidal, S., Schott, K., Stumpp, C., Hogan, P., Pavlin, L., Strauss, P., and Blöschl, G.: Isotopic hydrograph separation in a small agricultural catchment, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-6209, https://doi.org/10.5194/egusphere-egu21-6209, 2021.

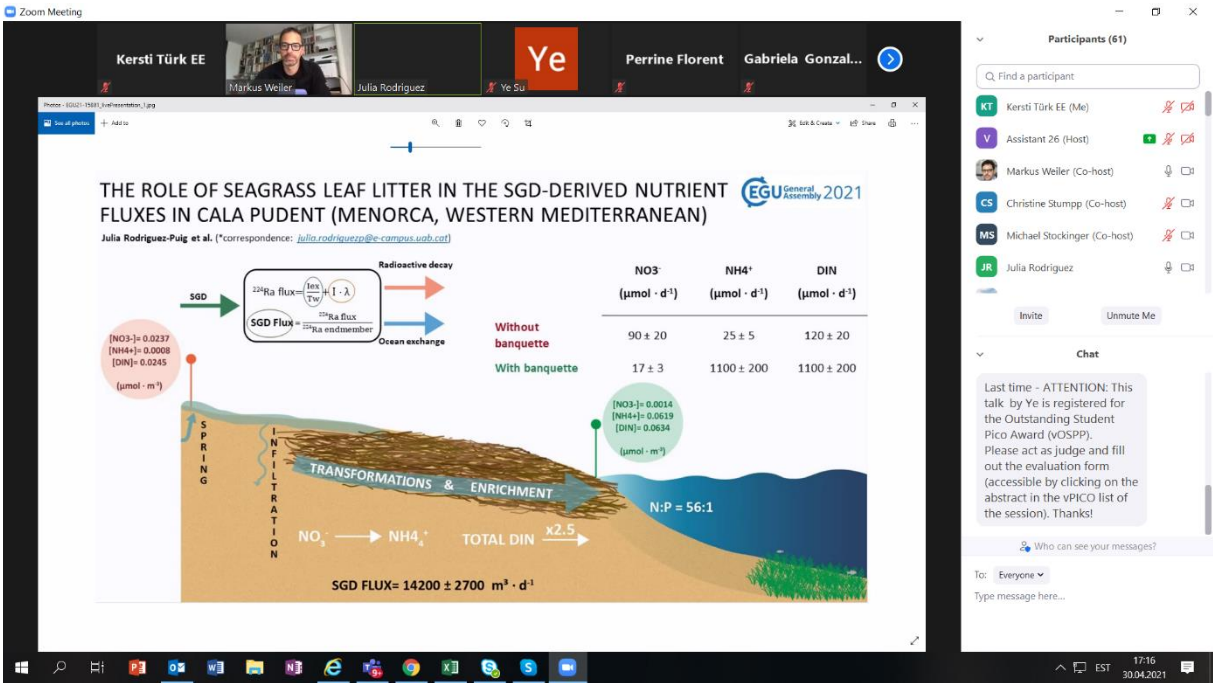


The role of seagrass leaf litter in the SGD-derived nutrient fluxes in Cala Pudent (Menorca, western Mediterranean)

Julia Rodriguez-Puig, *Irene Alorda-Montiel, Marc Diego-Feliu, Aaron Alorda-Kleinglass, Valentí Rodellas, and Jordi García-Orellana*

The assessment of the biogeochemical cycles in coastal environments often relies on riverine inputs as the main source of nutrients and other dissolved compounds from land to the ocean. However, the discharge of groundwater through continental margins, commonly known as Submarine Groundwater Discharge (SGD), is also recognized as relevant sources of nutrients to the coastal ocean, particularly in oligotrophic and semi-arid environments, such as the Mediterranean Sea. In this study, we use radioactive tracers (radium isotopes and radon) to i) quantify the magnitude of SGD-driven nutrient fluxes to a Mediterranean cove (Cala Pudent, Menorca, Balearic Islands) and ii) characterize the nutrient transformations occurring in the beach before groundwater discharges to the sea. Cala Pudent is a limestone coastal cove with a restricted connection to the open sea. In this system, groundwater from a permanent spring infiltrate through an organic substrate dominated by thick deposits of seagrass (*Posidonia oceanica*) leaf litter and flows into the sea. This substrate, together with the dynamic groundwater-seawater mixing, are chiefly influencing the nutrient enrichment and transformation occurring in the beach and thus modulating the SGD-derived nutrient input to the sea. The ecological implications of these inputs are also assessed, particularly for the *Posidonia oceanica* and *Cymodocea nodosa* meadows located near the study site.

How to cite: Rodriguez-Puig, J., Alorda-Montiel, I., Diego-Feliu, M., Alorda-Kleinglass, A., Rodellas, V., and García-Orellana, J.: The role of seagrass leaf litter in the SGD-derived nutrient fluxes in Cala Pudent (Menorca, western Mediterranean), EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-15881, https://doi.org/10.5194/egusphere-egu21-15881, 2021.



Long-lived Radioactive Elements and REE as Fingerprints of Deep Groundwater Flow

Marina Ćuk Đurović, *Maja Todorović, Igor Jemcov, and Petar Papić*

Groundwater originating from great depths provide a valuable geochemical sampling medium for exploring the development of the Earth's crust, geological, and hydrogeological resources. This particularly applies to sites of natural springs, where favorable hydrogeological conditions enabled regional discharge. Despite the numerous occurrences of mineral and thermal waters in Serbia, the current understanding of the regional groundwater flow is associated with many open questions that need to be addressed. From a geological standpoint, Serbia is part of the Alpine-Mediterranean mountain belt. From the middle of the Mesozoic to the present, this area underwent processes of subduction, collision, and extensions with accompanying voluminous magmatism and volcanism. As a result of the mentioned geodynamic events, the Serbian territory was a zone of intensive tectonomagmatic processes which had a significant impact on the formation of the hydrogeological structures for forming groundwater enriched with specific elements and elevated temperatures.

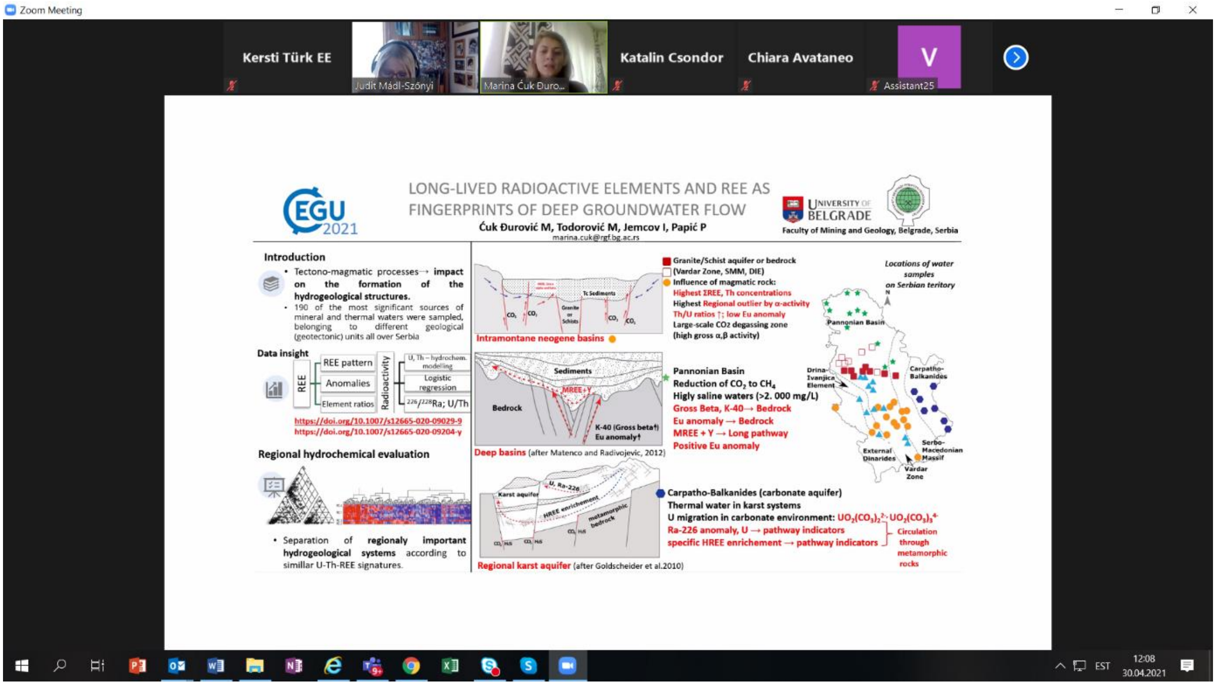
Understanding groundwater origin and characterization of a deep circulation is a big challenge since the groundwater pathways and aqueous chemistry are significantly influenced by various factors. To contribute to the characterization of the hydrogeological systems in which the mineral and thermal waters of Serbia are formed, a general hydrochemical study was conducted. During this research 190 of the most significant sources of mineral and thermal waters were sampled, belonging to different geological (geotectonic) units all over Serbia. The applied hydrochemical approach of recognition of deep circulation patterns is based on an analysis of rare earth elements (REE) and natural radioactivity. REE and long-lived radionuclides ^{40}K, ^{238}U, ^{232}Th, $^{226,228}Ra$, gross alpha, and beta radioactivity, have proven to be significant fingerprints of water-rock interaction as well as groundwater flow tracers.

The integrated approach of the hydrogeochemical analysis and multivariate statistical method, including spatial mapping of obtained results, was an important process for meaningful interpretation of the data set. The applied approach summarized the complex hydrochemical properties on a general level defining specific hydrochemical fingerprints of hydrogeological systems with distinct geochemical characteristics and flow patterns. Geochemical behavior of natural tracers (REE) and radioactivity contributed to further characterization of deep hydrogeological systems in basins structures, hard rocks (igneous and metamorphic rocks), as well as carbonate environments.

Rare-earth element data (including abundances and fractionation patterns along with anomalies of Ce and Eu and interelement ratios), relationships of U and Th as elements with different geochemical behavior, and the content of Ra in groundwaters have been singled out as important indicators of deep hydrogeological systems. The results showed that the isolated regional hydrogeological systems are in the function of significant tectonic structures/dislocations, but also hydrogeological characteristics and circulation conditions. Further use of the proposed methodology will provide important data from the assessment of the origin of hydro-geofluids in Serbia and contribute to the wider picture in the understanding of the hydrogeological evolution of regional groundwater flow.

Keywords: natural radioactivity, rare earth elements, hydrogeochemical fingerprints, regional groundwater flow

How to cite: Ćuk Đurović, M., Todorović, M., Jemcov, I., and Papić, P.: Long-lived Radioactive Elements and REE as Fingerprints of Deep Groundwater Flow, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-7079, https://doi.org/10.5194/egusphere-egu21-7079, 2021.



The effect of river regulation on the hydrological conditions of the Viiankiaapa mire in a mining development site in Northern Finland

Susanne Åberg, *Kirsti Korkka-Niemi, and Annika Åberg*

Central Lapland Greenstone Belt is highly prospective for gold and Ni-Cu-PGE deposits. The study area in Sodankylä, in northern Finland, has been glaciated during last ice ages forming complex sedimentary succession with low conductivity till and highly variable sorted sediments, which hydraulic conductivity can be orders of magnitudes higher. The complex Quaternary sediments usually cover weathered/fractured bedrock, which is preserved due to weak glacial erosion and can host bedrock aquifers, as well. Rivers, lakes, streams and mires are common features in northern boreal and subarctic regions and their hydraulic interactions are usually poorly understood.

Planning of mining operations in such environments needs a detailed understanding of water balance and groundwater discharge and recharge patterns, which are linked to subsurface sediments. In baseline studies, present hydrogeology, hydrology and ecology of the development site has usually been studied intensively. However, main rivers in northern Finland have been regulated since the 1970s and surrounding environments are not in their natural stage. The understanding, how much the environments could have been changed due to the regulation, is needed.

The study area locates in the western part of Natura 2000 protected Viiankiaapa mire, which lies about 300 meters above high-graded Ni-Cu-PGE deposit. The regulated River Kitinen is running close to the western edge of the Viiankiaapa mire. The construction of the hydroelectric power plants and the regulation of the River Kitinen has changed the hydrology of the study area from the 1970s onwards. The Matarakoski power plant built in 1995 affected the study area most directly by ending the regular spring floods and rising the river stage.

The changes in the groundwater flow and recharge/discharge patterns were studied with 3D groundwater flow modelling with MODFLOW-NWT and flood modelling with HEC-RAS. Pre-regulation situation was compared to the present stage with two different groundwater flow models in order to understand how regulation of river has affected the groundwater recharge/discharge patterns and flow patterns of the mire. Flood modelling was used to simulate the pre-regulation flood distribution.

The regulation of the River Kitinen has affected the western part of Viiankiaapa mire by raising the water table and smoothing the hydraulic gradient towards the river leading to partial wetting of the mire. Annual water table variations decreased due to ending of the flooding and the regulation created a more stable hydrological environment in mire area. The stabilization of the hydrological environment, as well as the rising of the water table, might have affected the distribution of habitats of endangered moss species *Hamatocaulis vernicosus*. The mire might have become more favorable for *Hamatocaulis vernicosus*, which is resistant to flooding and high-water table. This study emphasizes the importance of understanding the interactions of surface water and groundwater and the present and pre-regulated stage of the river in order to assess the difference between the present and natural stage of the mire.

How to cite: Åberg, S., Korkka-Niemi, K., and Åberg, A.: The effect of river regulation on the hydrological conditions of the aapa mire in a mining development site in Northern Finland, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-16188, https://doi.org/10.5194/egusphere-egu21-16188, 2021.

Annex 15

Capacity building at Nordic Hydrogeological Conference 2022

The Nordic Hydrological Conference (NHC2022) - Hydrology and Water-related Ecosystems

Tallinn University, Tallinn, Estonia, 15-18 August, 2022

Conference program:

Tuesday, August 16, 2022

Time	Tallinn Hall (Auditorium M218)	Auditorium M225
8:00-9:00	Registration (Mare building first floor) with coffee and snacks (Atrium Mare building 3rd floor)	
	Tallinn Hall (Auditorium M218, 2nd floor)	
9:00-9:20	WELCOME	
9:20-10:00	Keynote1: **Tarmo Soomere**. *Knowledge gaps in the interactions between hydrology, ecosystems and global change*	
10:00-10:40	Keynote2: **Nathan D. Stansell**. *Knowledge gaps in the interactions between hydrology, ecosystems and global change (online)*	
10:40-11:00	*Coffee break (Atrium Mare building 3rd floor)*	
	Tallinn Hall (Auditorium M218)	Auditorium M225
	Session 1-A Theme I: **Water and ecosystems for human well-being** CHAIR: ***Tor Håkon Bakken***	Session 2-A Theme II: **Knowledge gaps in the interactions between hydrology, ecosystems and global change** CHAIR: ***Diana Meilutyte-Lukauskiene***
11:00-11:20	Oral1.1. Linus Zhang; Zhu, Y. From Sponge City to Sponge Earth	Oral2.1. Mäkelä, M., et al. Effect of supplementary subsurface drainage on field scale nutrient fluxes
11:20-11:40	Oral1.2. Kiraz, M., et al. Signatures of hydrologic services: Quantification for catchments across Great Britain	Oral2.2. He, C., et al. Large-scale vegetation restoration and its feedbacks to land-atmospheric interactions and regional water cycles
11:40-12:10	Oral1.3. Khodaei, B., et al. Estimating peatland carbon sequestration in southern Sweden using InSAR	Oral2.3. Kriaučiūnienė, J., et al. Impact assessment of hydropower plants and climate change on river runoff and fish habitats in lowland rivers
12:10-13:20	*Lunch (Atrium Mare building 3rd floor)*	
	Tallinn Hall (Auditorium M218, 2nd floor)	
13:20-14:00	Keynote3: **Pertti Ala-aho**. Hydrological and ecological modelling	
14:00-14:15	*Break*	
	Tallinn Hall (Auditorium M218)	Auditorium M225
	Session 3-A Theme III: **Hydrological and ecological modelling** CHAIR: ***Līga Klints***	Session 2-B Theme II: **Knowledge gaps in the interactions between hydrology, ecosystems and global change** CHAIR: ***Diana Meilutyte-Lukauskiene***
14:15-14:35	Oral3.1. Akstinas, V., et al. Hydromorphological approach for the evaluation of ecological changes in Lithuanian rivers	Oral2.4. Chen Z., et al. The end-timing of rainfall events modulates post-rainfall sap flow and its environmental controls
14:35-14:55	Oral3.2. Kmoch, A., et al. Soil and land use data quality and resolution impact on the uncertainty of the SWAT model in a long-term study watershed Estonia	Oral2.5. Nazarenko, S., et al. Spatial analysis of low flow in Lithuania and its relation to drought indices
14:55-15:15	Oral3.3. Barna, D. M., et al. Regional Flood-Duration-Frequency Models for Norwegian Catchments	Oral2.6. Pärn, J., et al. Nitrate dynamics and its connection to seasonal groundwater recharge in karst springs of the Sõmeru River catchment, Northern Estonia
15:15-15:35	Oral3.4. Veinbergs, A.; Lagzdins, A. Can nitrogen concentrations be used for the quantification of runoff components?	Oral2.7. Klante, C., et al. Dependence of browning in Lake Bolmen, Sweden, on physical processes including land use
15:35-15:55	Oral3.5. Salo, H., et al. FLUSH model – Hydrological simulations with open data resources and recent developments of a hydrological computational platform	Oral2.8. Eensalu, M., et al. Holocene hydro-climate variability record from Lake Nuudsaku, Estonia
15:55	*Coffee break (Atrium Mare building 3rd floor) (together with poster session)*	
16:00-17:00	**Poster session (Atrium, Mare building 3rd floor)**	
18:00	**Reception of Tallinn city in City Hall, Old Town Raekoja plats 1, 10114 Tallinn)**	

Wednesday, August 17, 2022

Time	Tallinn Hall (Auditorium M218)	Auditorium M225
	Session 3-B Theme III: **Hydrological and ecological modelling** **CHAIR:** ***Tor Håkon Bakken***	**Session 2-C** Theme II: **Knowledge gaps in the interactions between hydrology, ecosystems and global change** **CHAIR:** ***Anna-Kaisa Ronkanen***
9:00-9:20	Oral3.6. Salla, A., et al. Controlled drainage in agricultural peatland fields – calibration and validation of FLUSH model	Oral2.9. Nilsson, B.; Orvomaa, M. Knowledge share for protection and restoration of GDE nature sites in The Nordic countries: National monitoring
9:20-9:40	Oral3.7. Di Natale, C., et al. Climate change adaptation using low impact development techniques in an urban catchment	Oral2.10. Uvo, C. B., et al. The Freshwater Competence Centre in Finland
9:40-10:00	Oral3.8. Uuemaa, E., et al. ML-based water quality modeling at national level in Estonia	Oral2.11. Briede, A., et al. Trends and regime shifts in climatic parameters and river runoff in Latvia for the period 1951–2020
10:00-10:20	Oral 3.9. Lagzdins, A., et al. Implementation of River Basin Management Plans of Latvia towards good surface water status - LIFE GOODWATER IP	Oral2.12. Koit, O., et al. Conceptualizing transboundary aquifer systems using geochemical signatures of springs
10:20-10:40	*Coffee break*	
	Tallinn Hall (Auditorium M218)	**Auditorium M225**
	Session 3-C Theme III: **Hydrological and ecological modelling** **CHAIR: Līga Klints**	**Session 4-A** Theme IV: **Approaches for monitoring, assessment, protection and restoration of water and ecosystem services** **CHAIR: Jonas Olsson**
10:40-11:00	Oral3.11. Saaremäe, E., et al. The effect of design storm choice on urban drainage system by using SWMM	Oral4.1. Ronkanen, A-K., et al. Long-term groundwater monitoring can be used to assess changes in climate and land use
11:00-11:20	Oral3.12. Isomäki, K., et al. Combined effects of controlled drainage and main ditch damming on water table and water balance in a Nordic agricultural field	Oral4.2. van't Veen, S., et al. What affect high-resolution nitrate sensor monitoring in streams? Experiences from four Danish headwater streams
11:20-11:40	Oral3.13. Blåfield, L., et al. Meander change and sediment connectivity - combining field data and morphodynamic modelling of one hydrological year	Oral4.3. Mayaud, C., et al. Hydrogeology of the shallow karst aquifer of the Pivka Valley (Slovenia)
11:40-12:00	Oral3.22. Kitterød, N.-O. et al. Nordic Region Hydrogeochemistry	Oral4.4. Vainu, M. Assessment of aquatic ecosystem services in Estonia: methodology and application in Viru subcatchment
12:00-13:00	*Lunch (Atrium Mare building 3rd floor)*	
	Tallinn Hall (Auditorium M218, 2nd floor)	
13:00-13:40	Keynote4: **Håkan Tropp.** Water policy and governance	
13:40-13:50	*Break*	
	Tallinn Hall (Auditorium M218)	**Auditorium M225**
	Session 3-D Theme III: **Hydrological and ecological modelling** **CHAIR: Jonas Olsson**	**Session 4-B** Theme IV: **Approaches for monitoring, assessment, protection and restoration of water and ecosystem services** **CHAIR: Anna-Kaisa Ronkanen**
13:50-14:10	Oral3.14. Koivusalo, H., et al. Warming winters at the edge of snow-affected conditions in an urban area	Oral4.5. Šimanauskienė R., et al. Assessment of raised bog ecohydrological features by remote sensing methods (case study of Čepkeliai, Lithuania)
14:10-14:30	Oral3.15. Paavonen, E., et al. Modelling spatio-temporal extent of water level control in an agricultural ditch network	Oral4.6. Kobets, Y.; Reihan, A. Development of harmonised water discharge calculation method of the transboundary Narva River, Estonia
14:30-14:50	Oral3.16. Engeland, K., et al. Estimation of design values for peak floods	Oral4.7. Schwamback, D., et al. Assessing soil moisture oscillations under different tropical land covers
14:50-15:10	**Bjørn Kløve,** *Hydrology Research (IWA Publishing)*	
15:10-15:30	*Coffee break (Atrium Mare building 3rd floor)*	
15:30-17:00	NHF General Assembly	
19:30-23:00	**Conference dinner at Lennusadam (Seaplane Harbor Museum, Vesilennuki 6, 10145 Tallinn)** **Celebrating of NHF 50th anniversary**	

Thursday, August 18, 2022

	Tallinn Hall (Auditorium M218)	Auditorium M225
	Session 3-E Theme III: **Hydrological and ecological modelling** **CHAIR:** ***Kolbjørn Engeland***	**Session 4-C** Theme IV: **Approaches for monitoring, assessment, protection and restoration of water and ecosystem services** **CHAIR:** ***Elve Lode***
10:00-10:20	Oral3.17. Pons, V., et al. How many extreme events to estimate the density of performance of green infrastructures?	Oral4.8. Paat, R., et al. Assessing vertical hydraulic conductivity of peat with atmospheric pressure movements using buried pressure transducers
10:20-10:40	Oral3.18. Abdalla, E.M.H., et al. Evaluating the transferability of green roof hydrological models between different cities using Pareto fronts	Oral4.9. Donati, F., et al. (presenter Choffel, Q.) A new vision of the river sections upstream weirs : the weir pool ecotone
10:40-11:00	Oral3.19. Godara, N., et al. Flash flood modelling in small catchments using a hydrodynamic rainfall-runoff model (HDRRM)	Oral4.10. Pedusaar, T.; Pachel, K. The Role of the Small Urban River in the Past and Present in the City of Tallinn
11:00-11:20	Oral3.20. Karttunen, K., et al. Modelling and classifying alluvial forests and swamp woods	Oral 4.11. Yiwo, E. et al. Investigating Stakeholders' Flood Risk Perception In Ghana From A Socio-technical Perspective
11:20-11:40	Oral3.21. Bakken, T. H., et al. Retrofitting of non-hydropowered dams – Results from three continents	Oral4.12. Terasmaa, J., et al. Citizen science for spring monitoring - an alternative way to collect groundwater data
11:40-12:00	*Coffee break (Atrium Mare building 3rd floor)*	

Tallinn Hall (Auditorium M218)

12:00-13:00	**Closing session and invitation to the NHC2024**
13:00	*Coffee*

Posters

Theme II: **Knowledge gaps in the interactions between hydrology, ecosystems and global change**	Theme III: **Hydrological and ecological modelling**
Poster 2.1.Patro, E. R., et al. A comprehensive assessment of dam and its removal in Finland	Poster 3.1. Andis Kalvans. Run-on contribution to the soil water balance to the temperate forests
Poster 2.2. Lin, Z., et al. Evolution of river system and its hydrological effect: A urban agglomeration perspective	Poster 3.2. Raidla, V., et al. Geochemical processes controlling ionic composition of water in the Kilpisjärvi area, Northern Finland
Poster 2.3. Päkkilä, L. Peatland hydrological changes after restoration activities	Poster 3.3. Hunt, M., et al. Modeling of the water balance in the Selja River basin northern Estonia with the PRMS hydrological model
Poster 2.4. Xu, C.-Y., et al. Variability of Norwegian annual precipitation and its relation to teleconnections	Poster 3.4. Retike, I., et al. The infilling performance of missing data for groundwater hydrographs based on clustered gap patterns
Poster 2.5. Stansell, N., et al. Holocene hydroclimate variability in the eastern Baltic region inferred from open and closed-basin lake sediment stable isotope and pollen records from Estonia	Poster 3.5. Beldring, S., et al. Event-based decision support indicators for hydrological pressure in Norway
Poster 2.6. Pärn, J., et al. Extent of the active water exchange zone in the aquifers of the Viru Sub-basin, NE Estonia	Poster 3.6. Gohari, A., et al. (presenter Torabi Haghighi, A.). A century of variations in extreme flows across Finnish Rivers
Poster 2.7. Mikomägi, A., et al. Water quality of mine water outlets and their impact on surface water	Poster 3.7. Olsson, J. et al. GlobalHydroPressure: model-based global assessment of hydrological pressure
Poster 2.8. Lode, E., et al. Patterns of mire groundwater levels during the hydrological minimum period; Are ecotope analogues applicable?	Theme IV: **Approaches for monitoring, assessment, protection and restoration of water and ecosystem services**
Poster 2.9. Lintunen, K., et al. Long-term changes of the flood and river ice regimes	Poster 4.1. Nurminen, J., et al. Long-term monitoring of nutrient losses from arable clay fields in southern Finland
Poster 2.10. Linkevičienė, R., et al. Hydrological diversity of raised bog, case study of Čepkeliai (Lithuania)	Poster 4.2. Levachou, Y., et al. Seasonal dynamics of reflectance and vegetation indices in Žuvintas Lake macrophytes
Poster 2.11. Kysely, J.; Beranova, R. Links between large-scale heavy precipitation and atmospheric circulation over Central Europe in CORDEX regional climate models	Poster 4.3. Männik, M., et al. Modification of DRASTIC method according to the geological peculiarities of formerly glaciated areas
Poster 2.12. Kløve, B., et al. A water-energy-food nexus assessment of climate change impacts on biomass and hydropower resources - WatNEX	Poster 4.4. **Kasi**, S. Air movements in soil
Poster 2.13. Adžgauskas, G.; Jakimavičius, D. Climate change impact on the hydrokinetic energy resources of Lithuanian rivers	Poster 4.5. Vandel, E.; Vaasma, T. Bathymetric mapping by the Institute of Ecology (Tallinn University, Estonia)
Poster 2.14. Meilutyte-Lukauskiene, D., et al. Changes in hydrological regionalization of Lithuanian rivers	Theme V: **Water policy and governance**

	Poster 2.15. Orvomaa, M., et al. What accumulated snow can reveal of anthropogenic pollution	Poster 5.1. Raidla, V., et al. Quality problems of Quaternary Vasavere groundwater body, northeastern Estonia
	Poster2.16. Stefánsdóttir, G. Hydromorphological pressures in Iceland - impact on waterbody types and natural resources	Poster 5.2. Raidla, V., et al. Intrusion of saline water into a coastal paleo-groundwater aquifer in Estonia
	Poster 2.17. Xiong B., et al. Improving the Extreme Flood Risk Estimation under Non-stationary Conditions at Downstream of the Three Gorges Reservoir from 1470 to 2017	Poster 5.3. Siksnane, I.; Lagzdins, A. Impact of the catchment area and land use on nutrient concentrations in the water bodies selected within the LIFE GOODWATER IP project

Monday, 15th August

Field course in karst geomorphology and hydrology of the Kohila karst region

Oliver Koit

Four people from Latvian Environment, Geology and Meteorology Center (LEGMC) (Krišjānis Valters, Dāvis Borozdins, Jekaterina Demidko and Aiga Krauze), one person from University of Latvia (UL) (Jānis Bikše) and one person from Tallinn University (TU) (Oliver Koit) participated in the field course where the Kohila karst region was visited. Altogether five places with different geomorphological and hydrological conditions were visited.

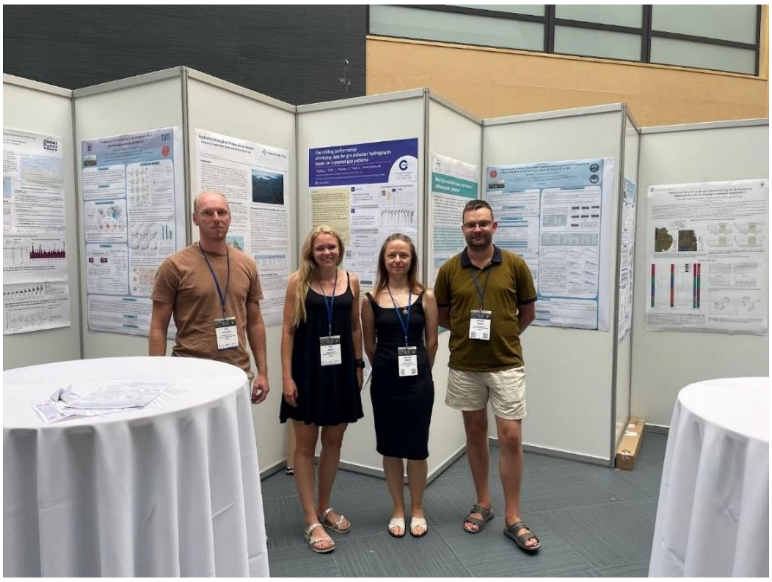
First place visited was Kõnnujärv bog lake:

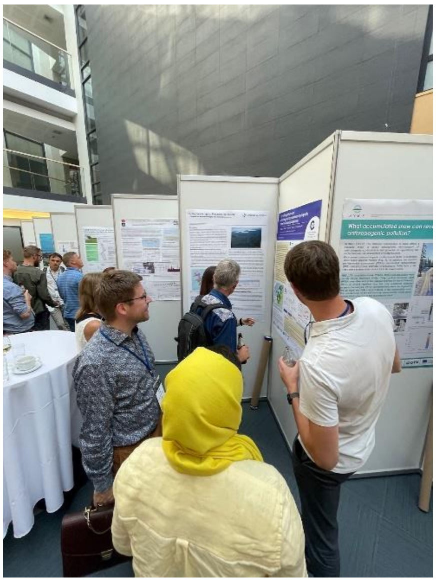
Second place visited was a spring, where Oliver Koit demonstrated measurements, he has done over the years:

Third and fourth places visited were a couple of karst sinkholes. Participants had the opportunity to climb down and explore these sinkholes, as well as one cave:

The last place visited was a well that overflows seasonally:

Tuesday, 16th August: official opening of the conference, study presentations and posters

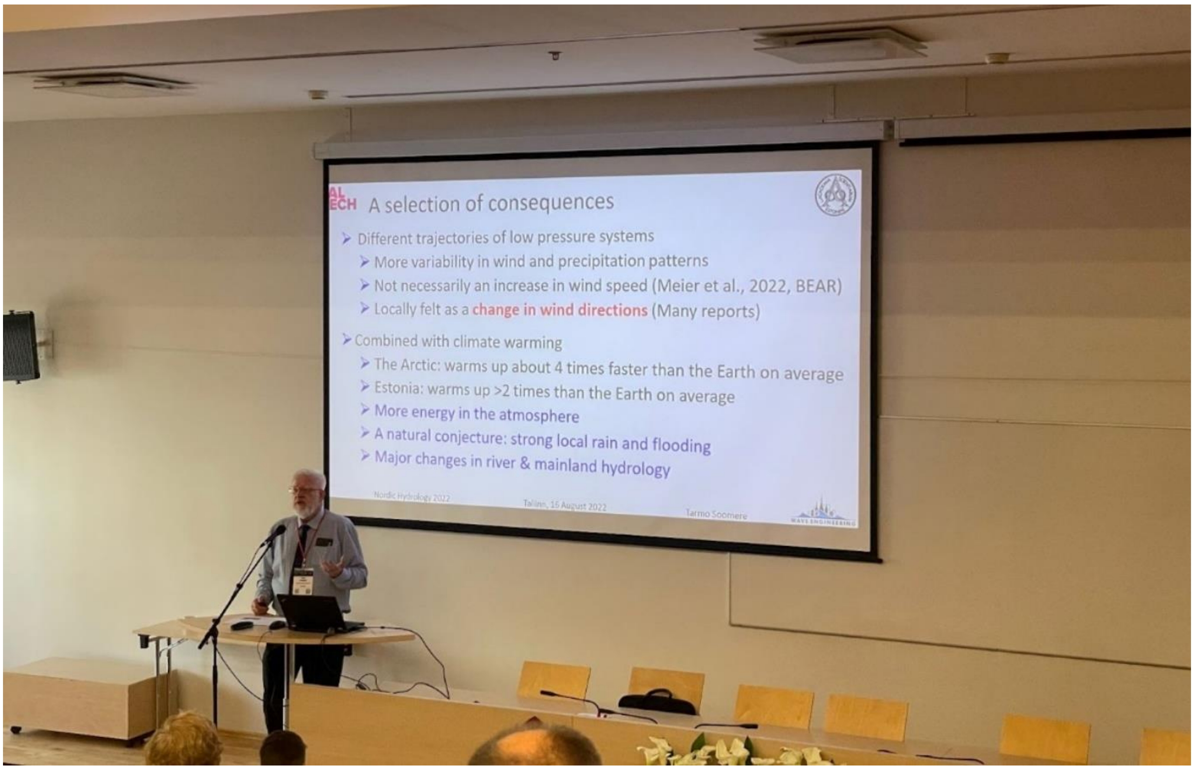




Keynote speech 1

Knowledge gaps in the interactions between hydrology, ecosystems and global change

Tarmo Soomere



Keynote speech 2

Knowledge gaps in the interactions between hydrology, ecosystems and global change (online)

Nathan D. Stansell

Effect of supplementary subsurface drainage on field scale nutrient fluxes

***Mäkelä, M.,** Myllys, M., Nurminen, J., Äijö, H., Salo, H., Koivusalo, H.*

Artificial land drainage is extensively needed in arable soils under Nordic climate conditions to ensure good growing conditions and prevent soil compaction. In Finland, about 70% of the arable land area is subsurface drained. Changes in field hydrology due to drainage have also impact on erosion and transport of nutrients. The objective of this study was to quantify effects of improvement of an old tile drainage system on hydrology and nitrogen, phosphorus and sediment losses. The experimental set up consisted of two clayey field sections in southern Finland originally subsurface drained in 1952. In June 2014, in the field (3.4 ha) with drain spacing of 32 m two new drains were installed between the original drains resulting in a drain spacing of 10.7 m. The other field section (1.3 ha) with drain spacing of 16 m was used as a reference. Before the supplementary drainage, drain flow and tillage layer runoff in both fields were measured for seven years (June 2007−May 2014).

Concentrations of total P, PO_4-P, total N, NH_4-N, NO3-N and suspended solids were determined from flow weighted composite water samples. The respective measurements after the supplementary drain installation covered five years (June 2014−May 2019). Nutrient and sediment fluxes via drains increased significantly after the renewal of the drainage system mainly due to the increased drain discharge. Whereas the losses via tillage layer runoff diminished along the smaller volume of runoff. No systematic changes in the concentrations could be detected. Groundwater discharge under drain spacing of 32 m and 10,7 m was evaluated using results of a simulation study on the field water balance. The simulated groundwater discharge decreased with the denser drain spacing which is expected to result in lower nutrient fluxes, too. Measurements on groundwater discharge and quality would be needed to comprehensively understand the effects of drainage measures on nutrient loading to surface water bodies.

Large-scale vegetation restoration and its feedbacks to land-atmospheric interactions and regional water cycles

***He, C.,** Zhang, B., Wang X.*

Large-scale vegetation restoration (LVR) programs such as reforestation and afforestation have been promoted globally to mitigate climate change and anthropogenic impacts on environments and ecosystem services. Potential benefits of LVR programs include greater carbon storage, reduced soil erosion, conservation of biodiversity, increased gross/net primary productivity (GPP/NPP), improved water quality, and higher incomes. Despite numerous benefits from such LVR programs, unintended negative effects have been widely reported, including reduced water yield, decreased farmland, increased drought, and declines in soil moisture and groundwater storage. Yet, little is known about the feedbacks of LVR to land-atmospheric interactions and regional climate, and water resources, particularly in water-stressed regions. Based on our study and literature review of regional LVR, we suggest research and management priorities to understand the land–atmosphere feedback of LVR and explore science-based processes and solutions to support informed water resources management across watershed boundaries. These include: 1) understanding the effects of bioclimatic conditions, critical patch size, composition, pattern, and spatial and temporal scales of LVR on moisture recycling and water cycles ; 2) tracking and quantifying the LVR-atmospheric feedbacks to regional precipitation and the water cycle across spatial and temporal scales; 3) defining the teleconnections of LVR; and 4) establishing proper form of governance of moisture recycling for coordinating transboundary water resources management. As LVR is being increasingly promoted to mitigate global change impacts and improve ecosystem services, there is an urgent need for concerted research to address the trade-offs of LVR to maximize the benefits of LVR and prevent unexpected hydrological consequences.

Impact assessment of hydropower plants and climate change on river runoff and fish habitats in lowland rivers

Kriaučiūnienė, J., *Šarauskienė, D., Virbickas, T., Akstinas, V.*

Hydropower plants (HPPs) significantly affect the ecological status of water bodies. They destroy the river's integrity, alter hydromorphological parameters, cause hydro-peaking and runoff fluctuations, and lose biodiversity. In this research, for the first time in Lithuania, the impact of HPPs on river runoff and availability of fish habitats was assessed and projected using the mesohabitat modeling methodology and the ecological flow approach. Using cluster analysis, hydrological regionalization of Lithuanian rivers was performed, distinguishing homogeneous regions (Western, Central and Southeastern). Using statistical analysis methods, the average annual and bio-period runoff maps are generated. Specific runoff isoline data of gauged rivers were used to estimate the runoff of ungauged rivers. The effect of HPPs in Lithuania significantly decreased the number of habitat-intolerant fish species (schneider, salmon, trout, bullhead, barbel), while the relative abundance of less specialized eurytopic species (bleak, roach, perch) increased. In the pilot rivers (selected from each hydrological region), hydromorphological and fish field investigations are performed to collect data for fish habitat modeling; and hydrological models are developed for evaluation of runoff projections. The results of mesohabitat modeling in the pilot rivers proved that the HPP activities negatively impact rheophilic benthopelagic and pelagic fish species adapted to live in higher currents; fish communities in the river sections below HPPs have changed. Therefore, the current environmental flow cannot guarantee the long-term existence of viable populations. Based on the results of mesohabitat and runoff modeling, ecological flow (e-flow) is defined as the average minimum 30-day discharge. E-flows were determined in all studied HPP-affected rivers in Lithuania. This research has received funding from the Research Council of Lithuania, agreement No. S-SIT-20-3.

Wednesday, 17th August: study presentations and posters

Controlled drainage in agricultural peatland fields – calibration and validation of FLUSH model

Salla, A., *Salo, H., Koivusalo, H., Tähtikarhu, M., Liimatainen, M., Marttila, H., Läpikivi, M.*

Controlled drainage is gaining more interest to be used in regulating groundwater levels and water outflow pathways in adapting to wet and dry conditions. In peatlands, controlled drainage also has potential in mitigating greenhouse gas emissions, as maintaining shallow groundwater levels reduces peat decomposition resulting from soil drainage. Our objective was to computationally describe the hydrological behavior of a field with shallow peat soil drained with controlled subsurface drainage and an open collector ditch. The study site is a 2.97 ha agricultural field with 40–80 cm thick peat cover located in central Finland managed by the Natural Resources Institute Finland (LUKE). A 3-dimensional process based hydrological model FLUSH was parameterized to describe the field site. FLUSH divides the soil porosity into soil matrix and macropore domains simulating the effects of slow and fast flow domains, respectively. The simulations were run with 1-hour timesteps. Initial parameterization was based on field data on soil properties and subsurface drainage settings. Water retention parameters were obtained by fitting the van Genuchten model against measured pF curves from four soil layers (three peat layers and a bottom mineral soil layer). FLUSH was calibrated and validated against measured groundwater levels and drain discharge. The calibration focused on saturated hydraulic conductivities in soil matrix and macropore systems. The preliminary model calibration results showed good correlation between hourly simulated and measured groundwater levels with mean absolute differences of 0.15 m for soil matrix and 0.21 m for macropore systems. The calibrated and validated model forms a tool to quantify how different controlled drainage scenarios can affect groundwater levels and water balance components and to study the potential of controlled drainage in maintaining groundwater level in the desired depth during hydrologically varying climate conditions.

Climate change adaptation using low impact development techniques in an urban catchment

Di Natale, C., *Koivusalo, H., Tamm, O.*

Climate change refers to the average long-term changes over the whole Earth. Regarding the northern Europe, future climate projections show a general increase of temperature over all seasons. In cold conditions, this change will strongly affect the hydrological features over a year. Stormwater management is seen as one option to adapt to a changing hydrology. In order to evaluate local climate change impacts on the hydrology and then realize a climate change adaptation through low impact development (LID) solutions, an urban catchment in Espoo, in southern Finland, was studied. The analysis was performed in three-time windows: historical, mid- and far-future, according to the RCP 8.5 emission scenario. Air temperature and precipitation time series from HARMONIE-AROME regional climate model were used as input to simulate the hydrological processes in the study catchment using the Storm Water Management Model (SWMM). This study focuses on analyzing changes in urban runoff and snow dynamics. Their behavior was analyzed seasonally and within the water year together with temperature and precipitation. When the projected mean air temperature increased, snow water equivalent reduced leaving almost no snow in the far-future period. This in turn altered the seasonal runoff behavior both in mid- and far-future periods. In fact, mid-winter runoff was modeled to increase considerably, while spring runoff was expected to decrease with respect to historical periods. In order to alleviate climate change impacts on urban hydrology, the stormwater management can be used for adaptation by installing LID solutions. The sub-catchments with the highest total runoff volumes were identified to select locations for LID implementation with high impacts on runoff. The performance of bioretention cells, permeable pavements and green roofs was evaluated to investigate if and to what extent can LID solutions aid in the mitigation against climate change impacts on the urban runoff regime.

ML-based water quality modeling at national level in Estonia

Evelyn Uuemaa, *Holger Virro, Alexander Kmoch, Marko Vainu*

Nutrient runoff from agricultural production is one of the main causes of water quality deterioration in river systems and coastal waters. Water quality modeling can be used for gaining insight into water quality issues in order to implement effective mitigation efforts. Process-based nutrient models are very complex, requiring a lot of input parameters and computationally expensive calibration. Recently, ML approaches have shown to achieve an accuracy comparable to the process-based models and even outperform them when describing nonlinear relationships. We used observations from 242 Estonian catchments, amounting to 469 yearly TN and 470 TP measurements covering the period 2016–2020 to train random forest (RF) models for predicting annual N and P concentrations. We used a total of 82 predictor variables, including land cover, soil, climate and topography parameters and applied a feature selection strategy to reduce the number of dependent features in the models. The SHAP method was used for deriving the most relevant predictors. The performance of our models is comparable to previous process-based models used in the Baltic region. However, as input data used in our models is easier to obtain, the models offer superior applicability in areas, where data availability is insufficient for process-based approaches.

Implementation of River Basin Management Plans of Latvia towards good surface water status - LIFE GOODWATER IP

Lagzdins, A.*, Siksnane, I., Sudars, R., Veinbergs, A., Grinberga, L.*

The LIFE GOODWATER IP project aims to improve the status of water bodies at risk in Latvia. Four water bodies at risk with previously identified pressures from agricultural sources were selected for comprehensive water quality monitoring activities and targeted implementation of nutrient retention measures including V046 Eda, V093 Slocene, G264 Age, and L118 Auce. The share of agricultural land varied from 50% in G264 Age to 72% in V093 Slocene according to the Corine Land Cover 2018. Water quality monitoring activities were started in March, 2021 and will be continued until 2027. Water samples were collected using a grab sampling approach on a monthly basis and tested for concentrations of total nitrogen (TN), ammonium - nitrogen (NH_4-N), and total phosphorus (TP). The number of water sampling points in the selected water bodies ranged from 13 to 15. The existing monitoring results showed pronounced differences among the selected water bodies in terms of the specific character of nutrient losses. In V046 Eda, the mean concentration of TN in four upstream sampling sites exceeded the threshold of good water quality. In V093 Slocene and L118 Auce, the mean concentration of NH4-N and TP rarely exceed the respective threshold values for good water quality, while TN concentrations were exceeded at all sampling sites indicating a strong impact from agricultural activities.

The water quality monitoring results in combination with geospatial data analysis, e.g., digital elevation model, land use, subsurface and surface drainage network, have been used to identify suitable locations for targeted implementation on nutrient retention measures.

This work was supported by the integrated project "Implementation of River Basin Management Plans of Latvia towards good surface water status" (LIFE GOODWATER IP, LIFE18 IPE/LV/000014) funded the LIFE Programme of the EU and the State Regional Development Agency Republic of Latvia (www.goodwater.lv).

Long-term groundwater monitoring can be used to assess changes in climate and land use

Ronkanen, A-K., *Tammelin, M., Orvomaa, M., Anttila, A., Mäkinen, R., Uusikivi, J.*

Groundwater (GW) is a critical resource that maintains steady baseflow in boreal streams, rivers, and lakes. Due to its unique geochemical, physical, and biological characteristics, its discharge and interactions with surface waters create specific ecosystems, which are degraded in many parts of the world. GW also has important aspects in supporting biodiversity and maintaining well-being and resilience of societies to climate change. To study these, the availability of high-quality long-term GW monitoring data is needed. In Finland, the national hydrological monitoring network produces basic information about GW levels and quality in different types of hydrogeological formations improving understanding on the sustainable use of GW reservoirs. Today the network contains approximately 80 stations across Finland, in which GW level is monitored with a varying number of standpipe wells (1-52 wells, median 10). The longest datasets are from 1970 providing more than 51 years of data. Measurements have typically been made manually biweekly throughout the year, but after the first automation of monitoring in 2005, high resolution data have been available for certain monitoring stations. The aim is to get a fully automated network by the year 2023. Temporally high-resolution data offers a great opportunity to study how hydroclimate controls GW resources under a changing environment. At some monitoring stations, changes in GW levels and in the range of fluctuation reflected a slight deviation from long-term average, which could be explained by prolonged drought periods of specific years. Seasonal changes were particularly visible in areas characterized by small and shallow groundwater formations. However, GW systems are also sensitive to changes in land cover and soil disturbance (e.g. drainage and logging), which can confound the influence of climate change. Therefore, it is essential to monitor land cover changes in monitoring stations as well.

What affect high-resolution nitrate sensor monitoring in streams? Experiences from four Danish headwater streams

van't Veen, S., *Laugesen, J., Kristensen E., Kronvang, B.*

This study investigates the use of Nitrate sensors (NITRATAX plus sensor from HACH) in four Danish headwater streams over a period of 6 years. The nitrate sensor works according to the UV measuring principle and can measure the nitrate (NO_3) concentration in streams with high-resolution down to every minute. Together with high-frequent discharge measurement, this can improve the NO_3 transport calculations. Thus, it is possible to achieve a much more accurate NO_3 transport and much more detailed insights into sources and processes governing NO_3 concentrations in catchments linked to catchment models (E.g. SWAT). The NO_3 sensor was installed in Jegstrup stream in 2016 (NO3-concentrations ranging 9-2.3 mg N/L), in Saltø stream in 2017 and 2018 (NO_3 conc. ranging 0.005-23 mgN/L), in Horndrup stream continuously from 2019 to now (NO_3 conc. 0.44-8 mgN/L) and in Lyby-Grønning Stream continuously from 2021 to now (NO_3 conc. 0.02-18 mgN/L). We defined four overall factors that may affect the sensor measurement in the streams: i) zero offset of a sensor; ii) sensor drift; iii) sensor interference; iv) sensor disturbances. In all streams, we found challenges with zero offset, which may be due to chemically/biologically driven causes such as high concentrations of dissolved iron in the stream, biofilm or other biologically introduced interferences. The zero-offset shows to be different from season to season and different between the streams. In this study, we are investigating the zero drift of NO_3 sensors during a year in different streams in an attempt to quantify the seasonal and inter-stream variation and possible causes. We are establishing robust correlations between NO_3 concentrations measured with the sensor and in grab samples analyzed in the laboratory ($R^2 > 0.90$). Therefore, it is possible to calibrate the NO_3 sensor measurements in each stream and use these data to analyze the importance of using sensor measurements against traditional discrete sampling programs.

Hydrogeology of the shallow karst aquifer of the Pivka Valley (Slovenia)

Mayaud, C., *Kogovšek, B., Petrič, M., Ravbar, N., Blatnik, M., Gabrovšek, F.*

The Pivka Valley (Slovenia) is located 30 km SW from Ljubljana and belongs to the catchment of the Unica and Malenščica springs, the latter being a drinking water supply for 21.000 inhabitants. The Pivka River emerges from several temporary karst springs and flows for 20 km in a S-N direction before disappearing into a ponor. This river is permanently active in the valley lower part, which is composed of flysch rocks. Conversely, the valley upper part is made of limestone and the river is dry for about 50 % of the time. The shallow karst aquifer located below the Upper Pivka is connected to the larger Javorniki karst aquifer that borders the valley E side. The main flow direction goes towards the Unica and Malenščica Springs in the N. During high water periods, the regional groundwater level rises up to 50 m and water appears at the surface. The discharge of the Pivka River can surpass values of 20-25 m3/s, while the rise of the regional water level creates 17 temporary lakes. Some of these lakes have a maximum extension larger than 1 km2 and last for several months. Due to the need to find a back-up drinking water supply to the Malenščica spring, a monitoring network has been progressively established in the Pivka Valley since 2016. Water level, specific electrical conductivity and water temperature have been recorded at a 30-min interval in all caves having access to the regional water level. Similarly, the hydrological dynamics of the main temporary lakes and springs have been measured. The data collected have been analyzed and combined with data collected in the water active caves of the Javorniki karst aquifer and at the Unica and Malenščica Springs. The results show that the shallow karst aquifer below the Upper Pivka River acts as an overflow of the Javorniki karst aquifer during high water periods, while it flows back into the Javorniki aquifer and further toward the Malenščica spring during the recession.

Conceptualizing transboundary aquifer systems using geochemical signatures of springs

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According to the EU WFD, the Member States sharing TGWBs should carry out joint evaluation of the groundwater resources. To ensure this, it is important to establish a representative cross-border groundwater monitoring network. The transboundary area of Estonia (EE) and Latvia (LV) is sparsely populated and features a relatively scarce monitoring network. Springs are natural groundwater outflows that may provide information on a significantly greater catchment area than monitoring wells. Monitoring springs can be cost-effective, however, selecting the most representative springs requires a thorough assessment. In this study, we screened 46 springs in the EE-LV transboundary area for 60 hydrochemical parameters. Additionally, we evaluated 31 various wells to define the groundwater system end-members. In total 409 groundwater observations were analyzed. The sampled springs were pre-classified to one of the three aquifer systems: Quaternary (Q), Upper-Devonian (D_3) and Middle-Devonian (D_2). There were significant differences among the presumed groups in terms of spring elevation, Q thickness and discharge. All the assessed springs featured relatively homogenous ion chemistry. There was a significant difference in median TDS between Q and bedrock aquifer systems, but little between D_2 and D_3. Out of 83 parameters or ratios assessed, only 17 showed significant differences between D_2 and D_3 systems. By applying multivariate and machine learning methods, among other parameters, the differences in barium concentrations were the most significant in linking the springs to the most importantly contributing aquifer systems.

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Assessment of aquatic ecosystem services in Estonia: methodology and application in Viru subcatchment

Marko Vainu

The EU Biodiversity Strategy for 2020 stated that member states should map and assess the state of ecosystem services in their national territory by 2014. The initial methodology for assessing the provision and consumption of aquatic ecosystem services in Estonia was developed in 2016, but it was never applied in practice. Since 2019, work with the methodology has continued in the framework of the project LIFE IP CleanEST. Its general aim is to improve the status of water bodies in the Viru subcatchment in northeastern Estonia. One of the project actions is to compile a practically applicable methodology for assessing aquatic ecosystem services in the whole of Estonia, and to test that methodology on water bodies in the project area. The assessment will be carried out three times and the results will be used at the end of the project to evaluate the success of other project activities. If the assessment of ecosystem services proves to be an applicable and effective measure, then the Ministry of Environment is interested in applying it more generally in Estonian aquatic resources management.

Altogether 17 ecosystem services provided by riverine and 19 services provided by lacustrine ecosystems were considered relevant for Estonia. Classification of these services follows CICES v.5.1. Ca. 70 indicators for measuring the provision/status and the consumption/pressure of the services for both lakes and rivers were developed. The methodology was applied on 20 flowing water bodies and two standing water bodies in the Viru subcatchment. The results show clear differences between the water bodies in the provision and consumption of specific services, as well as services altogether. That demonstrates the usefulness of the applied methodology for pinpointing both natural differences of the water bodies and services affected by anthropogenic pressures. The presentation covers the methodology, results of the assessment, encountered challenges and possible policy inputs.

Modelling spatio-temporal extent of water level control in an agricultural ditch network

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Water level control implemented by adjustable damming in the main ditch of an agricultural area increases flexibility of managing agricultural drainage systems. The aim of the damming is to periodically detain water in the ditch during low drainage needs and enable full drainage capacity during wet conditions. The objective was to create a modeling tool to simulate damming effects on main ditch water levels and assess the potential storage capacity of such damming options.

The model discretized the ditch network to segments and produced numerical solutions of Saint-Venant equations for unsteady one-dimensional flow in the network. The model was set up to describe water flow in a main ditch network of an agricultural field located in Sievi, Northern Ostrobothnia, Finland. The ditch network had a total length of 3.2 km, an average depth of 2.0 m and a mean slope of 0.3%. A dam was set as a downstream boundary with a specific discharge curve describing the outflow as a function of water level. Lateral inflow from the surrounding areas was calculated based on the land area connected to the ditch segments. The model was also parameterized to simulate the ditch hydraulics without damming.

Preliminary results obtained from a steady-state simulation show the damming effects on the water levels to be most prominent in the ditch segments near the dam (400-500 m upstream) during low inflows (0.16 mm/h) and with a dam height of 0.5 m. The scenario simulation results of different damming options will further demonstrate the potential water storage capacity of the agricultural ditch network. The created modeling tool can be used in assessing how damming of the main ditch affects the drainage conditions of surrounding subsurface drained fields with or without other water management control options such as controlled subsurface drainage. Concurrent control of the water level in the ditch and the water table in the subsurface-drained fields is a key to flexible water management.

Assessing soil moisture oscillations under different tropical land covers

***Schwamback, D.**, Watanabe, A. M., Zepon, F. A. de O., Scutti, L. C., Castro, L. F. S, Wendland, E. C.*

Soil water storage capacity and infiltration rates are affected mainly by vegetation, pedology, and climatology. Thus, soil moisture monitoring is essential for a better understanding of phenomena dependent on soil-vegetation-atmosphere synergies, such as surface runoff, erosion, and infiltration capacity. In this paper, we aimed to assess soil moisture oscillations under different tropical land curves monitored through low-cost technologies. The study area is in Itirapina municipality, central region of the State of São Paulo, Brazil (22o10'S, 47o52'W, elevation of 790m). The region's mean annual rainfall is about 1486 mm and has a humid subtropical climate, with hot summers and dry winters. Field monitoring adopts the concept of experimental monitoring plots (100 m2 and 9% slope) under different land covers: sugarcane, Cerrado (Brazilian savanna), soybean, and bare soil. The field monitoring is run by capacitive sensors (model SKU:SEN0193) at 10-, 60-, and 90-centimeters depth (SR10, SR60, and SR90, respectively) operating under low voltage (3.3V) controlled by Arduino and powered by solar cells. SR10 presents daily sinusoidal oscillation of the output signal due to water vapor in the soil resulting from solar radiation. After a precipitation event, SR10 immediately indicated soil moisture rise, while there is a gradual delay in the response of the other sensors as the wetting front advances in the soil depth. Comparing the infiltration rates under different vegetation covers, it was observed that the presence of roots serves as a preferential flow, increasing the infiltration speed. Additionally, forest litter reduces soil evaporation and smoothes the occurrence of sinusoidal oscillations of soil moisture. Brazil is a continental country with a climatic and cultural vocation for agriculture. The proper management of natural resources and increase in agricultural production will only be feasible through the construction of a local water resources database.

General Assembly 2022

At the end of the third day, conference participants attended the Nordic Association for Hydrology General assembly 2022. During the assembly board members, financial reports, budget for the following year were introduced. Election of board members and deputy members happened. Also an announcement of the next Nordic Hydrological conference was made – it will happen in Iceland in 2024.

Thursday, 18th August: study presentations and posters

Assessing vertical hydraulic conductivity of peat with atmospheric pressure movements using buried pressure transducers

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Hydraulic conductivity of peat is one of the key parameters to understand the water movement inside a mire and in its surroundings. More is known about the lateral hydraulic conductivity of peat as it is measured with conventional methods. Less information is gathered about the vertical hydraulic conductivity, which is far more difficult to assess. However, in situations where there is a possible increase in vertical gradients, for example lowering of water pressure in aquifer beneath the peatland due to nearby underground mining, knowledge about the vertical conductivity is necessary. This parameter is mostly measured in the laboratory using samples of retrieved peat cores. Getting a representative sample of peat for laboratory measurements from greater depths however is challenging. We used specially designed 3D printed casings to push in and bury automatic pressure loggers into peat at different depths. Atmospheric pressure was also logged on site with the same time interval as the water levels in peat. A Python script was written to use an analytical solution to calculate the water level response based on the atmospheric pressure fluctuations and compare it to the actual measured pressure time series. This approach allows us to assess the hydraulic diffusivity of peat above buried pressure transducers. Separate laboratory oedometer tests were carried out with retrieved peat samples to determine compressibility and with that the specific storage of peat for vertical hydraulic conductivity estimates. Preliminary results show a relatively good fit between calculated and measured hydrographs thus allowing to assess the hydraulic diffusivity of peat. Coupling it with separate specific storage assessments gives reasonable values of vertical hydraulic conductivity. This approach shows potential usage for other fine-grained sediments.

A new vision of the river sections upstream weirs: the weir pool ecotone

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The weir pools are the spaces formed by the raising of the water line and the slowing of the current caused by weirs, overflowing hydraulic structures, generally of small dimensions, very widespread in contemporary rivers. The nature of these environments is still poorly understood and water sciences struggle to classify them in known continental aquatic environments. Some see them as degraded segments of watercourses, which have totally or partially lost the typical features of lotic environments; others consider them as ecosystems as such, with their own functionalities and their own role to play in environmental dynamics. In research that we have recently published, we equate weir pools operation with ecotones operation and we would like to explore this hypothesis in further detail in this paper. Indeed, weir pools and ecotones are controlled by environmental gradients and seem to have the same functionalities, such as the ability to filter matter, to store and redistribute substances and to provide a real habitat for different types of organisms. This new vision of weir pools can even be extended to other man-made aquatic environments, ponds for example. Thus, new research and management outlook arise as this type of environment will no longer be considered as a mere obstacle within rivers, but as environments which are fully integrated into today's fluvial landscapes with their own functionalities.

The Role of the Small Urban River in the Past and Present in the City of Tallinn

Pedusaar, T.*, Pachel, K.*

Many cities have developed around rivers due to the resources that they provide including water, food, power and transport. Urban development has often overlooked the value of functional aquatic ecosystems. Urbanization is considered to be one of the most dramatic causes of alterations to water ecosystems. There is increasing recognition of the benefits, or services, that cities derive from urban aquatic ecosystems. Large urban rivers provide ecosystem services that can be quantified relatively easily, such as navigation, hydropower, and water supply. In contrast, small urban rivers have not had significant economic interest, neither in the past nor the present. Still, in practice, small rivers provide benefits on local scales and often have merits that have no material benefits.

River Mustjõgi is one of sixteen rivers in the territory of Tallinn City. Once long with many branches, now mostly culverted under central Tallinn, the Mustjõgi flows into the Baltic Sea. The river has not ever had navigation potential, but legend tells of its rich fisheries in the past. Now, most of the open river reaches flows through small properties creating idyllic rural landscapes. Erosion, poor water quality and high flood risks are considered the major problems facing the Mustjõgi today.

We will review the impact of urbanization on the River Mustjõgi. Changes in provisioning, regulation and cultural services will be considered from the 17th century up to the present. We will show changes in river route, catchment size and its land use since the beginning of the 20th century based on topographical maps.

Investigating Stakeholders' Flood Risk Perception In Ghana From A Socio-technical Perspective

Yiwo, E.*, Brito, M.M., Jato-Espino, D.*

Flooding has dreadfully affected the globe. In the developed, developing, and under-developed jurisdictions, people have died, assets and the environment have suffered vehemently as a result of flooding. In the case of Ghana, mitigation flooding and its effects have not been met due to limited resources. This paper aimed at studying the representation of flood management in Ghana to ascertain the propulsions and prospective lasting solutions. By considering both social and engineering dimensions, a questionnaire was developed and distributed to respondents across (16 regions) the country in the categorization as citizens, volunteers, flood-related workers, policymakers, and academics. The questionnaire was disseminated to the shortlisted participants via online applications and a sample of responses used for validation. Using the R program, the collected responses were statistically tested, and key texts were mined as well. The study captured insight on land covering, urbanization, flood concepts and stakeholder participation in Ghana, and latent contribution to other developing countries. The investigation revealed that major emphasis is played on the need for citizens to get involved in the flood mitigation processes. The trending shift of replacing the natural land with artificial patterns has been identified to be a contributing condition that pushes the button to flood. Interestingly, the decision-makers were the only class that did not assign significance to surface permeability as a flood mitigation mechanism. It is, therefore, needful to consider projecting and augmenting the awareness of nature-based solutions and green infrastructure to build the envisaged resilience so far as flooding is concerned.

Citizen science for spring monitoring - an alternative way to collect groundwater data

Terasmaa, J., *Vainu, M., Koit, O., Abreldaal, P., Sisask, K.*

In many countries citizen science and volunteer water quality monitoring programs have already generated valuable datasets for analyzing changes over time. Data collection by volunteers is relatively time- and cost-efficient, it helps collect valuable information on water bodies that otherwise may go unmonitored. Using volunteers for water monitoring also supports local communities by raising awareness about the connections between water quality and our actions. Springs, as natural groundwater outflows, can fill gaps in monitoring networks and in our collective knowledge, as connections between groundwater and groundwater dependent ecosystems are often not understood. Monitoring springs is cost-effective (no installation or maintenance costs), water sampling is easy (does not require time-consuming water pumping), and their water can provide information on a significantly larger area than monitoring wells. Many springs are accessible to the general public, making simple observations and reporting easily performable. For this purpose we started a citizen science initiative for spring monitoring for Estonia and Latvia. The goal was to collect new information about known springs - their exact locations, current conditions and water quality, but also to find new springs.

Web-based map application (allikad.info and avoti.info) was launched in February 2021. The initiative was introduced in newsletters, journals, radio shows, national TV and social media platforms. Initially the map application had 1609 known springs (1486 from Estonia and 123 from Latvia). During the one-year period 194 users joined and collectively added 455 new springs to the database. Locations of 270 previously known springs are corrected. Also, 839 observations were made - this includes water quality measurements and descriptions. The number of added photos is 2237. This valuable information is being continuously rechecked and many corrections are already made on the Estonian Land Board base map.

This study is financed by the Interreg Estonia-Latvia cooperation program project "WaterAct", the EEA and Norway Grants Fund for Regional Cooperation project "EU-WATERRES", and by performance-based funding of University of Latvia Nr.AAP2016/B041 within the "Climate change and sustainable use of natural resources" program.