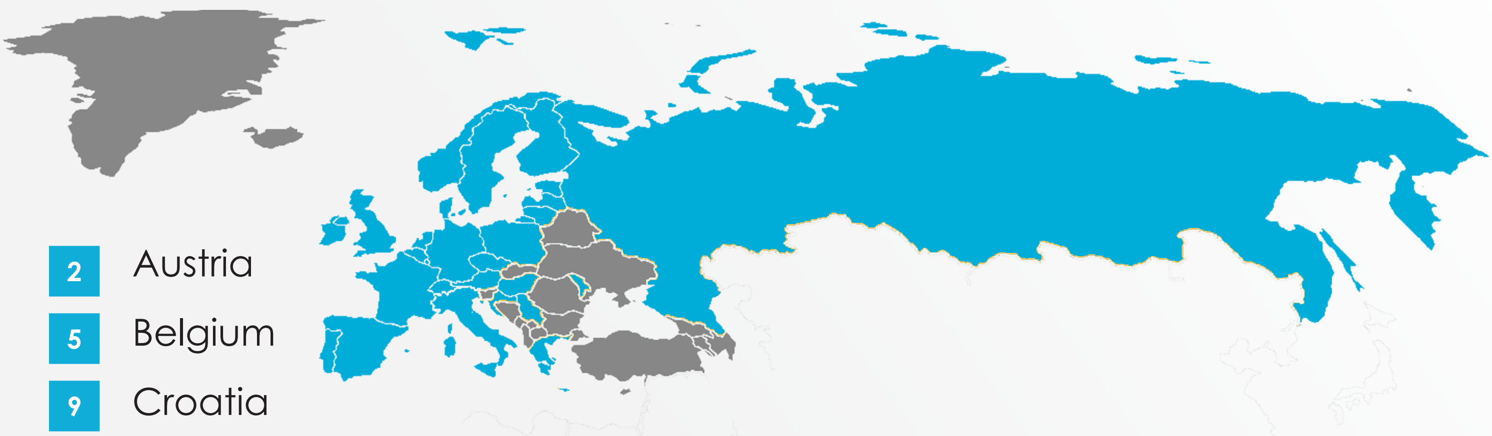
igrac
International Groundwater Resources Assessment Centre

WMO

NATIONAL GROUNDWATER MONITORING PROGRAMMES

EUROPE & CAUCASUS



2	Austria
5	Belgium
9	Croatia
10	Czech Republic
12	Denmark
14	Estonia
16	Finland
18	France
21	Germany
23	Greece
25	Hungary
26	Ireland
28	Italy
29	Latvia
30	Lithuania
32	Luxembourg
33	Moldova
34	Netherlands
37	Norway
39	Poland
41	Portugal
43	Russian Federation
45	Serbia
47	Spain
48	Sweden
50	Switzerland
52	United Kingdom

Austria

Capital city: Vienna
Inhabitants: 9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Sub department Water Balance (Wasserhaushalt – Hydrographisches Zentralbüro) belonging to the Department of Water Management in the Federal Ministry for Agriculture, Regions and Tourism (BMLRT) coordinates the data collection, quality control, evaluation and publication of hydrographic information, including groundwater.

* Note that from January 8, 2018 to January 28, 2020 the Ministry was called Federal Ministry for Sustainability and Tourism (BMNT). Before 2018, it was called Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). Older publications refer to BMLFUW or BMNT as the institution in charge of groundwater monitoring in Austria.

CHARACTERISTICS OF THE NETWORK

Since 1893, the results of the observations of quantitative monitoring have been summarized in the Hydrographic Yearbook of Austria, which includes a chapter dedicated to the status of pore groundwater since 1948 and a chapter with hydrologic properties of springs to characterise joint and karst aquifers since 1995. According to the Yearbook 2016, the observation network of the Hydrological service has a national coverage of around 83,850 km2, and comprises 3535 groundwater level measuring points, 1518 groundwater temperature measuring points and 91 springs. Groundwater levels are collected either weekly (41% of the measuring-sites) or continuously in 15minutes to 1hour-intervals, and groundwater temperature is collected in the same way, the percentage of continuous sites about 89%. At springs all parameters (water level/discharge, water temperature and electrical conductivity referred to 25 °C) are measured every 15 minutes.

There also exits a soil-water-monitoring network in Austria partly since 1995. In open-land-sites values of water-content, soil-moisture-tension and soil-water-temperature are collected continuously in 4 to 7 depths from 5 to 160 cm underground. In lysimeters infiltration water is collected in buckets and measured continuously or weekly. Since 2019 there are special sites to monitor the surface-water-content. These data are not published yet.

The web-GIS-platform eHYD – hydrological data in the internet shows the location and the ID of all monitoring points with published data on the map "monitoring points and data" (Messstellen und Daten), Figure 1.

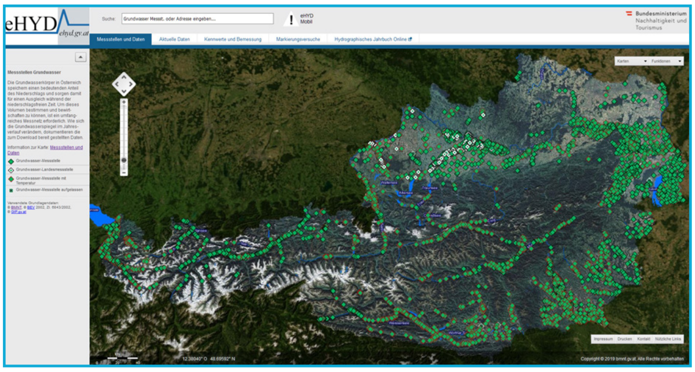


Figure 1 – eHYD platform. Map: monitoring points and data (Messstellen und Daten) - groundwater monitoring points

PROCESSING

Until 2012 the Hydrographic Yearbook auf Austria was printed and contained a short description of the hydrological processes in the respective year and a large number of tables with measured values and statistics. From 2013 the tables are only published online, and the printed part of the Hydrographic Yearbooks of Austria contains a detailed description and analysis of the hydrological conditions during the year. To assess the status of the groundwater resources in Austria three different methods are used.

The first method compares the annual average with the mean of a selected historical record. In the case of 2016, for each monitoring point, the annual average value for 2016 was compared with the mean for the period 1981-2010. Only monitoring points with values from 1981 to 2016 were included, Figure 2.

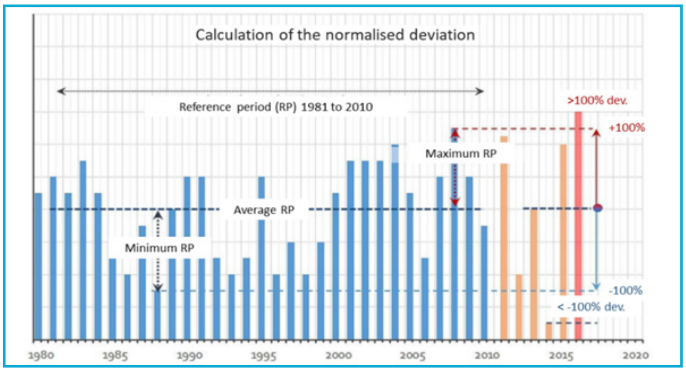


Figure 2 – Calculation method for normalised deviation

Annual averages greater than 100% or less than -100% for the period 1981-2010 are considered as values that have never occurred before or during the comparison period. Values between -100% and 100% correspond to the variances observed in the comparative period.

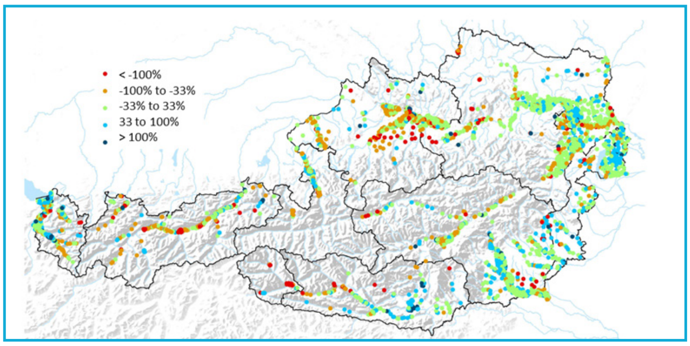


Figure 3 – Deviation of the average groundwater level for the year 2016 from the reference period 1981-2010 as a percentage of the maximum or minimum values in the reference period 1981-2010

The second method is an analysis of seasonal change, based on comparison of daily groundwater level mean values at selected monitoring points with their long-term daily mean, minimum and maximum, Figure 4. The same is done for springs.

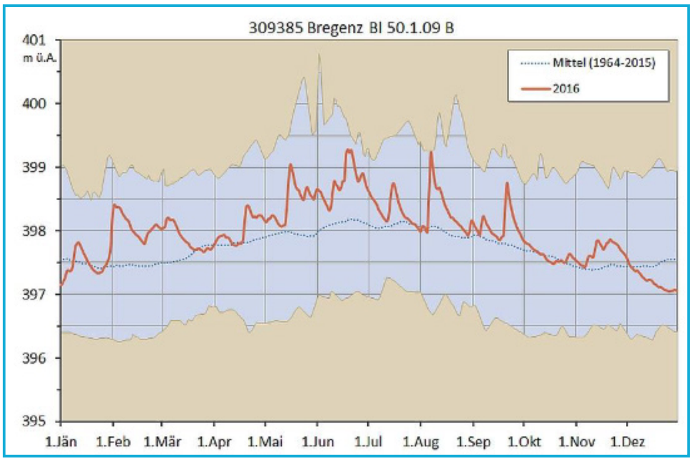


Figure 4 – Daily average groundwater level of 2016 for a single monitoring point in Bregenz, compared to long term daily mean, minimum and maximum. Source: Hydrographic Yearbook of 2016

The third method is used to estimate the volume of water recharged or discharged from a catchment area. During the year, the groundwater volume fluctuations in each catchment area are calculated daily and presented in hydrographs, Figure 5. Each catchment area is composed of several groundwater areas.

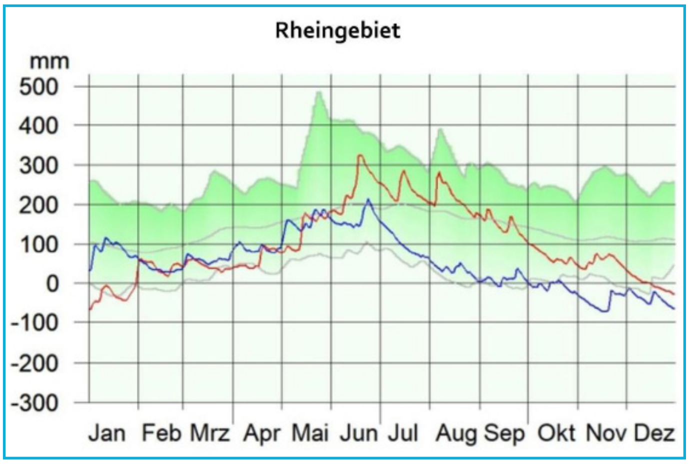


Figure 5 – Changes in groundwater volume (VOLPA VOLume Per Area within 1 year (blue: hydrograph in 2015, red: 2016) in Rhein River Basin. The green area indicates the range of fluctuation between the daily minimum and daily maximum since 1990. Source: Hydrographic Yearbook of 2016

Starting from 1 January 1990 until the end of 2015, groundwater levels (contour lines) for each groundwater area were constructed for each day using Kriging, and the volume change was calculated considering the average porosity per each groundwater area.

These changes were summed up within all catchment areas covered by groundwater monitoring stations and displayed in mm per area. The porosity values were derived from data from the Geological Survey, by assigning average porosities to the lithological units (from 7 to 25%). All catchment areas are shown in Figure 6.

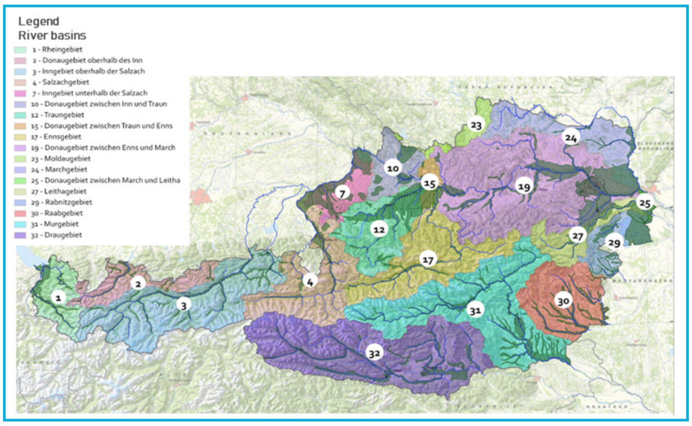


Figure 6 – Overview of the river basins after the WKEV (Water Cycle Survey Regulation) and the groundwater areas. Source: Hydrographic Yearbook of 2016

DISSEMINATION

Hydrographic Yearbooks of Austria beginning with 2004 are downloadable as PDF from the web page of BMLRT under the menu "Service" -> "Publications" or https://www.bmlrt.gv.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/jahrbuecher.html. Older printed Yearbooks can be asked for at the subdepartment Water Balance (wasserhaushalt@bmlrt.gv.at).

Since 2014 tables and evaluations in PDF-format are to be download separately from the web-application Hydrographic Yearbook online at https://wasser.umweltbundesamt.at/hydjb/. This application is part of the Water Information System Austria (WISA), which is a central platform to access data and information about the Austrian water sector. There are tables with monthly mean values, the annual mean, maximum and minimum of the year of groundwater level and groundwater temperature for every monitoring point grouped by river basin and groundwater basin. They are to be find under the menu "Download evaluations" (Auswertungen herunterladen) -> "River basins" (Flussgebiete).

Erstelldatum: 14.Mrz.2019 Hydrographisches Jahrbuch 2016 GWS 1

Monats- und Jahresmittel der Grundwasserstände mit Extremwerten (Hauptwerte)

- Grundwasserstände m ü.A. -

Nr.	Messstelle Messpunkt m ü.A. Beobachtungsbeginn	m ü.G. Daten verwendet ab	EDV-Mess-stellen-nummer beeinflusst / artesisch/gespannt	Messgerät	I VII	II VIII	III IX	IV X	V XI	VI XII	Jahr	Niederster und höchster beobachteter Grundwasserstand sowie allenfalls höchster beobachteter Überflutungswasserstand: im Berichtsjahr m ü.A.	im Berichtsjahr Datum	vor dem Berichtsjahr m ü.A.	vor dem Berichtsjahr Datum
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1	Hörbranz, Bl 40.1.04 418.36 1983	- 0.17	327700	D	404.20 405.38	404.80 405.16	404.83 404.64	404.33 404.21	405.22 404.37	405.82 403.99	404.74	403.58 406.79	04.01. 21.06.	402.49 408.87	07.01.1986 03.06.2013
2	Hörbranz, Bl 40.1.05 437.90 1983	0.73	327718	D	408.53 410.04	408.80 409.89	409.08 409.63	408.94 409.28	409.05 409.01	409.65 408.92	409.24	408.47 410.13	08.01. 02.07.	407.93 411.31	27.05.1991 18.11.2002
3	Hörbranz, Bl 40.1.06 410.55 1983	0.85	327726	D	405.18 405.45	405.47 405.42	405.42 405.18	405.15 404.97	405.51 405.20	405.78 404.94	405.31	404.76 406.24	31.12. 20.06.	403.67 407.49	28.10.1985 02.06.2013
4	Hörbranz, Bl 40.1.07 A 430.51 1994	0.90 03.12.2001	327767 1	D	417.11 418.30	417.35 418.32	417.65 418.18	417.63 417.94	417.78 417.80	418.11 417.66	417.82	417.00 418.38	08.01. 23.08.	415.91 418.42	05.10.2003 25.01.2011
5	Hörbranz, Bl 40.1.08 428.15 1984	1.09	327742	D	425.45 425.37	425.49 425.46	425.34 425.33	425.31 425.08	425.53 425.37	425.60 424.99	425.36	424.91 425.92 Ö	26.12. 13.05.	424.51 426.59	25.02.2008 01.07.1991
6	Hörbranz, Bl 40.1.09 A 468.87 1998	0.92 03.12.2001	327775 1	D	462.87 462.68	463.20 462.93	462.71 462.63	462.51 462.14	462.92 462.60	463.18 461.78	462.68	461.47 464.29	31.12. 01.02.	460.66 465.89	16.08.2004 02.06.2013
7	Lochau, Bl 40.1.02 399.03 1983	0.75	327684	D	396.60 396.85	396.67 396.73	396.59 396.58	396.56 396.46	396.72 396.55	396.97 396.46	396.64	396.41 397.28	17.10. 19.06.	394.01 397.64 396.64	08.02.1993 24.05.1999 06.09.2012
8	Lochau, Bl 40.1.03 416.73 1983	0.82	327692	D	405.60 406.86	406.35 406.73	406.27 406.17	405.82 405.56	406.87 405.96	407.41 405.05	406.22	404.73 408.26	31.12. 20.06.	403.53 410.09	30.10.1995 02.06.2013

Figure 7 – Table with monthly means, annual means, maxima and minima 2016 of groundwater level in the groundwater bain Leiblachtal in Rhein River Basin

For each observed spring a PDF with daily discharge means, monthly and annual means and extrema for all measured parameters (discharge, water temperature, electrical conductivity and in special cases turbidity) and hydrographs is downloadable under the menu "Download evaluations" (Auswertungen herunterladen) -> "Monitoring points" (Messstellen). The springs theirs PDFs wanted to be downloaded can be selected from a list or a map, Figure 8.

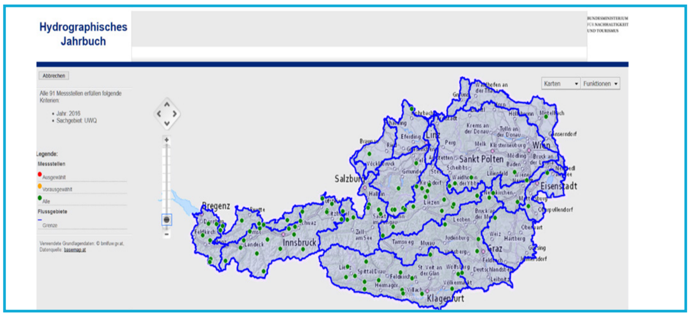

Figure 8 – Hydrographic yearbook online. Map with observed springs and borders of the river basins 2016

In order to give interested people access not only to PDF-Tables with values of one year, but also to long-term data in a format to be used further 2005 the web-GIS-platform eHYD went online. There, on the first register "Monitoring points and data" (Messstellen und Daten), data from the hydrographic archive can be downloaded. All measuring points published in the yearbook are displayed in position either all together on one map or divided into the subject areas precipitation, surface water, groundwater (Figure 1) and springs. Clicking on the symbol of a measuring point opens a tooltip with links for downloading the verified data available at this measuring point in CSV format. The data range from the beginning of electronic availability to the last year published in the form of the Hydrographic Yearbook. For groundwater there are downloadable monthly means as well as annual maxima and minima of groundwater level and groundwater temperature. For springs there are downloadable daily means of discharge, water temperature and electrical conductivity. On the second tab of eHYD, current unchecked values for runoff, groundwater and precipitation of stations equipped with remote data transmission are displayed on separated maps. In order to give a quick overview of the current situation, the colour of the measuring point symbols indicates the current status such as low, medium or high. The classification for groundwater and so the colouring of the symbols is done similar to the first method used in the yearbook for describing groundwater status. The deviation of the current groundwater level from the mean groundwater level of the reference period is converted to a percentage of the maximum overrun or underrun that occurred during the reference period at that day. There are five categories and colours, Figure 9. Green colour presents a current value that is accepted as average and lays between -25 and 25%. Values with a deviation between 25 and 100%, or -25 and -100% are classified as high or low groundwater levels (blue and orange respectively). Values with a positive or negative deviation of more than 100% are classified as very high or very low (purple and red respectively) since they have never occurred in the reference period on the considered day.

Category	Deviation (%)	Symbol and Colour	
Very high groundwater level	Higher than 100	purple rhombus	◆
High groundwater level	25 to 100	blue rhombus	◆
Middle groundwater level	-25 to 25	green rhombus	◆
Lower groundwater level	-100 to -25	orange rhombus	◆
Very low groundwater level	Lower than -100	red rhombus	◆
No current data available		white rhombus	◇

Figure 9 – Classification of current groundwater levels in eHYD

A click on the symbol of a groundwater measuring point opens a pop-up-graph which shows the daily mean values of the last eleven months in comparison to the average, minimum and maximum value of each day for the selected groundwater station, Figure 10, similar to the second method used in the Hydrographic Yearbook. The data are often displayed with one or two days of delay due to polling intervals and the calculation of the daily means.

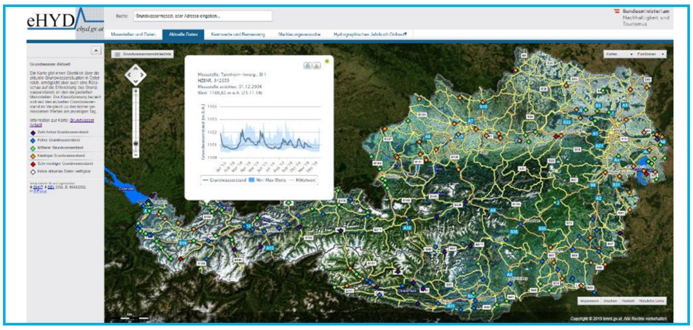

Figure 10 – eHYD platform. Map: Current groundwater levels (Grundwasser Aktuell)

Sources

- **BMLFUW changes to BMNT** - https://www.eea.europa.eu/publications/92-9167-032-4/page003.html;
- **Feedback from BMLRT** - received on 31-01-2020;
- **Link to hydrographic yearbook 2016 text** - https://www.bmlrt.gv.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/jahrbuecher/jahrbuch2016.html;
- **Link to hydrographic yearbook tables and evaluations** - https://wasser.umweltbundesamt.at/hydjb;
- **eHYD Portal** - www.ehyd.gv.at; and
- **Contact to subdepartment Water Balance at BMLRT** - wasserhaushalt@bmlrt.gv.at, Tel.: 0043 1 71100 606942.

Belgium

Capital city: Brussels
Inhabitants: 11 Million

Belgium is a federal state with three highly autonomous regions: Flanders in the north, Wallonia in the south, and the Brussels-Capital Region. Groundwater monitoring systems reflect this regional administration. The regional monitoring network of Wallonia is described below.

Flanders

INSTITUTIONAL SETTING

The application of Flemish and European legislation made it necessary to implement various target-specific monitoring networks.

The primary groundwater monitoring network in Flanders is managed by the Department of Operational Water Management of the Flanders Environmental Agency (VMM), and it is used for quantity, quality and operational monitoring.

For a better overview of the immense dataset, every monitoring well, (including the individual filters in the case of multilevel wells), is assigned to a specific measuring network. The classification is as follows (number of monitoring network and description):

1. Origin/manager unknown
2. Primary network – monthly measuring from VMM department Operational Water Management
3. Uncertain quality: mostly deeper measuring wells - initially part of the primary network, but with uncertain quality of monitored data and available well information from VMM department Operational Water Management
4. Measuring wells used for temporary projects from VMM department Operational Water Management
5. Wells from other Flemish and Belgian authorities or bodies
6. Wells from drinking water companies
7. Wells from private companies
8. Groundwater extraction wells
9. Phreatic monitoring network, especially shallow measuring wells, used for qualitative and operational monitoring from VMM department Operational Water Management
10. Usually phreatic shallow wells with a limited diameter from the WATINA (WATer IN NATURE) database operated by the Institute for Nature and Forest Research (INBO) and other nature conservation organizations. Biweekly for manual measurements and daily for measurements with a data logger
11. Wells that are constructed in the Flemish Regulations about Environmental Permits section 55 (VLAREM)

Some wells can belong to two different measurement networks, in particular networks 1 and 2. This occurs often at the level of screens.

PROCESSING

The VMM, the Department of Environment and the Department of Mobility and Public Works (MOW) work in a partnership to manage the Database Underground Flanders (DOV), which groups all information about the subsurface in the area of Flanders.

VMM produces two types of groundwater level indicators, namely for relative and for absolute status of groundwater. The analysis includes only phreatic aquifers and wells with continuous measurements for 11 years or more and an average head of 10 m-mv (meters below ground level) or less. The indicators are prepared monthly, and during very dry weather – also weekly. Performed analyses determine whether the groundwater level has increased or decreased compared to the last month and predict groundwater levels for the next month. Moreover, the locations of measurements are selected in a way to avoid the influence of human interventions as water extraction and drainage. The indicator shows the climate variability of the level.

Level measurements are supported by a SWAP model (Soil, Water, Atmosphere and Plant model). The model predicts the groundwater level for each measurement site based, among other things, on soil characteristics, the observed daily rainfall and evaporation. The results of the daily modelling are then combined with the monthly level measurements. The time series of daily simulated groundwater levels obtained in such way are processed into the indicator.

1. Indicator for the relative status of groundwater – What is the situation this time of the year?

For each monitoring location, the simulated groundwater level (combination of monthly level measurements and daily modelling with the SWAP) per day is compared with the simulated groundwater levels of the same day for the past 30 years. In statistical terminology: the percentile that corresponds to the groundwater level simulated for this year is read on the empirical cumulative distribution. The percentiles are divided into 5 classes: very low/very high (lower/higher occurs less than once in 10 cases), low/high (lower/higher occurs 1 to 3 times per 10 cases) and normal. The graph shows per day the percentage of monitoring stations that registered a very low, low, normal, high or very high groundwater level.

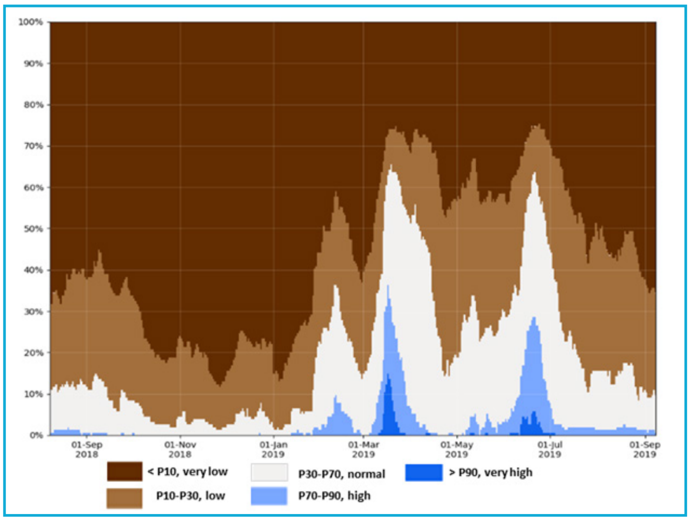

Figure 11 – Relative status of the groundwater level for selected period (September 01 2018 to August 26 2018)

2. Indicator for the absolute status of groundwater – Is the groundwater historically low or high?

The simulated groundwater level (combination of monthly level measurements and daily modelling with the SWAP model) per day is compared to the simulated groundwater levels of all days in the past 30 years. The method shows the percentage of cases the groundwater level is lower (or higher) than the simulated groundwater level for the day in question. The percentiles are divided into 5 classes: very low / very high (lower / higher occurs less than 10% of the days), low / high (lower / higher occurs 10 to 30% of the days) and normal.

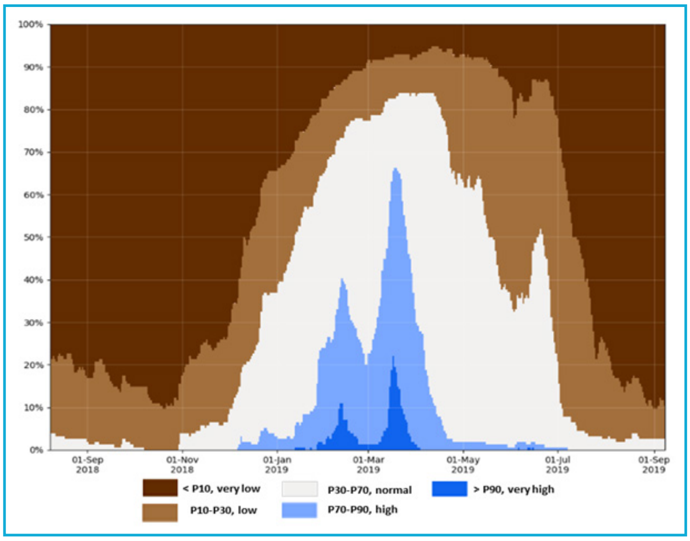

Figure 12 – Absolute status of the groundwater level for selected period (September 1, 2018 to September 1, 2019)

3. Increase or decrease of the water table

This is determined by comparing the current groundwater level with the groundwater level of the previous month. If the change in the groundwater level at a measurement location is more than 5% of the difference between the 10th and 90th percentile of the groundwater level at that measurement site, this is regarded as an increase or decrease. Otherwise, the situation is considered stable.

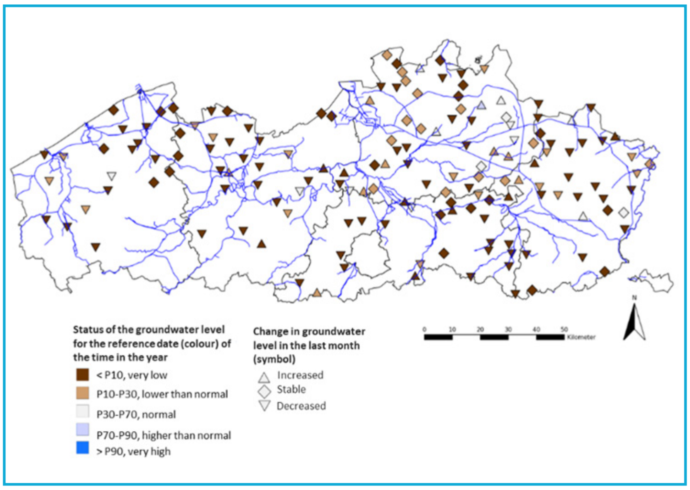

Figure 13 – Example of groundwater level changes map

4. Prediction of groundwater levels

Three scenarios are modelled to predict future groundwater levels: a wet, a normal and a dry situation for the next month. The amount of precipitation in these scenarios correspond to a historical precipitation period from the Royal Meteorological Institute of Belgium (KMI) in Ukkel. For the wet and dry scenario, a month with a precipitation that occurs every 10 years is selected. For the normal scenario, a month with an average rainfall is chosen. The expected groundwater levels according to the three scenarios are compared in relative terms (all measurements on the same day of the year) and absolute (measurements on all days of the year) with the groundwater levels of the past 30 years. A warning is only given if the expected groundwater levels are very high / low historically or for the time of the year.

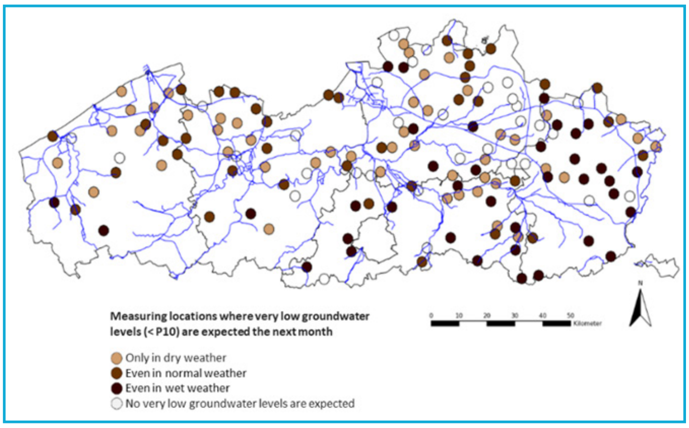

Figure 14 – Example of groundwater levels projection for the next month

DISSEMINATION

All wells are currently available in the DOV database through its web-based portal (DOV-Explorer).

In total, it is possible to access the data of 62.443 wells, of which 17.109 screens correspond to level measurements and 12.590 to screens from which a groundwater sample was taken.

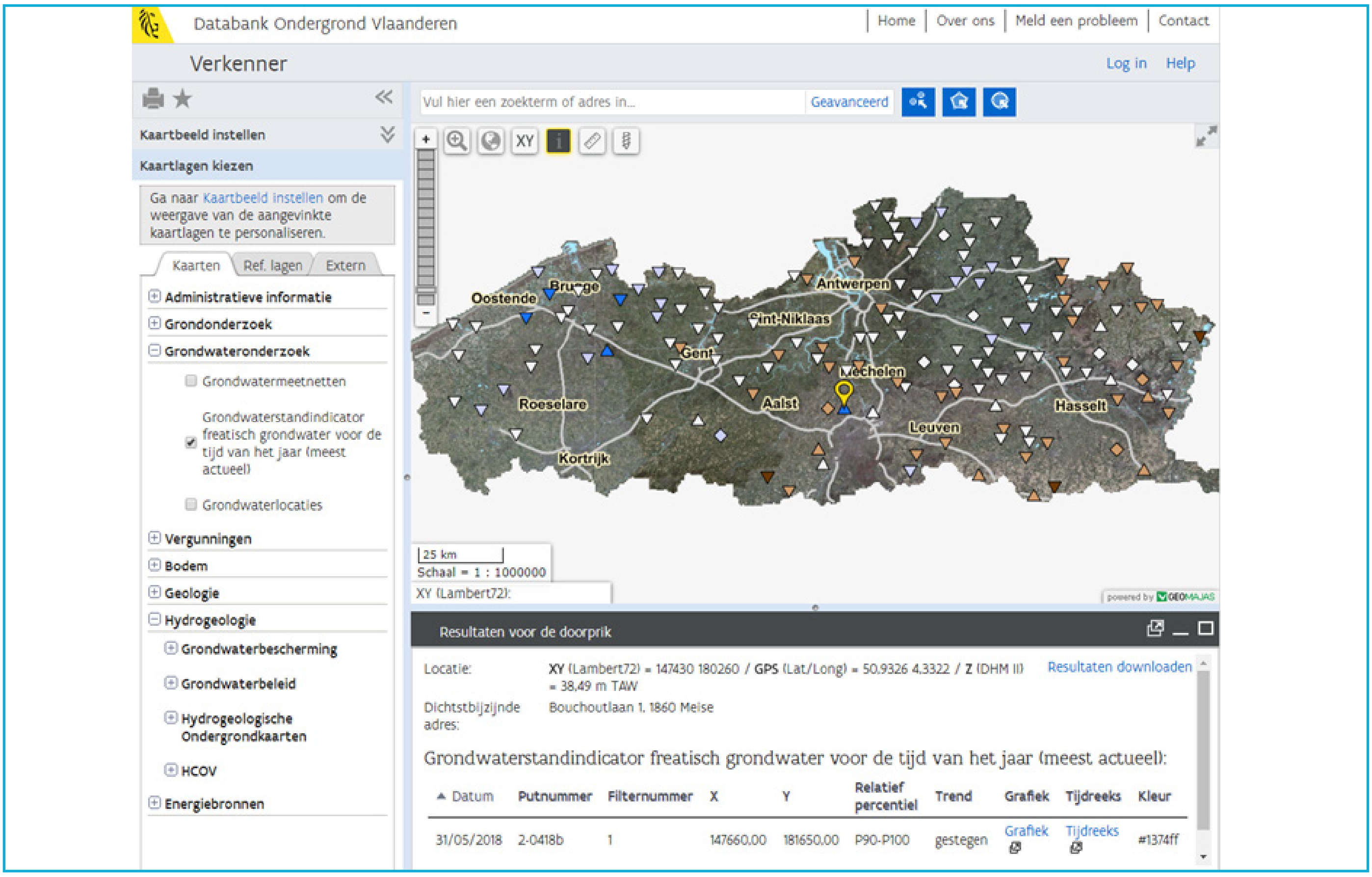

Figure 15 – Groundwater monitoring network of Flanders, DOV-Explorer

Wallonia

INSTITUTIONAL SETTING

The Directorate of Groundwater (part of the Department of Environment and Water, General Directorate of Agriculture, Natural Resources and Environment) is responsible for both quality and quantity groundwater monitoring networks in Wallonia including the acquisition and the maintenance of the network.

CHARACTERISTICS OF THE NETWORK

The general quantitative monitoring network comprises more than 260 monitoring stations, where 235 are equipped with an automatic measurement system. Manual measurements are taken monthly to yearly depending on the availability of personnel, conditions of accessibility to the station, and others. Stations, where quantitative status is measured (178 in total), are part of a groundwater monitoring program that is setup according to the EU WFD and measuring changes in groundwater bodies as the basic units. The DCE monitoring network consists of 553 monitoring stations and both quantity and quality of groundwater is measured at 20 locations.

There is a separate emergency network set up for several karst aquifers equipped with automatic, real time measurements of water levels and discharge.

PROCESSING AND DISSEMINATION

Most of the data recorded via automatic data loggers is retrieved by remote transmission (GSM/GPRS). The data are then imported automatically into the AQUALIM database developed by the Directorate of Non-Navigable Watercourses (DCENN). The recorded hourly measurements are checked regularly via validation software that allows, if necessary, the correction of anomalies. Once validated, the data are consolidated into daily data and automatically transferred to the Dixsous database.

Groundwater level data are available via the portal PIEZ'EAU, where locations, meta data and time series are available for visualization and downloading.

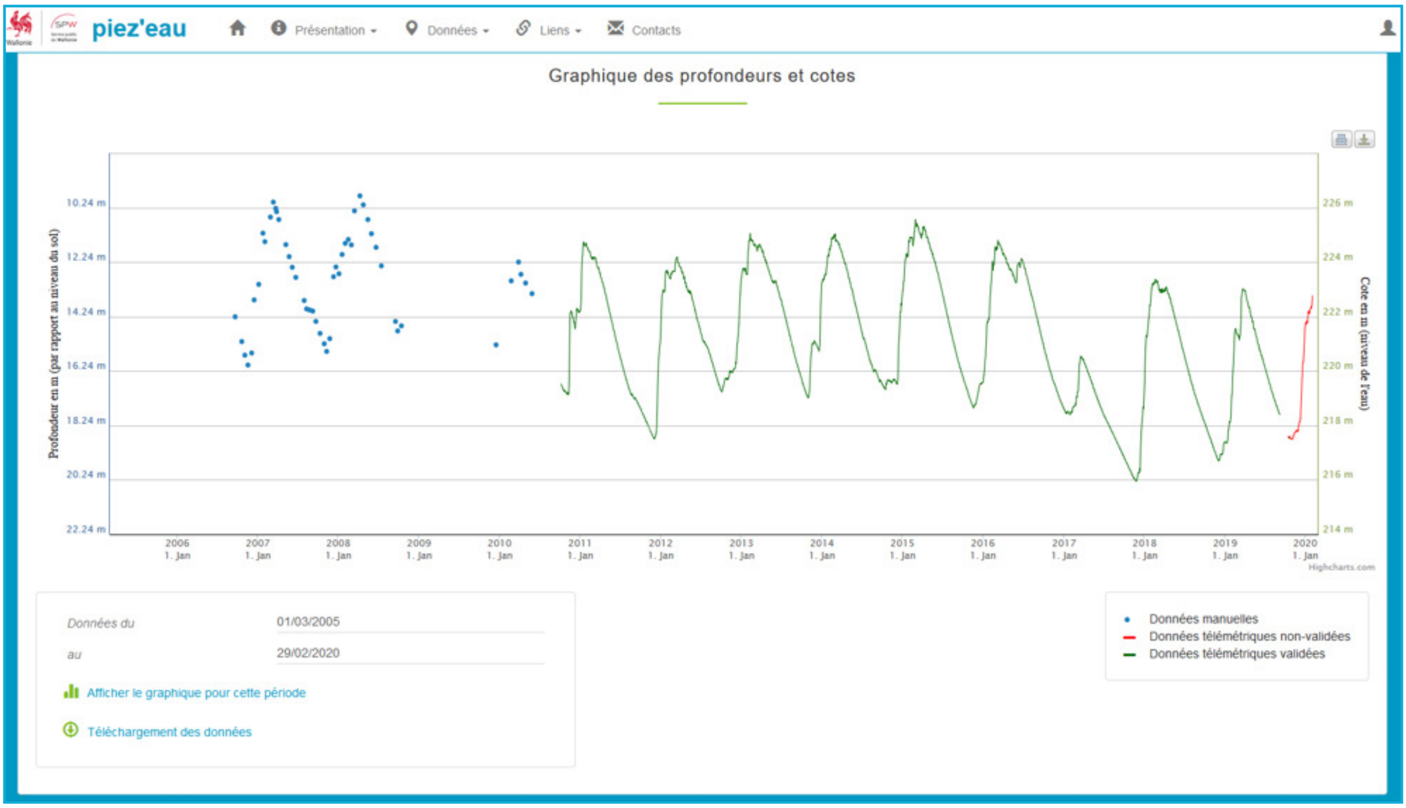

Figure 16 – PIEZ'EAU portal

Time series can be exported as an image in various formats and the observations can be downloaded in PDF format.

In Dixsous database, the Geocentric Approach tool allows to visualise locations of piezometers and production wells on a map in a circle around given coordinate of the centre and given radius.

Sources

Flanders

- **Database Underground Flanders (DOV)** - https://www.dov.vlaanderen.be;
- **DOV, Classification of groundwater networks** - https://www.dov.vlaanderen.be/page/grondwatermeetnetten;
- **DOV-Explorer** - https://www.dov.vlaanderen.be/portaal/?module=verkenner&bm=9bba534d-0745-46ef-aa95-c31788c2266a**;**
- **DOV, Groundwater level indicators** - https://www.dov.vlaanderen.be/page/opbouw-grondwaterstandindicator;
- **Feedback from VMM** - received on 20-02-2020; and
- **SWAP model** - http://www.swap.alterra.nl.

Wallonia

- **Public Service of Wallonia. Status of Groundwater in Wallonia** - http://environnement.wallonie.be/frameset.cfm?page=http://environnement.wallonie.be/de/eso/atlas;
- **Dixsous database and Geocentric Approach tool** - http://carto1.wallonie.be/10SousInt/Default.asp;
- **Feedback from Wallonie Environment SPW** - received on 03-02-2020; and
- **PIEZ'EAU portal** - http://piezo.environnement.wallonie.be/GeneralPages.do?method=displayStationsMap&time=2020-11-13%2016:29:49.621**.**

Croatia

Capital city: Zagreb
Inhabitants: 4 Million

INSTITUTIONAL SETTING AND PURPOSE

Croatian Waters is the national agency for water management, implementing the Croatian Water Act and the Regulations on Water Quality Standards. National monitoring is carried out for the assessment of groundwater quantity (groundwater levels in aquifers with intergranular porosity) and discharge of main springs (in karstic areas), as well as groundwater quality for the assessment of the status of groundwater bodies for the preparation of river basin management plans.

Croatian Meteorological and Hydrological Service (DHMZ) is a governmental body supporting the economic and sustainable development of Croatia by providing information on weather, climate, hydrological and ecological phenomena. DHMZ is in charge of hydrological and monitoring stations and the development and maintenance of various databases (meteorological, hydrological, air quality).

The objective of the national groundwater monitoring network of Croatia is to provide data to estimate the long-term state and trends of groundwater in the country, and provide input for the national water policy planning, regulatory agencies and the public.

CHARACTERISTICS OF THE NETWORK

The groundwater quantity monitoring network has 528 stations. Data are collected both manually and automatically (using data logger and automatic transmission). Automatic stations (data loggers) measure levels every day, and manual stations provide readings twice per week.

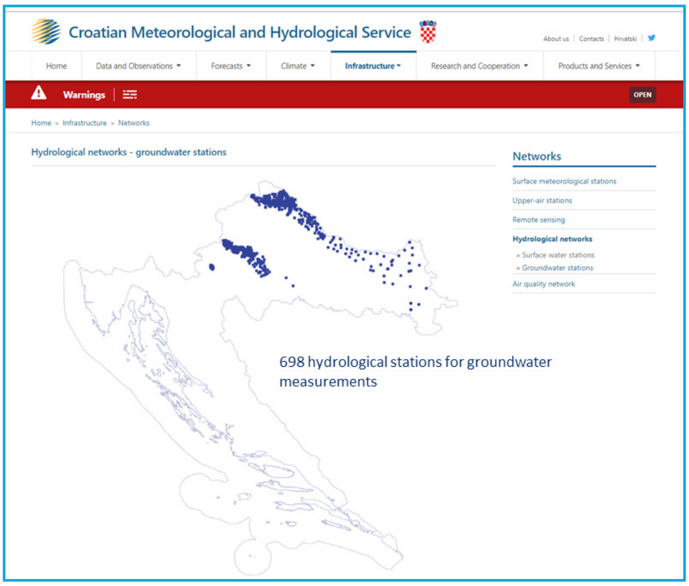

Figure 17 – Location of groundwater monitoring stations in Croatia. Source: DHMZ

PROCESSING AND DISSEMINATION

Data are used to perform time series analysis, statistical analysis and modelling. The groundwater observations are available for governmental institutions, and upon request. Additionally, all data are reported to the Water Information System Europe (WISE).

Sources

- **Feedback from Croatia Waters (answer to form)** - received in 2018;
- **National Hydrometeorological Institute of Croatia, Hydrological networks, Groundwater stations** - https://meteo.hr/infrastruktura.php?section=mreze_postaja&param=hm&el=podzemne_hm;
- **National Hydrometeorological Institute. Hydrology Division** - https://hidro.dhz.hr; and
- **Water Information System for Europe** - https://water.europa.eu.

Czech Republic

Capital city: Prague
Inhabitants: 10 Million

INSTITUTIONAL SETTING AND PURPOSE

The groundwater monitoring network of the Czech Republic is managed by the Department of Groundwater of the Czech Hydrometeorological Institute. The Institute is based within the Ministry of the Environment and operates the only countrywide groundwater observation network. The Groundwater Department conducts observation and measurements of groundwater levels and spring discharge, processes obtained data and store those in a database. The department also analyses time series, calculates impact of regime on hydrogeological structures and estimates groundwater components for the hydrological balance.

CHARACTERISTICS OF THE NETWORK

The Czech Republic has a monitoring network consisting of 1,058 shallow wells, 414 deep wells and 320 springs. Wells are measured on daily basis by automatic stations as well as approximately half of the springs. The rest of the springs are monitored weekly by observers.

PROCESSING AND DISSEMINATION

Several maps with information about the status of the groundwater resource can be found on the website of the Czech Hydrometeorological Institute. Two types of evaluation and visualization for the data are used: one for shallow boreholes and springs, and one for deep boreholes.

Maps for shallow boreholes and springs

The evaluation is based on the comparison of current level of the water table (or yield response) with the corresponding values of the 1981-2010 period (30 years). Monthly level (yield) values correspond to the averages recorded usually four times that month (one value per week). Boreholes and springs that have datasets for at least 30 years are used for the analysis.

The period of 1981-2010 is also known as normal period. This period has been selected as a reference because most of the boreholes and springs have been observed since the 1970's and 1980's. Thus, it has sufficient long-term time-series.

The method is also applied only to assess weekly and monthly changes of the levels in shallow boreholes and springs. They are grouped on a basis of their location in river basins. The groups are defined as areas containing sub-basins (2nd and 3rd order river basins) and are determined by orographic watershed. The resulting classification and the colour of the area will be the average of the objects (boreholes or springs) within it, figure 18. The comparison makes use of the empirical Cumulative Frequency Curve (CFC).

The water level corresponding to the non-exceedance probability less than 5 % is labelled as extremely low, the band with 5-15 % as severely low and 15-25 % as moderately low. The level classified between 25-75 % is considered normal. The water level above normal is classified in a similar way. This method was employed to quantify the drought episode in 2015 in the Czech Republic. For example, to produce the map for September 2019, the monthly average was calculated using the Wednesday-values, and this result was compared with each value of September from 1981 to 2010 through the CFC curve.

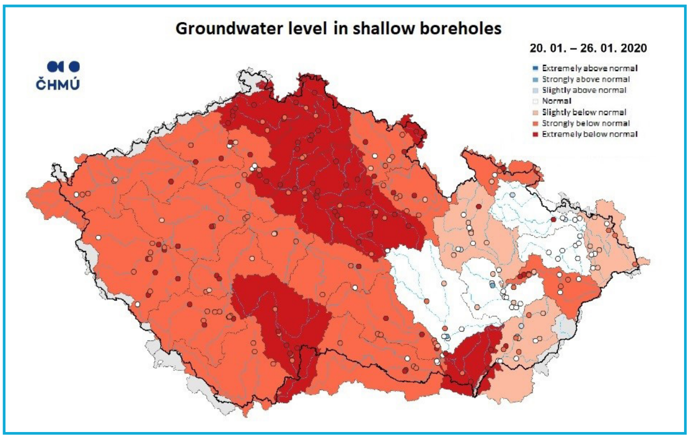

Figure 18 – Results of weekly evaluation within river basins, for shallow boreholes. Source: Czech Hydrometeorological Institute

Maps for deep boreholes

The second type is monthly evaluation of deep boreholes and the principle of visualization is similar as for shallow boreholes and springs. The only difference is the application of hydrogeological zones (HGR) instead of the river basin groups. The HGR are based on the general hydrogeological map of the Czech Republic.

Deep boreholes lack of long time-series data, therefore the water level change is just compared with the previous month (figure 19).

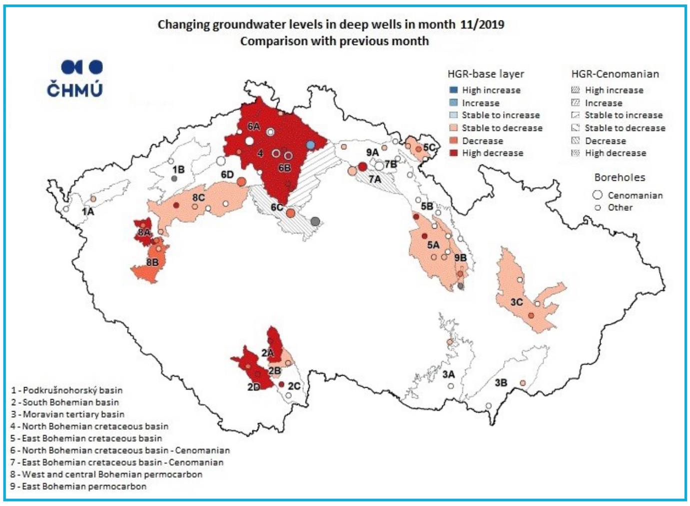

Figure 19 – Groundwater level change in deep wells compared to the previous month. Source: Czech Hydrometeorological Institute

Flood Forecasting Service also provides data on groundwater levels and yields for shallow and deep wells, and springs. When an object is selected from the main map, an additional window opens with the information on yield change, figure 20. Data on water levels can be accessed through the View Region option.

The portal of the Czech Hydrometeorological Institute also publishes annual reports on hydrometeorological situation including the status of groundwater.

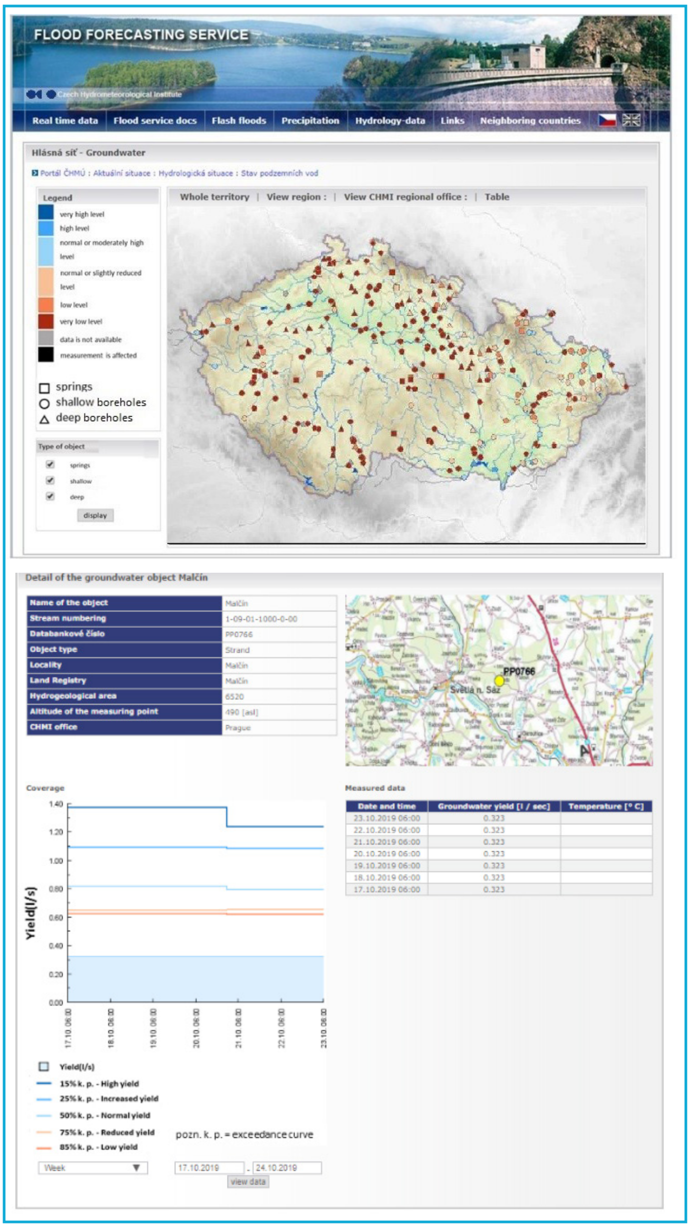

Figure 20 – Flood Forecasting Service. Source: Czech Hydrometeorological Institute

Sources

- **Czech Hydrometeorological Institute (In English)** - http://portal.chmi.cz/?l=en;
- **Czech Hydrometeorological Institute, Flood Forecasting Service** - http://hydro.chmi.cz/hpps/hpps_pzv.php;
- **Czech Hydrometeorological Institute, Groundwater portal** - http://portal.chmi.cz/aktualni-situace/hydrologicka-situace/stav-podzemnich-vod;
- **Czech Hydrometeorological Institute, Hydrological information and reports** - http://portal.chmi.cz/aktualni-situace/hydrologicka-situace/hydrologicka-situace; and
- **Feedback from the Czech Hydrometeorological Institute** - received on 04-02-2020.

Denmark

Capital city: Copenhagen
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Food of Denmark is in charge of environmental protection, farming and food production, with the Danish Environmental Protection Agency as one of the Departments in the Ministry.

The National Groundwater Monitoring Network (GRUMO) is part of the National Monitoring Program for Aquatic Environment and Nature (NOVANA). GRUMO, along with other related monitoring programmes as the Agricultural Catchment Monitoring Program (LOOP) included in NOVANA, was initiated in 1988 to monitor quality and quantity of groundwater throughout the country.

The National Geological Survey for Denmark and Greenland (GEUS) acts as a data centre and scientific advisor/reporter for the collection of groundwater and borehole information.

The objective of the groundwater monitoring programme, GRUMO, is to establish representative time series for the quality and quantity of the groundwater resources to ensure good quality of drinking water for the future. In addition to this, the program aims to provide data to monitor status and trends of groundwater bodies (administrative units to be used according to the WFD). Data collected are also to be used in the development of models for river basin management.

The Agricultural Catchment Monitoring Program (LOOP), which has a groundwater component, is dedicated to monitoring groundwater quality in the unsaturated zone, tile drains and shallow groundwater (approx. 3 to 5 meters depth) in six agricultural catchments in sandy and clayey areas across Denmark, mainly focusing on leaching of nutrients (N and P) to groundwater.

Moreover, the National Groundwater Level Monitoring Programme (Det Nationale Pejleprogram) was set up to monitor groundwater levels through sounding stations within five regional areas.

GRUMO was originally designed to provide a picture of the groundwater's condition and development in a number of selected catchments – the GRUMO areas – which were considered to be representative for groundwater of the country. The GRUMO program has since been updated and adapted continuously on the basis of greater knowledge and due to the varying administrative needs, including the fulfilment of the reporting obligations under EU directives, particularly the WFD and the Nitrates Directive.

CHARACTERISTICS OF THE NETWORK

Groundwater levels are monitored through approx. 1,000 GRUMO monitoring wells and the National Groundwater Level Monitoring Programme, where the groundwater level readings are taken several times daily for approximately 160 boreholes. In addition, all water abstractions (except single households) are reported on an annual basis as abstracted water volumes to the joint public database Jupiter hosted by GEUS.

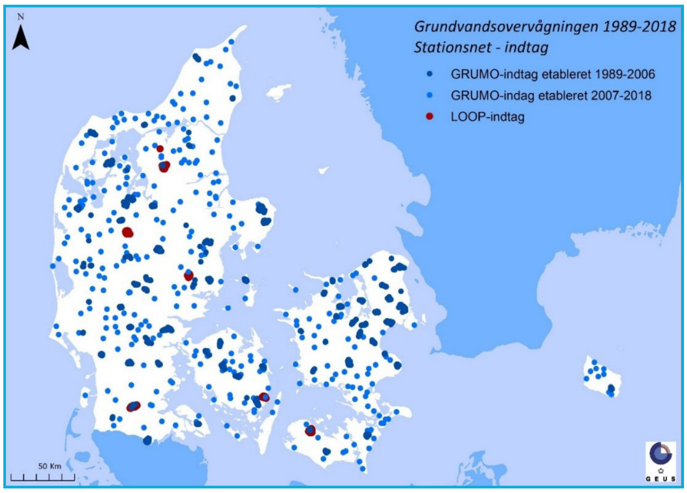

Figure 21 - Monitoring points in the 73 groundwater monitoring areas ('GRUMO-indtag' 1989-2006) and monitoring wells in the distributed network established in the period 2007-2017 for the WFD ('GRUMO-indtag' 2007-2018). LOOP monitoring of six agricultural catchments are also included, one of which was later closed in Central Jutland. (Source: Thorling et al., 2019)

Monitoring wells included in the program in 2017, with a top screen depth of approximately 40 meters, are more or less evenly distributed over Denmark, while deeper monitoring points show significant regional differences. Thus, on Bornholm (easternmost island), the vast majority of monitoring points are within the upper 20 meters, while the vast majority of deep boreholes (80-372 m below the ground surface, b.g.s.) are found in Jutland (continental Denmark) with the largest occurrence in southern Jutland.

The situation is different for monitoring wells and "waterwork wells" (wells for drinking water) in 2018. 50-60% of GRUMO monitoring points are established within the upper 20 m, while just 10% are established deeper than 50 m below the ground surface. In the waterworks wells, the screens are placed deeper. Here, 50% of the waterworks boreholes have the top of the screen located at a depth greater than 40 m b.g.s., and 10% at depths greater than 80 m b.g.s.

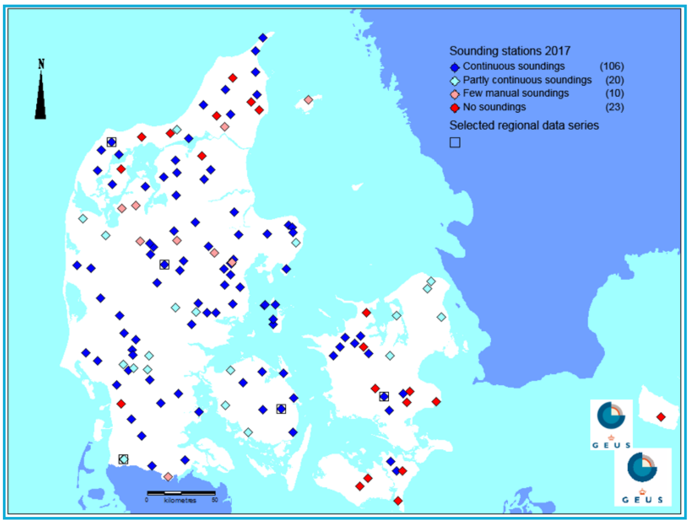

Figure 22 - Geographical distribution of wells that are part of the National Groundwater Table Monitoring Programme in 2017, including five regional indicator measurement stations with long time series (Source: GEUS)

PROCESSING AND DISSEMINATION

All monitoring data are freely available on GEUS homepage. Figure 2 shows the location of boreholes through the GEUS portal. It is also possible to download data in Excel format.

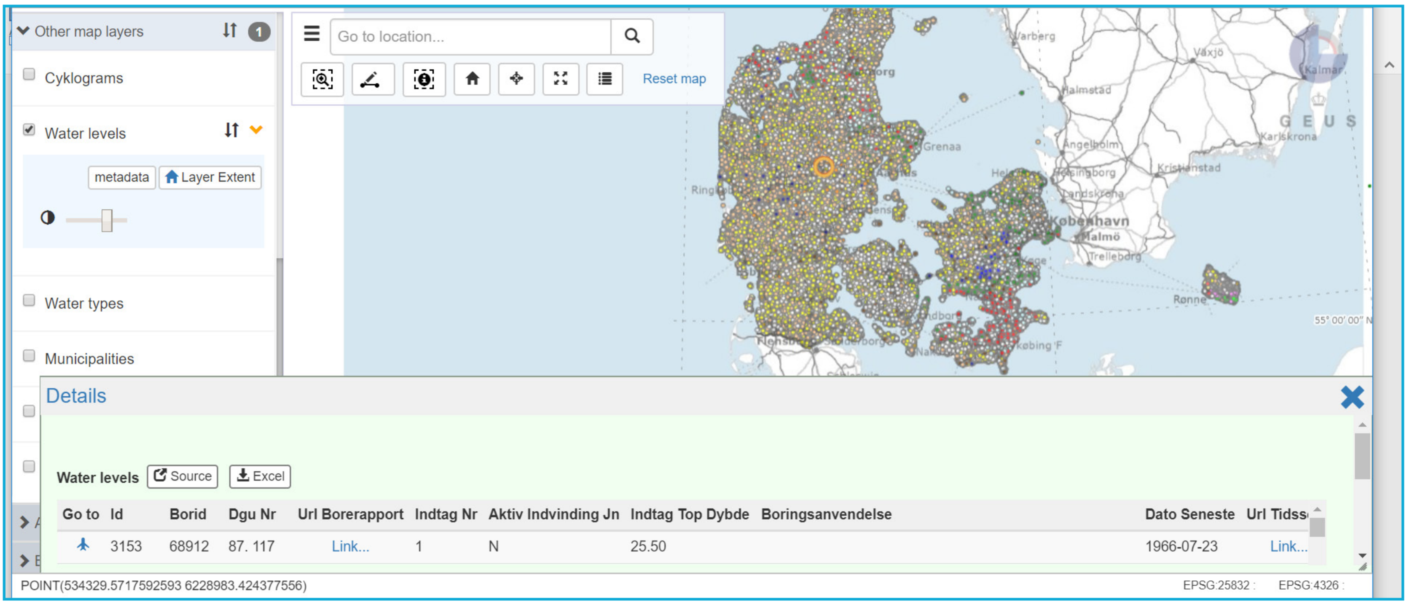

Figure 23 – GEUS portal for groundwater analyses with points measuring water level. Source: GEUS)

Sources

- **Data management by GEUS** - https://www.eea.europa.eu/publications/92-9167-032-4/page005.html;
- **Feedback from GEUS** - received on 27-01-2020;
- **Geological Survey of Denmark and Greenland (GEUS)** - https://www.geus.dk/vandressourcer/overvaagningsprogrammer/grundvandsovervaagning/;
- **Hansen B., Thorling L., Dalgaard T., Erlandsen M. 2010. Trend Reversal of Nitrate in Danish Groundwater - a Reflection of Agricultural Practices and Nitrogen Surpluses since 1950** - https://pubs.acs.org/doi/pdf/10.1021/es102334u; and
- **Jupiter (GEUS's nationwide drilling database for groundwater, drinking water, raw material, environmental and geotechnical data)** - https://data.geus.dk/geusmap/.

Estonia

Capital city: Tallinn
Inhabitants: 1 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment of the Republic of Estonia is the general coordinator of the monitoring programme in cooperation with the Environmental Board, the Environmental Inspectorate, the Environment Agency and the Environmental Investment Centre.

The National Environmental Monitoring Programme consists of sub-programmes, and one of them is the Groundwater Monitoring programme. This sub-program is divided into sections: monitoring of groundwater bodies (31 units) and monitoring of groundwater in the nitrate vulnerable zone. All groundwater bodies are subject to surveillance monitoring.

Changes in groundwater levels are monitored for the evaluation of the quantitative status of groundwater. The network for monitoring the chemical status of groundwater aims at providing a reliable evaluation of groundwater quality at every groundwater body. The monitoring network also aims to describe the natural and anthropogenic changes in the chemical composition of groundwater and the significant and constant changes in pollutant concentrations; and to evaluate the achievement of environmental objectives for areas that are dependent of groundwater and need protection. Based on the data collected, it is possible to plan the sustainable consumption of groundwater, prevent depletion and to assess the quality and suitability of groundwater for drinking purposes.

CHARACTERISTICS OF THE NETWORK

The monitoring of the quantitative status of groundwater bodies includes measuring groundwater levels and, if necessary, groundwater flow in springs and discharge points in water courses or other inland bodies of surface water. In relatively homogeneous confined groundwater bodies (sand, sandstone), it is sufficient to measure the water level 3-5 times per month and in homogeneous unconfined groundwater bodies, 5-10 times per month. The measuring frequency of Silurian-Ordovician confined groundwater bodies with fissures and karst should be 5-10 times per month and in unconfined groundwater bodies with fissures and karst 10 times per month.

Data about pollutants which put the good status of a groundwater body at risk or cause a bad chemical status of a groundwater body are collected during operational monitoring of chemical status.

In areas at risk of agricultural pollution, nitrogen compounds (especially NO3 and NH4) must be monitored, and, depending on the level of protection of the groundwater body, also the possible content of pesticide and fertilizer residues in shallow layers. Additionally, the content of nitrites and phosphorus-containing compounds in groundwater should be also monitored.

The monitoring program also includes the conductance of surveys. They are used to identify pollution sites, assess the groundwater status of contaminated and polluting areas and plan implementation of safeguard measures.

The monitoring programme has been prepared in accordance with the WFD for a period of 6 years, therefore it may be subjected to changes upon concluding monitoring agreements.

PROCESSING AND DISSEMINATION

Monitoring networks of groundwater bodies and nitrate vulnerable zones are presented with the Esri Map story on the Environmental Agency website, figure 24. When a user selects an observation point, the information on its relation to a river basin, groundwater body name and ID, hydrogeological layer, xy coordinates, number of water level measurements per year, sensor type are shown.

The National Support Observation Network of Estonia consists of stations recording groundwater levels and the main physical and chemical parameters.

Updated monitoring programmes are available on the website of the Ministry of Environment. Results of monthly and annual average, minimum and maximum groundwater levels of monitoring wells, results of chemical analysis and field measurements are transferred into a groundwater monitoring database.

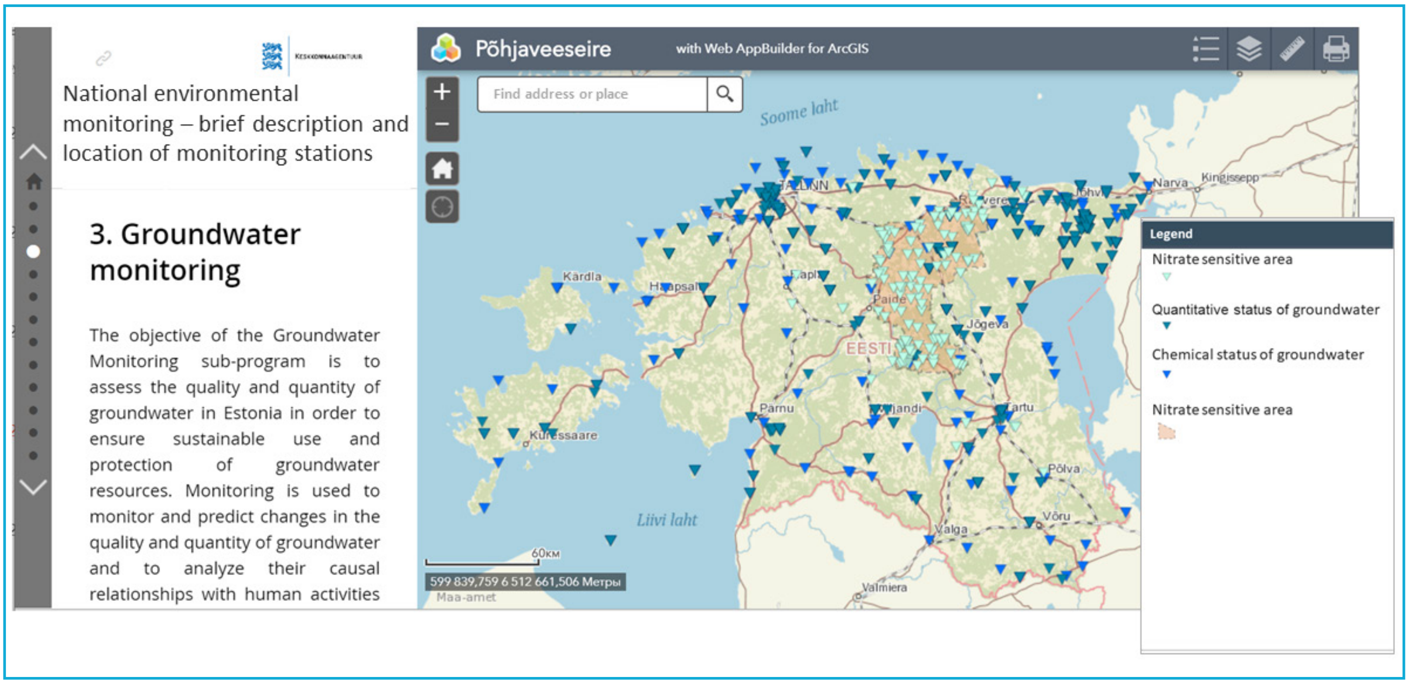

Figure 24 - ESRI map story compiled with the National Environmental Monitoring Program

Figure 25 - Antu blue springs lake, Estonia, Europe, by: Artenex

Sources

- **Environment Ministry of Estonia, groundwater** - https://www.envir.ee/et/eesmargid-tegevused/vesi/pohjavesi;
- **Feedback from the Ministry of the Environment** - received on 22-04-2020;
- **The Environmental Agency of Estonia, environmental monitoring** - https://www.keskkonnaagentuur.ee/et/seire;
- **Environment Ministry of Estonia, groundwater monitoring system in Ida-Viru County** - https://www.envir.ee/et/eesmargid-tegevused/vesi/pohjavesi/pohjaveeseire-susteem-ida-viru-maakonnas; and
- **Updated monitoring programmes, Ministry of Environment** - http://www.envir.ee/et/kavade-ja-programmide-eelnoud.

Finland

Capital city: Helsinki
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and the Ministry of Agriculture and Forestry are in charge of nation-wide surface and groundwater monitoring programmes in Finland. These programmes are coordinated by the Finnish Environment Institute (SYKE).

The actual water quantity monitoring is carried out by private laymen or by automatic monitoring equipment. Groundwater quality sampling is coordinated by SYKE and the regional ELY-centres (Centres for Economic Development, Transport and the Environment)..

CHARACTERISTICS OF THE NETWORK

The national groundwater monitoring network of Finland has ca. 95 monitoring stations distributed in 13 administrative regions, figure 26. The monitoring stations represent variable climatic conditions, soil types and terrains where human impact has been subtle. A typical groundwater station has about ten observation tubes and one observation well. Groundwater levels are measured manually twice a month, and the average record length is almost 40 years. Additionally, many stations have groundwater table data loggers with automatic transmission of hourly data. Groundwater quality is monitored 2-4 times per year, which is dependent on the monitoring programme of each station.

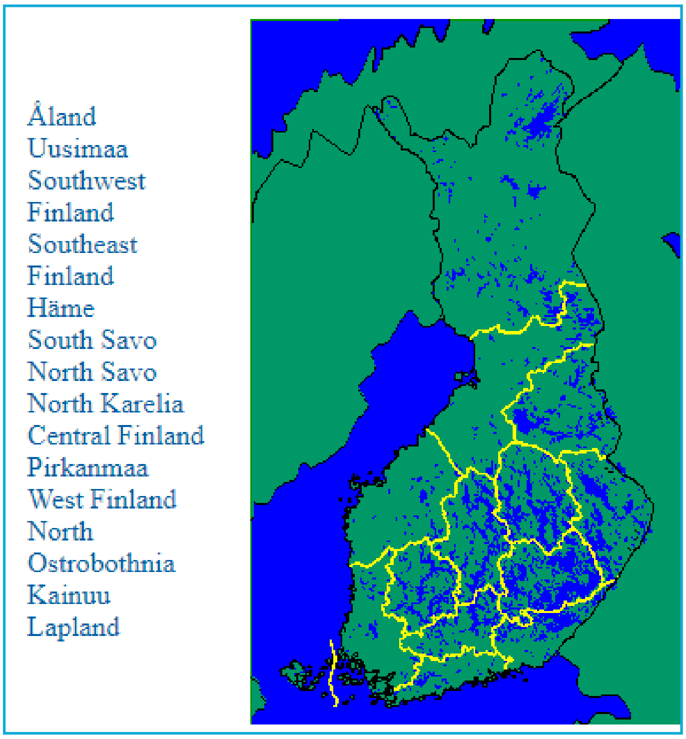

Figure 26 - Administrative regions with groundwater level monitoring. Source: SYKE

PROCESSING AND DISSEMINATION

Outcomes of groundwater quantity and quality monitoring performed within the national programme are stored into the groundwater data system (POVET). The time series of groundwater levels are also presented in graph form e.g. on SYKE's website. By clicking on an administrative region, groundwater level graphs for the previous year are shown, figure 27. The averaged groundwater levels of the monitoring stations are presented in metres above sea level, as recorded every two weeks at monitoring sites around Finland, together with long-term monthly averages, maximums and minimums. For fully automated stations, daily groundwater levels are shown.

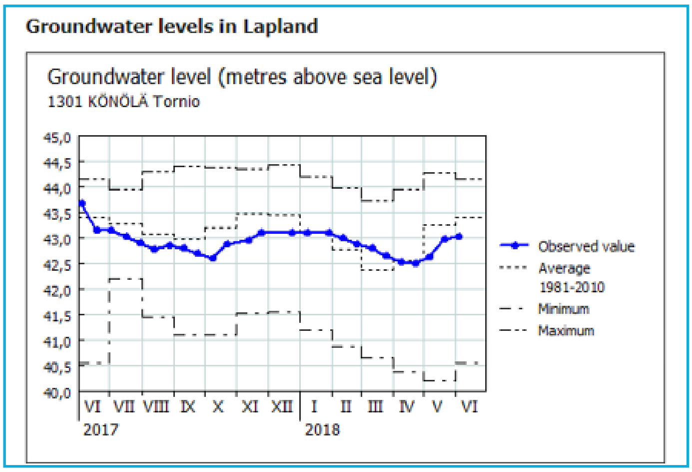

Figure 27 - Administrative regions with groundwater level monitoring. Source: SYKE

Short-term groundwater table forecasts are simulated with the Watershed Simulation and Forecasting System (WSFS), developed by SYKE, using the data from the groundwater stations, figure 28. The water simulation uses groundwater quantity data e.g. for forecasting floods. Short-term forecasts are calculated for approximately 50 stations.

A suggestive model of nation-wide hypothetical groundwater tables is calculated with the WSFS based on approximately 50 groundwater stations, figure 29. The map classifies groundwater levels as: above the highest value, above the annual average, above average, below average, below the annual average and below the lowest value. The system also forecasts groundwater levels for the next 3 and 9 days. Detailed maps in the same section allow users to see contour lines of groundwater levels across Finland for the last 90 days in mm.

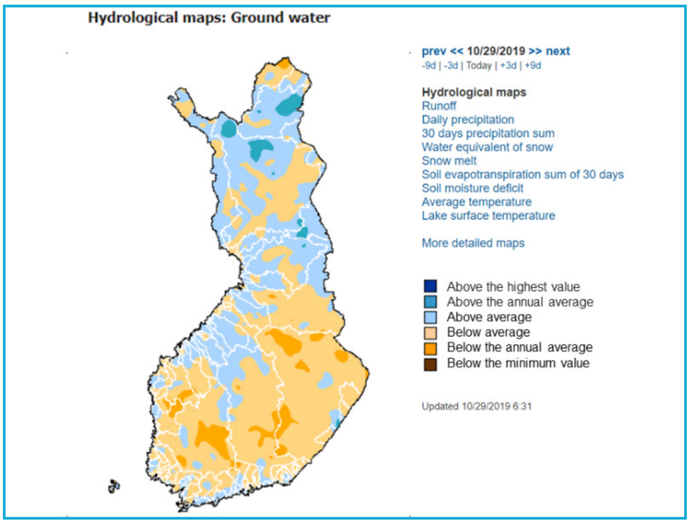

Figure 28 - Suggestive simulation of groundwater level in Finland as of October 29, 2019. Source: SYKE

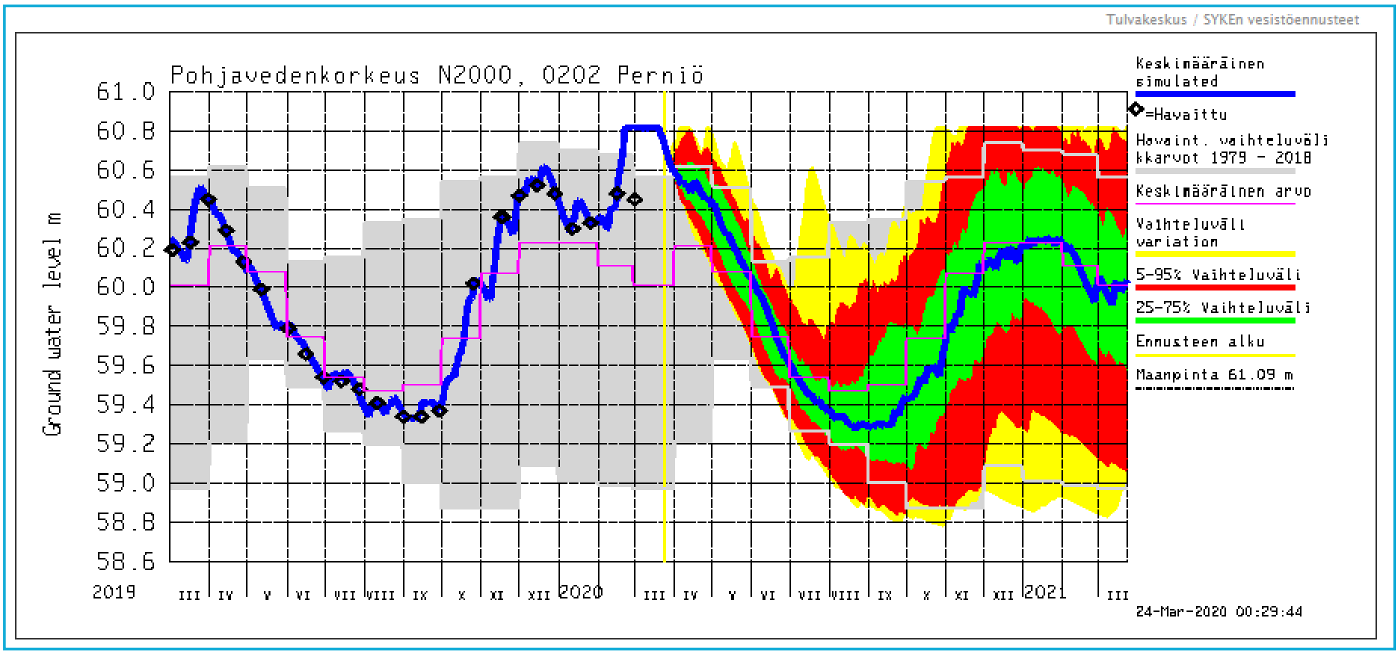

Figure 29 - Short-term forecast and actual observations for Perniö groundwater station

Sources

- **Environment.fi – Joint website of Finland's environmental administration. Quantitative and chemical status of groundwater** - https://www.ymparisto.fi/fi-FI/Vesi/Pohjavesien_tila;
- **Environment.fi. Monitoring of groundwater status** - https://www.ymparisto.fi/fi-FI/Vesi/Pohjavesien_tila/Pohjavesien_tilan_seuranta;
- **Environment.fi. Groundwater levels in Finland** - http://wwwi3.ymparisto.fi/i3/paasivu/eng/pohjavesi/pohjavesi.htm;
- **Environment.fi. Hydrological maps, groundwater** - http://wwwi2.ymparisto.fi/i2/90/gvyy2/tanaan_en.html;
- **Environment.fi. Water model system, groundwater forecast** - http://wwwi2.ymparisto.fi/i2/pohjavesiasemat.html;
- **Environment.fi. Water maps: Groundwater replenishment within 90 days** - http://wwwi2.ymparisto.fi/i2/94/finngvdfb.html;
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- **Finnish Environment Institute SYKE** - Watershed simulation and forecasting system (WSFS) Brochure (2 and 6 pages); and
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France

Capital city: France
Inhabitants: 65 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of the Ecological and Inclusive Transition (MTES) is in charge of water management and implements the EU Water Framework Directive in France. Surveillance for groundwater quality is mentioned as one of the water policy actions on the ministerial website. There are various groundwater monitoring networks in France, and it is not always clear which governmental institution manages them.

CHARACTERISTICS OF THE NETWORK

At a national level, the National Quantitative Monitoring Network for Groundwater (RNESP) monitors the quantity of aquifers of national interest. Minimum monitoring point density has been specified for this network, according to the CIS/EU guidelines type and size of the aquifer: 1 point every 500 km2 in unconfined aquifers (including wetlands), 1 point every 1000 km2 for small confined aquifers of less than 1000 km2, 1 point every 3000 km2 for large confined aquifers of more than 1000 km2, and 1 point every 7000 km2 in deep aquifers (higher densities have sometimes being selected). The network has 1,843 stations, among them 1,775 are active at the moment. According to the CIS/EU guidelines, the minimum frequency of monitoring is weekly, and monthly for confined aquifers.

Other groundwater monitoring networks are the parts of the surveillance network reporting results to Eaufrance in 12 regions. These networks provide an overview of the status of water in each catchment and sub-catchment, including groundwater.

PROCESSING AND DISSEMINATION

The National Portal for Access to Groundwater Data (ADES), maintained by the French Geological Survey (BRGM) and the product of the Water Information System (SIE), is the national database of public quantitative and qualitative groundwater data for metropolitan France and overseas departments. Main partners in data provision are BRGM, French Office for the Biodiversity, Water Agencies; Regional Directions for the Environment, Planning and Housing (DREAL); Regional Health Agencies (ARS), local authorities and other public bodies. Regularly updated information is available by point, river basin, region and aquifer. Currently, 15,992,803 water levels and 82,956,553 water analyzes are available online.

Groundwater level monitoring stations can be accessed online, and their metadata and data can be visualized and exported (including coordinates), figure 30.

For 1,450 monitoring points of the 1,600 managed by the BRGM, observation data are available in real time. They can be viewed on ADES every day.

Figure 30 - Well BSS001MXUY from Loire-Bretagne Basin. Source: ADES Portal

Since 1988, the BRGM is preparing the National Hydrological Situation Bulletin (BSH) for groundwater. BSH describes the quantitative status of aquatic environment (streamflows, groundwater, reservoirs) through indicators.

The Standardised Piezometric Indicator (IPS), in use since 2017, is set up to provide a homogeneous info about the status of aquifers. It is based on other indicators such as the Standard Precipitation Index (SPI) and the Standardised Groundwater level Index (SGI).

To calculate the IPS the following steps are applied:

- The construction of piezometric levels series over the period of N years.
- Calculation of the average piezometric level over n months (the current month and the n-1 previous months) with n=3, 6, 9, 12 months or more. These months represent different time scales that may correspond to periods of precipitation deficit.
- A continuous curve of IPS n-month is obtained over the entire period of N years.

The IPS_1 month allows to compare the average level of the current month with the values of the same month of the N years. IPS_6 month compare the average level over the last 6 months (including the current month), etc.

“Current month” means the month preceding the edition of the bulletin, for example for the bulletin on June 1st, the current month corresponds to the data of May. The rolling average of groundwater levels and the IPS value is calculated every month (12 values of IPS per year). Example: figure 31 shows the density histogram of the average levels of the months of May and the fit of a probability density estimator.

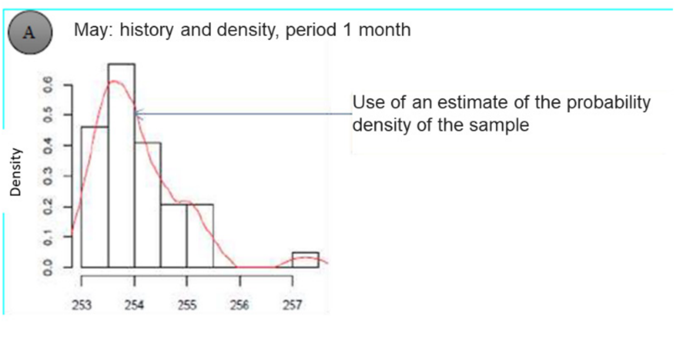

Figure 31 - The density histogram of the average levels of May months. Source: Gourcy et al, 2018

Figure 32 (B) shows the cumulative distribution of adjusted frequency of the average levels of the month of May, projected over cumulative frequency in Figure 3 (C).

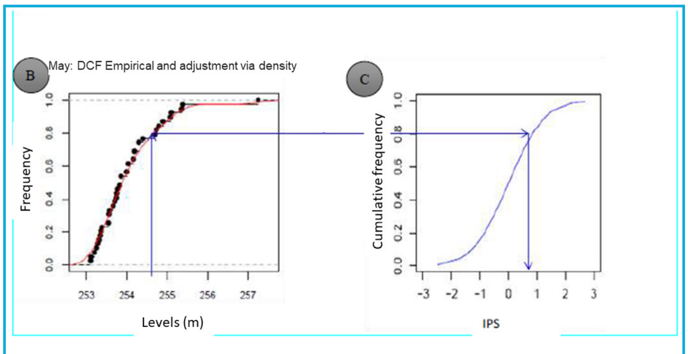

Figure 32 - The cumulative distribution of adjusted frequency of the average levels of the month of May (B) and cumulative frequency (C). Source: Gourcy et al, 2018

The value of IPS ranges from -3 to +3, Figure 33. Seven classes are defined based on the IPS values, from “very low” to “very high”.

IPS Classes			
Min.	Max.	Level qualification	Return period
≥1.282	≤3.000	Very high level	> 10 years wet
≥0.842	<1.282	High level	From 5 to 10 years wet
≥0.253	<0.842	Moderately high levels	From 2.5 to 5 years wet
≥-0.253	<0.253	Levels close to the average	From 2.5 years wet to 2.5 years dry
≥-0.842	<-0.253	Moderately low levels	From 2.5 to 5 years dry
≥-1.282	<-0.842	Low levels	From 5 to 10 years dry
≥-3.000	<-1.282	Very low levels	> 10 years dry

Figure 33 - IPS classification. Source: Gourcy et al, 2018

The IPS is calculated for all indicators points when data of 15 years or more are available. For stations with a short series of historical data (10 to 15 years), a Position Indicator (IP) is calculated monthly:

$$IP = \frac{(moy_{mois} - mini_{serie})}{(max_{serie} - min_{serie})} \cdot 100$$

Where:

- **moymois:** groundwater level monthly average of the current month
- **miniserie:** monthly minimum groundwater level of the series
- **maxiserie:** monthly maximum of groundwater levels of the series
- **maxserie** and **minserie** include the current month. Therefore, the indicator position is between 0% (low water never encountered before) and 100% (high water situation never encountered before).

The classes of position indicators will be distributed similarly to the IPS from -3 to +3, between 0 and 100%, Table 2.

IP Class	Classification
≥ 90%	very high levels
≥75% and <90%	high levels
≥55% and <75%	moderately high levels
≥45% and <55%	around the average
≥25% and <45%	moderately low levels
≥10% and <25%	low levels
<10%	very low levels

Figure 34 - IPS classification

BRGM produces press publications of the groundwater level status in France every month including a groundwater trend map, figure 35. The publications describe the evolution of groundwater levels and expected trends.

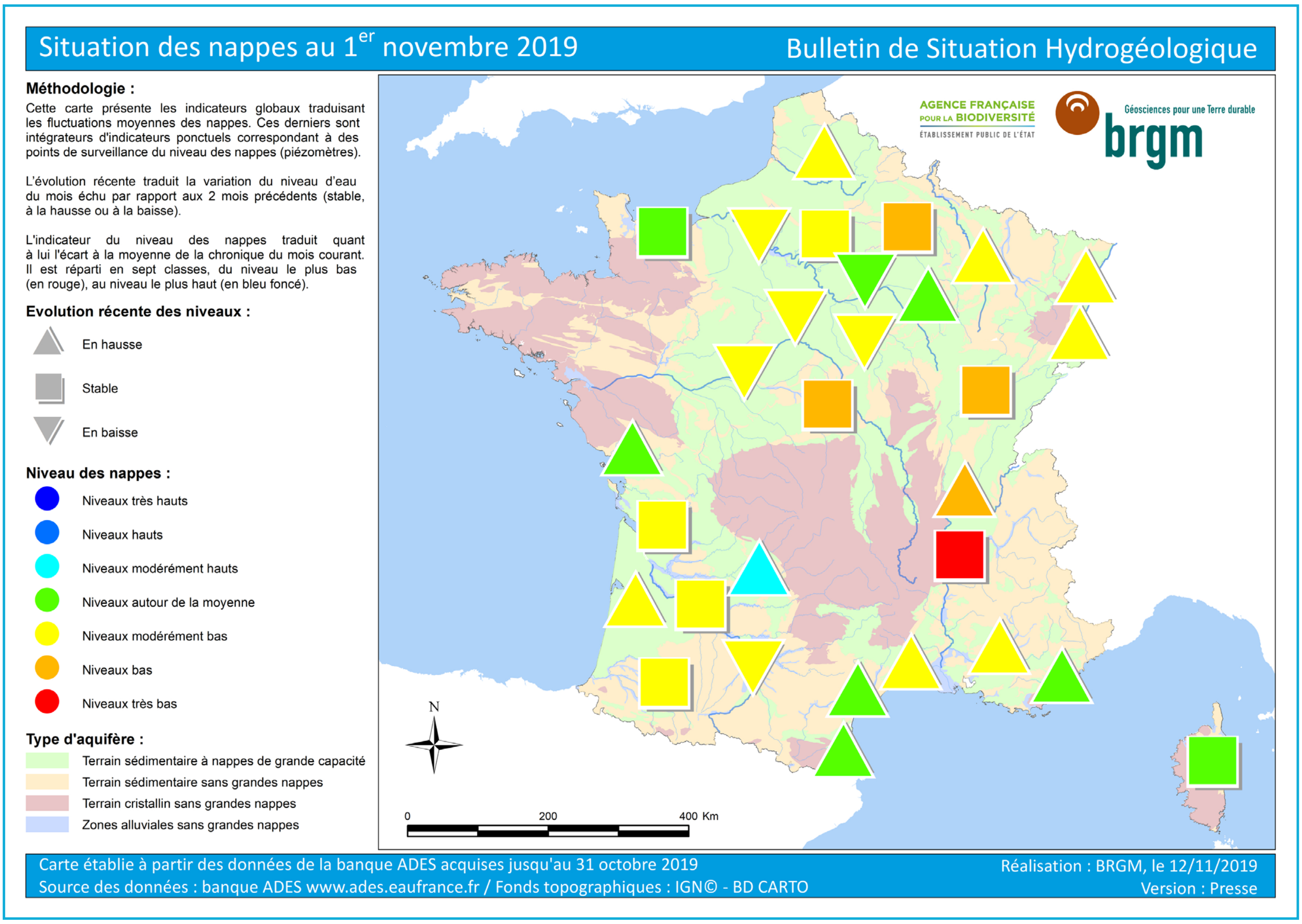

Figure 35 - State of groundwater in France in November 2019. Source: BRGM

The map shows indicators that reflect the average fluctuations of the water levels with respect to the previous 2 months (Recent evolution: stable – square, levels go up – triangle or levels go down - inverted triangle).

The colours show how much the current values move far away from the historical average. The range is divided into seven classes, from the lowest level (in red) to the highest (in dark blue).

Sources

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- **ADES, National portal for access to groundwater data** - https://ades.eaufrance.fr;
- **Feedback from BRGM** - received on 25-03-2020;
- **Gourcy L., Seguin J-J., Hélène B., Mougin B., Vigier Y., Nicolas J., Loigerot S., Allier D, 2018. Herramientas para la Gestión de las Aguas Subterráneas durante Eventos Extremos. El Agua Subterránea: Recursos sin Fronteras: Acuíferos Transfronterizos, El Agua Subterránea y las Ciudades. Planificación y Gestión. Rodolfo Fernando García [et al.]. Primera Edición. 2018. p 165-170** - ISBN 978-987-633-535-5;
- **Groundwater levels on 1st November 2019** - https://www.brgm.fr/actualite/nappes-eau-souterraine-1er-novembre-2019;
- **Ministry of the Ecological and Inclusive Transition. Water management in France** - https://www.ecologique-solidaire.gouv.fr/gestion-leau-en-france; and
- **Monitoring programs** - http://surveillance.eaufrance.fr.

Germany

Capital city: Berlin
Inhabitants: 83 Million

INSTITUTIONAL SETTING AND PURPOSE

The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) is responsible for regulating the water resources through the Federal legislation. State Geological Surveys (SGDs) are the specialized institutions of federal states in charge of subsoil information, including groundwater. The federal states are responsible for collection, processing and dissemination of regional data and related products. The case of the federal state of Bavaria is shown below as an example.

The Bavarian Environment Agency (LfU) offers several web services. Among these, the Low Water Information Service (NID) of Bavaria was created in order to classify the actual situation and to offer decision makers and the public a basis to evaluate and, if necessary, to prepare against dry periods on an early stage. The NID provides data from regional monitoring networks (surface water and groundwater) and, in case of low water conditions, publishing short reports interpreting those data.

CHARACTERISTICS OF THE NETWORK

The Bavarian Environment Agency operates, together with the regional water authorities, a monitoring network of around 3,000 groundwater monitoring sites. This network consists of the basic network (620 monitoring sites), the compaction network (341 monitoring sites) and regional networks (2,063 monitoring sites). Additionally, a network of around 110 spring sites is monitored.

A high number of monitoring sites is equipped with continuously recording instruments (electronic data loggers) to collect the groundwater data. The basic network focuses on supra-regional and representative aquifers with high water management importance. The monitoring sites in the basic network are usually equipped with remote data transmission devices. The compaction network complements the work of the basic network. It is usually used for hydrogeological tasks for a limited period or only at certain times. The regional networks are set up for small-scale groundwater investigations, mainly for a limited period. The depth of the monitoring sites ranges between 2 m to 1400 m below surface.

PROCESSING AND DISSEMINATION

The NID web service offers groundwater data of selected monitoring sites to the public and various users such as planners or municipalities. Overview maps with a daily groundwater classification of each monitoring site situated in shallow (figure 36, left) and deeper aquifers (figure 37, left) are provided. This information is also available in a table format. When a user selects an observation well from the map or the table, time-series of groundwater levels are presented for the entire monitoring period, an annual period (figure 36 and figure 37, right) as well as an annual comparison.

Values for each well are classified in new lowest value (or level), very low, low, no low water, no classification, and currently no data. This classification is based on a statistical analysis of the available data which is carried out only at measuring points with more than 5 years of measurements available. The statistical limits are calculated for a 31-day moving period to account for natural, seasonal variations in the water levels.

- No low water (kein Niedrigwasser): current value belongs to the highest 25% of previous values (higher than 75-percentile);
- Low (niedrig): current value is lower than the 75% of previous values (less than 25-percentile);
- Very low (sehr niedrig): current value is lower than 90% of previous values (less than 10-percentile);
- New lowest value (neuer Niedrigstwert): current value is lower than the lowest value documented up to that point in time.

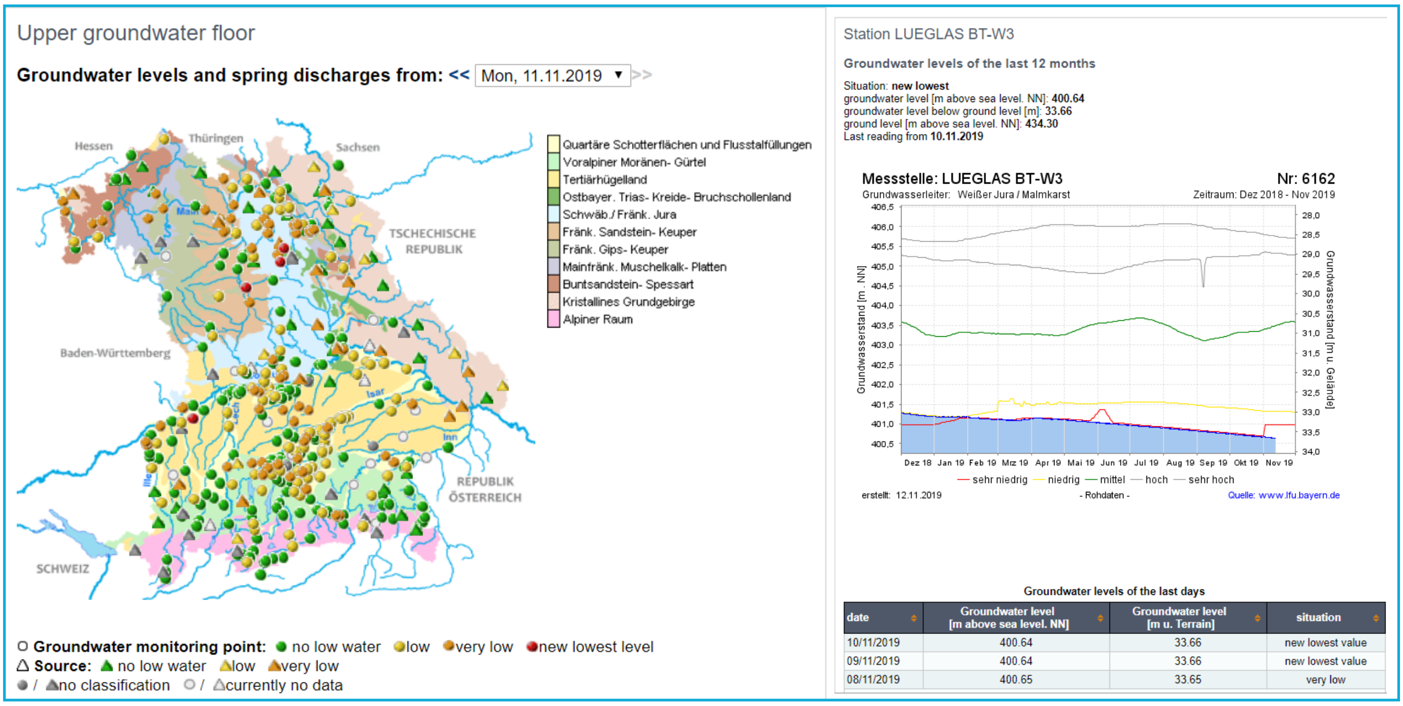


Figure 36 - Classified groundwater monitoring sites for the shallow aquifer with time-series from the station LUEGLAS BT-W3. Source: www.nid.bayern.de/grundwasser

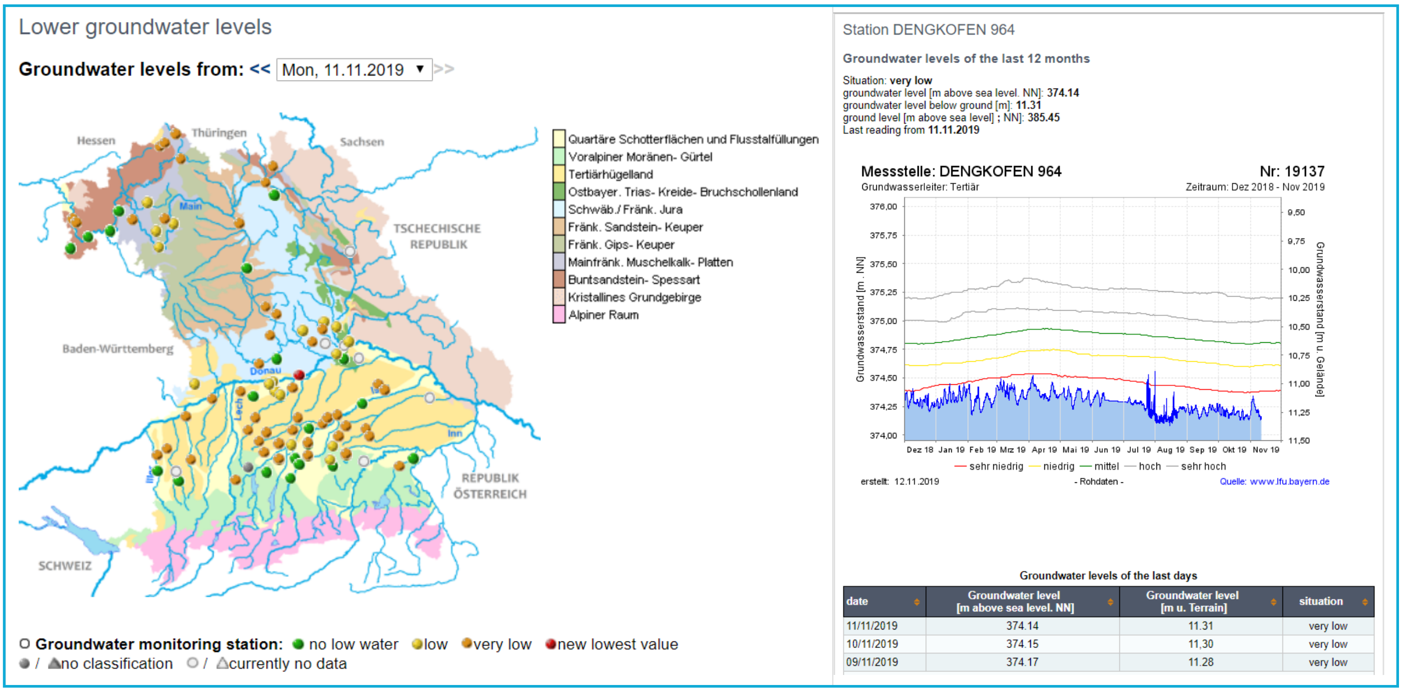


Figure 37 - Classified of groundwater monitoring sites for the deep aquifer with time-series from the station DENGKOFEN 964. Source: www.nid.bayern.de/grundwasser

Sources

- **Bavarian Environment Agency, groundwater level** - https://www.lfu.bayern.de/wasser/grundwasserstand/index.htm;
- **Feedback from the Bavarian Environment Agency** - received on 17-04-2020;
- **Low water information service Bavaria, groundwater** - https://www.nid.bayern.de/grundwasser; and
- **State Geological Surveys of Germany** - https://www.infogeo.de/Infogeo/EN/Startseite/startseite_node_en.html.

Greece

Capital city: Athens
Inhabitants: 10 Million

INSTITUTIONAL SETTING AND PURPOSE

The Special Secretariat for Water under the Greek Ministry of Environment and Energy is in charge of the National Monitoring Programme of Greece. Regarding groundwater, the Institute of Geology and Mineral Exploration (IGME) has been the main promoter of the programme since 2000. The National Monitoring Network has been active since 2012.

In addition, each of the 14 prefectures of Greece have their own monitoring programmes through private boreholes.

CHARACTERISTICS OF THE NETWORK

The National Monitoring Network operates 1392 stations dedicated to groundwater quality and quantity in the main groundwater bodies of the country. Stations are divided in two categories: surveillance and operational stations. While surveillance stations monitor water bodies of good status only during a certain period, operational status stations continuously monitor water bodies that failed at achieving good status.

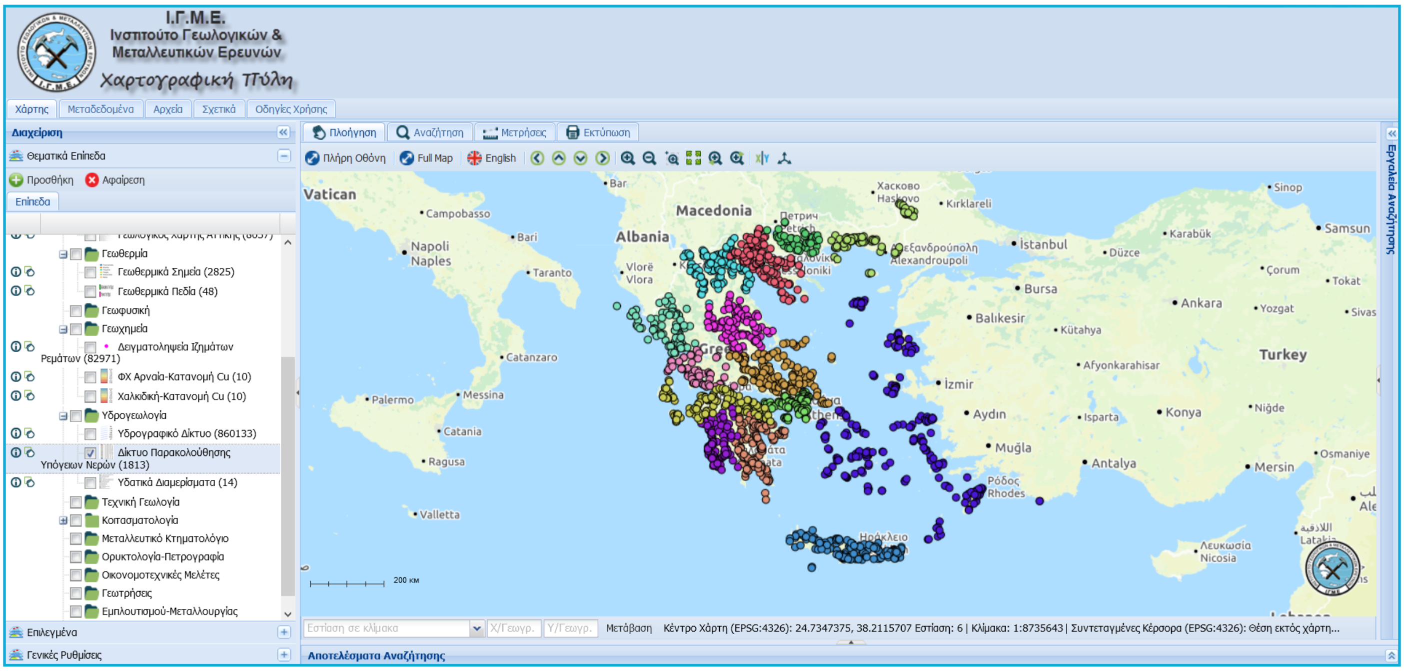


Fig. 38 - Groundwater monitoring network. Source: National Mineral Exploration Research Centre Geoportal

Data can be found in several sources, for instance, in the National Data Bank of Hydrological and Meteorological Information (NDBHMI) and in the website and map portal of the National Water Monitoring Network. One product available in this portal are the boundaries and characterisation of groundwater bodies (GWB) per River Basin District, developed in the framework of River Basin Management Plans under the EU WFD, depicting the quantitative and qualitative status of groundwater bodies.

Monitoring data can be obtained directly via the website, but can also be requested via the Special Secretariat for Water. In addition, data from the 14 prefectures of Greece can be obtained through their water resources directorates.

The geoportal of the National Mineral Exploration Research Centre also provides open geospatial data and services for Greece, and data can be obtained from here via request. It is noteworthy that, in general, all official data can be found in the National Geodata Portal as well.

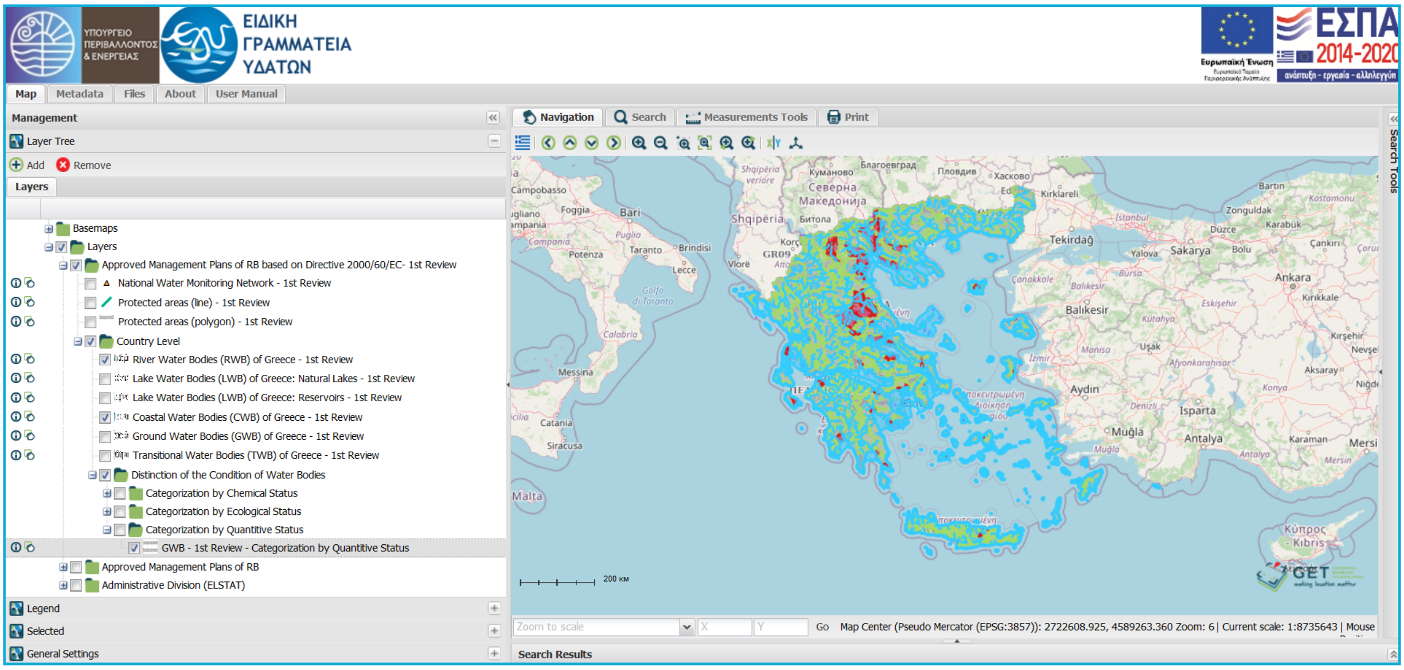


Fig. 39 - Quantitative status of groundwater bodies. Source: National Water Monitoring Network, map portal

Sources

- **Feedback from Dr. Emmanouil Varouchakis, PhD geostatistics, School of Environmental Engineering Technical University of Crete, Greece** - varuhaki@mred.tuc.gr;
- **Panteli N.-M. and Theodossiou N., 2016. Analysis of groundwater level measurements - Application in the Moudania aquifer in Greece. Available in** - http://www.ewra.net/ew/pdf/EW_2016_55_07.pdf;
- **Ministry of Environment and Energy** - https://ypen.gov.gr/;
- **National Data Bank of Hydrological and Meteorological Information (NDBHMI)** - http://ndbhmi.chi.civil.ntua.gr/en/index.html;
- **National Geodata Portal** - http://geodata.gov.gr/maps/?package=42b085a2-d390-4bd4-a9a0-6f1b3ec2ee9b&resource=646ab5b9-71ed-4b35-934f-78eec37978d1&locale=el;
- **National Mineral Exploration Research Centre Geoportal** - https://www.igme.gr/geoportal/?lang=gr;
- **National Network for the Monitoring of water status – Groundwater Monitoring Stations** - http://geodata.gov.gr/en/dataset/ethniko-diktuo-parakoloutheses-tes-katastases-ton-udaton--stathmoi-sta-upogeia-udata/resource/306aeda1-e7bc-4f99-88c0-7ade3c1d7007?inner_span=True;
- **National Water Monitoring Network** - http://nmwn.ypeka.gr/?q=en/content/national-monitoring-network**;**
- **National Water Monitoring Network, map portal** - http://wfdgis.ypeka.gr/?lang=EN;
- **National Water Monitoring Network, groundwater data** - http://nmwn.ypeka.gr/?q=groundwater-stations;
- **Report on the implementation of the Water Framework Directive River Basin Management Plans** - https://ec.europa.eu/environment/water/water-framework/pdf/4th_report/Greece_CORRECTED_5_EN_autre_document_travail_service_part1_v5-1_FINAL.pdf;
- **River Basin Management Plans** - http://wfdver.ypeka.gr/en/home-en/ and http://wfdver.ypeka.gr/en/management-plans-en/; and
- **Special Secretariat for Water, contact information to request data** - http://wfdver.ypeka.gr/en/contact-en/.

Hungary

Capital city: Budapest
Inhabitants: 9 Million

INSTITUTIONAL SETTING AND PURPOSE

The General Directorate of Water Management (OVF) is a central government body under the direction and supervision of the Ministry of Interior. It supervises, coordinates and controls the activities of the water directorates.

The National Hydrographic Monitoring Network contains data on surface water and groundwater, as well as precipitations, snow cover and soil moisture. It has been designed to provide national and local overviews, and an input for prognoses. The collection and assessment of the data are carried out by the regional water management directorates, coordinated by the OVF. The data are measured and processed according to uniform principles.

CHARACTERISTICS OF THE NETWORK

The deep groundwater monitoring network (deeper than 20 m) contains around 550 monitoring stations, while the shallow groundwater network (not deeper than 20 m) contains more than 1500 monitoring stations.

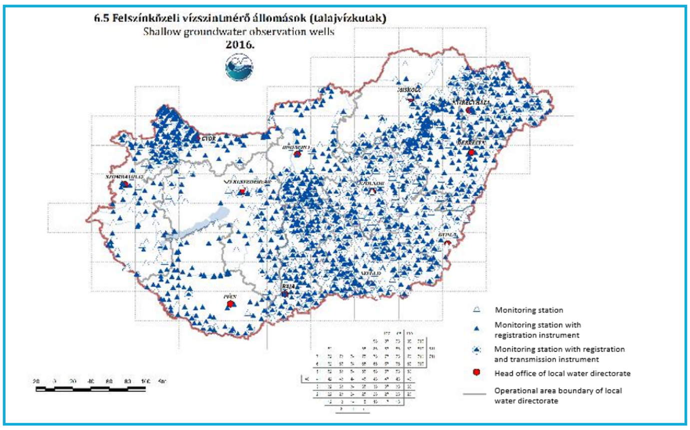


Fig. 40 - Shallow groundwater observation wells. Source: OVF

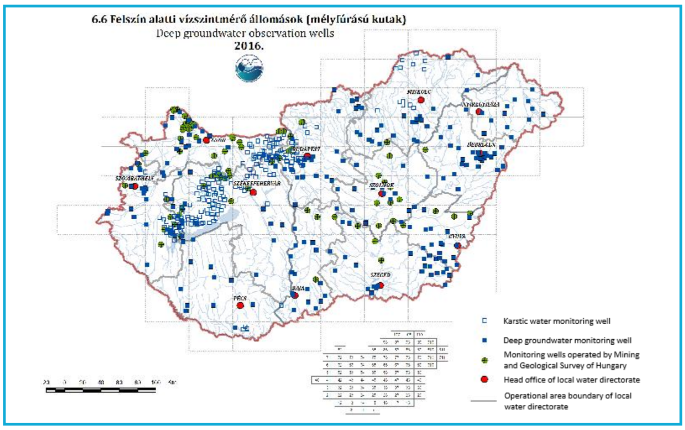


Fig. 41 - Deep groundwater observation wells. Source: OVF

PROCESSING AND DISSEMINATION

The National Adaptation Geo-information System (NAGiS) is a platform created to facilitate the policy-making, strategy-building and decision-making process necessary to improve climate change adaptation measures in Hungary. The NAGiS is a source of information on the climate trends of Hungary. The NAGiS GeoDat is a web-application where groundwater level data are shown in a table or a graph format. Data are available in Hungarian for registered users.

Moreover, the Hydrographic Yearbook of the hydrographical service of Hungary, first published in 1887, consist of hydrographic measurements as well as the most important data describing hydrological and hydrometeorological conditions, including a summary introducing the hydrological and hydro-meteorological events and characteristics of the given year. Tables containing daily data of karstic and groundwater levels (shallow and deep) are provided. The spatial location of monitoring networks is shown in thematic maps.

Sources

- **Feedback from OVF** - received on 25-03-2020;
- **Hydrographic Yearbooks** - https://www.vizugy.hu/print.php?webdokumentumid=1524;
- **Hungarian General Directorate of Water Management (OVF)** - http://www.ovf.hu/en/vizugy-tortenet-en;
- **OVF, Hydrographic monitoring** - http://www.ovf.hu/hu/vizrajzi-monitoring; and
- **NATER Project, NaGIS web application** - https://nater.mbfsz.gov.hu/hu/user/login?destination=cas/login.

Ireland

Capital city: Dublin
Inhabitants: 4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Environmental Protection Agency (EPA) of Ireland manages the Groundwater Monitoring Programme, following the Article 8 of the Water Framework Directive (WFD). The purpose of the Network is to assess the general status of groundwater quality and levels in the Republic of Ireland to protect the source for public and private drinking water supplies and associated surface water and ecological receptors. Additional groundwater monitoring is carried out by the local authorities, academic research institutions, private consultants and the Geological Survey of Ireland.

CHARACTERISTICS OF THE NETWORK

The groundwater level monitoring network is focused on groundwater bodies that are considered "at risk" from depletion due to over-abstraction, which are very few in Ireland. Its purpose is to help assess how groundwater levels and flows to surface water receptors are affected by groundwater abstractions. At the moment, the network has 126 active monitoring stations.

Other monitoring networks are dedicated to "not at risk" groundwater bodies with the purpose of helping to improve the conceptual understanding of the flow of groundwater.

Both wells and springs are part of the groundwater monitoring network. In wells, the groundwater level is measured using a combination of data loggers and manual dipping. Discharge from springs is generally measured using water level/flow rating curve relationships, with ultrasonic flow measurement devices at some sites. At some other spring sites, stop flows are measured using flow meters without continuous flow measurement. Where there is no continuous water level (and stage-discharge rating curves) or velocity measurements at springs, single spot flow measurements are taken, i.e. the flow is measured at the time of the water quality sample to calculate chemical loads from the springs.

The EPAHydroNet portal shows the location of the groundwater levels monitoring stations, and time series data, which is also available for downloading, figure on next page.

As groundwater abstractions are typically not a significant issue in Ireland (~80% of the volume of water comes from surface water), groundwater levels are not something EPA extensively monitor.

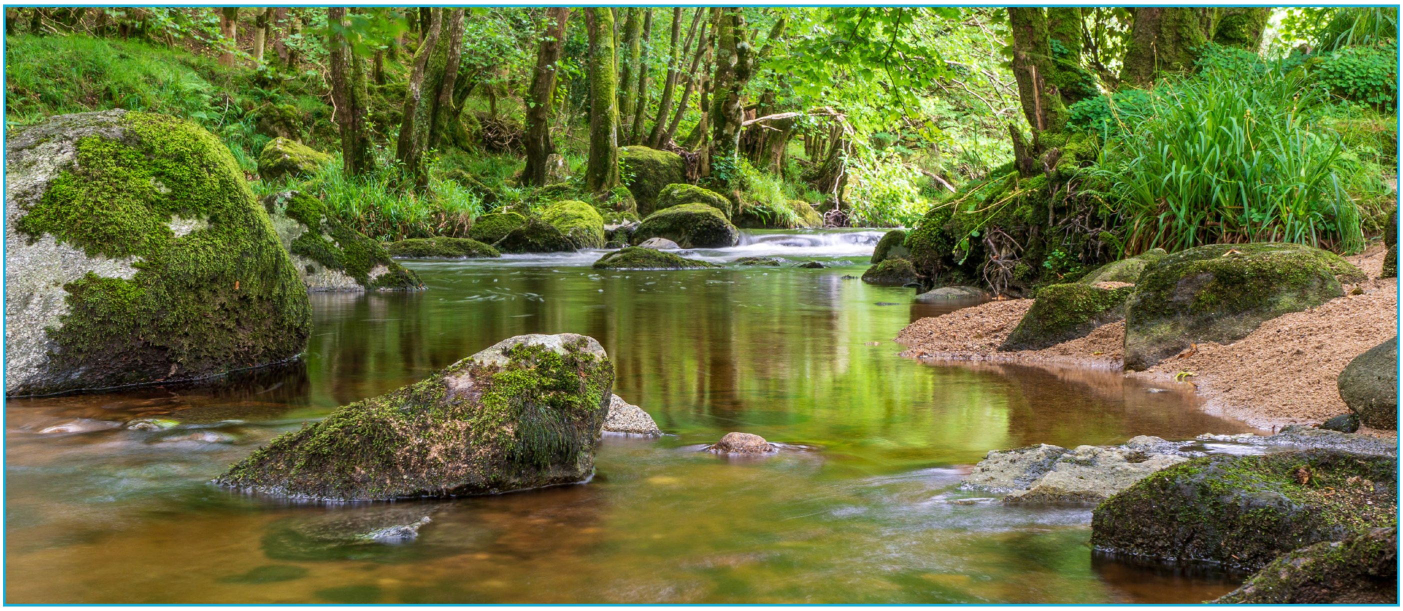


Fig. 42 - Glencree River slow moving through green trees

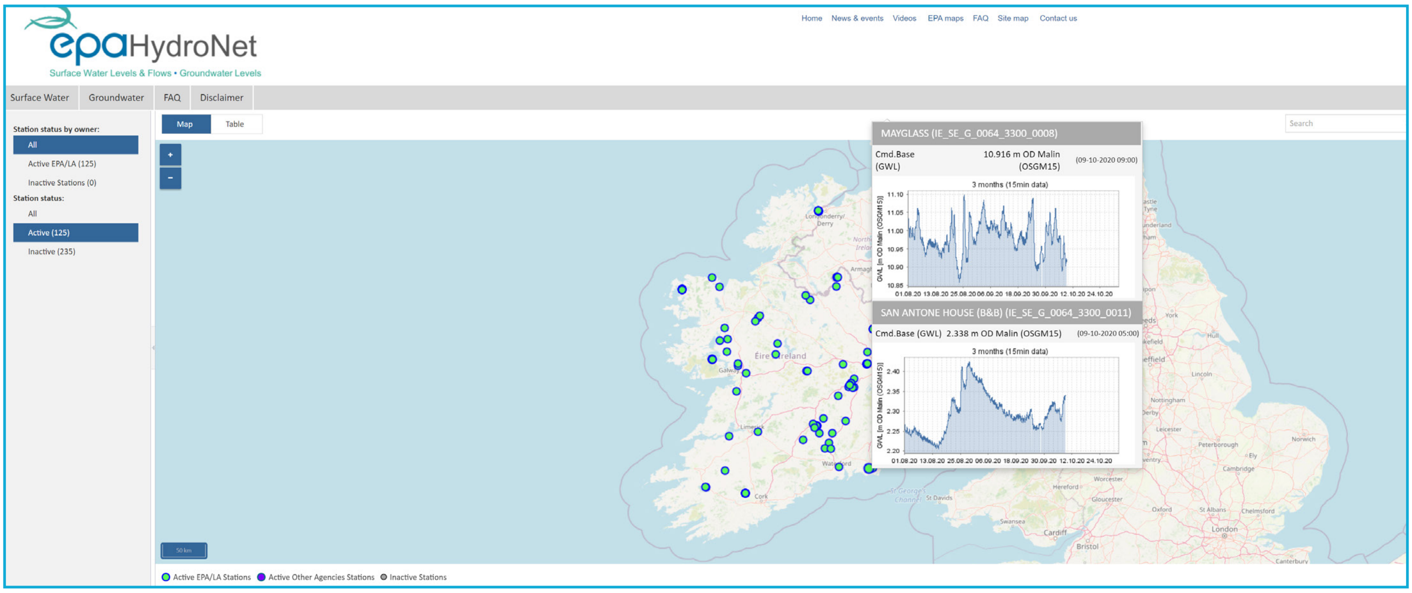


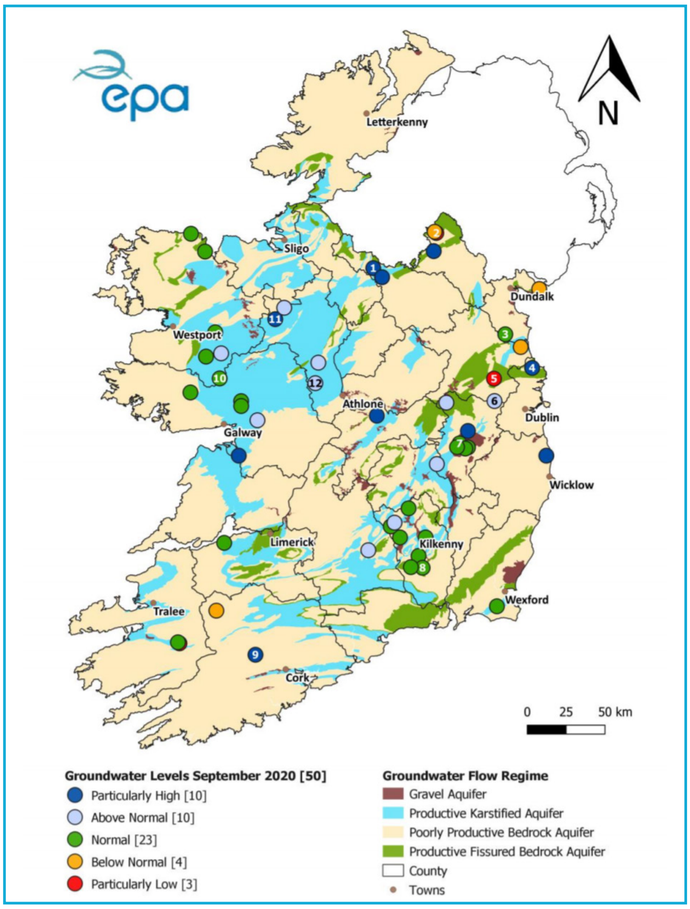
Fig. 43 – EPAHydroNet web portal

PROCESSING AND DISSEMINATION

Groundwater level data is used to support WFD assessments. Separate to this, EPA just completed water resource and abstraction impact assessments for groundwater and surface water, and material relating to this will be going on the official website later on this year.

EPA is also developing a 1-page water bulletin, that graphically/visually shows how groundwater levels, river flows and lake levels are relative to the seasonal averages and 95%iles. EPA completed the work and is in the process of preparing them for online publication; the aim being to have monthly bulletins.

Fig. 44 – Groundwater levels reported in September 2020, source: EPA Water Bulletin



Sources

- **Environmental Protection Agency (EPA), groundwater level monitoring** - http://www.epa.ie/water/wm/groundwater/level;
- **EPA HydroNet, groundwater levels** - http://www.epa.ie/hydronet/#Groundwater; and
- **Feedback from EPA** - received on 20-03-2020.

Italy

Capital city: Rome
Inhabitants: 60 Million

INSTITUTIONAL SETTING AND PURPOSE

The Italian Institute for Environmental Protection and Research (ISPRA) acts under the Italian Ministry for the Environment and the Protection of Land and Sea (MATTM). It was established in 2008 as a result of integration of the Agency for Environment and Technical Services (APAT), the Institute for Marine Environmental Research (ICRAM) and the Institute for Wild Fauna (INFS). ISPRA is composed of 20 Regional and 2 Provincial Environmental Agencies (named ARPAs and APPAs, respectively) and links the knowledge and experience of local environmental issues with national and European policies.

ISPRA's one of the main activities is data collection and validation of the National Environmental Information System (SINA).

The groundwater monitoring network in Italy is not centralized and consists of a group of regional groundwater monitoring networks that are managed by ARPAs. An example of Piedmont groundwater monitoring network is described below.

CHARACTERISTICS OF THE NETWORK

Piedmont Regional Groundwater Monitoring Network (RMRAS) has 605 wells (data from 2012) most of them private and measured manually.

There are 119 piezometers where water level is measured automatically. 116 wells are used for qualitative monitoring as well.

PROCESSING AND DISSEMINATION

The piezometric reference level in the RMRAS is represented by the range of fluctuation between the 1st and 3rd quartiles of monthly long-term average values (9-15 years). The range is considered as the natural annual fluctuation of the groundwater in that given piezometer of the network. Values of the piezometric level below 15-30% of the reference level are considered critical conditions for the quantitative state of the water body.

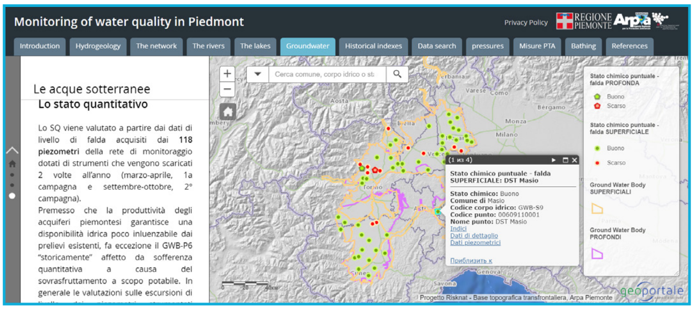


Fig. 45 – Piedmont groundwater monitoring web portal. Source: ARPA Piemonte

The data from the Network is available on the Piedmont ARPA web portal. When a user selects an observation point, a pop-up window appears with the possibility to see the depth to the groundwater level and its long-term fluctuation, figure 45 and figure 46.

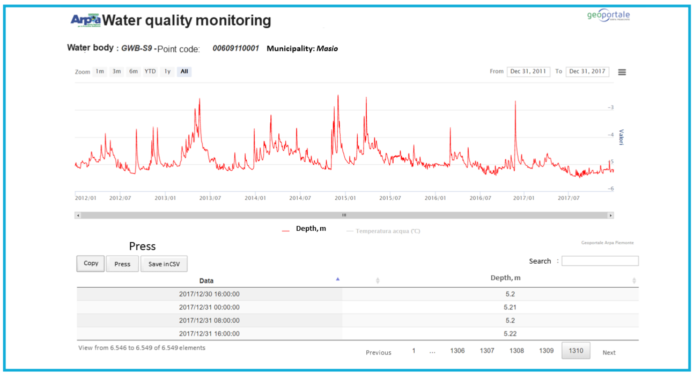


Fig. 46 – Groundwater level fluctuation time-series. Source: ARPA Piemonte

Sources

- **Regional Agency for Environmental Protection (ARPA) of Piemonte. Groundwater monitoring network** - http://www.arpa-piemonte.it/approfondimenti/temi-ambientali/acqua/rete-di-monitoraggio/rete-di-monitoraggio-delle-acque-sotterranee;
- **ARPA of Piemonte, water resource analysis** - http://www.arpa.piemonte.it/approfondimenti/temi-ambientali/idrologia-e-neve/idrologia-ed-effetti-al-suolo/documenti-e-dati/rapporto-situazione-idrica-piemontese.

Latvia

Capital city: Riga
Inhabitants: 1.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Latvia Environment, Geology and Meteorology Centre (LEGMC, www.meteo.lv/en/) is in charge of the state groundwater monitoring network. Its objective is to provide data on long-term state and trends of groundwater in the country, and input for national water policy planning, regulatory agencies and the public. Specific objectives of groundwater monitoring in Latvia are:

1. assessing quantitative and qualitative status of groundwater resources and the impact of various sources of pollution,
2. developing river basin management plans and measures for a rational use of groundwater resources, and
3. assessing the effectiveness of measures taken.

CHARACTERISTICS OF THE NETWORK

The network covers the whole territory of Latvia and provides observations from all exploited water horizons (aquifer system layers), focusing on the layers which are mainly used for water supply. The largest density of network is in Rīga, Jūrmala and Liepāja, the cities with the highest groundwater extraction rate and with the most potential sources of groundwater contamination. The groundwater level observation network consists of 305 wells distributed over 60 stations.

Data on groundwater quantity and quality are collected both manually and automatically (data loggers and automatic transmission). 197 wells distributed in 41 stations are equipped with automatic loggers measuring the level every day. In the case of manual observations, the frequency ranges from once a month to four times a year, depending on the aim of monitoring.

PROCESSING AND DISSEMINATION

The evaluation is based on large-scale and long-term observation datasets. Time series analysis, spatial interpolation and statistical analysis are used to process the data. On the LEGMC website, it is possible to download groundwater monitoring data and statistically processed information, figure 47. The Data Accessibility tool provides info on kind of observation that can be found at each station whereas the Data Search tool has a data download option as well. The results of long-term and not-digitalized observations can be requested from the Environmental Data Archive (also a part of the LEGMC).

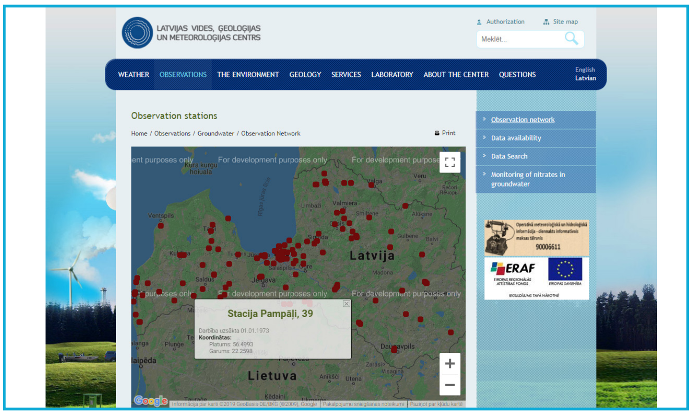


Figure 47 – Location of observation points from LEGMC website

Sources

- **Feedback from LEGMC** - received on 27-05-2020;
- **Feedback from LEGMC (answer to form)** - received in 2018;
- **Latvian Environment, Geology and Meteorology Centre. Monitoring stations** - https://www.meteo.lv/pazemes-udens-staciju-karte/?&nid=474;
- **Latvian Environment, Geology and Meteorology Centre. Groundwater** - https://www.meteo.lv/lapas/noverojumi/pazemes-udens/pazemes-udens_ievads?id=1330&nid=473;
- **Latvian Environment, Geology and Meteorology Centre. Data Search** - http://www.meteo.lv/pazemes-udens-datu-meklesana/?nid=475; and
- **Latvian Environment, Geology and Meteorology Centre. Data availability** - https://www.meteo.lv/pazemes-udens-datu-pieejamiba/?&nid=476.

Lithuania

Capital city: Vilnius
Inhabitants: 2.8 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment (MoE) is in charge of water resources management in Lithuania. The Lithuanian Geological Survey (LGS) under the MoE implements the EU Water Framework Directive related to groundwater and manages its monitoring, classifies the status of groundwater bodies and establishes objectives for groundwater bodies. Additionally, groundwater monitoring in Lithuania is carried out in accordance with the State Environmental Monitoring Program. The network is focused on determining the state and trends on groundwater quantity and quality. It includes groundwater level measurements and groundwater sampling for laboratory analysis.

CHARACTERISTICS OF THE NETWORK

The quantitative groundwater monitoring network in Lithuania consists of 76 observation wells. Measurements of the groundwater level and temperature are performed daily. The measurements are collected twice a year and processed by the Geological Survey. The majority of groundwater quantitative monitoring stations are installed in shallow aquifers (60 wells), which are sensitive to the change in meteorological conditions.

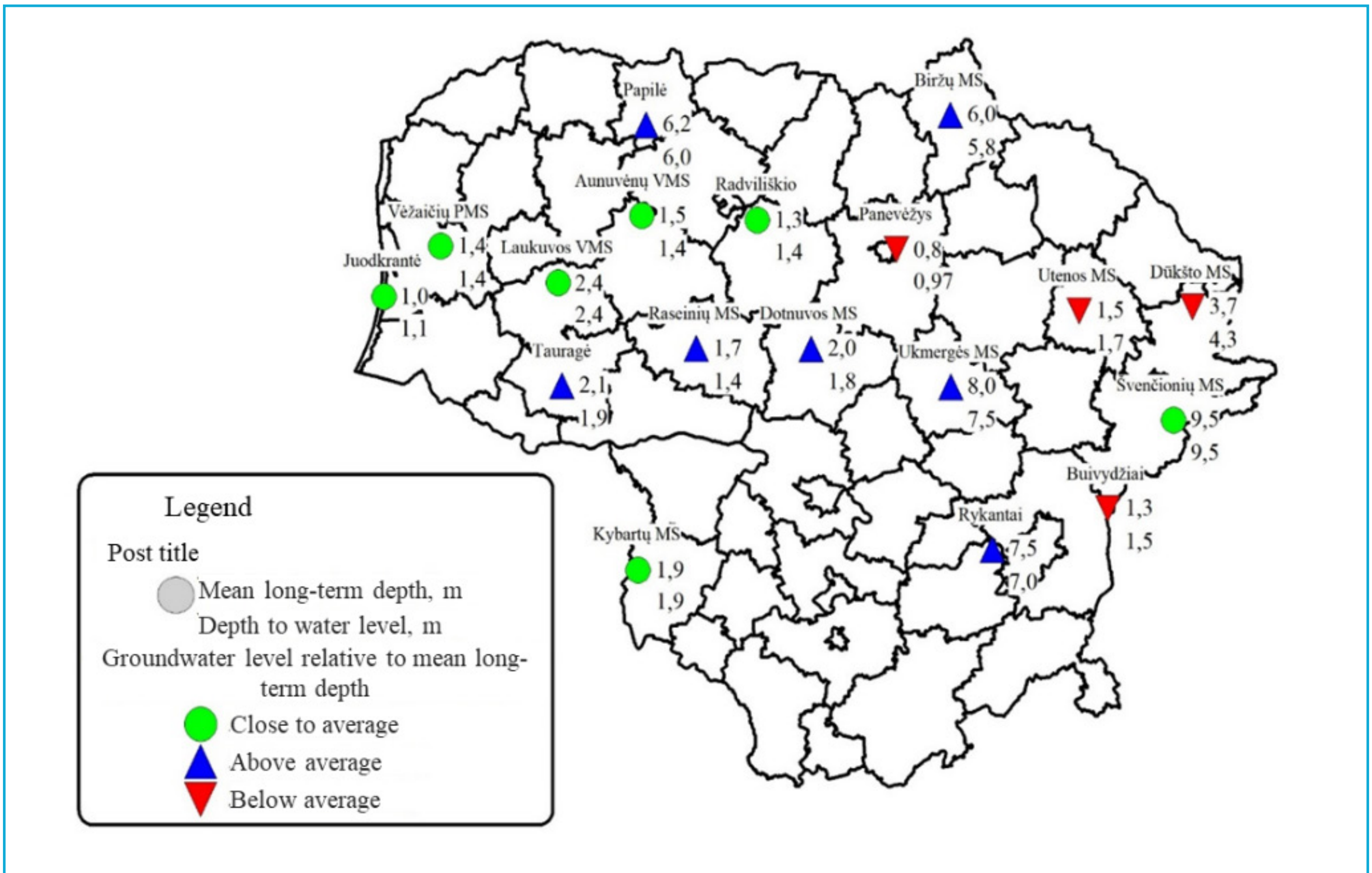


Figure 48 - Groundwater levels in 2017 in comparison with levels from 2006-2017 period

PROCESSING AND DISSEMINATION

National Groundwater Monitoring Statistics is available at the LGS website (https://www.lgt.lt/) based on monitoring data from 1990 till 2018. The information can be grouped by counties, districts, municipalities, river basins and aquifers.

Limited data from the observation wells is available on the web portal of the LGS, figure 49. When selecting an observation point, a user gets the code, name and type of the well with XY coordinates, monitoring type, measured parameters and the name of an aquifer.

Apparently, data from the National Groundwater Monitoring Network are accessible by logging in as a Lithuanian resident, business entity or public sector through the E-Government Gateway.

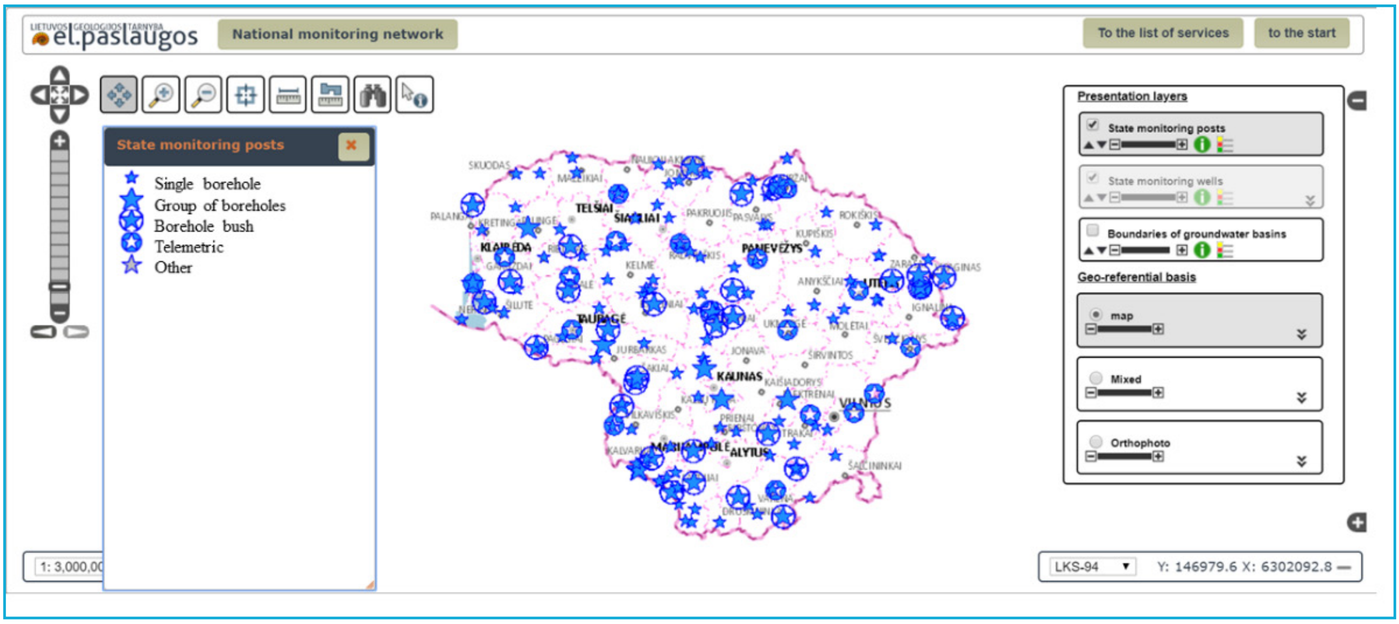


Figure 49 - National monitoring network in Lithuania. Source: LGS web portal

Sources

- **Food and Agriculture Organization of the United Nations (FAO) AQUASTAT, 2016** - http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/LTU;
- **Groundwater Information System (PozVIS)** - https://www.lgt.lt/epaslaugos/index.xhtml;
- **Lithuanian Geological Survey** - https://www.lgt.lt/; and
- **Lithuanian Geological Survey. Exploration** - https://www.lgt.lt/index.php?option=com_content&view=article&id=156&Itemid=1265&lang=lt.

Luxembourg

Capital city: Luxembourg City
Inhabitants: 0.6 Million

INSTITUTIONAL SETTING AND PURPOSE

The Administration of Water Management, under the Ministry of Environment, Climate and Sustainable Development, is in charge of groundwater monitoring in Luxembourg in accordance with the European Water Framework Directive. One of the missions of the Administration is to monitor and control the application of legal and regulatory requirements for water management including surface and groundwater.

CHARACTERISTICS OF THE NETWORK

Currently, there are seven operational monitoring stations in the network which register groundwater level and temperature.

PROCESSING AND DISSEMINATION

Geoportal.lu is Luxembourg official national geoportal. It is a platform for collection, description, visualisation and dissemination of geospatial data and related products, figure 50. The Administration of Cadastre and Topography (the national cadastre and mapping authority) developed the portal.

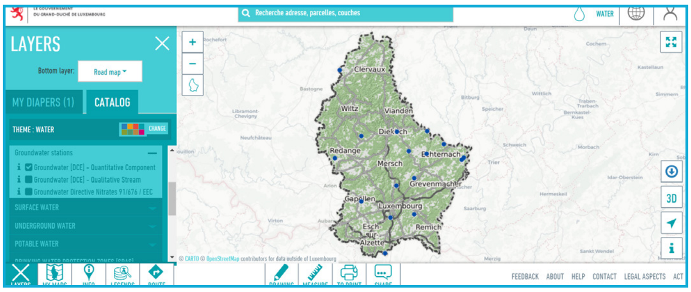


Figure 50 - Geoportal with quantitative groundwater monitoring points

Reports (that include location details, constructive details, geological maps, photos and quality analysis for several parameters) are provided for each monitoring station, figure 51.

Figure 51 - Documentation for measuring points on the Geoportal

Some data on groundwater abstraction are available as well. The Administration of Water Management publishes bulletins on the quantitative situation of groundwater in the country.

Sources

- **National official geoportal** - https://www.geoportail.lu/en;
- **General maps of the National official geoportal** - https://map.geoportail.lu;
- **Quantitative situation of groundwater** - https://eau.public.lu/eaux_souterraines/Situation-quantitative-des-eaux-souterraines/index.html; and
- **Quantitative data groundwater** - https://data.public.lu/en/datasets/quantitative-data-groundwater.

Moldova

Capital city: Chisinau
Inhabitants: 3.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The State Enterprise Hydro-Geological Expedition from Moldova, a state organisation under the Ministry of Agriculture, Regional development and Environment, carries out the Groundwater Monitoring project at the territory of the Republic of Moldova. The objective of this project is to study groundwater systems and determine physical and chemical trends in groundwater due to natural factors with the final goal to protect the resource from pollution and overexploitation.

CHARACTERISTICS OF THE NETWORK

The Republic of Moldova started regular groundwater monitoring activities in 1960. The national groundwater network has currently 33 stations, figure 52. The frequency of monitoring varies from 1 to 10 times a month. Temperature is measured together with water levels. For a limited amount of points, chemical analysis is done 2 times a year, for the rest once a year.

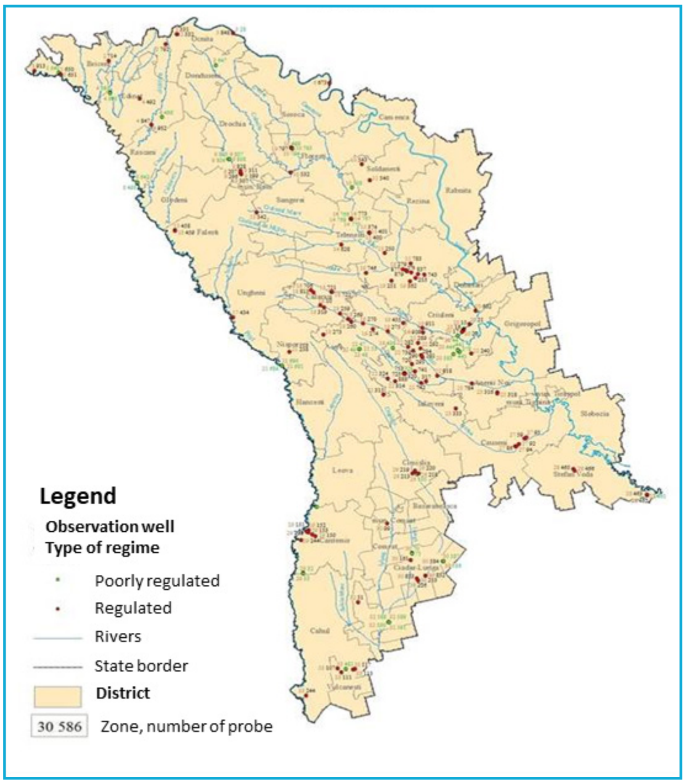


Figure 52 – Location of observation wells in the Republic of Moldova. Source: The State Enterprise Hydro-Geological Expedition from Moldova

PROCESSING AND DISSEMINATION

Information on the aquifer systems and horizons of the Artesian Moldavian Basin (which belongs to the Artesian Black Sea Basin and includes the whole territory of Moldova) can be found in the State Enterprise Hydro-Geological Expedition from Moldova website. Periodical reports on the state of groundwater levels can be found at the Enterprise, which are accessible via request.

Sources

- **Feedback from the State Enterprise Hydro-Geological Expedition from Moldova -** received on 24-06-2020;
- **State Enterprise Hydro-Geological Expedition from Moldova** - http://www.ehgeom.gov.md/en;
- **State Enterprise Hydro-Geological Expedition from Moldova, groundwater monitoring** - http://www.ehgeom.gov.md/en/proiecte-din-bugetul-de-stat/monitorizarea-apelor-subterane; and
- **Ministry of Agriculture, Regional Development and Environment, Government of the Republic of Moldova** - http://www.madrm.gov.md/ro/content/acte-departamentale.

The Netherlands

Capital city: Amsterdam
Inhabitants: 17.3 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Infrastructure and Water Management is in charge of the national groundwater monitoring programme in the Netherlands. Groundwater monitoring networks are managed on a national, regional and local levels. Provincial authorities and water boards take up the responsibility at the regional level, and municipalities and water supply companies are in charge of the groundwater monitoring at the local level. The establishment of the monitoring network started in 1970 with a goal to provide insights into the spatial distribution of hydraulic heads per aquifer.

CHARACTERISTICS OF THE NETWORK

The primary groundwater level monitoring network is developed and maintained by 11 provinces. In the past, the network used to measure the groundwater level every 14 days, but now data loggers collect it every hour. Total number of sites are 1,000 with 49,000 monitoring wells, 74,000 piezometers and 130 million groundwater levels/heads, figure 53.

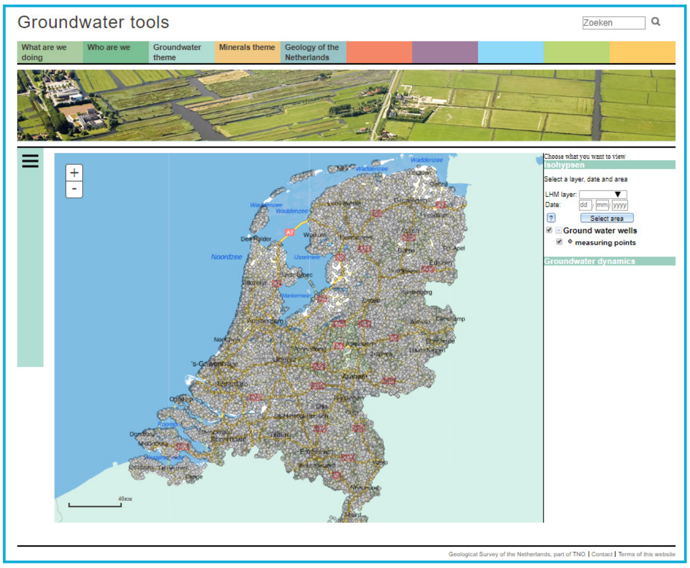


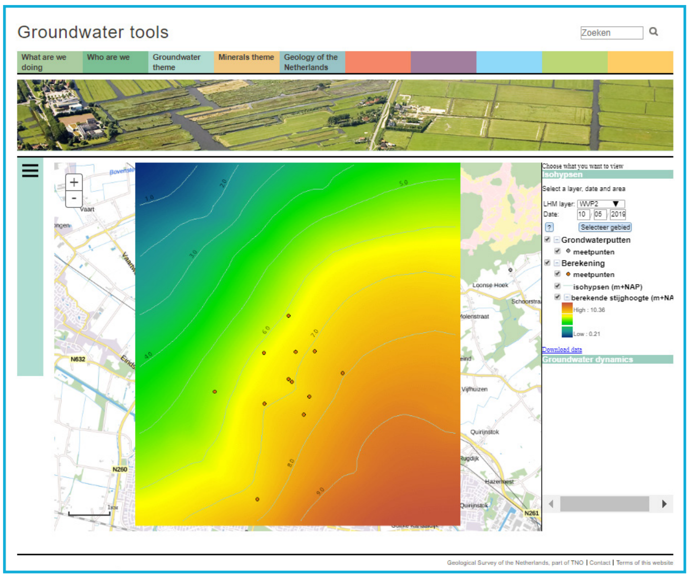
Figure 53 -Groundwater monitoring points in the Netherlands. Source: Grondwatertools viewer

The information on quantity and quality of the groundwater in the Netherlands can be accessed through DINOloket. The data are currently supplied in a format that the user can easily view in a spreadsheet (Excel format). However, a limited amount of data are currently being offered.

Grondwater Tools is an interactive portal designed to share information about groundwater in the Netherlands. The Groundwater Tool viewer allows the user to visualize the locations of monitoring wells in the Netherlands and use two powerful analysis tools: Contour lines (Isohypsen) and Groundwater Dynamics (Groundwaterdynamiek).

Contour lines

Contour lines are the lines with the same groundwater level on a map. They show the spatial pattern of levels and help to understand the direction of the groundwater flow. Grondwater Tool allows to choose for which date and in which aquifer a user want to see the contour lines, figure 54. The data are downloadable and the file includes piezometric levels (Excel format), semivariance graph, figure 54 (jpeg), Krigging results (Excel format) and contour lines (shape file). The contour lines are calculated based on rising ranges (groundwater levels) from the DINOloket, the NHI (Dutch Hydrological Instrumentation) and 3.0 hydraulic heads from the Deltares.



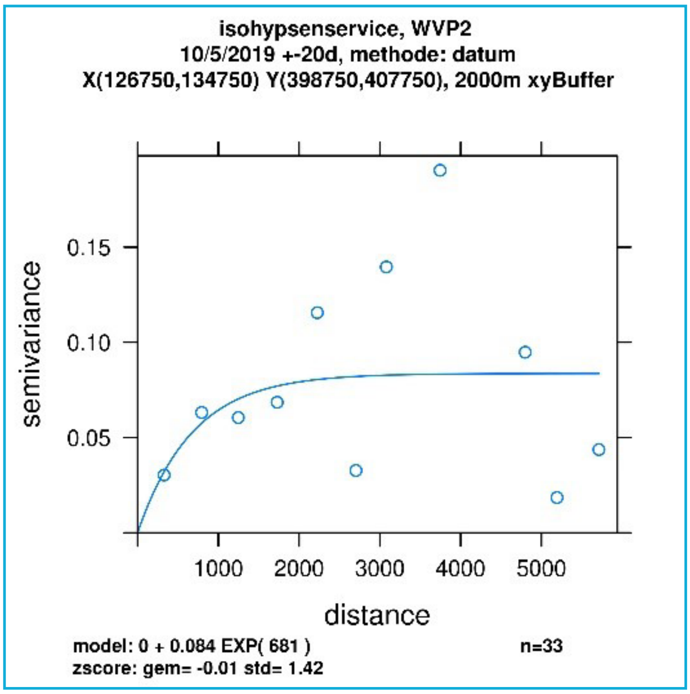


Figure 54 - Contour lines for Leikeven area, Tilburg, the Netherlands (previous page) – Grondwatertools viewer (above) – semivariance for groundwater levels from the selected area

Groundwater Dynamics

The system makes use of a transfer function-noise model with precipitation and evaporation as independent variables. An automated quality control is performed through a several steps in order to filter out time series that do not comply with the following criteria:

- Observations provide enough information about groundwater dynamics (enough amount of measurements in a long time period);
- Time series do not have a high number of errors (outliers, steps, drift);
- Small effect from other influences than precipitation and evaporation; and
- Linear behaviour of the groundwater system.

The three levels of model results are presented:

1. Groundwater levels time-series and associated statistics;
2. Components of time-series that can be explained by precipitation and evaporation; and
3. Regime curve based on at least 20 years simulation with the time-series model.

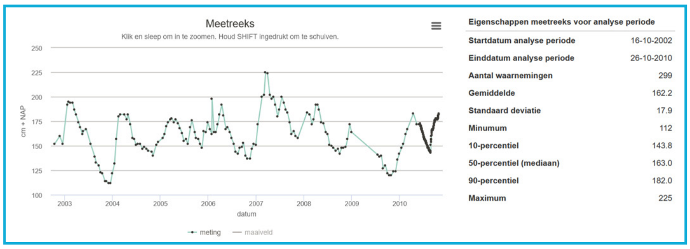


Figure 55 - Level 1 for one monitoring well. Source: Grondwatertools viewer

For Level 1 no specific criteria are used for the further interpretation. Statistics includes the average, standard deviation, maximum, minimum, and the percentiles 10, 50 and 90, figure 55.

Level 2 presents the result of the time-series modelling, requiring automated evaluation of the model results. Two sets of criteria are defined:

1. The first set of criteria assess the length and number of observations of the dataset;
2. The second set of criteria evaluates the model output. This step will be performed only if the first set of criteria is satisfied.

Level 3, or the regime curve, figure 55, is presented in the Grondwater Tools viewer when Level 2 is satisfied (e.g. if the calibrated time-series model is applied for the simulation). Furthermore, more criteria are added to evaluate the predictive performance of the model.

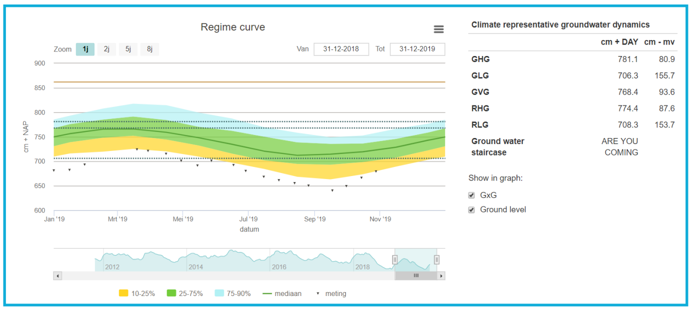


Figure 56 - Regime curve and climate representative groundwater characteristics for one monitoring well. Source: Grondwatertools viewer

To properly calculate the influence of the annual seasonal pattern (periodicity), several years of measurements are required; characteristics of groundwater regime are automatically calculated using the last 8 years of measurements. Then, the climate-representative groundwater characteristics are simulated over a period of 20 years.

This climate-representatives are:

- GHG: Average highest groundwater levels, which occur mainly in winter and early spring;
- GLG: Average lowest groundwater levels, which usually occur in late summer;
- GVG: Average spring groundwater level;
- GxG: The data set of GHG, GLG and GxG;
- RHG: 90-percentile based on the time-series model simulated over a period of at least 20 years;
- RLG: 10-percentile based on the time-series model simulated over a period of at least 20 years; and
- Grondwatertrap (groundwater stairs/category): This value is based on the values of GHG and GLG, (Table on next page).

Grondwatertrap	GHG (cm-mv)	GLG (cm-mv)
I	<20	<50
II	<40	50-80
IIB	25-40	50-80
III	<40	80-120
IIIB	25-40	80-120
IV	>40	80-120
V	<40	>120
VI	40-80	>120
VII	>80	-
VIII	>140	-

Figure 57 - Value ranges for groundwater categories

Groundwater Dynamics tool also provides an analysis of daily influence of precipitation and evaporation components (the distance from the shading to the explained part, figure below) on the groundwater levels.

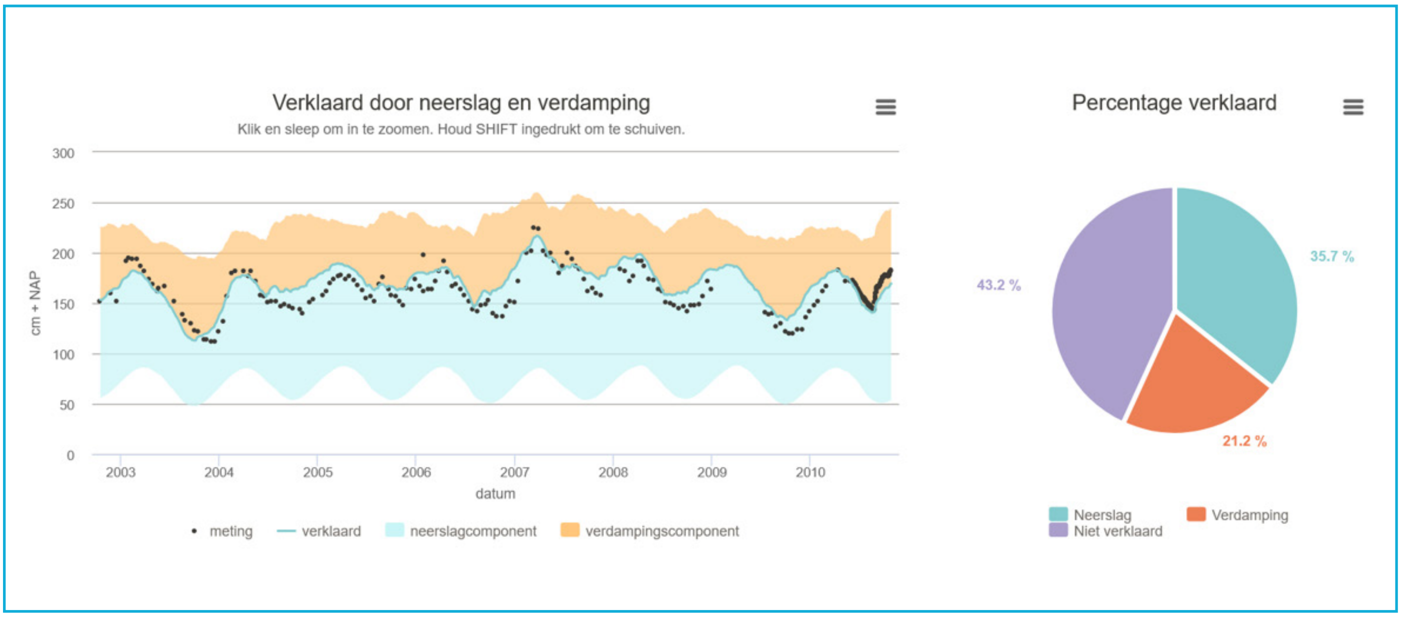


Figure 58 - Influence of precipitation and evaporation on groundwater levels for one monitoring well. Source: Grondwatertools viewer

Sources

- **DINOloket, Data and Information of the Dutch Subsurface. Levels** - https://www.dinoloket.nl/en/levels;
- **DINOloket, Subsurface models** - https://www.dinoloket.nl/ondergrondmodellen;
- **Grondwatertools** - https://www.grondwatertools.nl;
- **Grondwatertools** - https://www.grondwatertools.nl/regis-ii-0;
- **Grondwatertools** - https://www.grondwatertools.nl/isohypsen; and
- **Grondwatertools** - https://www.grondwatertools.nl/grondwatertools-viewer.

Norway

Capital city: Oslo
Inhabitants: 5.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Norwegian Water Resources and Energy Directorate (NVE) under the Ministry of Petroleum and Energy is in charge of groundwater monitoring in Norway, especially regarding groundwater levels and temperature. The main objective of the NVE is to ensure an integrated and environmentally sound management of the country's water systems, promote efficient energy markets and cost-effective energy systems, and contribute to efficient energy use.

Groundwater monitoring system operated by the NVE is used to monitor hydrological conditions including flooding, to analyse water resources changes related to climate change and to implement the EU Water Framework Directive as well as provide flooding and landslide warnings.

CHARACTERISTICS OF THE NETWORK

The network has about 80 stations, some of them are depicted in figure 59. All groundwater stations operated by the NVE are part of the National Groundwater Network (LGN), a collaboration with the Norwegian Geological Survey (NGU). NGU is responsible for mapping groundwater resources and recording the chemical state of the groundwater.

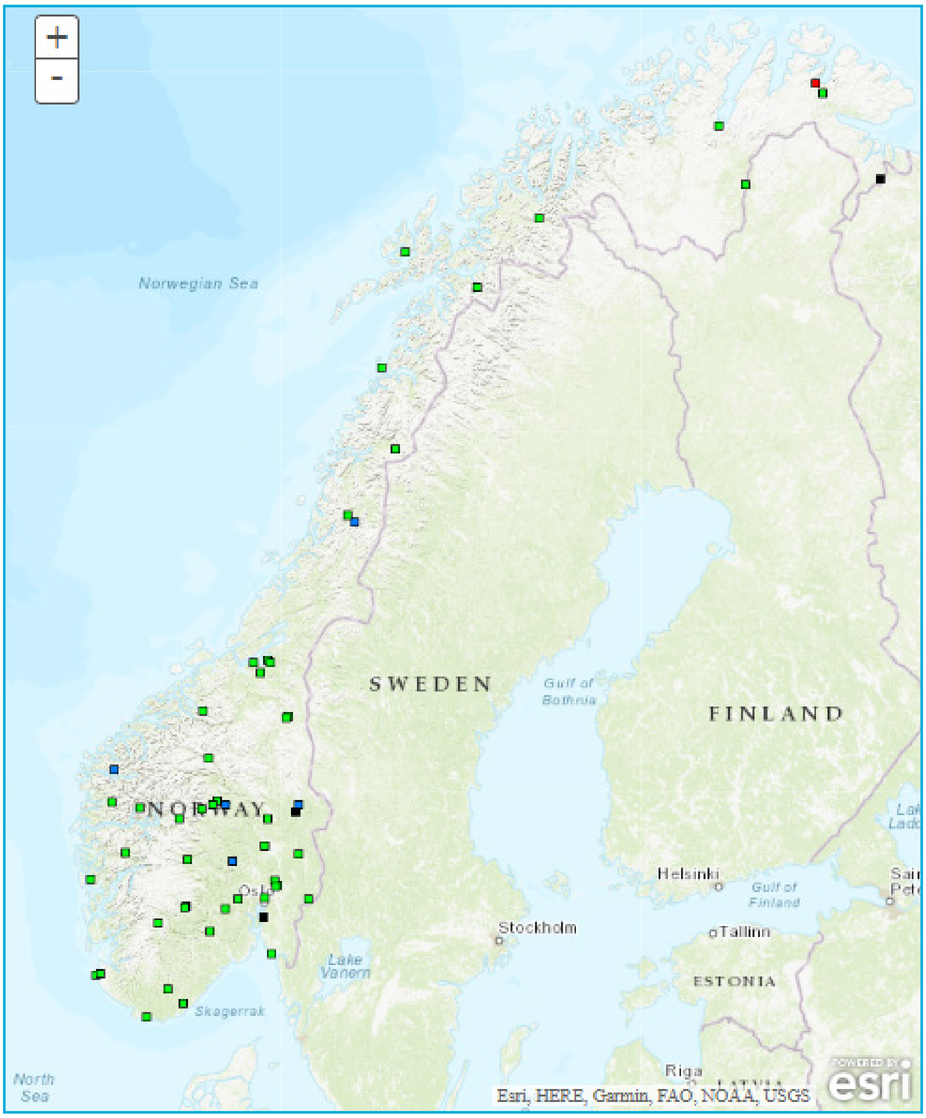


*Figure 59 - Groundwater Monitoring Network of Norway. Source: NVE website**

** Green = updated last week*
Blue = updated last 60 days
Red = data older than last 60 days
Gray = not updated

PROCESSING AND DISSEMINATION

Groundwater level data are analysed through median, 25% and 75% percentile and presented as a time series graph, Figure 2. The hydrological real-time data graphs show all measurements obtained in the displayed time period.

Hence it is possible to compare the current levels with the values on the same day in previous years, the reference period is from 1984 till 2002. In the portal, there is an option to download the data in textual or spreadsheet format for the last two years.

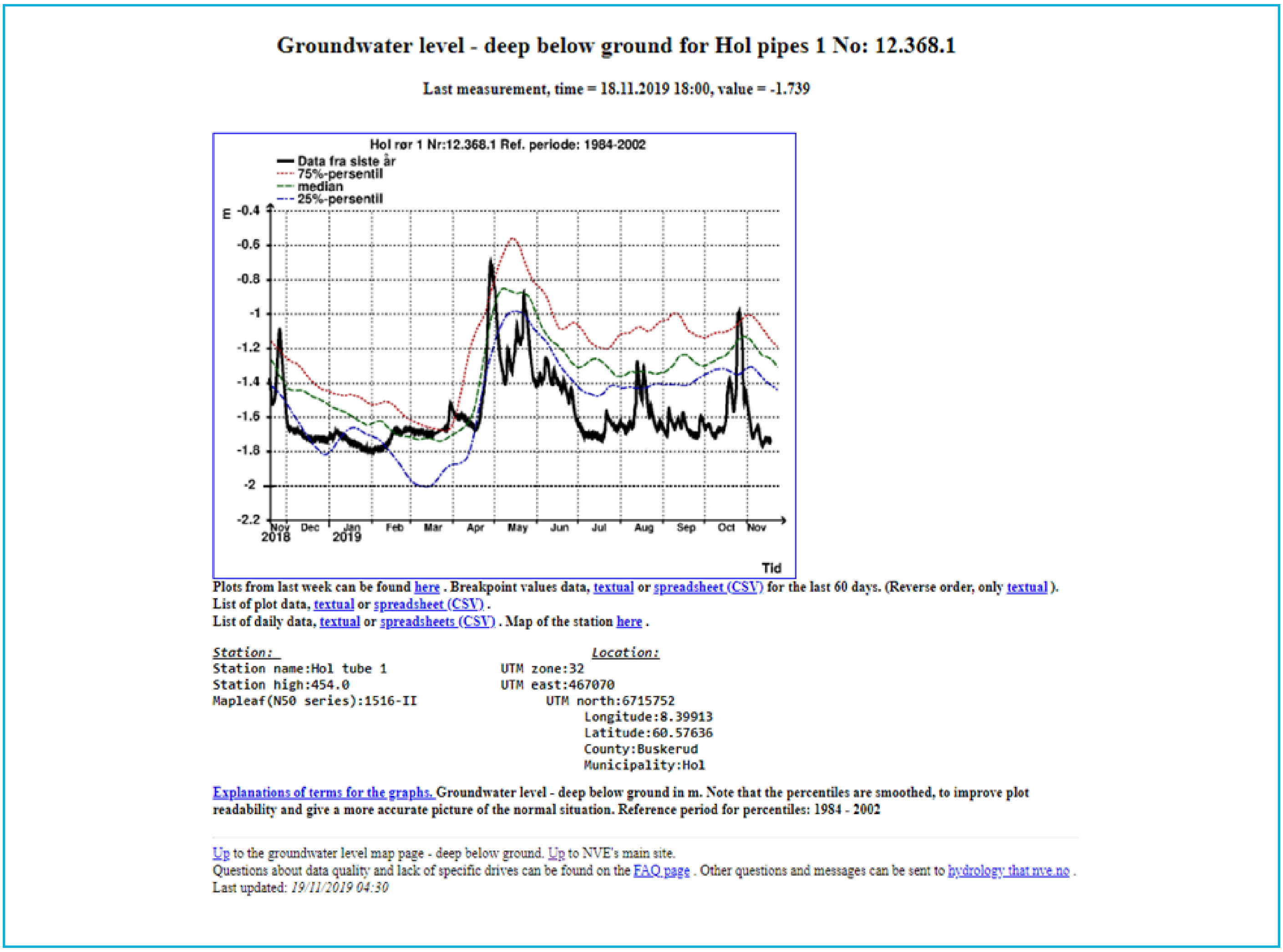


Figure 60 - Groundwater level data viewer. Source: NVE website

Sources

- **Feedback from the Norwegian Water Resources and Energy Directorate (NVE)** - received on 07-10-2020;
- **Groundwater level monitoring stations, deep wells** - http://www2.nve.no/h/hd/plotreal/GRW/index.html;
- **The Norwegian Water Resources and Energy Directorate (NVE), ground and groundwater** - https://www.nve.no/hydrologi/grunn-og-markvann/?ref=mainmenu; and
- **Geological Survey of Norway, Map viewers** - https://www.ngu.no/emne/kartinnsyn?field_temagruppe_tid=2358.

Poland

Capital city: Warsaw
Inhabitants: 38 Million

INSTITUTIONAL SETTING AND PURPOSE

The State Water Holding Polish Waters is a central administrative body responsible for water conservation, management and use. The main tasks of the Holding include development of the national water and environmental programme, keeping the water inventory country-wide, supervising the performance of the National and Regional Water Management Boards; and hydrological, meteorological and hydrogeological services.

In Poland, groundwater monitoring is carried out through national, regional and local networks. The institution responsible for the organization and coordination of monitoring studies is Chief Inspectorate for Environmental Protection.

CHARACTERISTICS OF THE NETWORK

The national network consists of selected, representative observation points.

First groundwater level monitoring in Poland began in the 1970s and quality monitoring in 1991. The network was formed to reflect specific features resulting from the unique geological structure and hydrogeological conditions in Poland. Particular attention is paid to the development of observation networks in recharge and discharge zones, as well as areas endangered by drought, flooding and degradation of groundwater quality. Since Poland joined the European Union, the organisation and scope of groundwater monitoring was adapted to comply with European Community directives and for that reason it relates to monitoring of groundwater bodies. For the current planning cycle there are 172 groundwater bodies in consideration, and there will be 174 for the cycle 2022-2027.

The depth of the water table is measured daily at so-called first order hydrogeological stations, and every Monday at the second order hydrogeological stations. The monitoring network currently comprises of ca. 1250 points (as of September 2020). In addition, 366 observation wells are equipped with automatic devices in which water level monitoring is measured every hour.

Monitoring of groundwater quality is performed within the surveillance and operational networks comprising of selected hydrogeological station of the first and second orders as well as public water supply and private wells. For the planning cycle 2016-2021 the surveillance monitoring was undertaken within ca. 1300 points and the operational in ca. 400.

Poland has also seven transboundary groundwater monitoring networks with seven neighbouring countries, with over 300 observation wells.

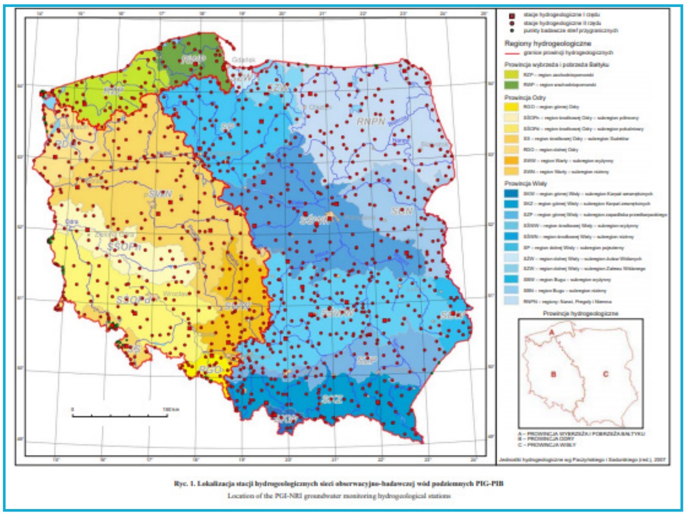


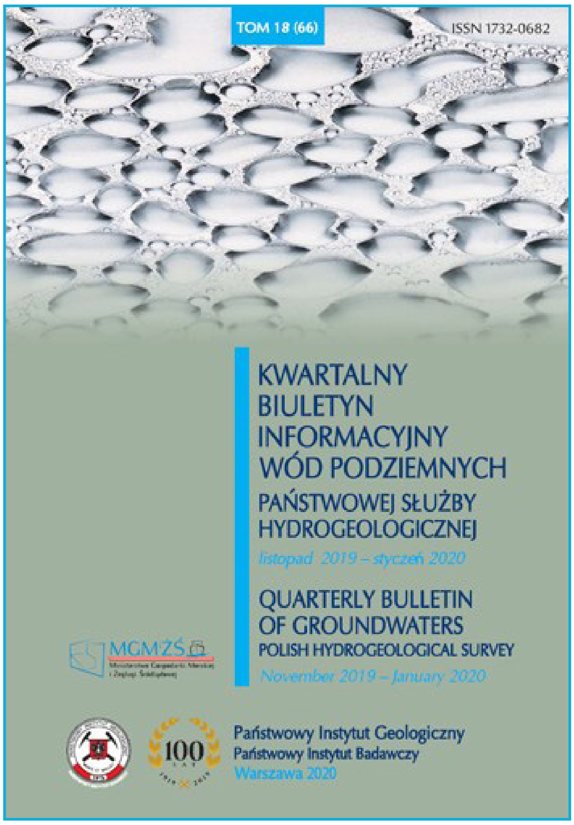
Figure 61 - Groundwater monitoring Network in Poland. Source: Polish Geological Institute – National Research Institute (PIG-PIB)

PROCESSING AND DISSEMINATION

Groundwater Monitoring database (MWP database) includes:

- Information on monitoring points;
- Groundwater level and spring discharge measurements (since 1974); and
- Groundwater chemical composition analysis (since 1991).

The monitoring data and the outcomes of analysis are published on-line in Quarterly Groundwater Information Bulletin and Hydrogeological Yearbook.



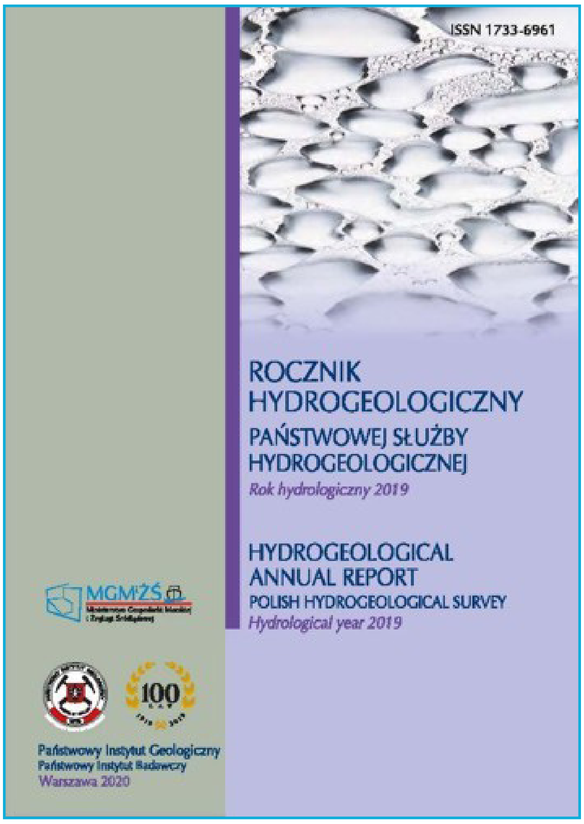


Figure 62 - Quarterly Bulletin of groundwaters and Hydrogeological Annual

Sources

- **Feedback from the Polish Geological Institute - National Research Institute (PIG-PIB)** - received on 05-10-2020;
- **National Water Management of Poland** - https://www.kzgw.gov.pl/index.php/en/about-kzgw/president-s-duties;
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring (1)** - https://www.pgi.gov.pl/en/phs/tasks/9031-groundwater-monitoring1.html;
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring (2)** - https://www.pgi.gov.pl/gdansk/wody-podziemne-pomorza/monitoring-wod-podziemnych/6389-monitoring-wod-podziemnych.html; and
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring and research network. Transboundary monitoring networks in 2012** - https://www.pgi.gov.pl/en/phs/tasks/9006-groundwater-monitoring-and-research-network.html.

Portugal

Capital city: Lisbon
Inhabitants: 10.3 Million

INSTITUTIONAL SETTING AND PURPOSE

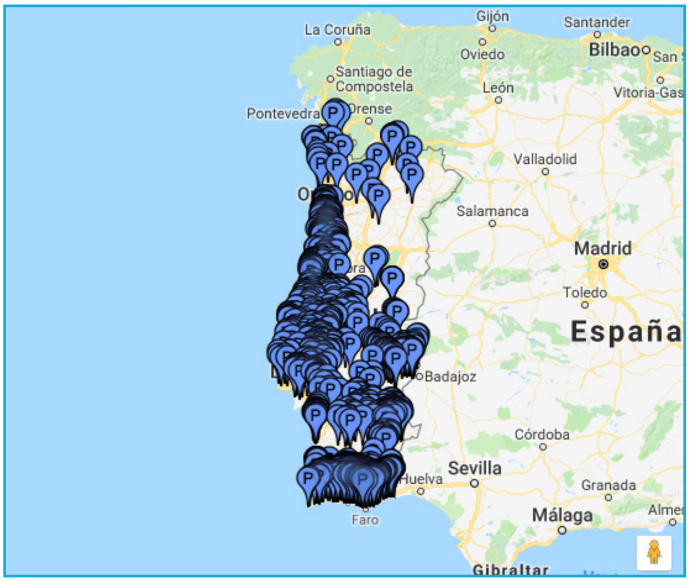
The Portuguese Environmental Agency (APA) is in charge of the National Groundwater Monitoring Network of Portugal.

The monitoring policy of APA includes not only the measurement networks but also measuring instruments, collection and validation procedures, the database system for data storage, and simulation models to support water management and planning.

CHARACTERISTICS OF THE NETWORK

The National Water Resources Information System (SNIRH) contains 22,639 groundwater registered points, 7,864 of them have detailed information. At a national level, 592 points belong to the 'quantity network' and 780 to the 'quality network'.

Figure 63 - Groundwater Monitoring Network of Portugal. Source: SNIRH



PROCESSING AND DISSEMINATION

The monitoring stations can be visualized in an interactive portal maintained by the SNIRH, figure 63.

The groundwater quantity report (Boletim de quantidade) is based on the quantitative groundwater monitoring network and contains an assessment of groundwater level change country-wide. In most of aquifer systems the measurements started in the 70's, and the frequency of observations is monthly. In last several years, some piezometers have been equipped with sensors and the data are monitored daily. The groundwater quantity report plays an important role, especially during drought periods to alert for the decreasing of groundwater level.

The average groundwater level and the 20%-percentile are determined for every month for each well from the beginning of the measurements until the end of the previous hydrological year. A new station is included in the calculations only after 3 years of recording data. For the current hydrological year, the value from the analysed month is compared with the previous statistics and divided in three classes: above average, between the average and the 20% percentile, and below the 20% percentile. Values below the 20% percentile are considered as "very low". At the end, a groundwater body is classified according to the class with highest frequency.

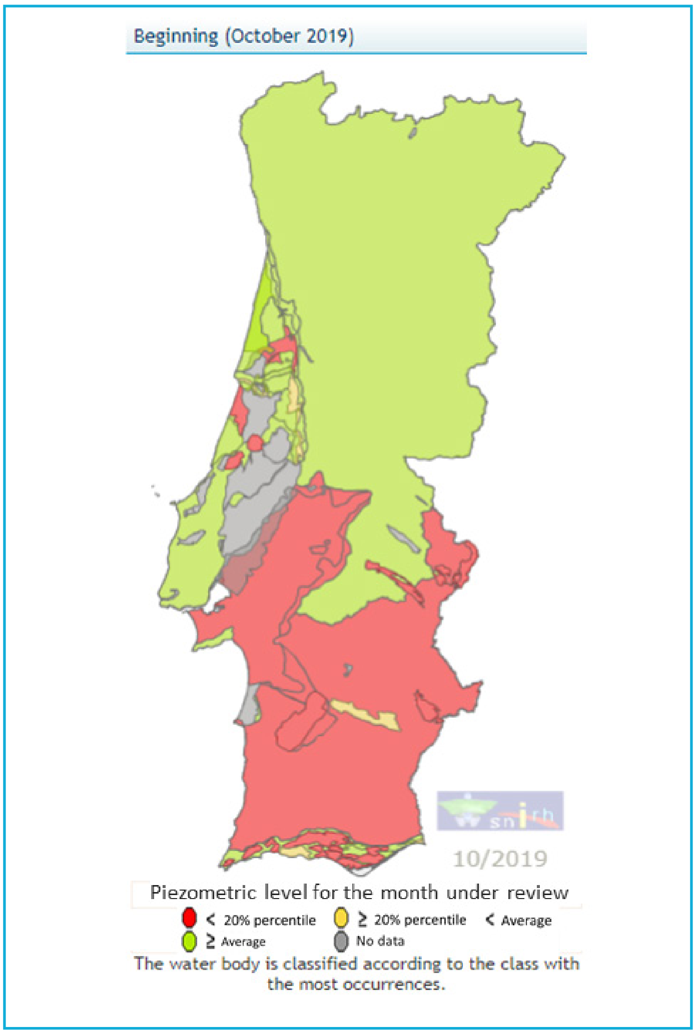


Figure 64 - State of groundwater levels in Portugal for October 2019. Source: SNIRH, monthly bulletin

If two classes have an equal number of occurrences, the classification considers the worst scenario according to the precautionary principle. Applying this principle, a map of piezometric levels for Portugal is built. For October 2019, the piezometric levels at 232 points were observed in 44 groundwater bodies, figure 64.

This analysis is done each month for all the individual groundwater bodies, including a graph with the monthly evolution of the hydrological year, figure 65.

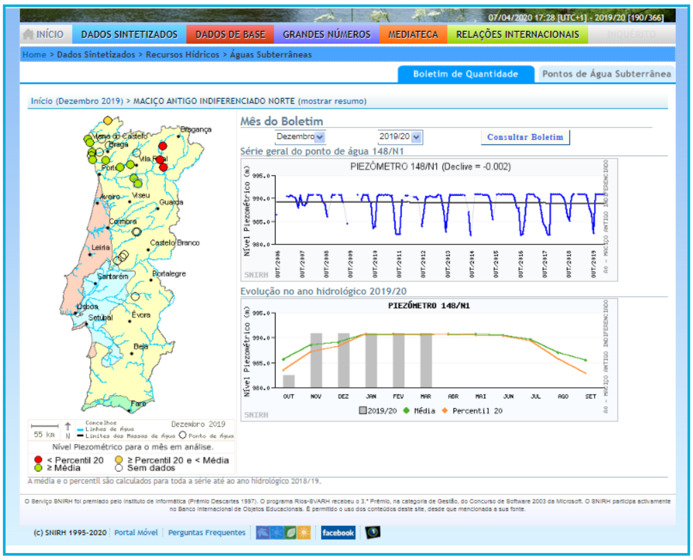


Figure 65 - Groundwater level analyses for selected monitoring point. Source: SNIRH, monthly bulletin

Sources

- **National Water Resources Information System (SNIRH), National Groundwater Monitoring Network** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4;
- **SNIRH, National Groundwater Monitoring Network. Framework** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4&idSubItem=BOL; and
- **SNIRH, National Groundwater Monitoring Network, Monthly bulletin** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4&idSubItem=BOL&massaagua=2039044.

Russian Federation

Capital city: Moscow
Inhabitants: 144.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Natural Resources and Environment (Minprirody) is in charge of policy making and regulation in the field of research, usage and conservation of natural resources. This includes the subsoil, water bodies, forest, fauna, hydrometeorology, wastewater, environmental monitoring and pollution control. Minprirody supervises the Federal Service for Hydrometeorology and Environmental Monitoring, and the Federal Agency for Water. National environmental monitoring includes groundwater monitoring as subsoil sub-monitoring program. At the same time groundwater is the part of water resources sub-monitoring program. The main purpose of the national groundwater monitoring program is to assess the status of groundwater resources and make forecasts; this includes an estimation of operational groundwater reserves and their current use. National network is composed of regional and local monitoring networks, the example of St. Petersburg's network is described below.

CHARACTERISTICS OF THE NETWORK

The Committee for Nature Use, Environmental Protection and Ecological safety established groundwater monitoring system in 2005 in St. Petersburg. By the end of 2018, the network was operated by 61 observation points, figure 66. Among them 49 wells are drilled in the shallow aquifer , 5 wells are in the Upper Intermoraine-, 1 well is in the Lower Intermoraine-, and 5 wells are in the Vendian Aquifer. 44 monitoring wells are equipped with automatic measuring instruments.

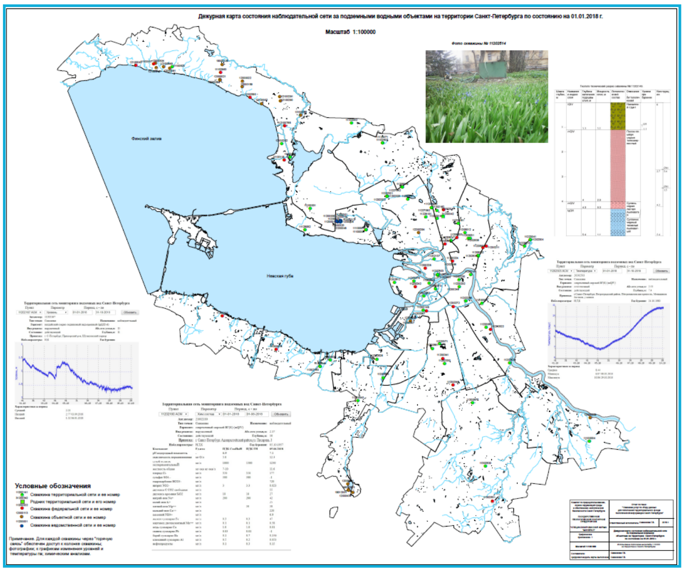


Figure 66 - Map of groundwater monitoring network status in St. Petersburg as of January 1, 2018

PROCESSING AND DISSEMINATION

The Centre for National Monitoring of subsoil and regional works "Hydrospetzgeologiya" under the Federative Agency on subsoil publishes reports on state and seasonal forecasting of groundwater levels. See figure on next page.

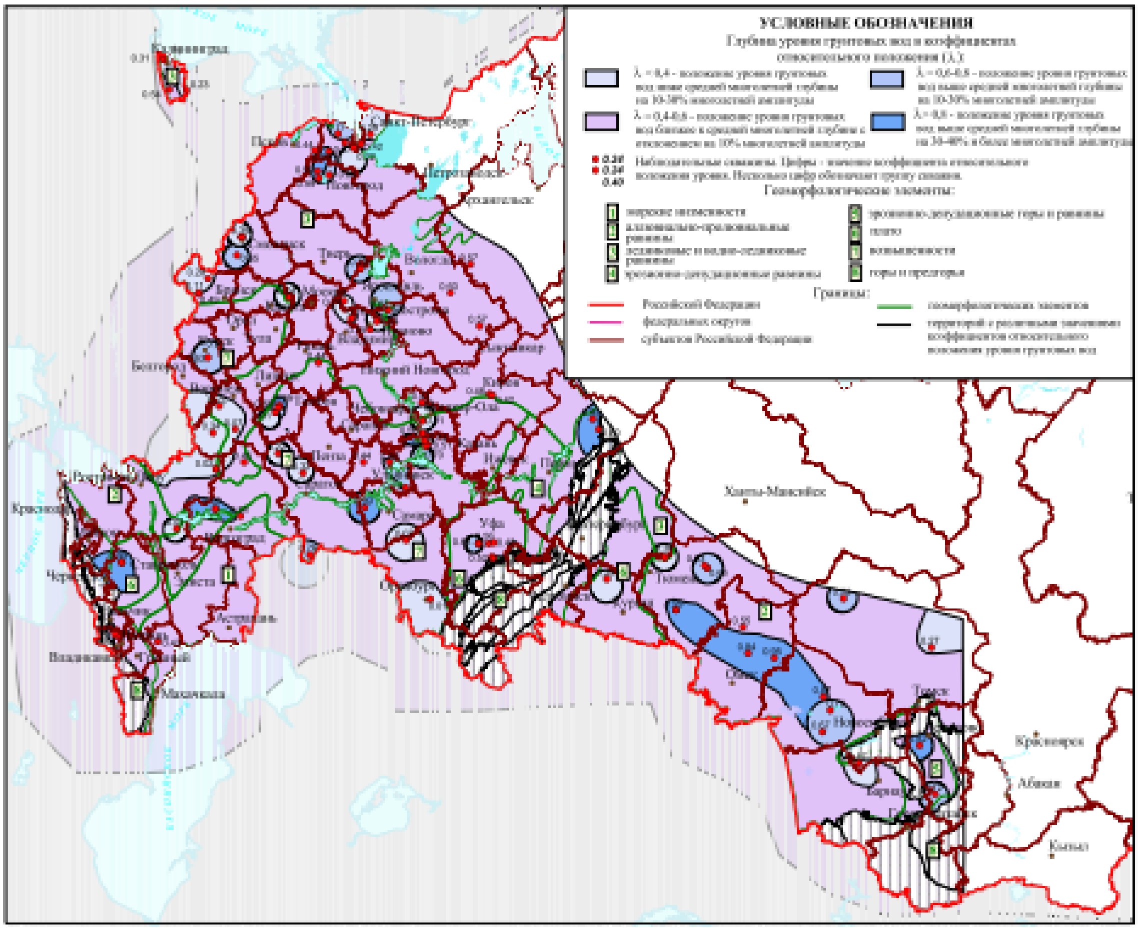


Figure 67 - The prognoses of maximal groundwater levels in the European part of Russia and the West Siberia (2020)

Sources

- **AQUASTAT. Country Profile - Russian Federation** - http://www.fao.org/nr/water/aquastat/countries_regions/RUS;
- **Ecological Portal of St. Petersburg. Groundwater Observation System** - http://www.infoeco.ru/index.php?id=243;
- **Information site on the state of the subsoil of the Russian Federation. Forecasts and reports** - http://www.geomonitoring.ru/inform_product_svodki.html;
- **Information site on the state of the subsoil of the Russian Federation. Newsletter on the status of subsoil in the Russian Federation** - http://www.geomonitoring.ru/inform_product_ib.html; and
- **Subsystem of monitoring of the state of the subsoil. Directions of work of the Ministry of Natural Resources of Russia** - http://mnr.gov.ru/activity/directions/gosudarstvennyy_ekologicheskiy_monitoring/podsistema_gosudarstvennogo_monitoringa_sostoyaniya_nedr.

Serbia

Capital city: Belgrade
Inhabitants: 6.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Republic Hydrometeorological Service of Serbia (RHMZ) is the organization in charge of the groundwater monitoring in Serbia.

The RHMS develops the national groundwater monitoring network, maintains wells installation, collects, records, controls and archives observed and measured data from the network and conducts analysis.

CHARACTERISTICS OF THE NETWORK

In 2015, it was reported that in Serbia there are 409 piezometers for groundwater table observation and 34 for groundwater quality observation. These piezometers are distributed in a total of 34 groundwater bodies in the country. Groundwater observation points are classified as: the main, the first order and the second order. The main stations are representative for larger areas.

Groundwater levels are measured daily and groundwater quality once per year. First order stations are placed in profiles perpendicular to the river flow, hence approximately along the line of the groundwater level. Measurements of the level and temperature are taken six times per month. Second order stations are addition to the first order, being as a network of squares and triangles between the profiles. Measurements of the level and temperature are taken three times per month.

PROCESSING AND DISSEMINATION

RHMS provides the data on groundwater level fluctuations as a graph with 10 last measured values, figure 68. Additionally, an interactive groundwater station network map is available, with links to lithological profiles, general data on stations, statistical analysis of groundwater levels, figure next page.

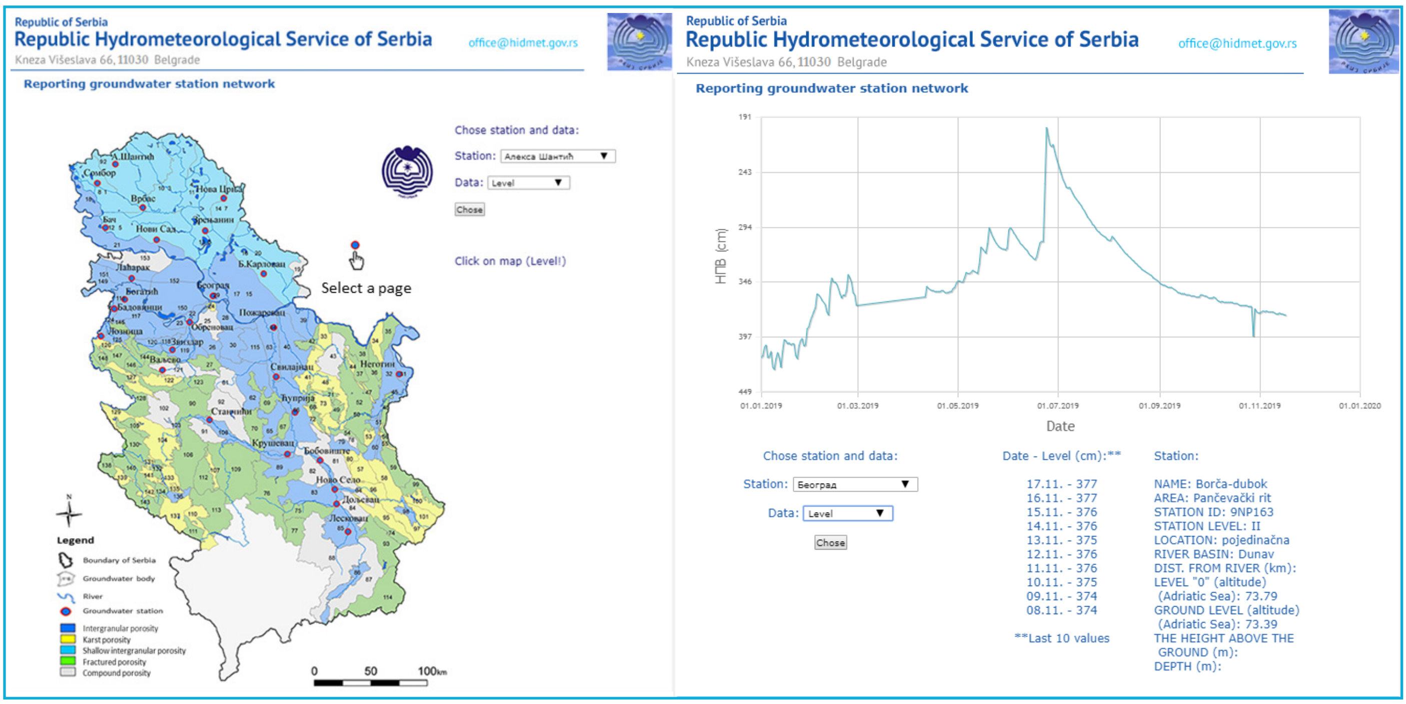


Figure 68 - Groundwater monitoring network in Serbia (left) and groundwater level fluctuation graph of Belgrade station (right). Source: RHMZ

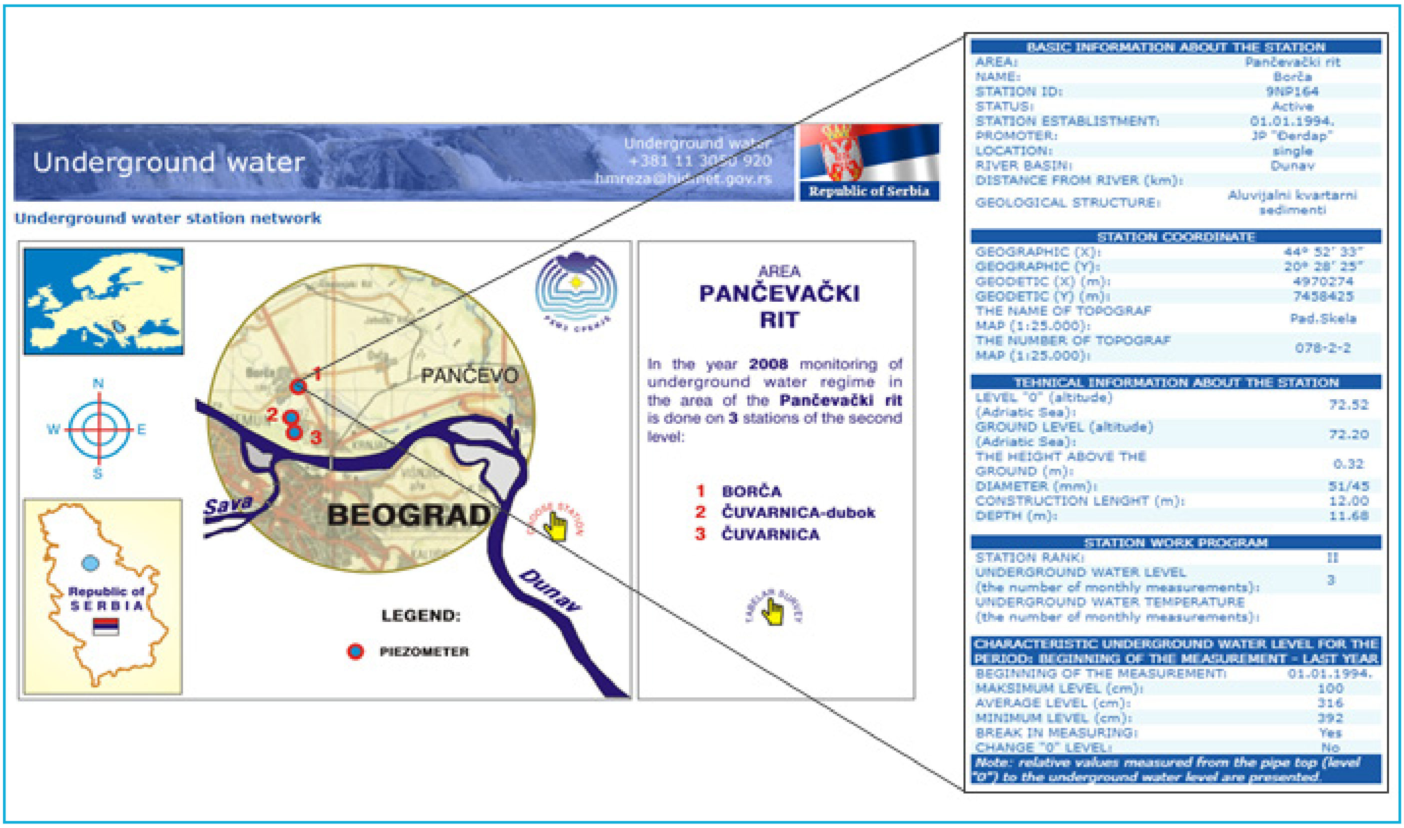


Figure 69 - Interactive station network map with observation points in Belgrade. Source: RHMZ

Sources

- **Republic Hydrometeorological Service of Serbia. Groundwater** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/o_odseku.php;
- **Republic Hydrometeorological Service of Serbia. Groundwater monitoring networks** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/9np.php; and
- **Republic Hydrometeorological Service of Serbia. Groundwater stations and profiles** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/naslovna.php.

Spain

Capital city: Madrid
Inhabitants: 46.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry for Ecological Transition and Demographic Challenge is in charge of groundwater monitoring in Spain. The Ministry executes the Governmental policy on energy and the environment for the transition to a more ecological and social productive model. The objective of the monitoring network was adapted in accordance to the EU Water Framework Directive when hundreds of new piezometers were introduced in every basin for determining chemical status of water bodies.

CHARACTERISTICS OF THE NETWORK

This network includes wells with one or two filters, and artesian wells. The data are measured once a month. In total, there are more than 2,700 piezometers included in the network.

PROCESSING AND DISSEMINATION

The Monitoring Network Information System from the Ministry of Agriculture and Fisheries, Food and Environment and the Ministry for Ecological Transition offers information about the hydrological monitoring in Spain, including the groundwater monitoring network. Since 2011, the management of the network is done by the General Water Authority (DGA).

By selecting a well, metadata (coordinates, elevation well depth and others) and time-series (all historical monthly data) are visualised in the system. This information can also be downloaded (in PDF or Excel files).

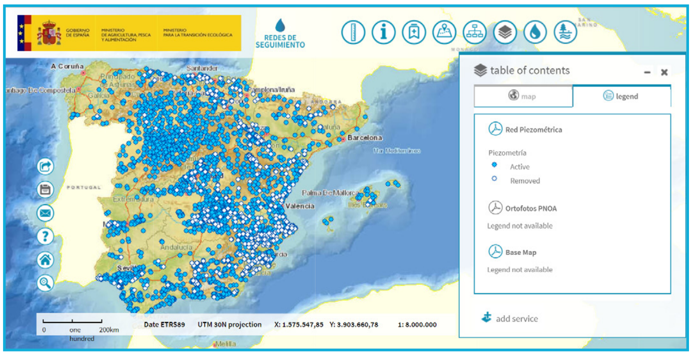


Figure 70 - Groundwater monitoring network of Spain. Source: The Monitoring Network Information System

Sources

- **Control network for the quantitative status of groundwater** - https://www.miteco.gob.es/va/cartografia-y-sig/ide/descargas/agua/red-piezometrica.aspx;
- **Information System of Monitoring Networks and Hydrological Information from MITECO** - http://sig.mapama.es/redes-seguimiento; and
- **Ministry for Ecological Transition and Demographic Challenge (MITECO). Piezometry and volume of groundwater** - https://www.miteco.gob.es/es/estadistica/temas/estadisticas-ambientales/pto3_4_sintesis03_tcm30-123726.pdf.

Sweden

Capital city: Stockholm
Inhabitants: 10.2 Million

INSTITUTIONAL SETTING AND PURPOSE

The Geological Survey of Sweden (SGU) has been commissioned by the Swedish Ministry of Enterprise and Innovation to carry out and manage national monitoring of groundwater.

The network aims to study temporal variation in quantity and composition of groundwater, in relation to geology, topography and climate, for reference purposes, forecasts, environmental control and resource estimations.

CHARACTERISTICS OF THE NETWORK

The groundwater network consists of 600 monitoring stations in some 200 areas (figure 71). Of these, about half date back to c. 1970, whereas the other half was established quite recently (2018-2020). As of today, the monitored levels are recorded automatically, 4-6 times per day, and transmitted to an online database. The historic part of the data set (c. 1970 to 2018) was measured manually at a typical frequency of twice a month.

The Swedish groundwater resources are mainly found in quaternary deposits on top of fractured crystalline bedrock; to reflect the different roles in drinking-water supply, as well as, differences in the dynamics of groundwater-level fluctuation, the resources are divided into two conceptual entities. Glaciofluvial eskers form the major resources, with potential to serve as supplies for municipal water works. In contrast, minor resources are abundant and widespread, but typically limited to supply private wells (drilled boreholes). Although the concept of a minor resource includes several hydrogeological settings, the most typical setting is a thin layer of glacial till (a few meters) on top of sparsely fractured crystalline bedrock.

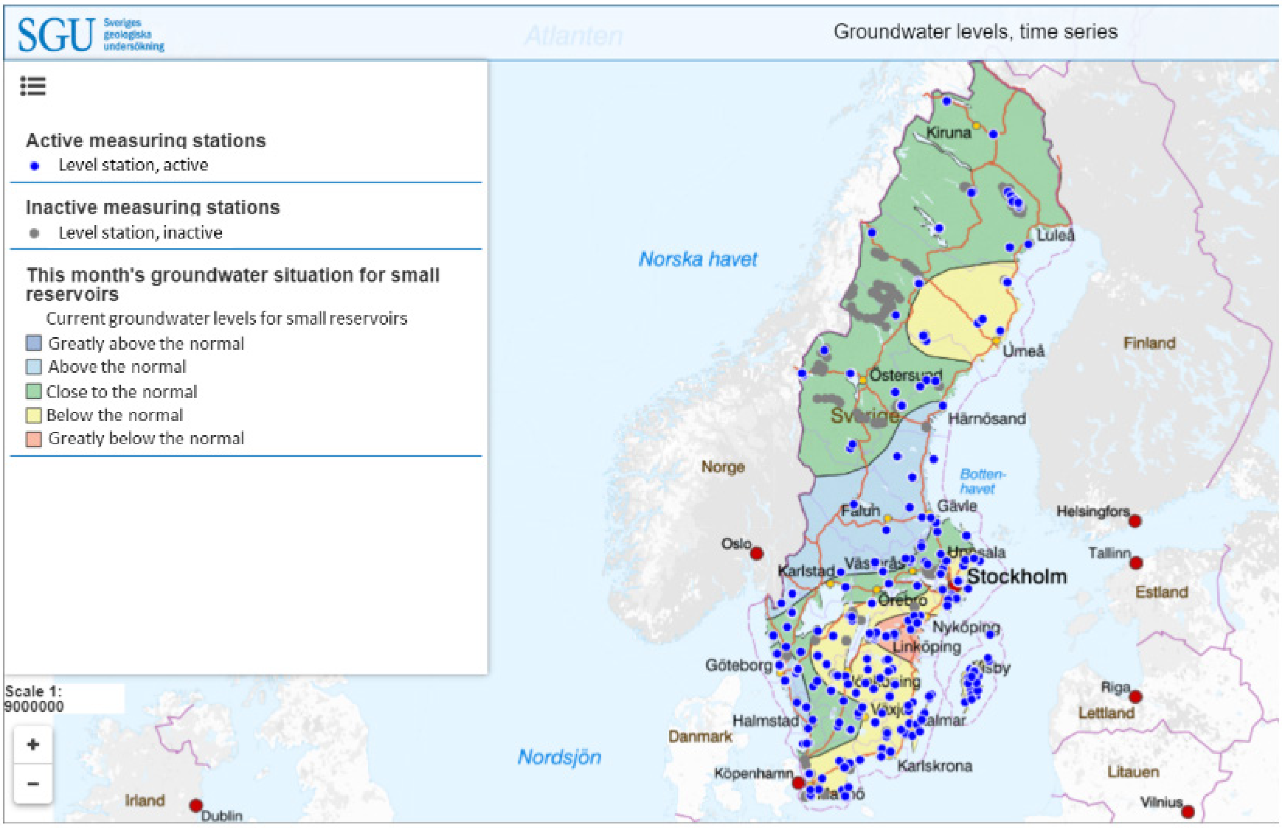


Figure 71 - Groundwater monitoring network in Sweden. Source: SGU

Groundwater data are used to set up a semi-distributed, process-based catchment model (HYPE; Hydrological Predictions for the Environment, developed by SMHI; the Swedish Meteorological and Hydrological Institute). The model is operated at the national scale to provide weekly reports of the prevailing groundwater situation (calculated groundwater level in context of its normal seasonal variation; figure 72). Moreover, the model estimates a range for the expected change in groundwater situation within the next 1 to 6 months, which is based on weather forecasts combined with climatological data.

Measured and simulated groundwater-level time-series are available for all monitoring stations (black line in figure 73) and presented in context of reference statistics (coloured fields in figure 73). The reference statistics is based on long-term monitoring (ranging from 10 to 50 years) and used to interpret groundwater levels in perspective of the past, either with respect to seasonal patterns (figure 73a) or, more simply, just in terms of historic variability.

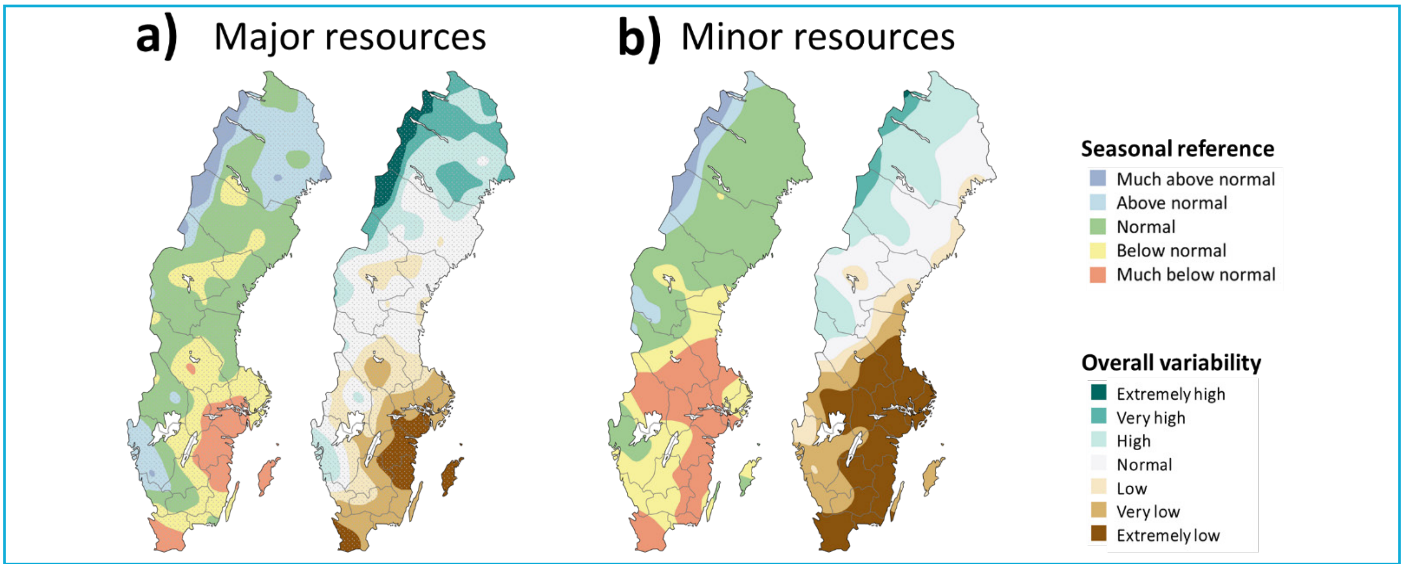


Figure 72 - Groundwater situation in Sweden, October 2020, in: a) major resources (i.e., glacifluvial eskers) and b) minor resources (e.g., thin glacial till on top of fractured crystalline bedrock). Two statistical references are employed: groundwater situation in context of seasonal variation and in terms of overall variability. Source: SGU

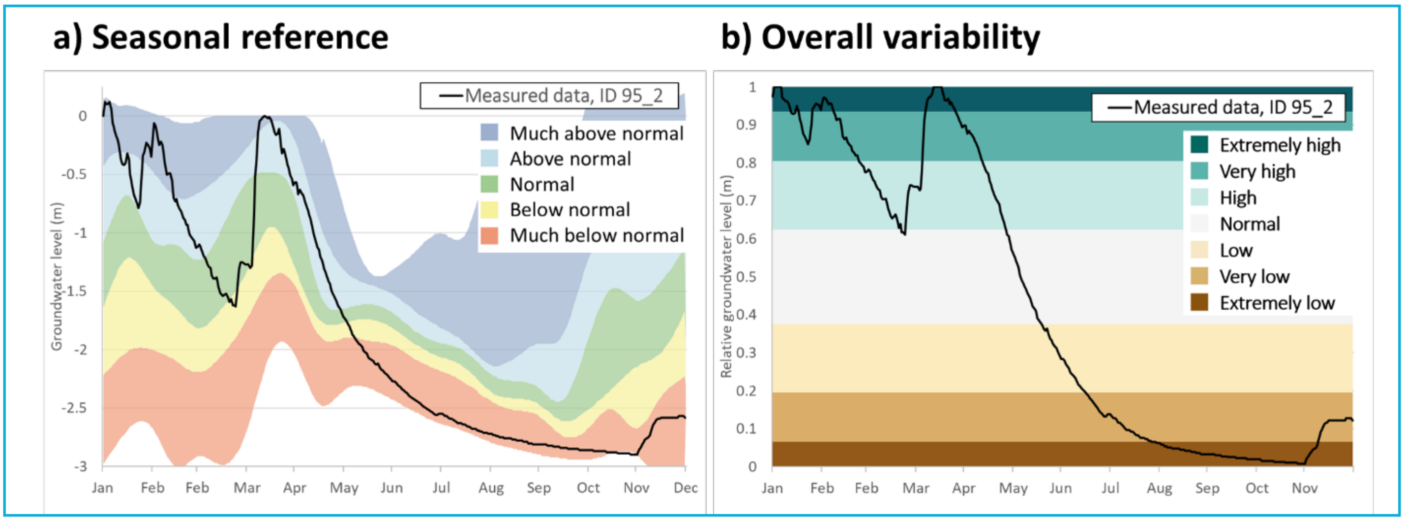


Figure 73 - Groundwater time-series (2018) for monitoring station 95_2; in context of a) seasonal variation and b) in terms of overall variability. Source: SGU

Sources

- **Feedback from SGU** - received on 13-10-2020;
- **SGU. General information on the SGU monitoring program and concepts used** - https://apps.sgu.se/grundvattennivaer/;
- **SGU. Current groundwater levels** - https://apps.sgu.se/grundvattennivaer/aktuella-grundvattennivaer.html;
- **SGU. Groundwater levels (map application)** - https://apps.sgu.se/kartvisare/kartvisare-grundvattenniva.html; and
- **SGU. Environmental monitoring of groundwater** - https://www.sgu.se/grundvatten/miljoovervakning-av-grundvatten/.

Switzerland

Capital city: Bern
Inhabitants: 8.6 Million

INSTITUTIONAL SETTING AND PURPOSE

More than 80% of Switzerland's drinking water derives from groundwater. The Federal Act on the Protection of Waters (Art. 57) requires the Swiss Confederation to carry out surveys of hydrological conditions with relevance to Switzerland as a whole. The National Groundwater Monitoring (NAQUA) programme is responsible for the monitoring of quality and quantity of groundwater resources nationwide. NAQUA is conducted by the Federal Office for the Environment (FOEN), in close collaboration with the cantonal authorities.

The purpose of NAQUA is manifold:

- to document the status and the trends in groundwater quantity and quality on a national level;
- identify the occurrence of problematic substances at an early stage and to systematically follow up any undesirable developments;
- check the effectiveness of protective measures already adopted (e.g. ecological measures in agriculture) and identify the need for further measures; and
- to characterise and classify the most important groundwater resources in Switzerland.

CHARACTERISTICS OF THE NETWORK

In total, 545 sites are available for groundwater quality monitoring and 91 sites for groundwater quantity monitoring. The quantity of groundwater is measured in springs, piezometers and extraction wells of the NAQUA programme's QUANT module (quantity monitoring). Half of the sites are operated by the federal administration and half by the cantons or water supply companies. Most monitoring sites are equipped for remote data transmission. Only few cantonal monitoring sites upload the data regularly, hence monitored data are only available with delay. 30 monitoring sites of the QUANT module are also part of the TREND module and 17 are part of the SPEZ module, both modules monitor groundwater quality.

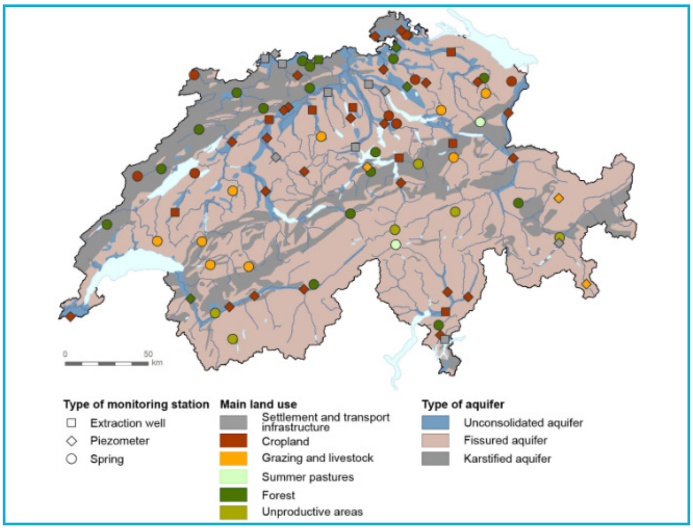
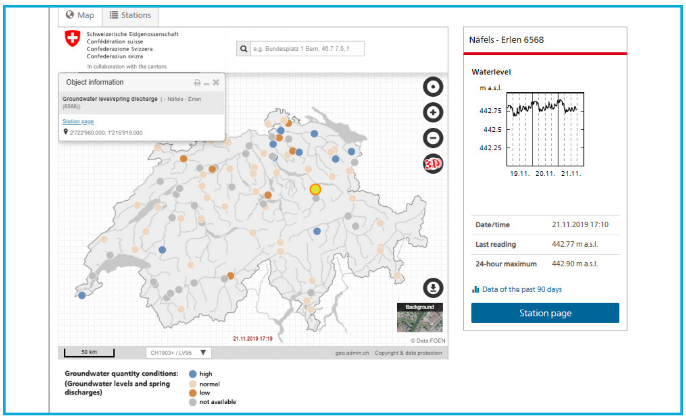


Figure 74 - QUANT module sites for monitoring groundwater quantity (2019 status). Source: NAQUA National Groundwater Monitoring

PROCESSING AND DISSEMINATION



The platform "hydrodaten.admin.ch" gives an overview of the current groundwater situation in Switzerland in stations that are equipped with remote data transmission, figure 75. Changes of the current groundwater levels and spring discharges are presented on a map and in a hydrograph; the values are compared with the expected conditions. The data are shown as below, above or equal to the long-term average for each month. The calculation is based on percentiles of the dataset for the full monitoring period (basic data in masl and l/min or m3/s). Lower

Figure 75 - Groundwater situation map as of 21.11.2019. Source: NAQUA National Groundwater Monitoring

groundwater level or spring discharge than the average conditions are reached if the current value is below the long-term 10% percentile, for example it is among the lowest 10% of all the data ever measured for the relevant month. A groundwater level or spring discharge between the 10% and 90% percentiles means that conditions are normal. If the current value is above the 90% percentile, a higher than the long-term average condition is reached, fgure 76.

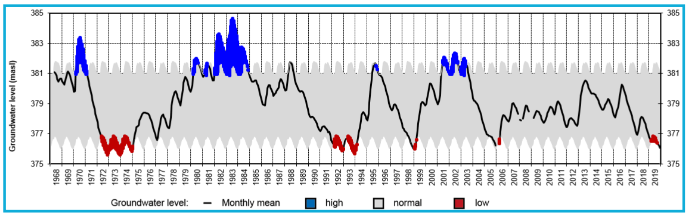


Figure 76 - Monitoring site with high, normal, and low groundwater level

The collected data from NAQUA are used in national and international reporting. Historical data for the individual monitoring sites can also be accessed on "hydrodaten.admin.ch". The relevant datasheets contain the daily averages for each year and the long-term mean groundwater levels and spring discharges. A Groundwater Bulletin is also available on the website of FOEN in French and German. It provides textual information on the state and changes of groundwater levels and spring discharge, figure 77.

The indicator "Groundwater levels and spring discharge rates" provides a national overview of the frequency of low, normal and high groundwater conditions year on year, figure785.

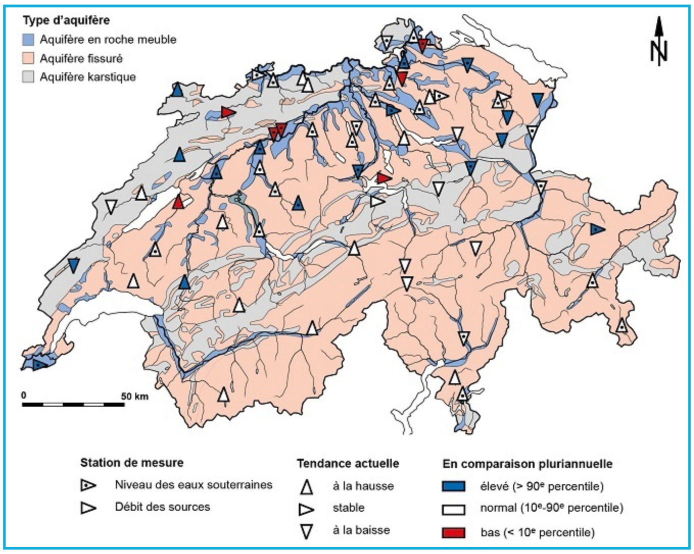


Figure 77 - Groundwater levels and spring discharge (status as of November 5, 2019) current trend and multi-year comparison. Source: NAQUA National Groundwater Monitoring

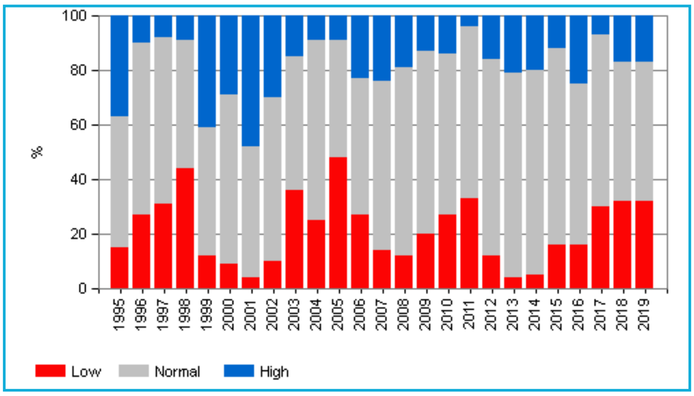


Figure 78 - Indicator Groundwater levels and spring discharge rates. Percentage of monitoring stations at which low, normal and high groundwater levels or spring discharge rates were recorded in each year. Source: NAQUA National Groundwater Monitoring

Sources

- **Feedback from the Federal Office for the Environment (FOEN)** - received on 05-10-2020;
- **Federal Office for the Environmental (FOEN). NAQUA National Groundwater Monitoring** - https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/naqua-national-groundwater-monitoring.html;
- **FOEN. Groundwater bulletin (available in German and French)** - https://www.hydrodaten.admin.ch/en/groundwater-bulletin.html;
- **FOEN. Groundwater quantity** - https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/groundwater-quantity.html;
- **FOEN. QUANT module** - https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/naqua-national-groundwater-monitoring/quant-module.html; and
- **FOEN. Indicator groundwater levels and spring discharge rates** - https://www.bafu.admin.ch/bafu/en/home/themen/thema-wasser/wasser--daten--indikatoren-und-karten/wasser--indikatoren/indikator-wasser.pt.html/aHR0cHM6Ly93d3cuaW5kaWthdG9yZW4uYWRtaW4uY2gvUHVibG/ljL0FlbURldGFpbD9pbmQ9V1MwNTYmbG5nPWVuJlN1Ymo9Tg%3d%3d.html.

United Kingdom

Capital city: London
Inhabitants: 66.7 Million

INSTITUTIONAL SETTING AND PURPOSE

The regulatory environment agencies are responsible for managing and protecting groundwater in the UK. As the UK comprises for devolved nations, each has an agency: Environment Agency (England), Scottish Environment Protection Agency (SEPA), Natural Resourced Wales (NRW) and Northern Ireland Environment Agency (NIEA).

Groundwater monitoring is one of the statutory activities carried out by the agencies to comply with the EU Water Framework Directive (WFD), EU Groundwater Directive (GD) and EU Nitrates Directive (ND) and UK legislation relating to water resource management and protection, e.g. status and trend assessment for the WFD and GD, nitrate vulnerable zone delineation (ND) and abstraction licencing .

In particular, the British Geological Survey (BGS) has a role to collate data for a sub-set of sites that are part of the environment agencies water level monitoring network. These data are used as is described in the following sections, for instance, to produce the Hydrological Summary (see below).

CHARACTERISTICS OF THE NETWORK

The groundwater monitoring network is comprised by 181 sites, from which 166 are in England, 3 in Northern Ireland and 1 in Scotland, figure 79. Data from 28 stations chosen as index wells are compiled every month to provide continually updated regional trends and variations in groundwater resources, in the Hydrological Summary for the UK.

Groundwater levels are measured manually using a dipper, or automatically using a pressure transducer. Automatic readings are either stored in a data logger (the site is visited periodically to retrieve the measurements) or sent automatically over the phone network to a database through telemetry.

It is important to notice that the monitoring networks operated by the national agencies comprise many more monitoring sites than are used for the Hydrological Summary. For instance, there are around 3500 groundwater quality (chemical) monitoring sites, possibly double this number for groundwater level.

Figure 79 - Groundwater situation map as of 21.11.2019. Source: NAQUA National Groundwater Monitoring

PROCESSING AND DISSEMINATION

This section focuses only in the processing and dissemination of data by BGS, although is it noteworthy that each national agency process and disseminate data and information from their own managed groundwater monitoring networks as well.

BGS hosts the National Groundwater Level Archive. It is the national repository for groundwater level data, and it also collects groundwater level data from their research projects.

The WellMaster database is another data storage (in addition to the National Groundwater Level Archive), where currently water level data from 60,000 boreholes are available. These data come from logs of boreholes drilled for water supply, and most of them are a single historical reading of the water level after drilling or when the borehole was surveyed.

The Hydrological Summary is produced monthly by the National Hydrological Monitoring Programme. The Programme is a collaboration between the Centre for Ecology and Hydrology (CEH) and the British Geological Survey (BGS). The Hydrological Summary includes information from rainfall, river flows, reservoirs and groundwater.

The data used for the Hydrological Summary are a small sub-set of the Environment Agency's monitoring network. The sub-set is the collection of data that is operated for water resource management purposes including EU Water Framework Directive status assessment and River Basin Management Plans (RBMP) reporting. Of the index boreholes on the BGS map, some of these are telemetered (all Environment Agency boreholes) and the data can be obtained directly by API, while others are dipped manually.

Normalisation methods are applied to display data in the Hydrological Summary. A spot map is created based on the end of month levels, figure 80.

For a given month, all measurements of that month in the period of record of each borehole are ranked. The map displays the rank of the current month with respect to all historical measurements of that month, figure 80. Then, the point is coloured according to the rank's ratio (total number of month/rank of current months), in seven possible categories, table below.

Category	Ratio
Exceptionally high levels	0.950000 – 1.100000
Notably high levels	0.870000 – 0.949999
Above normal	0.720000 – 0.869999
Normal range	0.280002 – 0.719999
Below normal	0.130002 – 0.280001
Notably low levels	0.050002 – 0.130001
Exceptionally low levels	0.000000 – 0.050001

Figure 80 - Categories applied to ratio of the rank

When a new high or low level is established for a given month/period, the spot is circled with arrows.

ArcMap documents and output image/PDF files are produced from spreadsheet files containing level ranking and ratios using a Python script.

Groundwater monitoring stations are used in the analysis only if they have high hydrometric data quality and long records of at least 30 years. The data collected for monitoring is used for modelling. Their objective is to simulate fluctuations in ground-

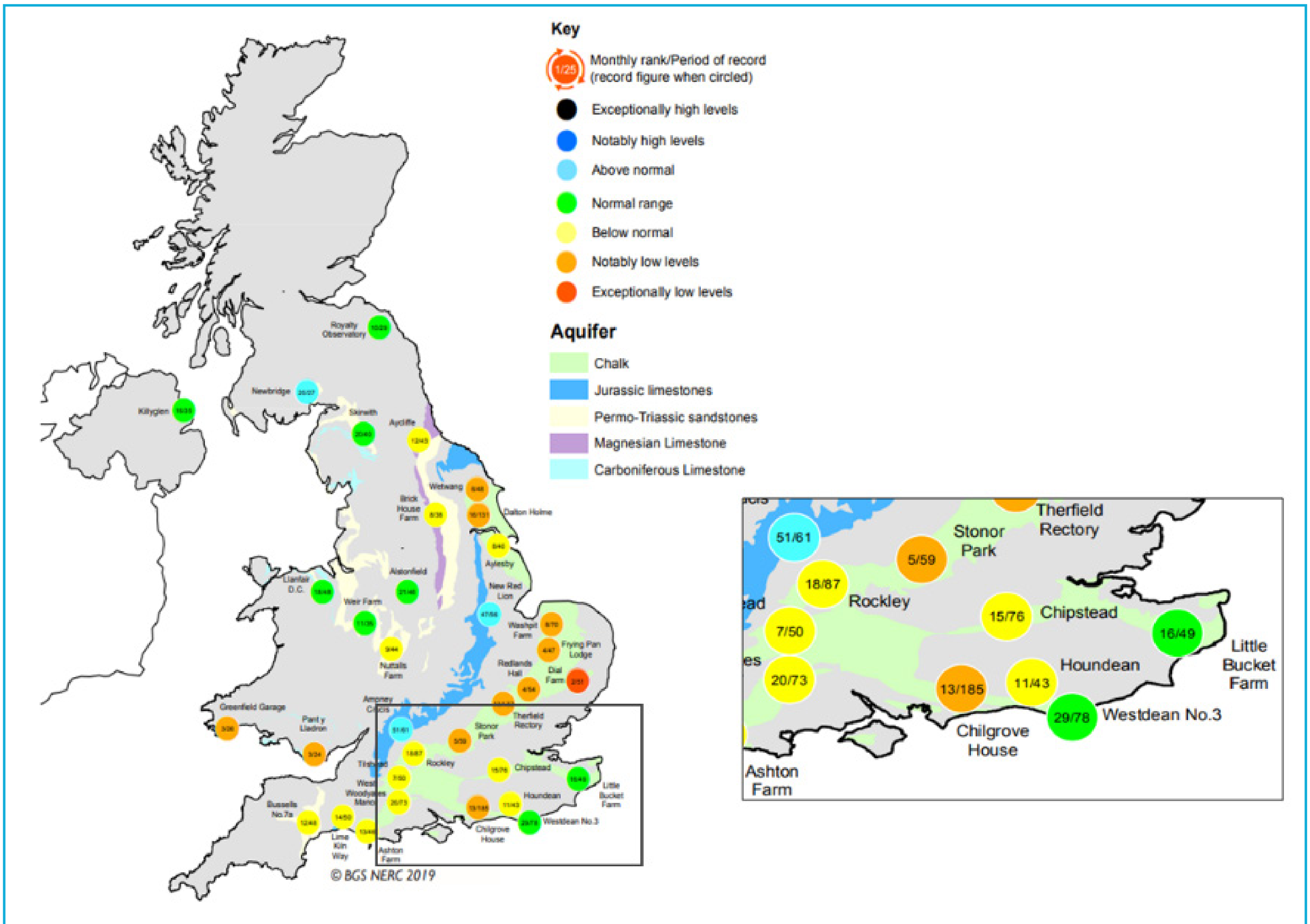


Figure 81 - Spot map for Groundwater levels July 2019 in the UK (left) and zoomed view with boreholes ranking (right). Source: BGS 2019

water level at 25 sites across the UK to forecast groundwater levels. Each of these models is driven by rainfall and evaporation time-series and has been calibrated against past observations of groundwater level. To forecast the change in groundwater level at a site over the coming one and three months, BGS uses 1 and 3-month ahead climate forecasts produced by a Met Office climate probabilistic model. Each of these two climate forecasts consists of an ensemble of up to 42 members and each member provides a projection of rainfall and temperature into the future. Each member of the two climate forecast ensembles is run through each groundwater model. Thus, a probabilistic groundwater level forecast is produced for each site.

BGS produces forecasts at sites located in most of the principal aquifers of the UK where groundwater abstraction has significantly modified the observed groundwater level, and a hydrograph have not been modelled yet.

Figure 82 - Fresh spring water at St Ann's Well, Buxton, by: Tom Parnell

Sources

- **British Geological Survey. Groundwater level information** - https://www.bgs.ac.uk/research/groundwater/datainfo/levels/home.html;
- **British Geological Survey. National Groundwater Level Archive** - https://www.bgs.ac.uk/research/groundwater/datainfo/levels/ngla.html;
- **Feedback from British Geological Survey** - received on 28-09-2020;
- **UK Centre for Ecology & Hydrology. Hydrological Outlook UK – Groundwater** - http://www.hydoutuk.net/methods/groundwater;
- **UK CEH Water Resources Portal** - https://eip.ceh.ac.uk/hydrology/water-resources/;
- **UK Centre for Ecology & Hydrology. National River Flow Archive** - https://nrfa.ceh.ac.uk/monthly-hydrological-summary-uk; and
- **World Meteorological Organization. Information provided internally through HydroSOS Project** - https://www.wmo.int/pages/prog/hwrp/chy/hydrosos/index.php.

NATIONAL GROUNDWATER MONITORING PROGRAMMES

A GLOBAL OVERVIEW OF QUANTITATIVE GROUNDWATER MONITORING NETWORKS

Groundwater is a vital natural resource, being increasingly under pressure of climate change and human activities. We need to monitor the invisible groundwater in order to use and protect it properly.

This document provides an overview of quantitative groundwater monitoring networks at national scale. It is prepared to encourage sharing of monitoring experience, assist in improvement of monitoring and data processing and increase awareness of a general lack of groundwater monitoring.

The full report, including analyses and country profiles of other regions is available on the IGRAC website:

www.un-igrac.org/global-monitoring-overview

igrac
International Groundwater Resources Assessment Centre