International Groundwater Resources Assessment Centre

WMO

NATIONAL GROUNDWATER MONITORING PROGRAMMES

THE AMERICAS

Argentina

Capital city: Buenos Aires
Inhabitants: 44 Million

INSTITUTIONAL SETTING AND PURPOSE

Water resources in Argentina are owned by the Provinces, but the National Hydrological Network (RHN), belonging to the Federal State, has its own hydrometric, surface water quality, limnometric and meteorological stations.

The main objective of the RHN is to provide data on water resources, status and trends in the medium- and long-term for the planning of water policies at the federal level, and to contribute to the integrated water resources management at the scale of transboundary basins.

RHN is in the process of installing its first piezometric stations, prioritizing transboundary basins. In addition, the RHN continues its tasks of incorporating and integrating into the information system the provincial stations of basin organizations (ACUMAR, COREBE, AIC, COIRCO, CIC-Plata, etc.), of research institutes (INA, INTA, IHLLA) and municipal early alert and other independent networks (e.g. Red Mate). At the moment there is no national groundwater monitoring network, but some local networks exist.

CHARACTERISTICS OF THE NETWORK

The monitoring networks of the basin and municipal organizations (early alert) usually collect data on groundwater quantity (levels) and quality. The RHN, for its future hydrogeological stations, plans to make measurements of quantity (level) and quality (conductivity, pH and temperature) with seasonal regularity.

There are manual, automatic and/or telemetric stations depending on the objective of the monitoring.

PROCESSING AND DISSEMINATION

Data from the basin organizations are available on their web pages. By national law, information produced with state funds at any level is public and must be accessible to all citizens, as long as it does not compromise the national security.

The Integrated Hydrological Database (BDH) portal contains time series of all the stations that it installs, maintains and operates. At the moment groundwater monitoring stations are not included in the website.

Dat.ar is the unofficial repository of open public data of Argentina; it contains information on about 5500 SIFAS (Federal Groundwater Information System) wells (update until 2015). Data from these wells can be downloaded, including name, type, coordinates and owner.

The georeferenced overview of wells used to be available through the SIFAS portal of the Ministry of the Interior, updated until 2015. At present, it is not possible to access the website.

EXAMPLE OF LOCAL NETWORK: BDH-AZUL

BDH-Azul is the Hydrological Database of the Azul basin, which depends on the Institute of Plains Hydrology “Dr Eduardo Jorge Usunoff” (IHLLA). The IHLLA has a wide monitoring network of meteorological parameters, surface water and groundwater throughout the basin. Some of them are also linked to the flood early warning system of Azul. This information is available for users since 2002 on a hydrological information management web portal.

On the BDH-Azul web portal (figure below) the georeferenced position of 149 wells is visualised and related data and metadata can be downloaded, such as coordinates of the wells and groundwater level time-series. Around half of these wells have been flagged as “exploitation” type, and the other half as “other”. The frequency of data collection is irregular, ranging from approximately 4 times a year to twice a month.

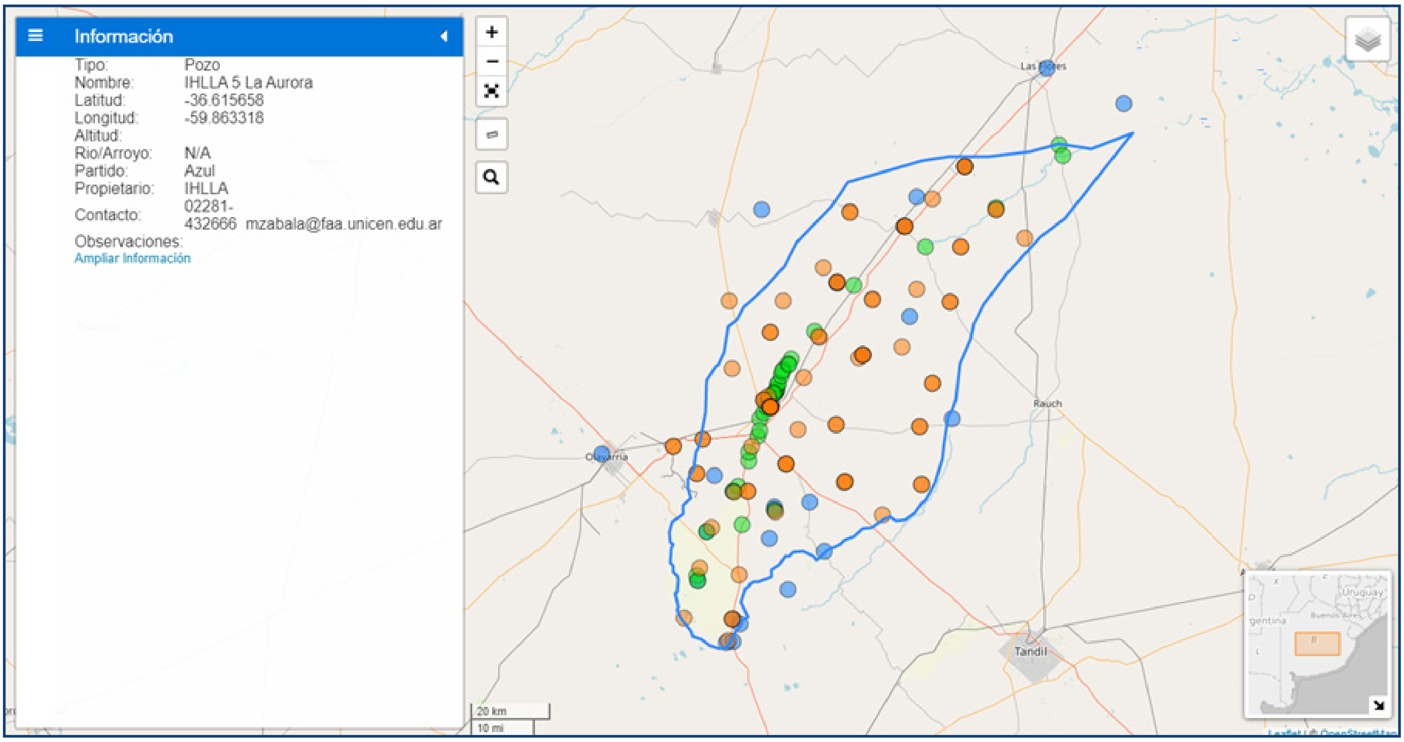


Figure 1 – BDH-Azul web portal

Figure 2 – Dry landscape of Cordoba, Argentina, by: Richard

Sources

- **BDH-Azul web portal** - http://www.azul.bdh.org.ar;
- **CeReGAS (Regional Centre for Groundwater Management in Latin America and the Caribbean)** - personal communication, 2019;
- **Feedback from IHLLA** - received on 28 February 2020;
- **Feedback from National Secretariat of Infrastructure and Water Policy - SIPH (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Integrated Hydrological Database of Argentina (BHD)** - http://bdhi.hidricosargentina.gob.ar;
- **National Water Institute (INA)** - email exchange, 2020;
- **SIFAS portal** - http://sisag.mininterior.gob.ar/SIFAS/ (no longer available); and
- **Unofficial repository of open public data of Argentina, Dat.ar** - http://datar.noip.me/dataset/pozos-sifas.

Bolivia

Capital city: Sucre
Inhabitants: 11 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Water (MMAyA) is in charge of water resources management in Bolivia and has three underministries being responsible for different fields. The Underministry of Water Resources and Irrigation contributes to the development and execution of plans, policies in Integrated Management of Watersheds and Irrigation, and designs strategies for the conservation and use of surface and groundwater. For instance, this underministry participates and coordinates the management of the Yrenda-Toba Tarijeño aquifer system within the framework of the Inter-American Committee of the Plata Basin with the Binational Commission together with Argentina, Paraguay and UVSMA/OAS and ISARM Americas.

There is no national groundwater monitoring programme in Bolivia but several local groundwater monitoring networks in place. For example, the groundwater monitoring network in the Katari River Basin and in the Yacuiba municipality.

CHARACTERISTICS OF THE NETWORK

1. Groundwater monitoring network in the Katari River basin

MMAyA is in charge of the Master Plan for the Katari River basin since 2010. Two aquifers are located in this area: the Purapurani and the Viacha aquifers (figure 3). They are being monitored since 2016 under the Purapurani and Viacha Aquifers Preliminary Management Plan (2016) with the objective to evaluate the spatial and temporal variation of the aquifer regime during the rainy and dry seasons and to assess the groundwater quality.

The monitoring of groundwater levels is carried out monthly and manually in 30 locations. Measurements are mostly carried out manually, but some wells are equipped with automatic sensors.

The data are used for calibration of the numerical flow model developed for this aquifer.

Data processing is done via statistical analysis and spatial interpolations.

2. Groundwater monitoring network from the Drinking Water and Sanitary Sewer Services Providers

According to the Bolivian Standard 512 (NB 512) on drinking water the Drinking Water and Sanitary Sewer Services Providers (EPSAs) must take water samples from wells twice a year. The EPSA of the Yacuiba municipality, in the Tarija department, has 28 wells. Measurements of groundwater levels are taken there manually once a month (static and dynamic levels), together with groundwater flow and energy consumption.

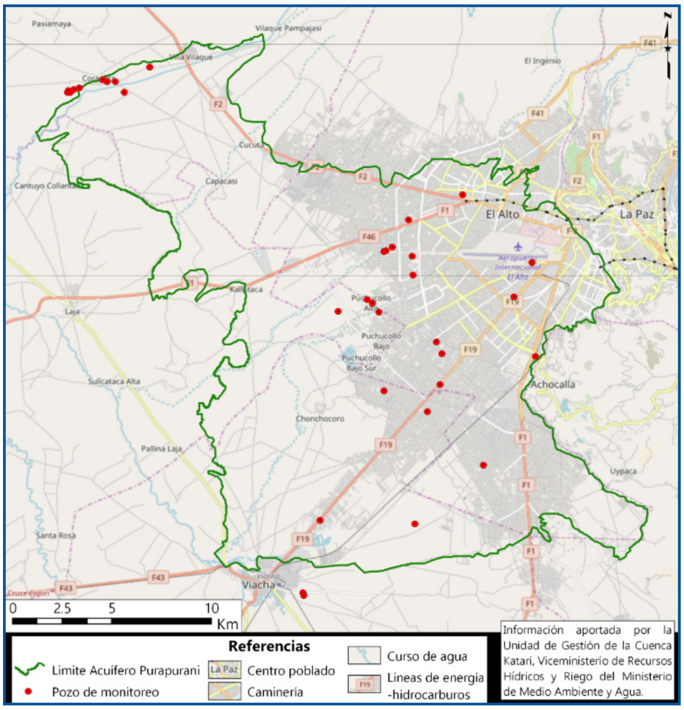


Figure 3 – Location of monitoring points in the Purapurani Aquifer. Source: Katari Basin Management Unit, Underministry of Water Resources and Irrigation of the Ministry of Environment and Water.

PROCESSING AND DISSEMINATION

Groundwater data collected under the Master Plan for the Katari River basin is accessible only for governmental organisations. Data collected by the EPSA of the Yacuiba municipality are available by request (at the municipality).

Additionally, two country-wide information systems contain metadata of wells and various hydrogeological information: SIHIBO and SIASBO.

The Mining and Geological Service (SERGEOMIN) of Bolivia launched the Hydrogeological Information System of Bolivia (SIHIBO) in 2016 (figure 4). SIHIBO contains information on 3000 water wells drilled by SERGEOMIN for more than 40 years. Among the data included per well are: lithological, geological, geophysical and geochemical data, water analysis and monitoring, as well as other socioeconomic variables.

The Ministry of Environment and Water hosts the Bolivian Groundwater Information System (SIASBO), a web platform where locations of wells (updated until 2016) can be visualised along with downloadable metadata.

Neither SIHIBO or SIASBO store groundwater level data so far.

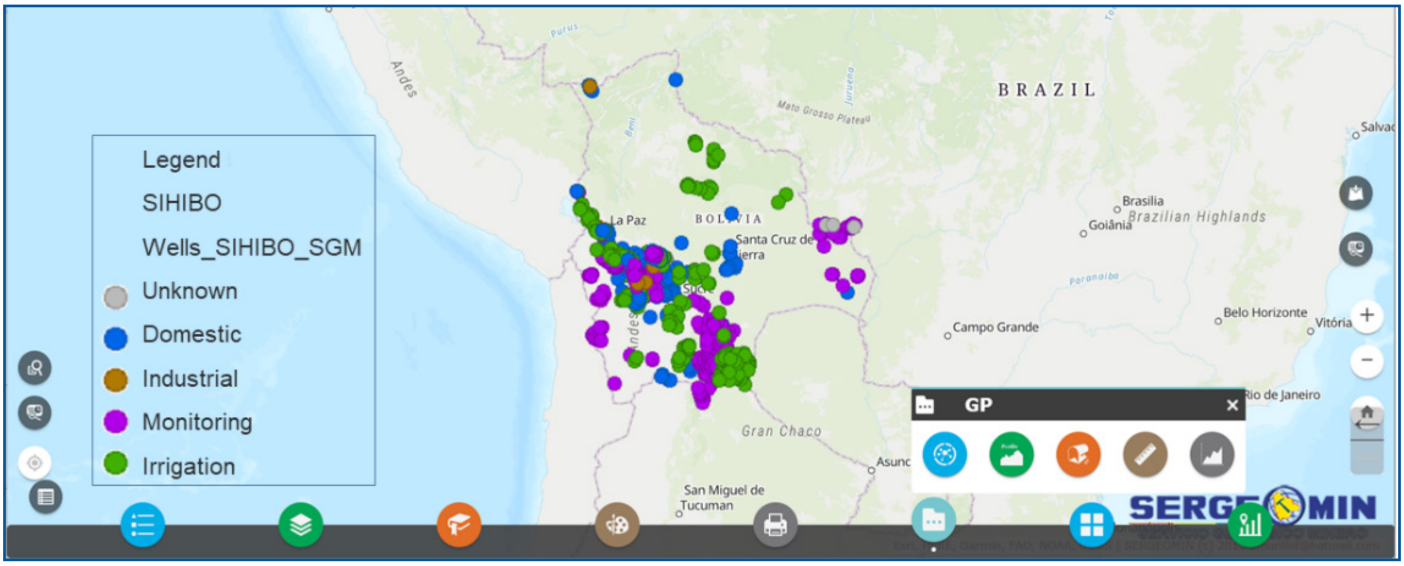


Figure 4 – SIHIBO

Sources

- **Feedback from German Cooperation PERIAGUA-GIZ (answer to form)** - received in 2018;
- **Feedback from MMAyA (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Vice Ministries -** https://www.mmaya.gob.bo/viceministerios/viceministerio-de-recursos-hidricos-y-riego/atribuciones;
- **SIHIBO -** http://ide.sergeomin.gob.bo/wsihibo;
- **SIASBO -** http://geosirh.riegobolivia.org/layers/geosirh:pozos_siasbo_1 (currently not available); and
- **Ward Quaghebeur, Riley E. Mulhern, Silke Ronsse, Sara Heylen, Hester Blommaert, Sid Potemans, Carla Valdivia Mendizábal, Jhonny Terrazas García, 2009. Arsenic contamination in rainwater harvesting tanks around Lake Poopó in Oruro, Bolivia: An unrecognized health risk -** https://doi.org/10.1016/j.scitotenv.2019.06.126.

Brazil

Capital city: Brasília
Inhabitants: 209 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Agency (ANA) is in charge of Planning, Monitoring and Management Support of Water Resources, providing information on water resources to other governmental water managing bodies and entities at the federal and the federal states level. The Agency is legally responsible for implementing the National Water Resources System (SINGREH), which is a combination of legal and administrative mechanisms established by the Water Law (1997). Its aim is to coordinate integrated water resources management and implement the National Policy of Water Resources. However, the Geological Service of Brazil (CPRM or SGB) is the institution that manages the Integrated Groundwater Monitoring Network (RIMAS), the national groundwater network of Brazil.

CPRM is responsible for planning and implementation of monitoring activities; data collection and maintenance of monitoring wells, as well as for data consistency and data dissemination through the national well database. The States are responsible for licensing groundwater use.

Data are collected with the objective of expanding hydrogeological knowledge, developing specific research and supporting the management of water resources.

CHARACTERISTICS OF THE NETWORK

RIMAS is comprised of approximately 400 monitoring wells located throughout the country. The collection of automatically recorded groundwater levels is done three to four times per year.

Selection of locations and equipment for monitoring wells was made by the CPRM and external consultants from universities, environmental agencies, and other organisations. New wells are constantly added to RIMAS to improve the spatial distribution of monitoring. The process for choosing monitoring locations, is done with the criteria on aquifers prioritization, namely:

1. Sedimentary aquifers;
2. Water of socio-economic importance;
3. Use of water for public supply;
4. Aspects of natural vulnerability and risks;
5. Spatial representativeness of the aquifer; and
6. Existence of monitoring wells.

Figure 5 – Foz do Iguaçu, water falls connected to Paraná river and thereby Guaraní aquifer, by: S. Siepman

PROCESSING AND DISSEMINATION

Data and reports can be visualized and downloaded from the RIMAS web platform. The CPRM is also responsible for the Groundwater Information System (SIAGAS), a national information system created to support groundwater management in the country. The SIAGAS is composed of a monitoring well database and modules for consultation, information extraction and report generation. The database is constantly updated and can be combined with other systems. At this moment, the SIAGAS has a total of 321,621 registered wells.

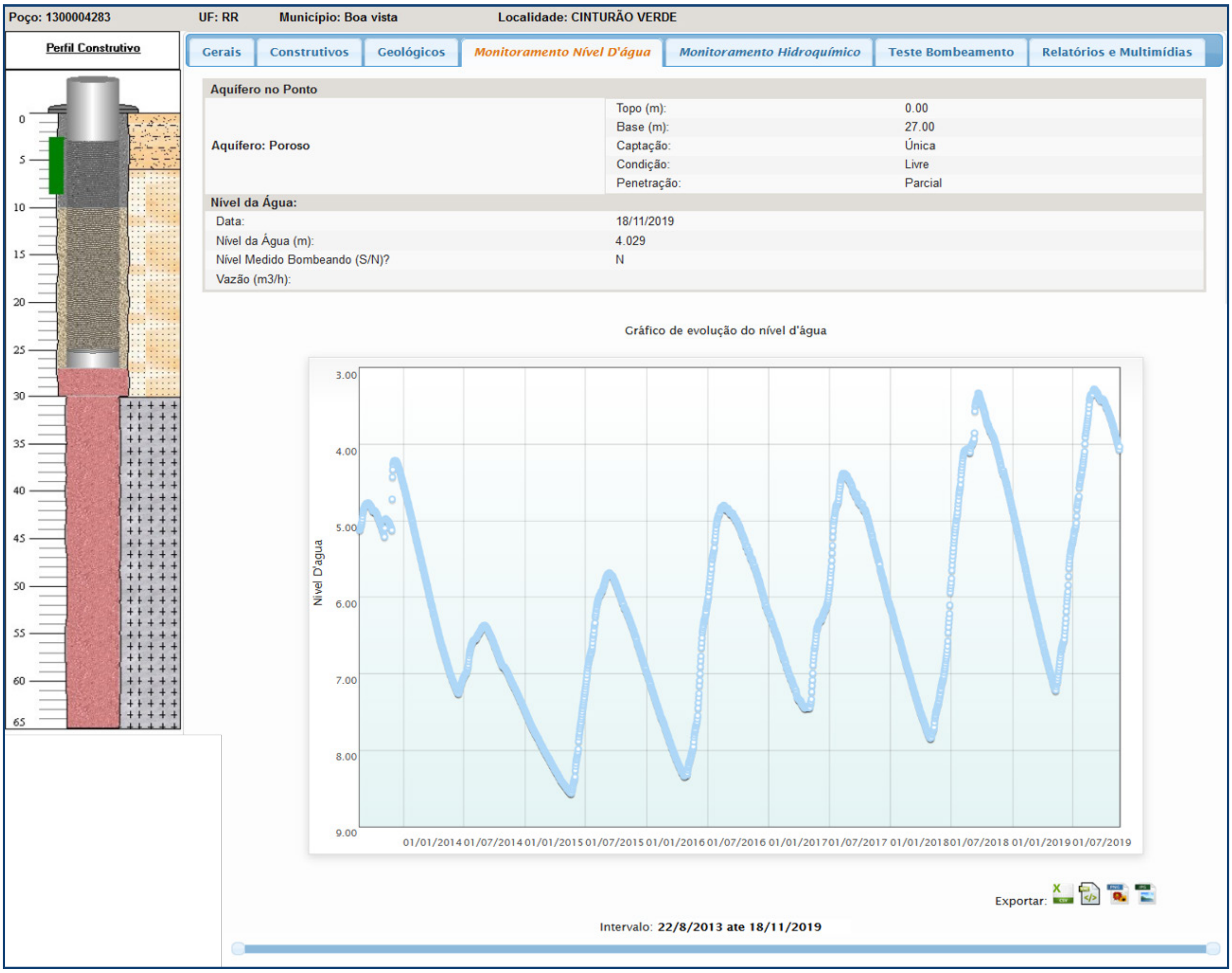


Figure 6 – Integrated Groundwater Monitoring Network

Sources

- **Integrated Groundwater Monitoring Network (RIMAS)** - http://rimasweb.cprm.gov.br/layout/apresentacao.php;
- **Groundwater Information System (SIAGAS)** - http://siagasweb.cprm.gov.br/layout/apresentacao.php;
- **Agência Nacional De Águas (ANA)** - https://www.ana.gov.br; and
- **Feedback from CPRM** - received of 17-03-2020.

Canada

Capital city: Ottowa
Inhabitants: 37 Million

INSTITUTIONAL SETTING AND PURPOSE

Under the Canadian constitution, responsibility for natural resources is shared by all levels of government, including federal, provincial, territorial, municipal, and indigenous.

Groundwater monitoring is carried out in a decentralized manner. Most Canadian provinces and territories have an active groundwater monitoring network, or “observation well network”, that integrates local and municipal networks. The objective of these networks is to monitor seasonal and annual long-term fluctuations. Many wells are located in important aquifers where stresses caused by anthropogenic groundwater extraction and/or climatic variations are monitored. This provides valuable insight on the magnitude of groundwater recharge and aquifer depletion.

The monitoring networks also play an important role in assessing aquifer sustainability, especially when limited data on actual groundwater use are available in parts of Canada.

CHARACTERISTICS OF THE NETWORK

The number of wells in provincial and territorial monitoring networks ranges widely, from tens to many hundreds. The Groundwater Information Network (GIN) then integrates much of this data into a single national network.

PROCESSING AND DISSEMINATION

GIN is a data network and web portal dedicated to the improvement of knowledge about groundwater systems by increasing access to groundwater information. Water well and water monitoring data, to name a few, are collected from provincial and territorial collaborators such as British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Nova Scotia, Newfoundland and Labrador, and Yukon. The GIN web portal allows users to view, download and query groundwater information online (Figure 1). Several types of groundwater information can be requested in formats such as GWML (Groundwater Markup Language), Excel, Google Earth, ESRI Geodatabase, ESRI shapefile and PDF.

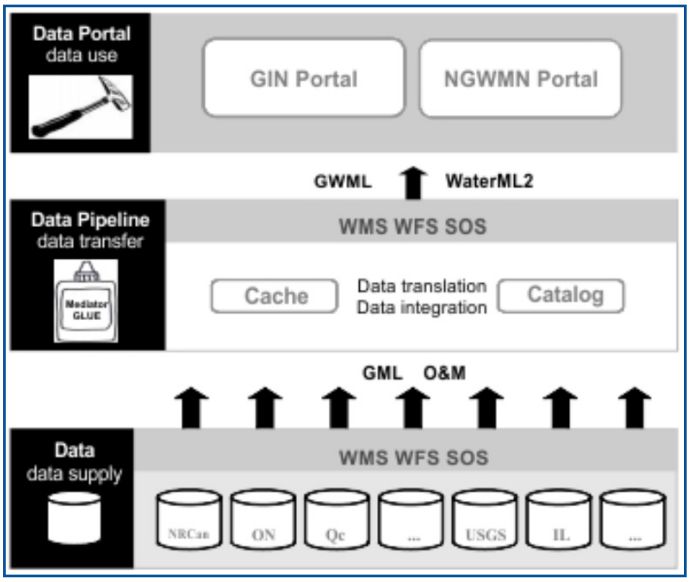


Figure 7 – GIN Portal pre-processing

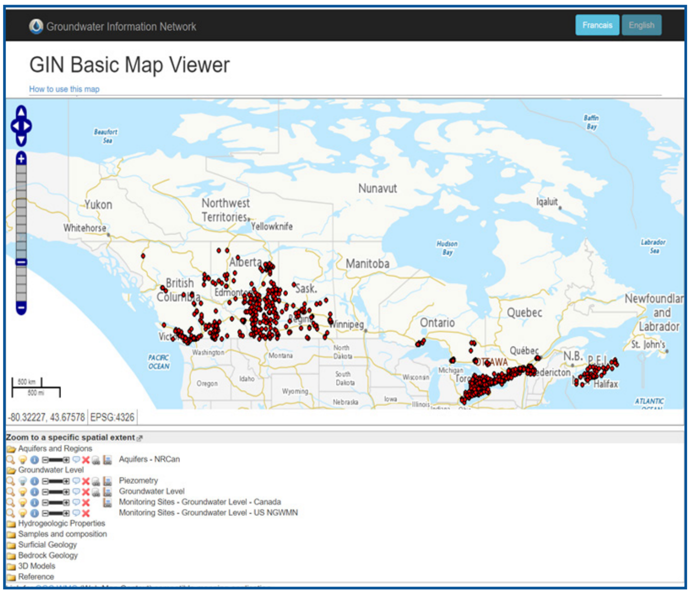


Figure 8 – Groundwater monitoring sites of Canada. Source: GIN

Monthly values of groundwater levels, related statistics, location and borehole characteristics are presented in the portal for each monitoring station (figure 9), where available.

NRCan (Natural Resources Canada) also worked closely with the U.S. Geological Survey (USGS) and the international community to develop the WaterML2 data standards and best practices, including GroundwaterWML2 (https://www.ogc.org/standards/waterml; Brodaric et al. 2018). Combined with the adoption of other data access standards and technologies from the Open Geospatial Consortium, this has resulted in the ability to seamlessly retrieve groundwater level data from either GIN or the National Groundwater Monitoring Network (NGWMN) of the United States (Brodaric et al. 2016).

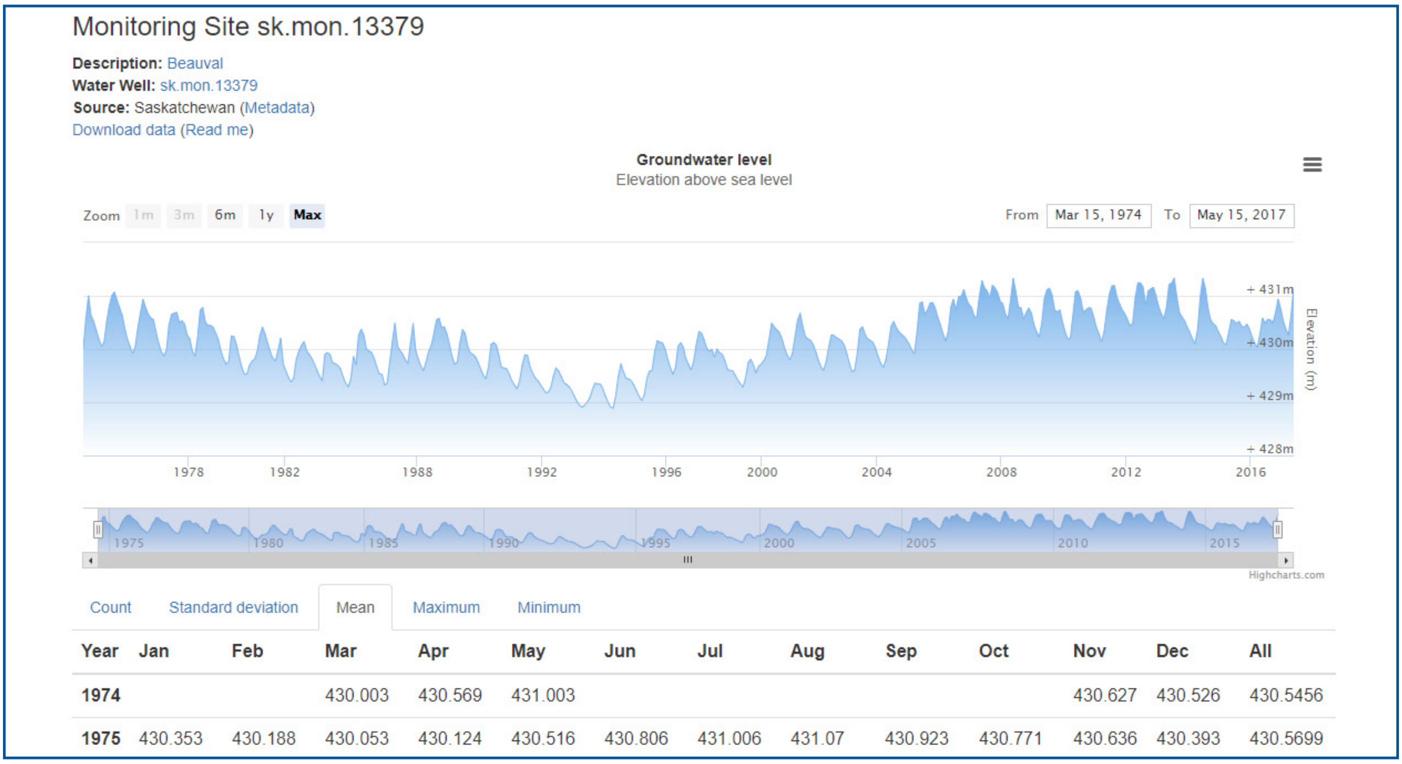


Figure 9 – Example of monitoring well from Monitoring Sites of Canada (GIN)

Sources

- **Brodaric, B., Booth, N.L., Boisvert, E., Lucido, J. Groundwater Data Interoperability. Journal of Hydroinformatics, 18(2):198-225** - https://doi.org/10.2166/hydro.2015.242;
- **Brodaric, B., Boisvert, E., Chery. L., Dahlhaus, P., Grellet, S., Kmoch, A., Letourneau, F., Lucido, J., Simons, B., Wagner, B. Enabling Global Exchange of Groundwater Data: GroundWaterML2 (GWML2). Hydrogeology Journal, 26(3):733-741** - https://doi.org/10.1007/s10040-018-1747-9;
- **Feedback from NRCan** - received on 06-07-2020;
- **GGMN People Network** - email exchange;
- **Groundwater Information Network (2020)** - http://gw-info.net. Accessed 28 January 2020; and
- **Rivera A (ed) (2014) Canada's groundwater resources. Geological Survey of Canada. Fitzhenry & Whiteside, Markham, ON** - ISBN: 978-1-55455-292-4 (HC).

Chile

Capital city: Santiago
Inhabitants: 18 Million

INSTITUTIONAL SETTING AND PURPOSE

The General Directorate of Water (DGA) is the state agency responsible for researching, monitoring and planning the development of the National Water Resources. It provides high-quality information about the National Water Resources in a systematic way, and disseminates the information generated by its own Hydrometric and Public Water Cadastre's Networks. The management of groundwater level and groundwater quality monitoring are some of the functions of DGA.

PROCESSING AND DISSEMINATION

Interactive maps of the national aquifers are available in the DGA Georeferenced Observatory build on an ArcGIS online platform, figure 10. The Groundwater Hydrometric Network is also shown in here, including an associated groundwater quality index per well, figure 11.

The National Water Information System (SNIA) managed by the DGA is aimed to improve the management of institutional information. Through this portal, users have access to several official statistical reports of hydrometeorological variables and water quality, including data on (static) groundwater levels from the national network.

The portal allows downloading reports of up to 10 stations simultaneously, defining a search period of up to 40 years for annual data, 10 years for monthly data, and 4 years for daily data. Reports are generated in Excel format.

Law No. 20,285 on transparency and access to public information allows to formally request information and data, which is relevant in the case of variables that are not available on the web platform, or when the complete data set of a certain variable is needed. This must be done through the Integral System of Information and Citizen Attention (SIAC) Platform.

Figure 10 – Aquifers of Chile

Figure 11 – Web platform of the Hydrometric Network, coloured dots show the quality of the monitoring wells

Sources

- **Bibliographic Catalogue, DGA** - https://dga.mop.gob.cl/estudiospublicaciones/Paginas/default.aspx;
- **Feedback from DGA** - received on 04-02-2020;
- **General Directorate of Water (DGA), Georeferenced Observatory** - http://snia.dga.cl/observatorio;
- **Groundwater monitoring data, DGA** - http://snia.dga.cl/BNAConsultas/reportes;
- **Official Hydrometeorological and Water Quality Information Online, DGA** - http://snia.dga.cl/BNAConsultas; and
- **Water Scenarios 2030: Water deficit indicator in Groundwater in Chile, May 2017** - https://www.escenarioshidricos.cl/wp-content/uploads/2018/12/Indicador-de-D%C3%A9ficit-H%C3%ADdrico-en-Aguas-Subterr%C3%A1neas.pdf.

Colombia

Capital city: Bogotá
Inhabitants: 50 Million

INSTITUTIONAL SETTING AND PURPOSE

The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), as an institution under the Ministry of Environment and Sustainable Development (MADS) and as a member of the National Environmental System (SINA), is responsible for generating information and knowledge about the state of the country's renewable natural resources. As a national research institute, it plays a fundamental role in the design of policies for the protection and improvement of the environment.

In recent years, IDEAM has worked hand in hand with MADS, the Regional Autonomous Corporations (CARs), and other national institutions in the development of strategies that contribute to the assessment and management of groundwater in Colombia. As a result, the National Groundwater Programme (PNASUB) was formulated. This programme seeks to generate instruments and tools to i) expand knowledge and hydrogeological research of aquifer systems of national and regional importance, ii) allow continuous strengthening of technical, operational and financial capacities of the institutions in charge of managing the groundwater resource, and iii) allow to have validated information and groundwater indicators available through an information system.

Among the expected results of PNASUB, the National Basic Groundwater Network (or reference network) was implemented in 2013, with the objective of collecting information on the natural system and long-term trends of groundwater (in terms of quantity and quality), as well as trends resulting from changes in land use and climatic variation in prioritized national aquifer systems. The network is linked to the CAR's regional monitoring programs.

CHARACTERISTICS OF THE NETWORK

The network monitors prioritized aquifers for which there is an acceptable level of hydrogeological knowledge. The CARs are in charge of monitoring the points chosen for the national network. Monitoring is carried out twice a year for groundwater quantity, characterizing the rainy and dry season, while groundwater quality is monitored once a year. Variables to be monitored are piezometric levels, total hardness, pH, temperature, electrical conductivity, total dissolved solids, dissolved oxygen, redox potential, alkalinity and major ions (Calcium, Sodium, Potassium, Chloride, Sulphate, Nitrate, Bicarbonate, Magnesium and Ammonia).

In total there are 114 monitoring stations in the aquifer systems of the Media Guajira, San Andrés, Valle del Cauca, Glacis del Quindío, Villavicencio - Granada - Puerto López, Golfo de Morrosquillo, Morroa, La Mojana, Cesar, Golfo de Urabá and Valle de Aburrá.

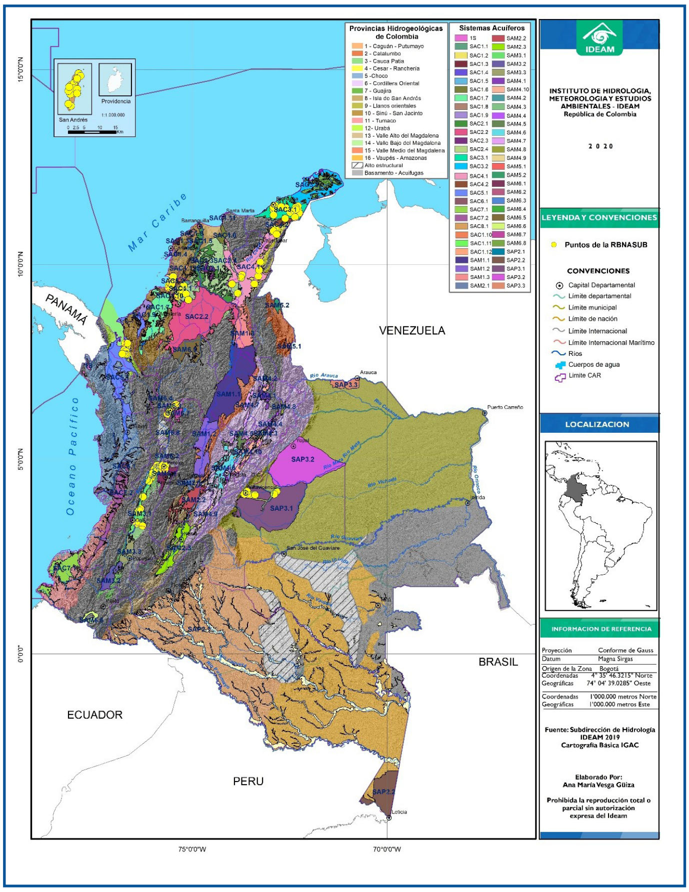


Figure 12 – Location of the monitoring points that are part of the National Groundwater Network

Figure 13 – Monitoring of well Gi_GEO_0041, located in Girardota municipality, Antioquia. AMVA

Figure 14 – Monitoring of well in Hacienda Suarez, located in La Paz municipality, Cesar- CORPOCESAR

Figure 15 – Monitoring of well Aremasain, located in Manaure municipality- Guajira - CORPOGUAJIRA.

PROCESSING AND DISSEMINATION

Data collected must be uploaded to the Water Resources Information System (SIRH), which systematizes and articulates the information related to water generated by the IDEAM and the Environmental Authorities.

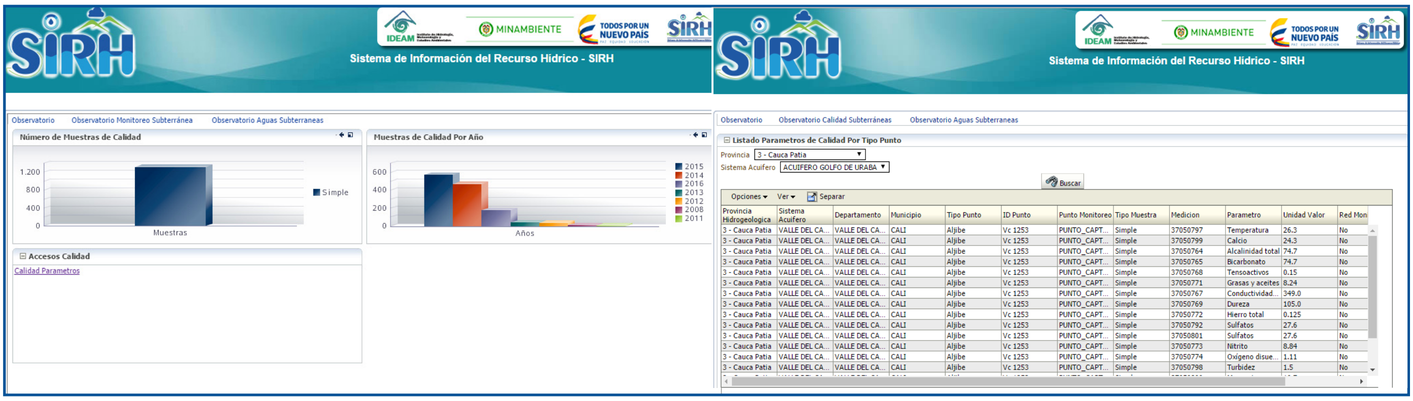


Figure 16 – View of groundwater information in SIRH

At the moment, users cannot view or download data. However, users can request data to the office of attention to citizens, which delivers it in the required format.

Currently, functionalities of the SIRH regarding reporting, spatialization and web service are being strengthened, which will allow viewing and downloading all information available from the National Groundwater Network. Below it is a proposal of what it is expected to have in the new network Geovisor.

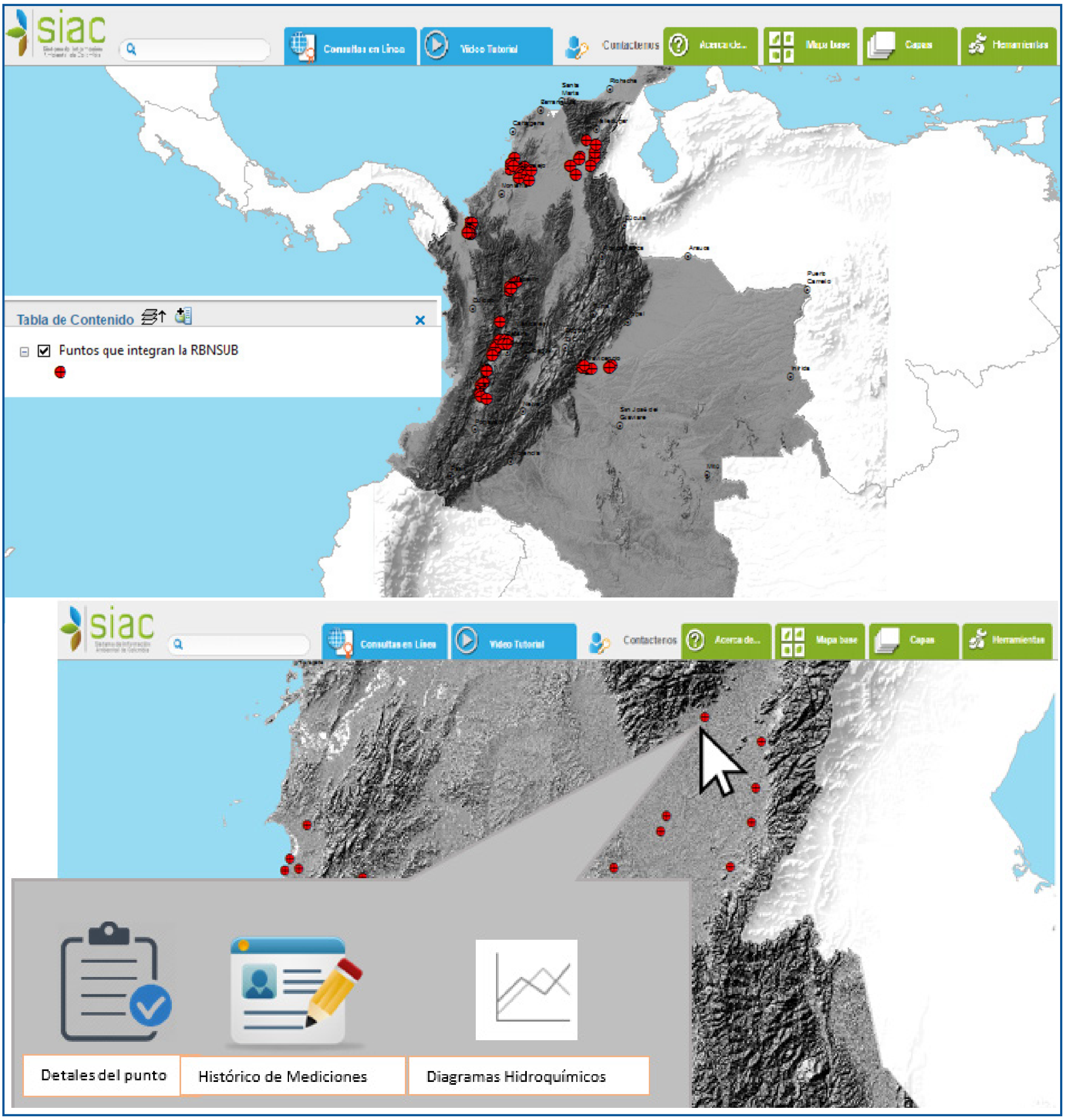


Figure 17 - Geovisor proposal with information from the National Basic Groundwater Network

Sources

- **IDEAM, Sub directorate of Hydrology (no year). National Basic Network for Groundwater Monitoring in Spanish. Available in -** http://capacitacion.sirh.ideam.gov.co/homeSIRH/HOME/RBSUB/RBASUB.pdf;
- **Feedback from IDEAM** - received on 20-05-2020;
- **Feedback from IDEAM (answer to form)** - received in 2019;
- **SIAC Geographic Viewer** - http://sig.anla.gov.co:8083/;
- **Ministry of the Environment and Sustainable Development, Directorate for the Integrated Management of Water Resources, 2014. National Groundwater Program (PNASUB), in Spanish. Available in** - http://www.minambiente.gov.co/index.php/gestion-integral-del-recurso-hidrico/planificacion-de-cuencas-hidrograficas/acuiferos/programa-nacional-de-aguas-subterraneas; and
- **Colombia's Environmental Information System** - http://www.siac.gov.co/monitoreo.

Costa Rica

Capital city: San José
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Water Directorate (DA) under the Ministry of Environment and Energy (MINAE) of Costa Rica, together with the Costa Rican Institute of Aqueducts and Sewers (AyA) and the National Groundwater, Irrigation and Drainage Service (SENARA) operates several quantitative networks of manual groundwater monitoring and coordinates one automatic network:

1. Automated registration of data via telemetric transmission (Real Time Groundwater Monitoring System, SIMASTIR), and semi-automated transmission (alliance with the Public Utility Company of Heredia, ESPH)
2. Manual monitoring with monthly frequency.

The main objective of these networks is to provide data on the state of groundwater and its long-term trends, and technical information for the proper planning of national policies by regulatory agencies. The data generated is also used to analyse the dynamics of aquifers in the face of climatic variations.

With these monitoring records, representatives of the Institutional Technical Committee (CTI) of Aquifer Management (conformed by Executive Decree 38449-MINE_MAG, DA (as coordinator), AyA and SENARA) proceed to analyse and interpret variations in groundwater levels. Results are made public either by presentation in communities and/or at the National Information System for Integrated Water Resource Management (SINIGHIR) online platform.

CHARACTERISTICS OF THE NETWORK

SIMASTIR (figure 18) is a national coverage project initiated in 2016 in the province of Guanacaste and extended to the provinces of Heredia and Alajuela by the end of 2020. Monitoring wells record hourly groundwater levels, temperature, and electrical conductivity (in some locations). In the case of automatic transmission, the recorded data is transmitted every 12 hours by cellular signal to the operations centre located at DA offices, where the data is stored and added to the historical records. In the case of semi-automatic transmission, the data is sent monthly by ESPH staff to DA, by email.

The current distribution of the SIMASTIR network by province is as follows:

- **Guanacaste:** 44 groundwater monitoring sites distributed in the following aquifers: right margin Sardinal-Tempisque, Nimboyores, Huacas-Tamarindo, Nicoya, Caimital, Cóbano - Montezuma, Playa Panamá, Coco, Brasilito, Potrero.
- **Alajuela:** 10 groundwater monitoring sites in Aguas Zarcas and Pital aquifers.
- **Heredia**: 21 groundwater monitoring sites in Barba and Colima Superior aquifers. The equipment and maintenance of these monitoring sites is under the responsibility of ESPH, which voluntarily shares the information recorded with SIMASTIR.

The manual network monitors groundwater levels monthly in 300 wells strategically distributed over 10 aquifers located mainly in Guanacaste and the Central Pacific area.

Figure 18 – Images from the SIMASTIR project

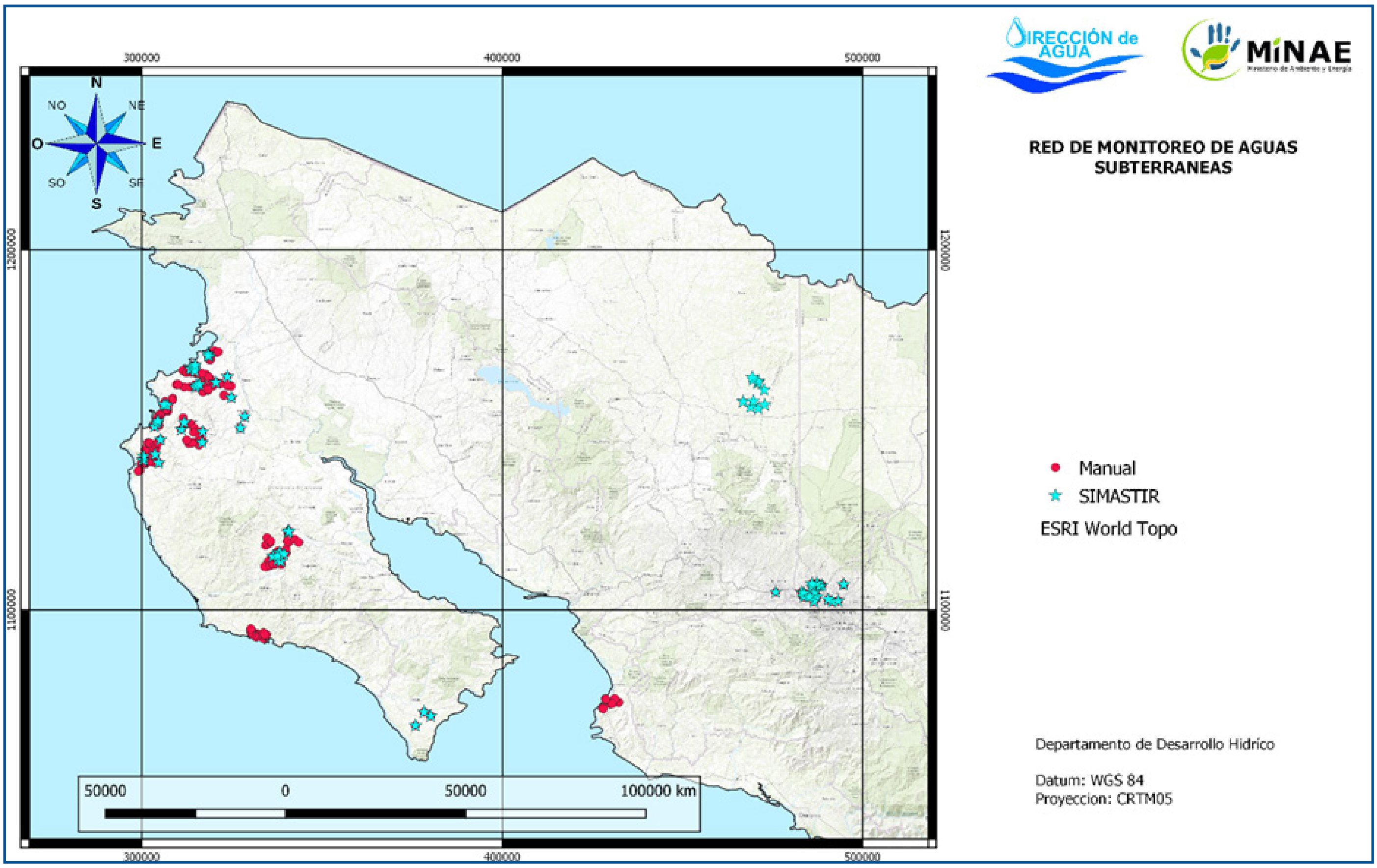


Figure 19 – Groundwater Monitoring Network of Costa Rica (source: DA under MINAE)

PROCESSING AND DISSEMINATION

Reports made by DA and CTI Aquifers Management are available online. Unprocessed records can be obtained from DA by request. Other detailed data from the monitoring sites can be seen using the SINIGIRH map viewer.

Sources

- **Aquifer Management, Water Directorate (DA) of Costa Rica** - http://www.da.go.cr/gestion-de-acuiferos;
- **Feedback from DA** - received on 06-02-2020;
- **Feedback from DA (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Sardinal Aquifer documents** - http://www.da.go.cr/documentos-acuifero-sardinal;
- **SINIGIRH map viewer** - http://mapas.da.go.cr/mapnew.php; and
- **Ministry of Environment and Energy of Costa Rica (MINAE), Water Directorate (DA), 2017. Real Time Groundwater Monitoring System (SIMASTIR), in Spanish** - Unpublished report. 15 pages.

El Salvador

Capital city: San Salvador
Inhabitants: 6 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Natural Resources (MARN) has constitutional power of protection, conservation and recovery of the environment with a specific mandate for the protection of water resources.

In 2007, MARN, through the former National Service of Territorial Studies, SNET (currently the General Directorate of the Observatory of Threats and Natural Resources, DOA) and the European Union, with the project Strengthening Environmental Management of El Salvador (FORGAES), launched the first network of groundwater monitoring wells in the metropolitan area of San Salvador and the Zapotitán Valley, which has been improved through several initiatives promoted by the Hydrology Management Office of MARN. The objective of the network is to provide data on the long-term status and trends of the national groundwater resource.

CHARACTERISTICS OF THE NETWORK

The network currently has 32 monitoring wells that register groundwater levels automatically using data loggers every 8 hours. On average, there are 8 years of records of groundwater levels in 17 of these wells. In 2018 and 2019, 15 new monitoring wells were drilled, which were provided with the equipment to perform automatic measurement of piezometric level and temperature.

Additionally, there is a monitoring network of around 100 hand dug wells where groundwater levels are measured manually. Water sampling for physical-chemical characterization is carried out twice a year (once during dry season and once during wet season). For these wells a record of 7 years of measurement is present.

PROCESSING AND DISSEMINATION

The data are processed by implementing time series analysis. The information on groundwater levels and physical-chemical parameters is published on-line via the Water Information System (SIHI), figure 20. SIHI was designed and developed by the MARN in collaboration with the Spanish Agency for International Cooperation for Development (AECID) through the Cooperation Fund for Water and Sanitation (FCAS).

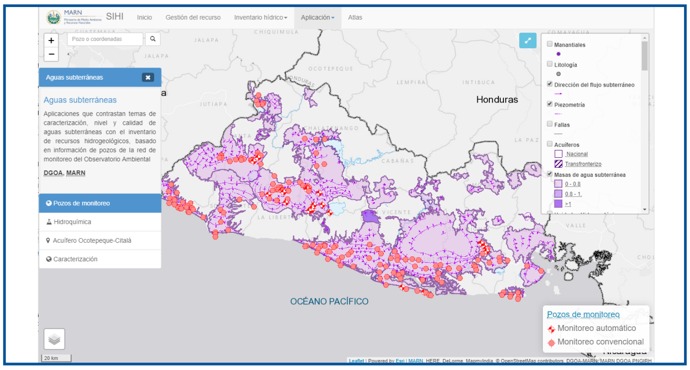


Figure 20 – Web platform of SIHI

Sources

- **Feedback from MARN -** received on 29-01-2020;
- **Feedback from MARN (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Ministry of the Environment and Natural Resources (MARN)** - http://www.snet.gob.sv/ver/comunicacion+social/noticias+y+temas+de+interes/noticias/ano+2007/inauguracion+de+la+red+de+monitoreo+de+aguas+subterraneas;
- **MARN, 13-09-2019. Rocks and Ashes Unveil Eruptive History of the San Salvador Volcano** - https://www.marn.gob.sv/rocas-y-cenizas-desvelan-historia-eruptiva-del-volcan-de-san-salvador/;
- **MARN Transparency Portal, Groundwater Monitoring Network** http://www.marn.gob.sv/red-de-monitoreo-de-aguas-subterraneas;
- **MARN Transparency Portal, Groundwater -** http://www.marn.gob.sv/agua-subterranea; and
- **MARN Water Information System (SIHI) -** http://srt.snet.gob.sv/sihi/public/app/1/pozosmonitoreo.

Mexico

Capital city: Mexico City
Inhabitants: 128 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Commission (CONAGUA) of Mexico is an administrative, technical, consultative and decentralized agency of the Ministry of Environment and Natural Resources (SEMARNAT). CONAGUA is responsible for administration of national water resources, management and control of hydrological systems and promotion of social development. It also manages the national groundwater monitoring network.

CHARACTERISTICS OF THE NETWORK

The national groundwater monitoring network is composed of more than 12,000 wells. These wells monitor 370 aquifers in total, which represent 57% of all Mexican aquifers. CONAGUA also carries out the management and assessment of collected data.

PROCESSING AND DISSEMINATION

CONAGUA maintains a web portal for the Piezometric Monitoring Network, figure 21. It was designed by the Water Geographical Information Sub-Directorate (SIGA) with the aim of offering a spatial information analysis platform populated with geo-referenced data on groundwater monitoring to CONAGUA users.

By clicking on a well icon in the platform, one can access metadata and a time-series graph of the groundwater level (when there is enough piezometric information to generate the hydrograph). Data are not available for downloading. The platform shows the map of Mexican aquifers with available metadata for each aquifer.

Additionally, SIGA designed the Geographic Information System for Aquifers and Watersheds of Mexico (SICAGUA). This system offers users a visualization of geographic elements and serves as a support in the determination of water rights payment, figure 22. Available layers are: availability of aquifers, type of climate, surrounding seas, urban localities, rural locations, states, municipalities, water bodies, major rivers, surface water use, groundwater use, and discharge of wastewater.

Figure 21 – Groundwater monitoring wells in Mexico. Source: SIGA

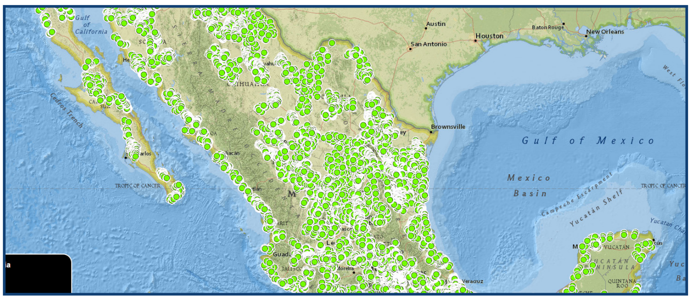


Figure 22 – SICAGUA web platform

Sources

- **GGMN Workshop Latin America 2013** - GeoVisor of CONAGUA;
- **National Water Commission (CONAGUA)** - https://www.gob.mx/conagua;
- **Piezometric Monitoring Network** - https://sigagis.conagua.gob.mx/rp; and
- **SICAGUA web platform** - https://sigagis.conagua.gob.mx/aprovechamientos.

Paraguay

Capital city: Asunción
Inhabitants: 7 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of the Environment and Sustainable Development (MADES), former Secretary of the Environment (SEAM) is a government agency responsible for policymaking, coordination, supervision and implementation of environmental actions, programs and projects concerning preservation and management of natural resources. In water management, MADES collaborates with the National Environmental Sanitation Service (SENASA), a government entity under the Ministry of Public Health and Social Welfare.

The General Directorate of Protection and Conservation of Water Resources (DGPCRH) of the MADES is in charge of monitoring the Patiño Aquifer, in conjunction with SENASA. Groundwater levels are monitored to understand impacts of growing aquifer exploitation from industry, households and agriculture.

CHARACTERISTICS OF THE NETWORK

Thanks to international cooperation (Inter-American Development Bank), there is a groundwater monitoring plan for the Patiño Aquifer since 2018. This plan includes a network of 47 wells for piezometric observation, where seven of them are equipped with data loggers for automatic recording of water levels and physical parameters. From these seven wells, four have data available on the website of the Directorate of Meteorology and Hydrology (DMH). The remaining 3 wells are in an adaptation stage in order to be available on the platform as well. Monitoring of the Patiño aquifer has been carried out since 2006, with an irregular frequency of data collection both regarding groundwater quantity and quality. However, in 2014 there were improvements in the data collection. In total, 30 of the 47 wells are fully operational, while the rest are being recovered The piezometers were distributed covering the upper, middle and lower basins of the Patiño aquifer area.

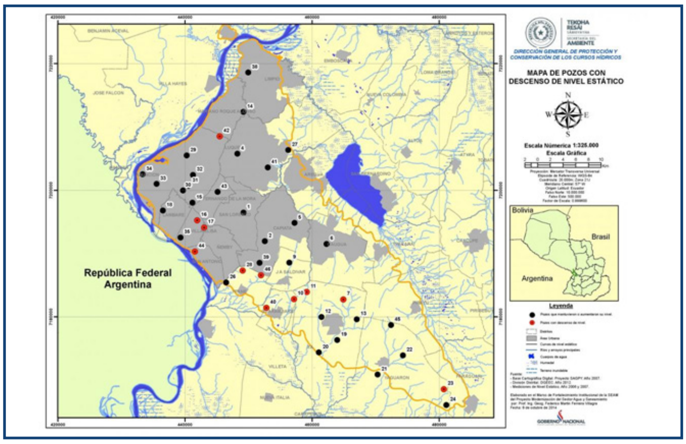


Figure 23 – Location of monitoring wells in the Patiño aquifer. Black boreholes represent stable water level and red boreholes show decreasing water levels. Source: SEAM

PROCESSING AND DISSEMINATION

There are 2 hydrogeological databases of 550 and 665 wells respectively available in Excel and PWIS (Paraguay Well Information System) formats. Each well has a unique identifying number, with a corresponding name.

PWIS contains information on water level, discharge and water quality, but also information on lithology and well characteristics. Information on this is available at the DGPCRH.

Sources

- **Directorate of Meteorology and Hydrology (DMH), Groundwater Levels** - https://www.meteorologia.gov.py/nivel-pozo/;
- **Feedback from the General Directorate of Protection and Conservation of Water Resources (DGPCRH), MADES** - received on 06-10-2020;
- **GGMN Workshop Montevideo (2013)** - https://www.un-igrac.org/news/regional-ggmn-workshop-latin-america-held-montevideo;
- **Inter-American Development Bank. Study of Water Resources and Climate Vulnerability of the Patiño Aquifer (in Spanish), information provided by CeReGAS** - https://publications.iadb.org/publications/spanish/document/Estudio_de_recursos_h%C3%ADdricos_y_vulnerabilidad_clim%C3%A1tica_del_acu%C3%ADfero_Pati%C3%B1o_es.pdf; and
- **SEAM 2016** - Modernization of the Potable Water and Sanitation Sector Project (PMSAS 7710-PY).

Peru

Capital city: Lima
Inhabitants: 32 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Authority (ANA) is the governmental body responsible for the national management of water resources.

CHARACTERISTICS OF THE NETWORK

The groundwater monitoring network of Peru consists of 6,901 wells, of which 3,491 monitor groundwater levels and 3,410 groundwater quality. From the groundwater level monitoring network, 150 wells collect data automatically and the rest is operated manually.

PROCESSING AND DISSEMINATION

The ANA, through the National Water Resources Information System (SNIRH), manages the Groundwater Observatory. It is a public platform with the map viewer and information on the wells of Peru, figure 24. The location of a well, its metadata with coordinates are provided when a user selects a well from a certain Water Administrative Authority and an aquifer.

The portal shows 8,470 wells distributed in 7 Local Water Administrations (ALA). However, it is not indicated if these wells are also used for groundwater monitoring.

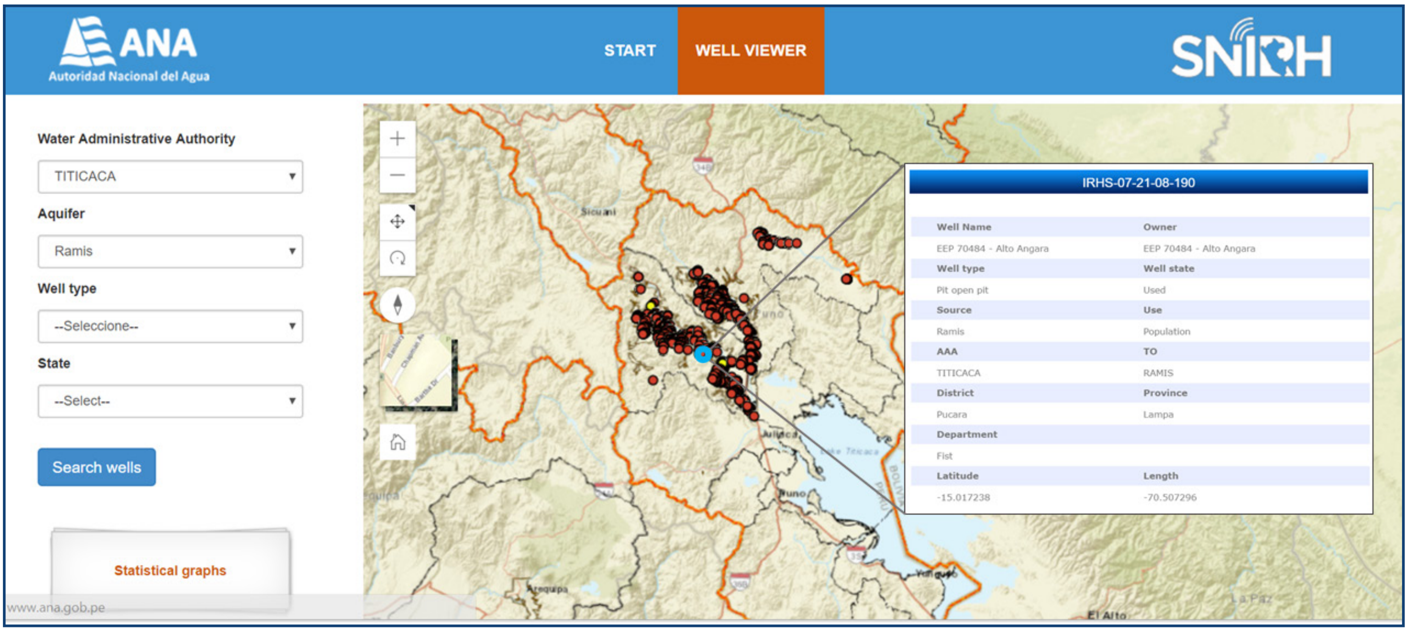


Figure 24 – Groundwater observation wells in Ramis Aquifer. Source: SNIRH

Sources

- **National Water Authority** - https://www.ana.gob.pe/;
- **GGMN Workshop 2013** - https://www.un-igrac.org/news/regional-ggmn-workshop-latin-america-held-montevideo; and
- **Groundwater Observatory** - http://snirh.ana.gob.pe/visorPozos/.

United States

Capital city: Washington DC
Inhabitants: 328 Million

INSTITUTIONAL SETTING AND PURPOSE

The United States Geological Survey (USGS) Water Resources Mission Area is responsible for providing data and information about the groundwater resources of the United States. Groundwater programmes which USGS undertakes contain various monitoring networks: National networks like the National Ground-Water Monitoring Network (NGWMN), Active Groundwater Level Network and Climate Response Network; Regional Networks like the High Plains Aquifer Monitoring Program with the objective to monitor storage changes in the High Plains Aquifer; state-based networks that are designed to monitor state-wide groundwater conditions; and local networks designed to monitor pumping effects. Some of the national networks are described in the following section.

CHARACTERISTICS OF THE NETWORK

The National Ground-Water Monitoring Network (NGWMN) is a selection of groundwater monitoring wells from Federal, State and local networks across the nation. Currently (as October 2020) it includes 14,378 water level monitoring wells and 3,408 water-quality wells from 32 contributing agencies, figure 25.

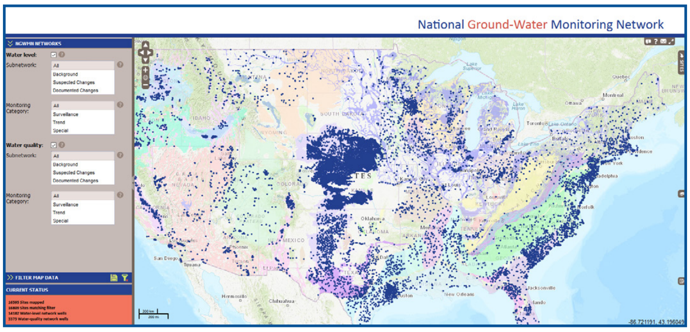


Figure 25 – National Ground-Water Monitoring Network. Source: USGS

The Active Groundwater Level Network contains data on water levels and well information from more than 18,340 wells. USGS or USGS co-operators take measurements at least once within the past 13 months, figure 26.

The Climate Response Network monitors the effects of droughts and other climate variability on groundwater levels and consisted of about 500 wells in 2006, figure 27. Among them 280 wells were equipped with real-time data loggers, 59 continuous wells measured the level hourly (not available in real time); and about 214 wells measured the levels from monthly to quarterly. The water-level changes in the Network should primarily reflect climatic variability and not human influences.

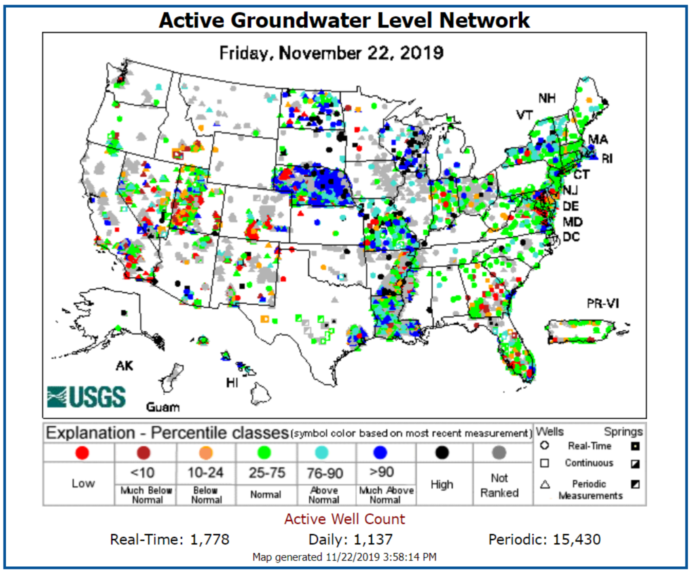


Figure 26 – Active Groundwater Level Network. Source: USGS

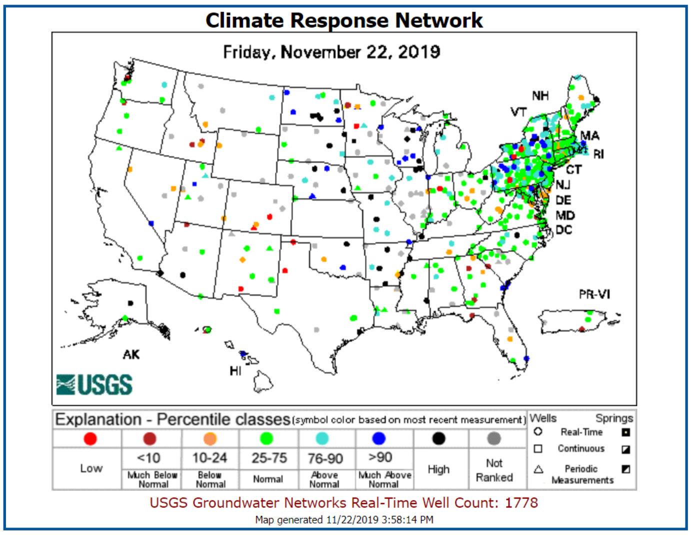


Figure 27 – Climate Response Network. Source: USGS

The Real Time Groundwater Level Network consists of 1,778 wells with “real time” data transmission instrumentation, figure 28. Real-time data are recorded at 15-60-minute intervals. The data are stored onsite, and then transmitted to USGS offices every 1 to 4 hours, depending on the data relay technique used. During critical events recording and transmission times may be more frequent. Data from real-time sites are sent to USGS offices via satellite, telephone, and/or radio and are available for viewing within minutes of arrival. All real-time data are provisional and subject to revision.

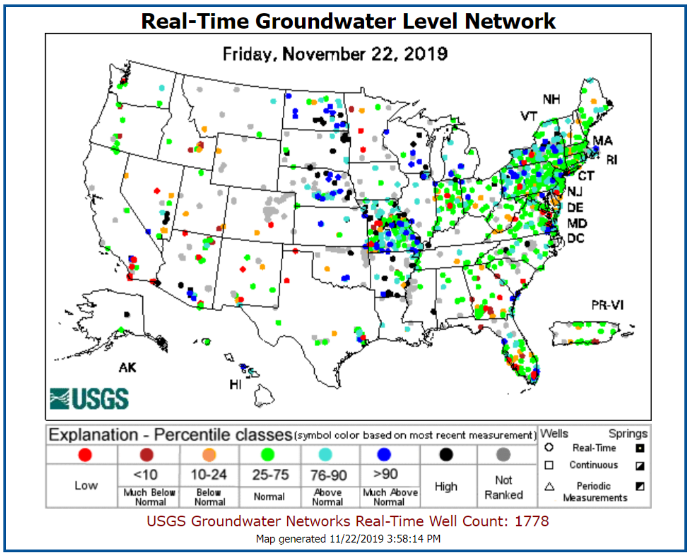


Figure 28 – Real-Time Groundwater Level Network. Source: USGS

The Below Normal Groundwater Level Network is aimed to analyse wells with groundwater levels below normal, figure 29. The wells must be in an active measurement program, i.e. appears on the Active Groundwater Level Network, and must have 10 or more years of record in the month of the most recent measurement.

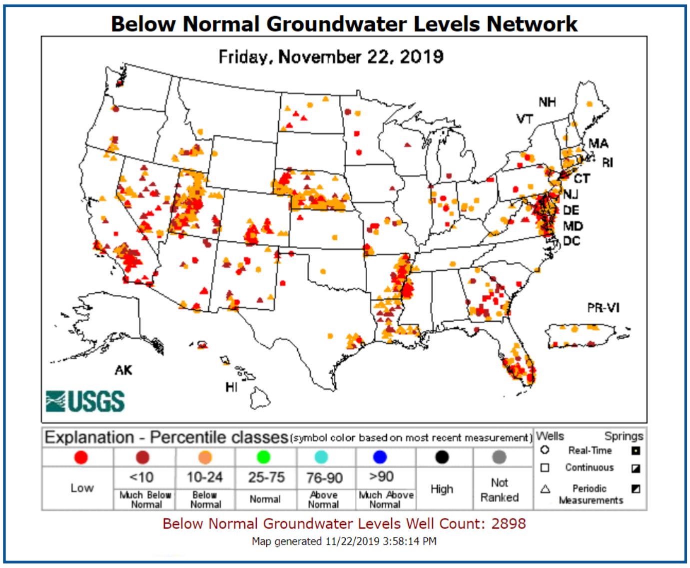


Figure 29 – Below Normal Groundwater Level Network. Source: USGS

PROCESSING AND DISSEMINATION

Data and information in a national information system are compiled from local/regional, distributed databases of the USGS. Information from all wells is served via the Internet through the National Water Information System Web (NWISWeb) Interface (https://waterdata.usgs.gov/nwis). NWISWeb provides all USGS groundwater data that are approved for public release. The large number of sites is not always user-friendly for all data retrievals in the networks.

Data from the NGWMN can be obtained via the NGWMN Data Portal, which is a web-based mapping application proving access to groundwater data from several databases. The portal contains current and historical data from both groundwater quantity and quality, lithology and well construction.

The USGS Groundwater Watch is an initiative of the Office of Groundwater that provides basic statistics about the groundwater levels collected by the USGS Water Science Centers and from customers through cooperative agreements. National, state and local networks can be accessed via the Groundwater Watch portal. It is noteworthy that this website is going to be deprecated on February 1, 2021, including all the associated network pages. However, USGS will continue collecting and serving data from all of the sites that are monitored as part of those networks, and they are in the process of building a replacement for the Groundwater Watch website which will have similar functionality. Currently, several networks are presented in beta viewers (see Sources).

Active Groundwater Level Network

The water levels (most recent measurements) are classified as much below normal (<10-percentile), below normal (between 10-24 percentiles), normal (between 25-75 percentiles), above normal (between 76-90 percentiles), and much above normal (>90-percentile). The symbol “High” indicates that highest median of the month of the most recent data value is the closest statistic to the most recent data value.

From the Groundwater Watch portal, a user can first select a state of the interest, then a new dialog opens with the map of that state and list of counties with all the monitoring sites for groundwater levels and spring discharges, figure 30. The statistics of a selected well is available in a graphical form, figure 31. Moreover, the information on daily and periodic groundwater data together with the whole period of records are included in the USGS Well Information section.

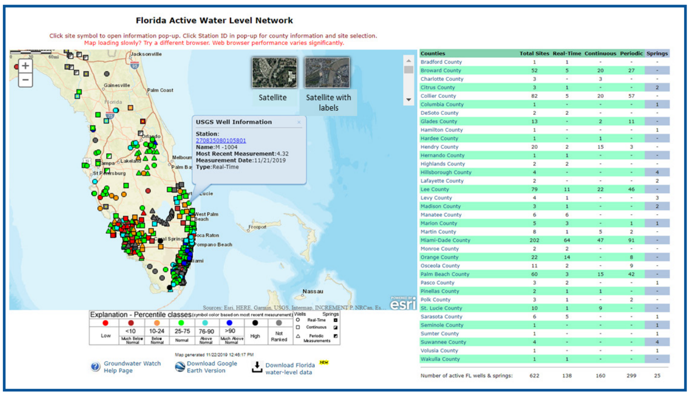
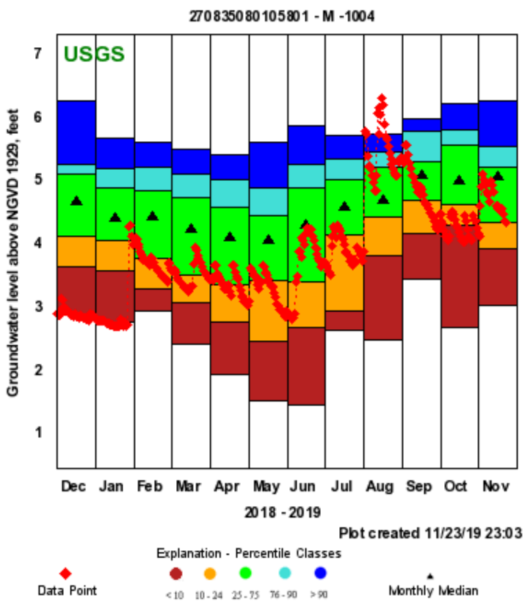


Figure 30 – Florida Active Groundwater Level Network (right) and list of counties in Florida with monitoring sites (right). Source: USGS

Site Statistics



Most recent data value: 4.22 on 11/24/2019
Period of Record Monthly Statistics for 270835080105801
Groundwater level above NGVD 1929, feet
All Approved Continuous & Periodic Data Used In Analysis
Note: Highlighted values in the table indicate closest statistic to the most recent data value.

Month	Lowest Median	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	Highest Median	Number of Years
Jan	2.75	3.56	4.04	4.40	4.87	5.18	5.67	34
Feb	2.92	3.29	3.75	4.42	4.83	5.20	5.59	35
Mar	2.40	3.07	3.50	4.21	4.73	5.09	5.49	34
Apr	1.93	2.75	3.35	4.08	4.58	5.01	5.41	34
May	1.50	2.46	3.41	4.05	4.43	4.88	5.59	35
Jun	1.44	2.67	3.38	4.29	4.88	5.25	5.86	33
Jul	2.62	2.92	4.13	4.56	5.00	5.34	5.71	33
Aug	2.48	3.80	4.41	4.67	5.20	5.44	5.73	33
Sep	3.43	4.15	4.68	5.07	5.28	5.77	5.97	33
Oct	2.66	4.28	4.61	4.98	5.56	5.79	6.20	35
Nov	3.02	3.91	4.32	5.04	5.20	5.52	6.26	35
Dec	2.87	3.62	4.12	4.66	5.09	5.24	6.25	35

.As of 11/23/2019 06:37-2

Statistics Options

View month/year statistics

Figure 31 – Below Normal Groundwater Level Network. Source: USGS

The most recent water-level measurement that belongs to the 24-percentile in the month of measurements over the period of record of the well is used for the analysis. If the measurement is lower than the 10-percentile, the well will be classified as "much below normal".

Climate Response Network

The snap-shot map is available on the Groundwater watch platform. Only wells having at least 10 years of measurements in a given month are considered for analysis and coded with colours to ensure that the calculated percentiles are representative of historical conditions. There are eight categories of groundwater levels: a new high for the month (black), greater than the 90th percentile (dark blue), 76th–90th percentile (light blue), 25th–75th percentile (green), 10th–24th percentile (orange), less than 10th percentile (brown), and new record low for the month (red), figure 27. The symbol is grey when the most recent measurement is more than 45 days old or less than 10 years of data are available.

National Aquifer Composite Hydrographs

As one of the methods composite water-level hydrographs are used to report on the United States' major aquifers in which water levels are declining, increasing or stable. Composite hydrographs provide a general overview of water levels in the Principal Aquifers, and they are useful to determine trends in them.

A composite water level is an average water level calculated from a group of index wells. It uses the median water level for the period of interest (annual or monthly) for each index well and then averages all index wells for the particular year or month. The composite water levels representing the average or mean water level of all the index wells is then presented on a hydrograph, figure 31, left.

The composite hydrographs minimize the effects of local or random fluctuations. The identification of appropriate index wells is an important factor. The index wells should come from an area that is similar in some hydrologic condition.

To calculate the groundwater level composite hydrographs for the Principal Aquifers of the United States, different factors are taken into account:

- The period used for the analysis is a moving 30-year hydrograph from the most recent year of record;
- Only index wells with no missing records are used, i.e. every index well has at least one measurement for every year in the 30-year period;
- There must be at least 9 index wells for a Principal Aquifer that meet the period of record criteria and have a reasonable areal distribution through the aquifer. The reasonable areal distribution is defined qualitatively;
- The variable calculated for each index well is the median water level for the year. The annual median water level is always the median of daily values (if exist) and periodic measurements;
- Data are presented in Below Land Surface values.

The advantage of the method is that the applied criteria are simple and there is no need to assess each potential well in the aquifer system. The disadvantage is that the wells might not be evenly spaced, and monitored for specific stresses that are not appropriate to represent the whole aquifer. By normalizing the original hydrograph, the composite annual percent variation can be calculated, figure 31, right. The example on how to calculate the normalized value for a single well, for one year is presented in Figure 30. Later, the mean or median will be calculated considering all the wells for every year, and the composite annual median percent variation graph will be generated.

California Coastal Basin Aquifer
Well: 340655117184005
Station Water-Level Index for Calendar Year 1988

$X = 64.74$

$X_{mean} = 156.01$

$X_{max} = 237.18$

$X_{min} = 64.74$

$$X_{norm} = (64.74 - 156.01) / (237.18 - 64.74) * 100 * (-1)$$

$$X_{norm} = (-91.27) / (172.44) * 100 * (-1)$$

$$X_{norm} = 52.93$$

Figure 30 – Calculation of a normalized value for the Well: 340655117184005

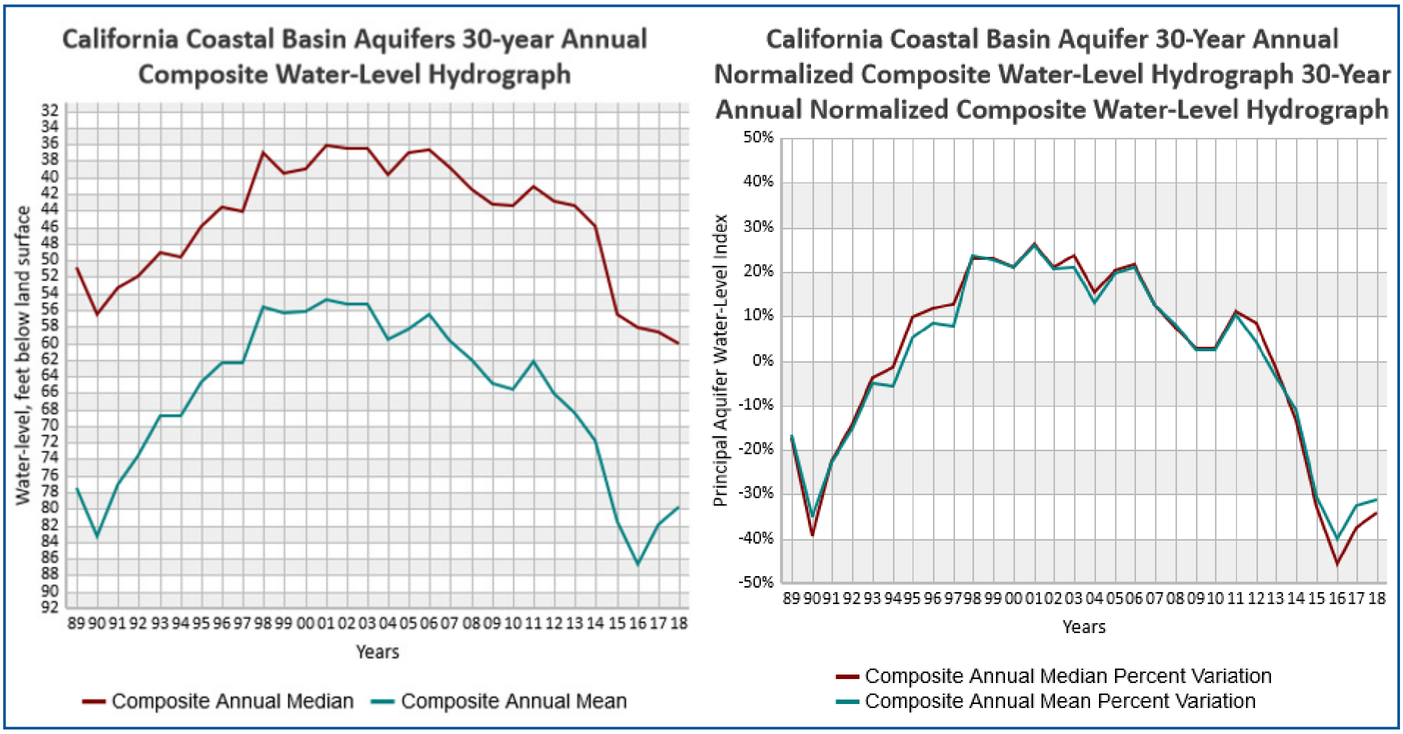


Figure 32 – Example of composite hydrograph (left) and example of normalized composite hydrograph (right). Source: USGS

Sources

- **Active Groundwater Level Network** - https://groundwaterwatch.usgs.gov/default.asp;
- **Active Groundwater Level Network** - https://waterdata.usgs.gov/networks/AGL/ (beta release);
- **Below Normal Groundwater Levels** - https://waterdata.usgs.gov/networks/LWL/;
- **Climate Response Network (Fact Sheet)** - https://pubs.usgs.gov/fs/2007/3003/pdf/2007-3003-lowres.pdf;
- **Climate Response Network** - https://waterdata.usgs.gov/networks/CRN/ (beta release);
- **Composite Water-Level Hydrographs (main page)** - https://groundwaterwatch.usgs.gov/compositehome.asp;
- **Composite Water-Level Hydrographs (complete description)** - https://groundwaterwatch.usgs.gov/composite/help/compositewaterlevels_helpdocument_7-7-2016.htm;
- **Composite Water-Level Hydrographs (alternative description)** - https://groundwaterwatch.usgs.gov/composite/help/CompositeGroundwaterLevelHelpDocument.docx.html;
- **Feedback from USGS, Water Resource Mission Area** - received on 01-10-2020;
- **National Ground-Water Monitoring Network (NGWMN), main page** - https://cida.usgs.gov/ngwmn/;
- **NGWMN Data Portal** - https://cida.usgs.gov/ngwmn/index.jsp;
- **USGS Groundwater Watch** - https://groundwaterwatch.usgs.gov/usgsgwnetworks.asp (interim version);
- **USGS Groundwater Watch. California Coastal Basin Aquifer Composite Hydrographs (as example)** - https://groundwaterwatch.usgs.gov/compositeaquifers.asp?ncd=CCB;
- **USGS Groundwater Watch. Site Number: 270835080105801 - M -1004 (as example)** - https://groundwaterwatch.usgs.gov/AWLSites.asp?mt=g&S=270835080105801&ncd=awl; and
- **USGS Water Data for The Nation Blog** - https://waterdata.usgs.gov/blog/.

Uruguay

Capital city: Montevideo
Inhabitants: 3.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Housing, Territorial Planning and Environment (MVOTMA) is responsible for the design and implementation of public water policies in Uruguay. The National Water Directorate (DINAGUA) under the MVOTMA is in charge of management, use and control of water resources with respect to extraction volumes, and the National Environment Directorate (DINAMA) is responsible for the quality of the water resources.

Within the framework of the National Water Plan (Plan Nacional de Aguas), approved in July 2017, a groundwater quality and quantity monitoring programme was proposed to be established. Its purpose is to monitor the status, quantity and the quality of the surface and groundwater resources through the knowledge of hydro-meteorological and environmental variables. Currently, there is no national groundwater monitoring network in Uruguay. Nevertheless, monitoring of groundwater is carried out locally.

CHARACTERISTICS OF THE NETWORK

The National Directorate of Mining and Geology (DINAMIGE) has been monitoring the Raigón Aquifer since 1986 and measuring mainly the groundwater level, conductivity and pH in approximately 40 wells twice a year (autumn and spring). Based on these measurements, a report is made and disseminated via the agency's website.

During 2013, DINAMIGE also resumed the monitoring of groundwater levels in the Salto-Arapey Aquifer that had been suspended in 1999.

Figure 34 – GGMN workshop in 2013

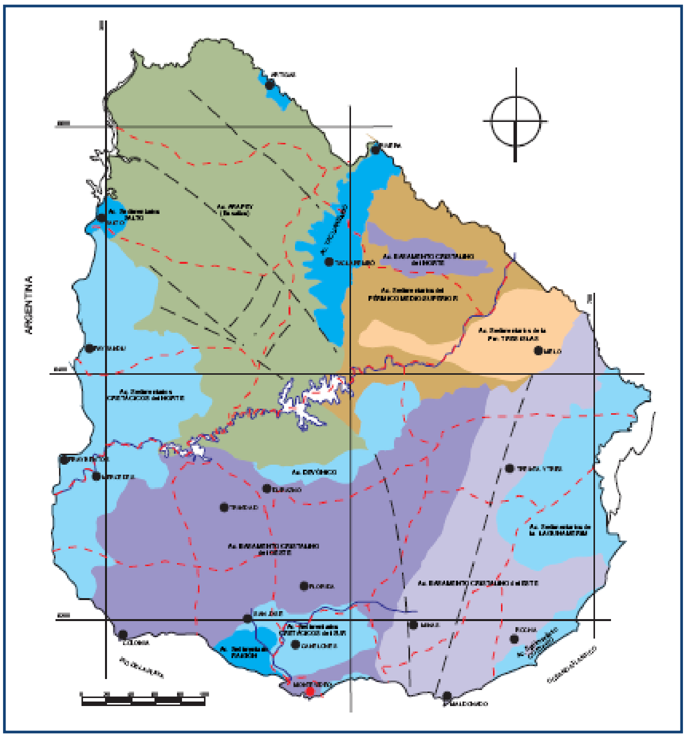


Figure 35 – Map of Aquifers of Uruguay

Sources

- **Feedback from CeReGAS (Regional Centre for Groundwater Management in Latin America and the Caribbean)** - received throughout 2019;
- **GGMN Workshop Montevideo** - 2013; and
- **Ministry of Industry, Energy and Mining. Monitoring of static levels & physical-chemical parameters in Raigón aquifer** - https://www.miem.gub.uy/mineria-y-geologia/monitoreo-del-nivel-estatico-y-medida-de-parametros-fisico-quimicos-en-el-1.

Venezuela

Capital city: Caracas
Inhabitants: 28 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Institute of Meteorology and Hydrology (INAMEH) is responsible for integrating meteorology and hydrology services offered by various Venezuelan governmental institutions. INAMEH is currently the institution in charge of the groundwater monitoring in Venezuela.

CHARACTERISTICS OF THE NETWORK

Hydrogeological and socio-economic studies conducted in Venezuela prior 2011 concluded that the national monitoring network located to the north of the Orinoco River should have 1,448 wells spread over 750 localities.

PROCESSING AND DISSEMINATION

The INAMEH has a portal where maps of the minimum, mean and maximum groundwater levels can be found. To access the information, a region and state or federal entity of interest must be chosen, and then the thematic maps of water levels will be displayed.

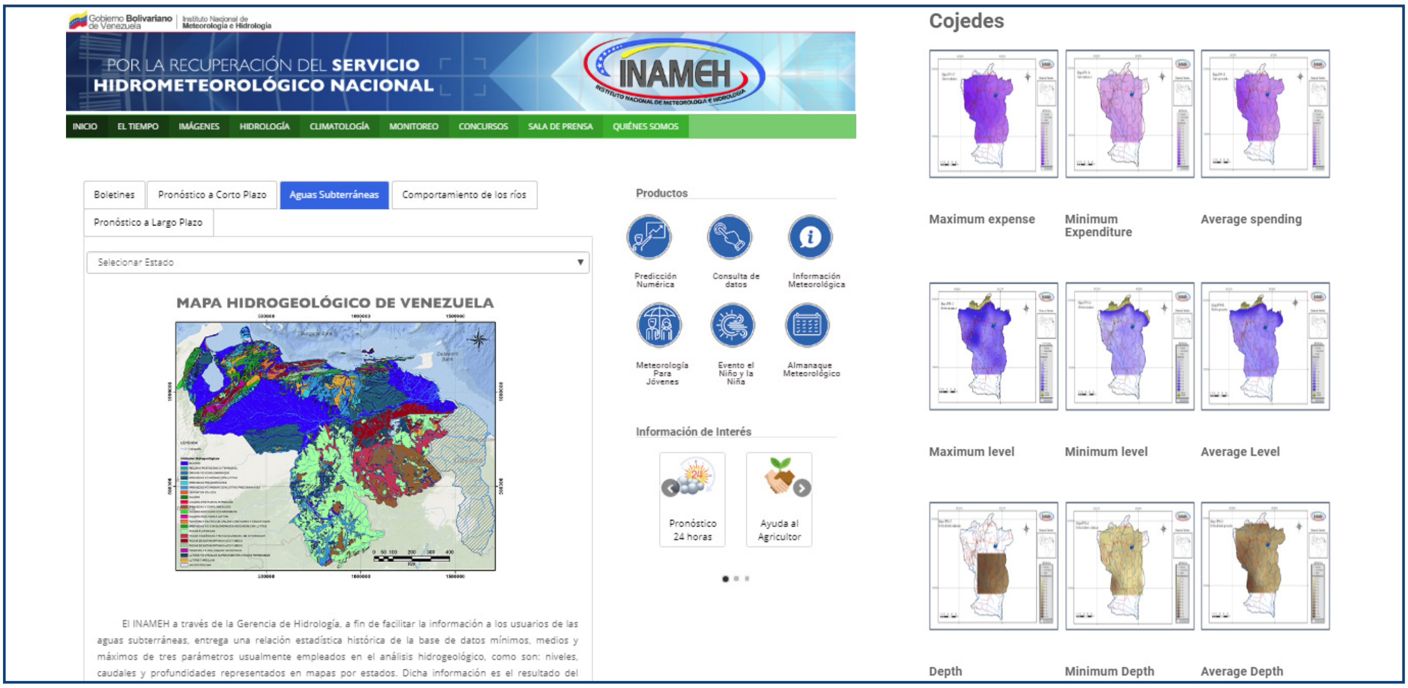
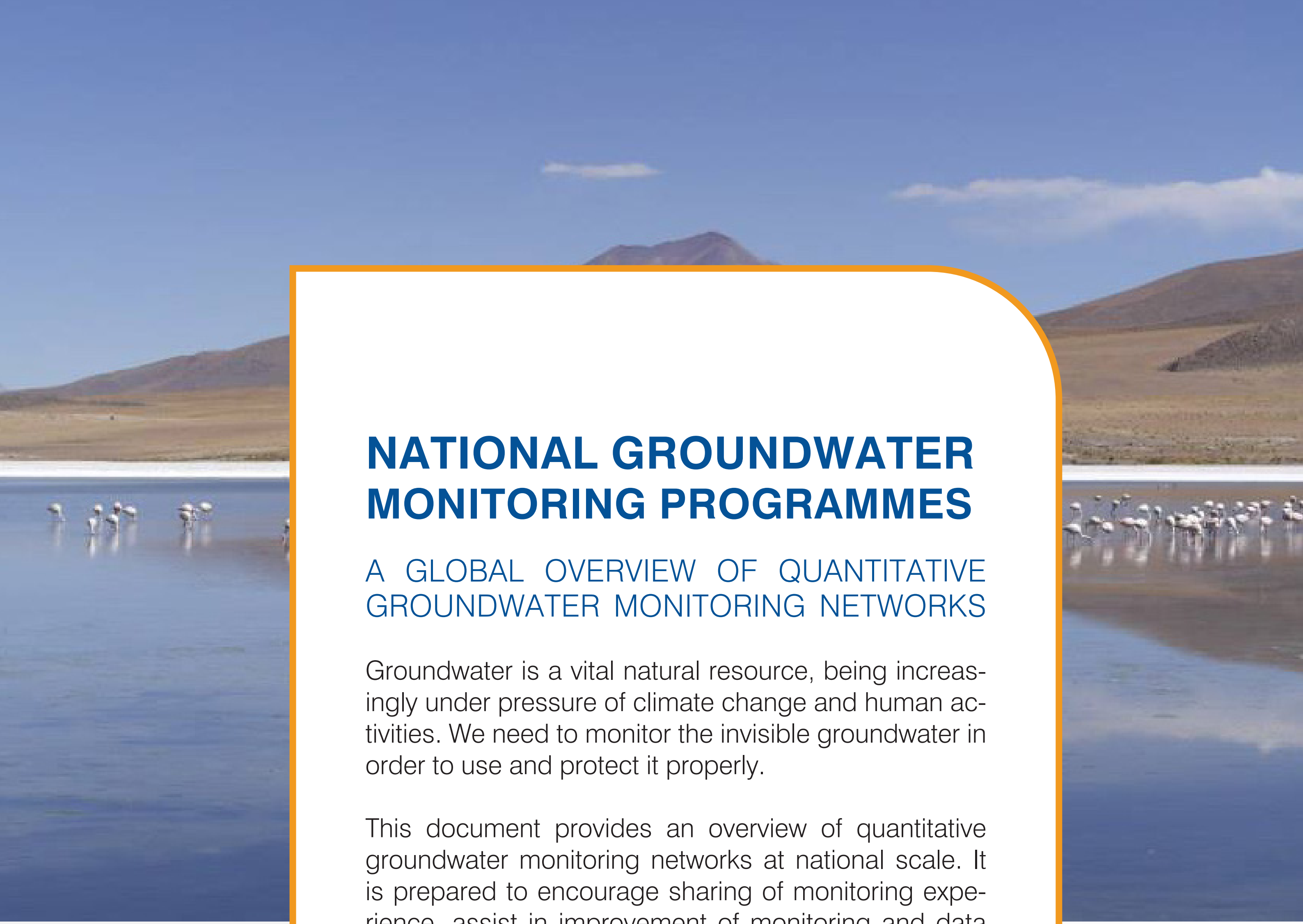


Figure 36 – Hydrogeological map of Venezuela (left) and groundwater level maps for Cojedes State. Source: INAMEH Portal

Sources

- **Decarli, F. 2011. Estado de las Aguas Subterráneas en Venezuela** - http://avias-aguassubterraneas.blogspot.com/2011/10/estado-de-las-aguas-subterraneas-en.html; and
- **INAMEH** - http://www.inameh.gob.ve/web/hidrologia2/hidrologia.php (no longer functioning).



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