VOLUME 5

GROUNDWATER

IN THE NATIONAL WATER RESOURCES POLICY

Series Training in Management of Water Resources

Management Education Diversity

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ANA
NATIONAL WATER AND SANITATION AGENCY - BRAZIL

NATIONAL WATER AND SANITATION AGENCY - BRAZIL
MINISTRY OF REGIONAL DEVELOPMENT

GROUNDWATER
IN THE NATIONAL WATER RESOURCES POLICY

Series
Training in Management of Water Resources
Volume 5

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Setor Policial, Area 5, Block 3, Headquarters Building, Building M
Zip Code: 70.610-200 – Brasília/DF
Phone: (61) 2109-5400 / 5252
Website: https://www.gov.br/ana/pt-br

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Authors
Pilar Carolina Villar
Ricardo Hirata
José Luiz Albuquerque
Ana Maciel de Carvalho

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Editorial Supervision
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Translation into English
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Revision
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ABAS ________ BRAZILIAN GROUNDWATER ASSOCIATION
ANA ________ NATIONAL WATER AND SANITATION AGENCY - BRAZIL
ANM ________ NATIONAL MINING AGENCY
ANVISA ________ NATIONAL HEALTH SURVEILLANCE AGENCY
APA ________ AQUIFER PROTECTION AREAS
BDNAC ________ NATIONAL DATABASE ON CONTAMINATED AREAS
CAF ________ LATIN AMERICA DEVELOPMENT BANK
CBH ________ HYDROGRAPHIC BASIN COMMITTEE
CEREGAS ________ REGIONAL CENTER FOR GROUNDWATER MANAGEMENT
CERH ________ STATE WATER RESOURCES COUNCIL
CNARH ________ NATIONAL REGISTER OF WATER RESOURCES USERS
CNRH ________ NATIONAL WATER RESOURCES COUNCIL
CONAMA ________ NATIONAL ENVIRONMENT COUNCIL
CPRM ________ MINERAL RESOURCES RESEARCH COMPANY
CS ________ SUSTAINABILITY COEFFICIENT
DNPM ________ NATIONAL DEPARTMENT OF MINERAL PRODUCTION
FAO ________ FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
GAC ________ CONTAMINATED AREA MANAGEMENT
GEF ________ GLOBAL FUND FOR THE ENVIRONMENT
GWP ________ GLOBAL WATER PARTNERSHIP
IBGE ________ BRAZILIAN INSTITUTE OF GEOGRAPHY AND STATISTICS

IWRM ———— INTEGRATED WATER RESOURCES MANAGEMENT
LC ———— COMPLEMENTARY LAW
LEBAC ———— BASIN STUDIES LABORATORY
LQP ———— PRACTICAL QUANTIFICATION LIMIT
MDR ———— MINISTRY OF REGIONAL DEVELOPMENT
MMA ———— MINISTRY OF THE ENVIRONMENT
MME ———— MINISTRY OF MINES AND ENERGY
MDGS ———— MILLENNIUM DEVELOPMENT GOALS
SDGS ———— SUSTAINABLE DEVELOPMENT GOALS
OAS ———— ORGANIZATION OF AMERICAN STATES
PAB ———— "GOOD WATER" PROGRAM
PAD ———— "FRESH WATER" PROGRAM
PEC ———— DRAFT AMENDMENT TO THE CONSTITUTION
PEI ———— IRRIGATION PLANS
PERH ———— STATE WATER RESOURCES PLAN
PNAS ———— NATIONAL GROUNDWATER PROGRAM
PNRH ———— NATIONAL WATER RESOURCES POLICY
PPA ———— MULTI-ANNUAL PLAN
PPP ———— WELL PROTECTION PERIMETER
PRA ———— STATE ENVIRONMENTAL REGULARIZATION PROGRAM
PSA ———— PAYMENTS FOR ENVIRONMENTAL SERVICES
PSAG ———— GUARANI AQUIFER SYSTEM PROJECT
PUB ———— BASIC UNIT PRICE
RHN ———— NATIONAL HYDROMETEOROLOGICAL NETWORK
RIMAS ———— INTEGRATED GROUNDWATER MONITORING NETWORK
RM ———— METROPOLITAN REGIONS
RNQA ———— NATIONAL WATER QUALITY MONITORING NETWORK
RPD ———— DIRECT POTENTIAL RECHARGE
RPE ———— EXPLORABLE POTENTIAL RESERVE
SAG ———— GUARANI AQUIFER SYSTEM
SE ———— ECOSYSTEM SERVICES
SGB ———— GEOLOGICAL SURVEY OF BRAZIL
SIAGAS ———— GROUNDWATER INFORMATION SYSTEM
SINGREH ———— NATIONAL WATER RESOURCES MANAGEMENT SYSTEM
SINIMA ———— NATIONAL ENVIRONMENTAL INFORMATION SYSTEM
SISNAMA ———— NATIONAL ENVIRONMENT SYSTEM
SNIRH ———— NATIONAL WATER RESOURCES INFORMATION SYSTEM
SNIS ———— NATIONAL SANITATION INFORMATION SYSTEM
SNSH ———— NATIONAL WATER SECURITY DEPARTMENT
SRHU ———— DEPARTMENT OF WATER RESOURCES AND URBAN ENVIRONMENT
STJ ———— SUPERIOR COURT OF JUSTICE
UNESP ———— UNIVERSIDADE ESTADUAL PAULISTA
VI ———— INVESTIGATIVE VALUE
VMP ———— MAXIMUM ALLOWED VALUE
VO ———— GUIDING VALUE
VP ———— PREVENTION VALUE
VRQ ———— QUALITY REFERENCE VALUE
ZA ———— AGROECOLOGICAL ZONING
ZC ———— CONTRIBUTION ZONE
ZEE ———— ECOLOGICAL ECONOMIC ZONING

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PRESENTATION

The integrated management of surface and groundwater is provided by the National Policy on Water Resources, established by Law No. 9,433/1997, and is a fundamental element to ensure water security in Brazil. Despite their natural and social invisibility, these waters are essential for maintaining the flow of rivers and various ecosystems, in addition to guaranteeing the supply of water for various uses, such as supplying vulnerable populations with no access to tap water. In this context, the members of the National Water Resources Management System (SINGREH) have been working to overcome the challenges in terms of the integrated management of water resources.

Given the importance of the topic, the United Nations (UN) has defined the theme *Groundwater – Making the Invisible Visible* for the 2022 World Water Day. The purpose of this choice was to explain the vital role of groundwater in water and sanitation systems, agriculture, manufacturing, ecosystems and adaptation to climate change.

Aware of the relevance of the groundwater issue and in line with national and international debates on water resources, the National Water and Sanitation Agency – Brazil (ANA) has conducted studies and projects to disseminate better knowledge and monitoring of Brazilian aquifers.

ANA has also been meeting a growing demand for training on this subject and, for that purpose, it has been producing didactic materials, such as the publication *Groundwater Governance: Challenges and Paths*, as well as this training book on the theme Groundwater in the National Water Resources Policy – publication made possible by ANA's partnership with the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Brazilian Cooperation Agency (ABC).

The Training Volume *Groundwater in the National Water Resources Policy* was coordinated by one of the pioneers in the study of groundwater legislation in Brazil, Professor Pilar Carolina Villar, from the Universidade Federal de São Paulo (Unifesp). Professor Ricardo Hirata, from the Groundwater Research Center of the Universidade de São Paulo (CEPAS/USP) and two researchers from the Technological Research Institute (IPT), José Luiz Albuquerque and Ana Maciel de Carvalho have also contributed to the publication.

Due to the technical quality of this training book and the relevance of the groundwater topic, this publication will also have versions in both Portuguese and Spanish so the information contained herein can reach an increasingly wider audience.

Have a good Read!

ANA Board of Directors

The National Water and Sanitation Agency – Brazil (ANA) has as one of its attributions to contribute to the implementation of the National Water Resources Policy and supporting initiatives focused on creating, maintaining and strengthening the National Water Resources Management System (SINGREH).

This strengthening seeks to contribute to decentralization and social participation in the management of water resources, thus allowing a public space for negotiation on the use of water, building agreements and engaging stakeholders in the protection, recovery and management of water resources.

Faced with this challenge, ANA offers a structured agenda of training actions that contribute to the strengthening of the various entities of SINGREH, especially the State Water Resources Councils, the State Water Resources Management Bodies, the Hydrographic Basin Committees and their supporting institutions, Delegate Entities and Support Offices.

Continuing with its challenging initiative to develop ongoing processes of education and training in water resources, ANA presents this new edition of the "Training Volumes" series, which will address various aspects related to relevant topics of the National Water Resources Policy and of SINGREH.

The novelty in this new edition is that the volumes have an interactive editorial and instructional line, with links available for in-depth content, favoring better knowledge management on the topics covered. Moreover, the development of these volumes was guided by the use of simple language principles, adapted to all audiences.

Another change was the thematic rearrangement of the volumes, aiming at facilitating the organization of information and knowledge. All 8 volumes[1] of the first series were regrouped into 4 volumes. We are also presenting a new volume on the theme of groundwater. The new series is, consequently, comprised of 5 volumes according to the following list:

Volume 1: River Basin Committees: what it is and what it does

Volume 2: Complementary Institutional Arrangements for Water Resources Management

Volume 3: Water Agency: what it is, what it does and how it works

Volume 4: Instruments of the National Water Resources Policy

Volume 5: Groundwater in the National Water Resources Policy

Volume 1 discusses one of SINGREH's entities: the Hydrographic Basin Committee, addressing the historical context of its institution, its attributions and its functioning. The organizational structure of the Commit-tees, the role of each of the component elements (Panel, Board, De-partment, Technical Chambers, Work Groups, etc.) are also presented.

The second **volume** addresses the Complementary Institutional Arrangements for the management of water resources. Successful examples of water management on local levels are presented, passing

1 Hydrographic basin committee: what is it and what does it do? (Volume 1); The River Basin Committee: Practice and Procedure (Volume 2); Organizational Alternatives for Water Resources Management (Volume 3); Water Agency – what it is, what it does and how it works (Volume 4); Water resource plans and frame-work of bodies of water (Volume 5); Granting the right to use water resources (Volume 6); Charging for the use of water resources (Volume 7); and Information systems in water management: having knowledge to decide (Volume 8).

through levels of reservoir management in the Semiarid, groundwater and institutional arrangements for water management in border and transboundary basins.

The third **volume** focuses on another entity of SINGREH: the Water Agency or Basin Agency. The jurisdictions, the requirements for the creation, the possible institutional arrangements for the constitution, the management contract in the water resources policy and other related topics are presented. This volume will deal with the Delegate Entities.

The fourth **volume** addresses the National Water Resources Policy Instruments including:

i. the water resources plan, an essential instrument in the implementation of water policies. The importance not only of drawing up plans, but also of their monitoring by the River Basin Committee will be highlighted. Furthermore, it will be necessary to address the challenges in its implementation, in which the exercise of governance among the various actors involved in this process is fundamental to reach the effectiveness of the projected goals;

ii. the classification of bodies of water in classes according to the main uses, deepening the concept, its application and, above all, the challenges of implementing this instrument;

iii. the granting of the right to use water resources. This presents a brief history of the instrument, its legal aspects, the grant for the various purposes of use, among others. In addition to the grant, it also presents some aspects of inspection and registration of users of water resources;

iv. charging for the use of water resources – the importance of the instrument, steps for its implementation, mechanisms and values, in addition to Brazilian experiences in the implementation of charging;

v. the water resources information system, a relevant instrument for advancing water management, with emphasis on the National Water Resources Information System (SNIRH).

This fifth **volume** addresses the issue of groundwater, corresponding to yet another effort to encourage reflection on the management of aquifers, synthesizing the material produced in the book "Aquifer Governance (groundwater: paths and challenges)", in a simpler and more direct approach. Its main goal is to present groundwater to society, identi-fying its importance and demonstrating how to promote its governance and integrated management.

It is worth noting that this new series "Training Volumes" does not end with the 5 volumes mentioned above. The series intends to incorporate other topics considered relevant for the management of water resources, such as sanitation, dam safety, inspection, among others.

With these publications, we hope to stimulate research and training of those interested in the management of water resources, especially SINGREH members, thus strengthening the entire system.

Have a good Read!

1
INITIAL CONSIDERATIONS

Photo: Ana Maciel/ANA Image Database
Fracture zone with presence of water in Couto de Magalhães de Minas - MG.

1 INITIAL CONSIDERATIONS

The management of water resources established by the National Policy on Water Resources (PNRH) has as a general guideline the integrated management of fresh water. Despite the challenges, efforts are gradually being made by the bodies and entities of the National Water Resources Management System (SINGREH) to promote the joint management of surface and groundwater.

The inclusion of groundwater faces multiple challenges, however, it is fundamental to guarantee national water security. Despite their natural and social invisibility, these waters are indispensable for maintaining the base flow of rivers and various ecosystems, in addition to guaranteeing the supply of water for multiple types of uses, including vulnerable populations without access to the tap water system.

The integrated management of water resources requires a governance scenario that allows the construction of a new pact, in order to include public, private and social actors. Groundwater is still little known by a large part of the population, its use is underestimated by the government, most users are in an irregular situation and SINGREH bodies prioritize the management of surface water. This scenario harms the governance of groundwater and threatens the national water availability of a resource that is already intensely exploited and whose demand increases in view of its natural quality and resilience in the face of the recurrence of prolonged periods of drought, which tend to intensify with climate change.

Therefore, this Training Book is yet another effort to encourage reflection on aquifer management, synthesizing the material produced in the book Groundwater Governance: Paths and Challenges, with a simpler and more direct approach. Its main objective is to present groundwater to society, identifying its importance and demonstrating how to promote its governance and integrated management. To that end, the structure of this Notebook is divided into the following chapters: i) **Groundwater in the hydrosocial cycle** - detailing the dynamics of groundwater in the hydrological cycle and the functioning of aquifers, as well as highlighting its ecosystem function and the main threats to this resource; ii) **The building of governance and management of groundwater** – defines the concepts of governance, governability and management, and also presents the main actors responsible for the inclusion of groundwater in national water policy; iii) **Groundwater management: from theory to practice** – presents the main water management tools and how they have been applied to groundwater; iv) **Governance of groundwater and the strengthening of integrated management of water resources** – aims at presenting the strategies and challenges that need to be faced in the search for governance and integrated management of groundwater; v) **Lessons learned and challenges** – lists the main actions and challenges to build a groundwater management agenda; vi) **Final considerations**; and vii) **References**.

The expectation is that this text will help the various social actors to understand the importance of groundwater and the way in which water management instruments can be used to promote the integrated management of surface and groundwater.

2

GROUNDWATER IN THE HYDROSOCIAL CYCLE

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2 GROUNDWATER IN THE HYDROSOCIAL CYCLE

Human actions alter the natural dynamics of the elements that make up the hydrological cycle, modifying the patterns of water availability and its territorial apportionment and distribution through time. Human beings are active agents in the processes of this cycle, interfering in order to increase or decrease these natural flows in the basin or outside it (Linton; Budds, 2014).

The circulation of water is influenced by the institutions, infrastructure and social practices of politicians, citizens, entrepreneurs, users and consumers. Bearing this in bind, the concept of the hydrosocial cycle of water has been strengthened, which politicizes the biophysical conception of the processes of the hydrological cycle. Water does not just move through rain, rock pores and air masses, but through a complex network of water mains, pipes, wells, treatment plants, cisterns, irrigation pivots, garden hoses, leaks, legal rights, quality standards, transport networks, markets and consumers (BUDDS; LINTON; McDONNELL, 2014).

Therefore, water availability is natural, but also social data, a fact that requires the following analyses: a) by whom and how is water used?; b) who has access or control over the water resource?; c) how does the use of water influence power relations in the countryside and in society?; d) how does its presence or lack determine the conformation of a society?; e) how do financial flows interfere with water flow independent of the hydrological cycle?; f) how does society interfere in the elements that make up the hydrological cycle?; g) which and who are the beneficiaries of hydraulic infrastructure? (LINTON; BUDDS, 2014).

Concerning groundwater, these represent the hidden dimension of the hydrological cycle and are underestimated in the hydrosocial cycle. Therefore, the challenge arises of understanding how the natural movement of the hydrological cycle takes place in the underground environment and how it relates to other bodies of water and, also, how human actions interfere in this natural dynamic and vice versa. To this end, the next sections explain the dynamics of these waters in the hydrological cycle, detailing the functioning of aquifers and their socio-environmental importance for the provision of various ecosystem services, including the supply of water for different types of uses.

2.1 The hydrological cycle and groundwater

Water is always in motion, circulating on surfaces (glaciers, icebergs, rivers, lakes, seas etc.), through the atmosphere (clouds) or underground (aquifers, aquitards). That cyclical movement, named *hydrological cycle* or *water cycle*, is related to exchange of energy between the atmosphere, the ocean and continents, sustaining the climate and a large portion of its natural variability (OKI; ENTEKHABI; HARROLD, 2004; COCKELL *et al.*, 2011). Sunlight (radiation) and the heat from the Earth's interior (emitted by radioactive nuclear reactions) are the energy sources that promote the transformation of water states (liquid, solid and gaseous) and, consequently, water's continuous movement on the planet.

Variations in the incidence of solar radiation; changes in the composition of the atmosphere and ocean water; ocean winds and currents; volcanism; the type, pattern and density of vegetation cover; variations in the spatial distribution and number of living beings; and the types of soil and subsoil influence the functioning of this cycle (COCKELL *et al*., 2011; Grotzinger; Jordan, 2013).

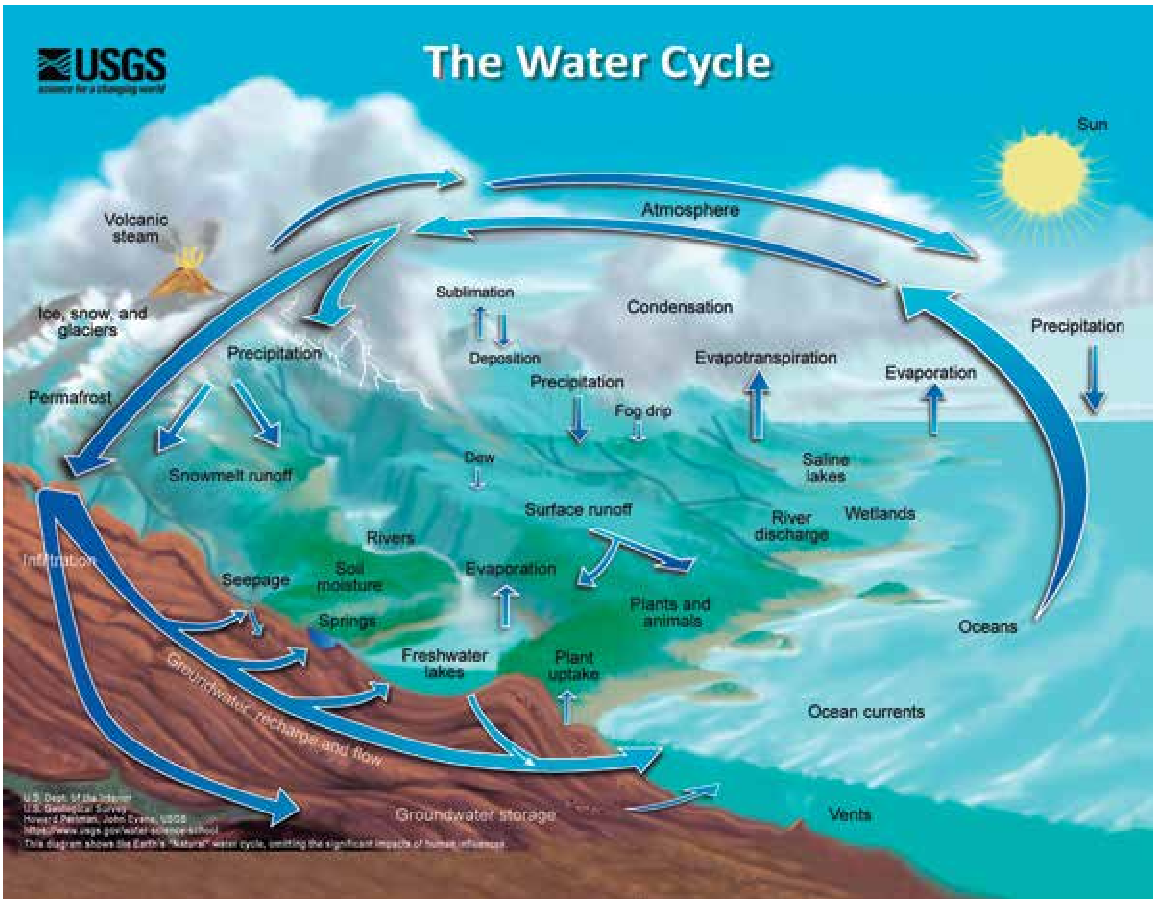
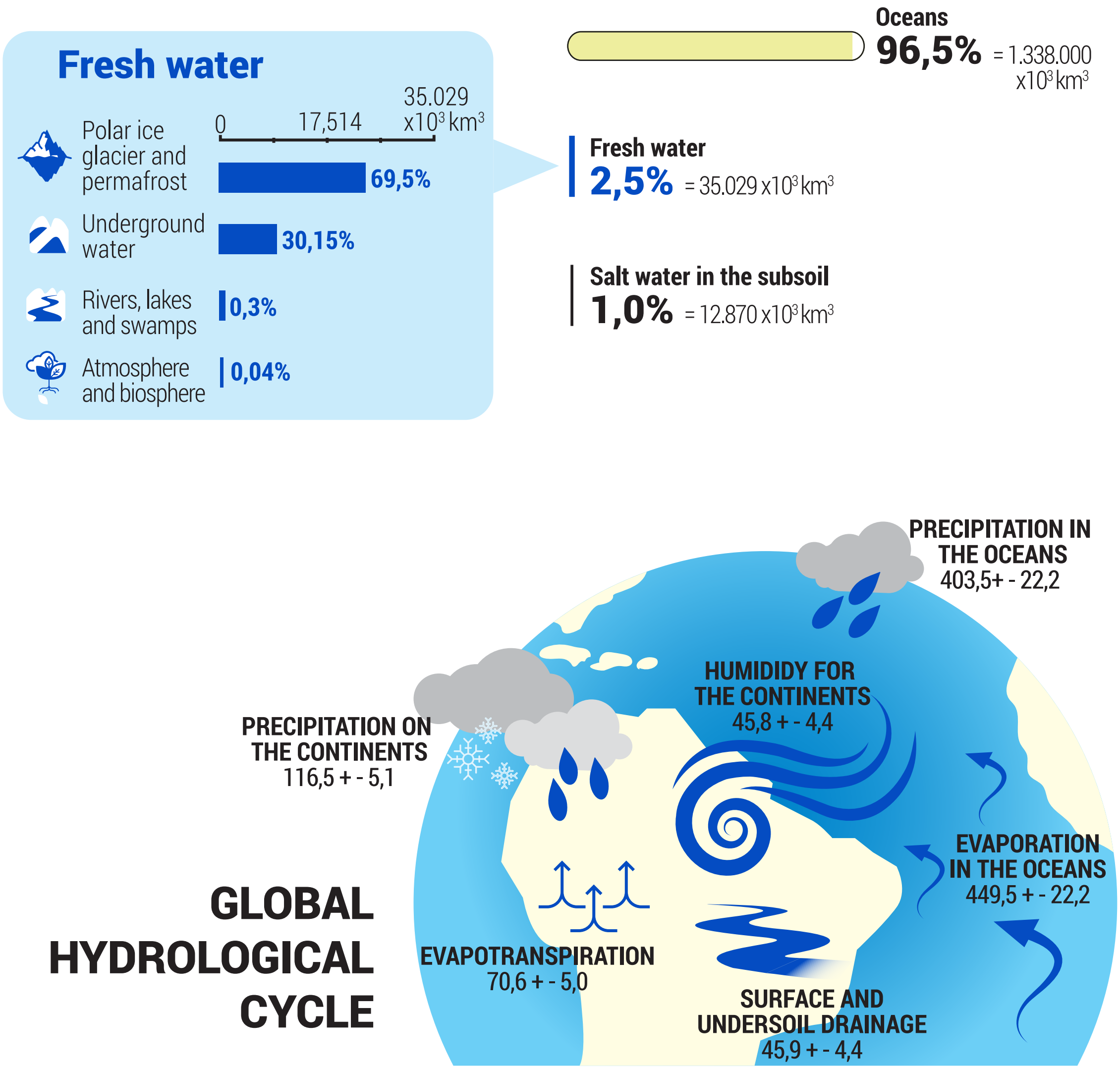


Figure 1 - Water cycle
Source: USGS (2019).

The amount of water on the planet is constant, however, its distribution in nature is uneven and cyclical. The largest volumes are concentrated in the oceans, while fresh water represents only 2.5% of the total. Most of this fresh water (69.5%) is concentrated in glaciers, i.e., it is not available; or underground, in the form of groundwater (30%). Surface bodies of water represent only 0.3% of fresh water. Figure 2 shows the distribution of these volumes and the annual average of flows in the global hydrological cycle.



Annual average of flows in the global hydrological cycle and associated uncertainties in years 2000 to 2010. Source: rodell et.Al. (2015)

Figure 2 - Water volume and annual average of flows in the hydrological cycle

Source: Shiklomanov and Rodda (2003); Rodell et al. (2015), adapted by Dora Atman.

This data shows that groundwater is the main water source available to humanity. To understand the dynamics of the global hydrological cycle, it is necessary to understand how the main processes that regulate water availability are structured: i) evaporation; ii) evapotranspiration; iii) precipitation; iv) surface outflow; v) base flow; and vi) infiltration. These processes form the drainages, which provide for recharge, discharge and percolation. The definitions of each of these terms are described below.

i. **Evaporation**: is a type of vaporization that occurs on the surface of a liquid as it passes into the gaseous (vapor) phase. It is a physical phenomenon of water and energy transfer induced by the flow of latent heat from water surfaces to the atmosphere.

ii. **Evapotranspiration**: is the removal of water from the surface to the atmosphere by the combination of two processes: evaporation plus plant transpiration. For example, evapotranspiration from the Amazon Rainforest impacts water availability in other basins and Brazilian regions. This forest releases into the atmosphere "20 billion tons of water per day", exceeding the flow that the Amazon River discharges into the sea (17 billion tons). Deforestation reduces evapotranspiration and, consequently, condensation, reversing the flows of moisture that go from land to sea, generating deserts and reducing rainfall in the Midwest, Southeast and South regions of Brazil (NOBRE, 2014, p. 13). These moist air masses are called flying rivers, as they can be equated with true "atmospheric waterways."

iii. **Precipitation**: is the process of condensation of atmospheric water vapor that agglutinates and precipitates or falls on the earth's surface. Water added to the Earth's surface from the atmosphere occurs in liquid (rain) or solid (snow or ice) form. Precipitation varies greatly across geographic space and time.

iv. **Surface outflow**: is defined by the flow of water that occurs on the surface of the soil when it is saturated with moisture or when it is impermeable. Water from precipitation can, successively, form floods, drainages (brooks, streams, rivers), lakes etc. This flow can occur in a diffuse or concentrated form, and form ephemeral flows along the valleys. Surface outflow depends on the intensity of rainfall and surface characteristics (such as slope, topography and type of vegetation cover).

- **Surface drainage**: represents the courses and flows of surface water that form brooks, streams, creeks and rivers. They can be either intermittent (when the water flows in their courses during the rainy and dry seasons), or perennial (when the water flow remains throughout the hydrological year and does not dry up). Intermittent streams are formed by surface and subsurface outflow of rainwater, while perennial streams also receive groundwater flows from aquifers.

v. **Infiltration**: is the passage of water from the surface into the soil. The infiltration capacity of a terrain depends on its topography, vegetation cover, degree of soil moisture, physicochemical properties and intensity and duration of rainfall.

- **Percolation**: process by which water moves vertically and downwards along the unsaturated zone (vadose or aeration zone) after infiltrating soils and rocks. The **unsaturated zone** is the portion of the subsurface where the spaces between soil and rock particles are filled with water and air (soil moisture). The percolation of water in the soil occurs when its infiltrated volume is sufficient to force the downward displacement of the water.

- **Recharge**: when water enters the subsurface, it is distributed in the voids in two main zones: **unsaturated zone** and **saturated zone**. Recharge occurs when water that percolates into the unsaturated zone descends and reaches the aquifer surface or phreatic surface (water saturated zone). In the saturated zone, the voids are completely filled with water. The threshold between these two zones is called the *water table* or *groundwater level*. At the base of the unsaturated zone is a wet region called the capillary fringe. This region has variable thickness and represents a transition from the unsaturated zone to the saturated zone. This is due to capillary forces that lift water from the aquifer into the voids of neighboring soils above. Recharge, therefore, occurs when water seeping into the unsaturated zone reaches the top of the aquifer (water-saturated zone).

Infiltration, *percolation* and *recharge* are portions of water that are difficult to estimate. Infiltration tends to be greater than the percolated volume, which, in turn, is greater than the recharge volume. The reason for that is that some of the water is trapped or adsorbed on soil or rock particles along the way, and some is evaporated in the process. If the saturated zone is very deep and precipitation or infiltration rates are low, infiltration and percolation can occur along the surface layers, but recharge will be zero. Therefore, aquifers are not supplied homogeneously, with areas that are more favorable to the processing of recharge, which can be altered with changes in land occupation. It is important that the management of water resources take this characteristic into account.

- **Discharge:** it is the process of water leaving aquifers, where groundwater emerges and flows on the surface (source locations) and, mainly, along water courses, such as rivers, lakes or oceans. Underground discharge is responsible for the perennialization of rivers and the formation of springs.

vi. **Base flow or groundwater flow**: is the movement of water along the saturated zone. Water in soil and saturated rocks flows through voids, such as pores, open fractures, and other voids left by the dissolution of minerals. These spaces need to be interconnected so that water can flow. The force of gravity and the pressure of the water column generate the movement of groundwater. Its flow always occurs in the direction of the highest to the lowest hydraulic head, which is the sum of the altimetric elevation load plus the pressure head of the water column at a given point in the underground reservoir. The hydraulic head is measured by monitoring wells, whose instruments are distributed along the underground reservoirs, in conjunction with knowledge of the hydrogeological system, allowing one to define the direction of the flow.

Contrary to popular belief, in most cases groundwater does not form underground rivers or streams of water[1], but fills pores and fractures in the way a sponge absorbs water, flowing slowly. In addition to their role in the hydrological cycle, these waters provide a series of ecosystem services (Manoel Filho, 2008).

2.2 Groundwater and its ecosystem services

Groundwater in the hydrological cycle provides several ecosystem services, for they are linked to the processes that regulate the volume, distribution and quality of water available on the planet. The concept of ecosystem services (ES) was introduced by Ehrlich and Ehrlich (1981) and it is defined as goods and benefits provided free of charge by ecosystems to humans in order to promote their well-being (Bergkamp; Cross, 2015). Its premise is that natural systems generate the support base for life on the planet. Groundwater sustains the SEs that are essential for the life and well-being of the population and ecosystems (Figure 3).

1 Exceptionally, it is possible to find some caves, lava and ice ducts or horizontal springs that resemble water currents.

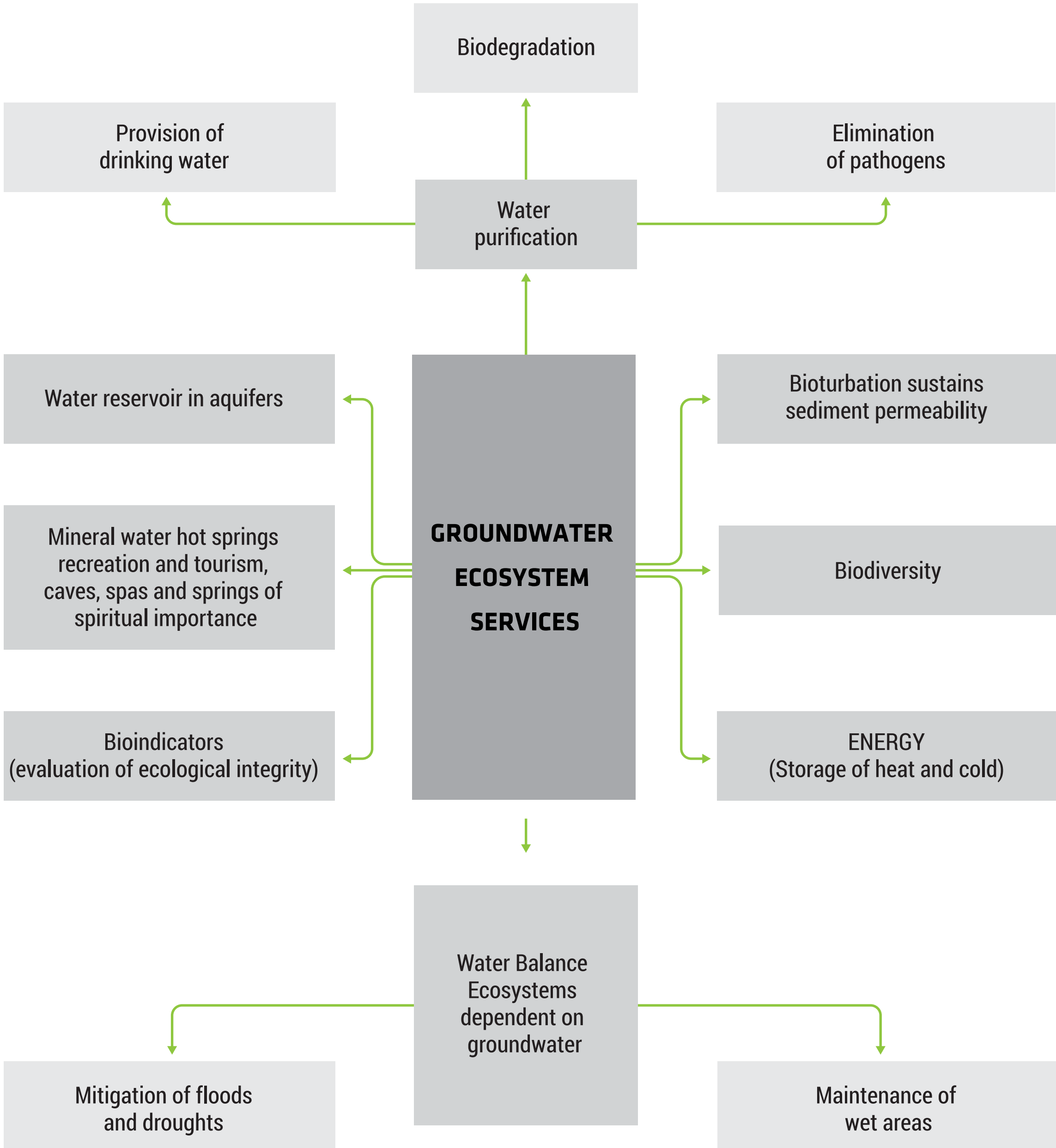


Figure 3 - Main ecosystem services provided by groundwater
Source: Griebler and Avramov (2015, page 356).

We note that groundwater's importance goes far beyond the supply of water for human beings. Among its multiple ecosystem functions, the following stand out: a) storage, regularization and perpetuation of the planet's hydrological cycle; b) treatment of the soil-aquifer system and groundwater quality; and c) maintenance of life and ecosystems and geological stability.

Photo: AdobeStock
Poço Azul at Chapada Diamantina - BA.

a) Regularization and perpetuation of the hydrological cycle on the planet

Groundwater functions as water reserves for rivers and lakes, as it continually contributes to the maintenance of the surface flow that sustains most water courses. The rates of discharge from aquifers are more regular than the distribution of precipitation, which ensures a constant minimum flow to surface water courses and provides stability to water systems. Therefore, these discharges have a regulatory function of the hydrological cycle in hydrographic basins and even on the scale of the planet. In Brazil, more than 90% of river basins have rivers fed by groundwater discharge (ANA, 2017a, p. 37) that perpetuate the river basins, even for those in climatic regimes with dry periods. This service extends to lakes, swamps and mangroves.

b) Treatment of the soil-aquifer system and the excellent quality of groundwater

The water that percolates into the aquifer goes through a filter-like process along its underground path. During infiltration and percolation in soils, part of the water and dissolved substances is absorbed by plant roots and adsorbed to solid particles. Water, throughout the hydrogeological cycle, acquires different chemical characteristics that vary according to the proportion and the type of dissolved solids. The amount of chemical elements in groundwater depends on the climate in the recharge areas, the chemical conditions of the vadose zone, and the geology of the groundwater system through which it flows. The interaction of water with soil and rock particles normally allows their enrichment thanks to the dissolution of minerals, whose process tends to increase with the time of interaction between water and rock and the reactivity of the solid material itself. In many cases, the result of this journey to the discharge points is water of excellent quality and rich in mineral salts. In some cases, however, the dissolution of these minerals can generate quality problems in the water, including natural anomalies that can compromise its potability.

c) Maintainer of life and ecosystems, and geological stability

The supply of water from aquifers is essential for the maintenance of ecosystems, especially in areas where there is interaction between groundwater and surface water. Groundwater discharges into surface bodies of water contribute to the maintenance of surface water flows, the regulation of water temperature, the exchange of nutrients and other hydrochemical parameters that influence the balance of conditions favorable to the life of animal and plant species.

Groundwater does not show sudden changes in temperature or in its physicochemical qualities, so the groundwater inflow provides a stable habitat for aquatic plants and animals. Moreover, the discharge of aquifers is essential to maintain coastal lakes and mangroves, as it allows dilution of the salinity of marine influences, distributes nutrients and regulates physicochemical conditions.

Even in cases where there are no outcrops, groundwater is relevant to ecosystems. For example, despite the absence of water courses and springs, it is common to find lush vegetation on the bottom of the valleys. This is explained because the water table in a valley is closer to the surface and the water level does not fluctuate as much. In the absence of rain, the water level in the higher parts is significantly reduced, but in thevalleys there may be no variation, as the water infiltrated in previous rains is still moving slowly towards the valley (Poeter *et al*., 2020). Therefore, vegetation has access to water throughout the year.

These waters also support extensive semi-arid and humid terrestrial ecosystems, without water courses, but with deep-rooted vegetation, which extracts moisture directly from the water table. In the "Cerrado" plain there are several species that have developed deep roots to absorb water from aquifers. Finally, there is an entire flora and fauna associated with hydrothermal springs, which are the places where heated and mineral-enriched waters emerge from a long underground path.

Furthermore, the waters contribute to geological stability, as they ensure the maintenance of the pore structure of rocks, preventing or reducing the risk of subsidence of land or cave ecosystems.

2.3 Groundwater in Brazil and its socioenvironmental importance

Unlike surface waters, the presence of groundwater and aquifers is not confirmed by merely observing the territory. Identifying them and determining the quantity and quality of these waters requires the availability of data, geological maps and models that contemplate rock and water interaction. Since the 1980s studies, especially those reports produced by the Brazilian Geological Survey (SGB-CPRM) have been carried out to delimit these bodies of water.

The number of aquifers in Brazil is still uncertain. ANA (2013a) distributed Brazilian groundwater into 181 aquifers and outcropping aquifer systems (Figure 4)[2]. Of these, 151 are sedimentary aquifers (higher productive potential) and 26 are karst. The fractured domain (lower productive potential) was grouped into four large blocks: Semi-arid Fractured Aquifer System, Northern Fractured Aquifer System, Central-South Fractured Aquifer System and Serra Geral Aquifer (ANA, 2013a, pp. 54-56).

2 For SGB-CPRM, the lithological units were organized into 202 hydrostratigraphic or aquifer units, of which 164 are outcrop units and 38 are non-outcrop units. (DINIZ *et al.*, 2014, p. 20).

2 GROUNDWATER IN THE HYDROSOCIAL CYCLE

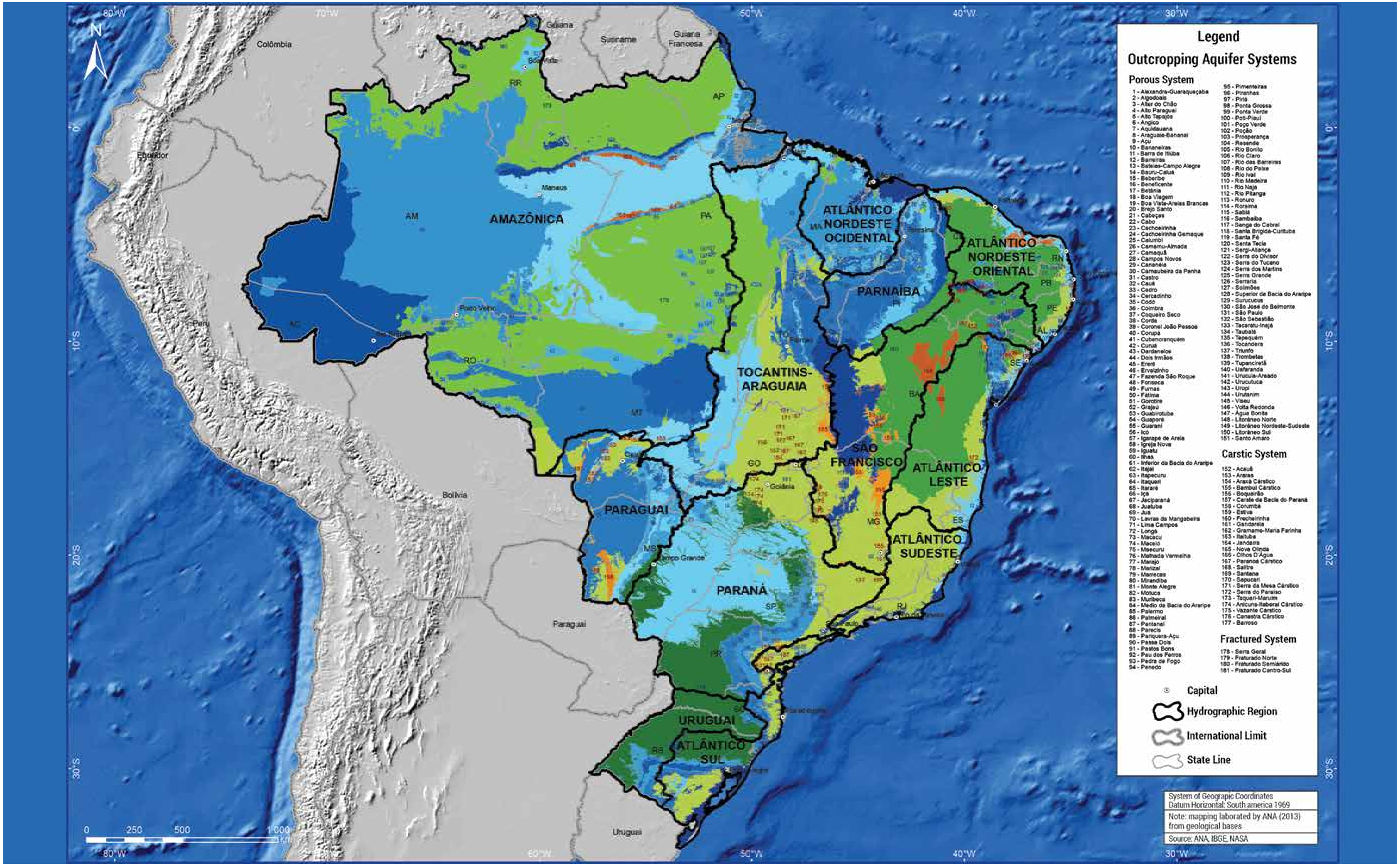


Figure 4 - Outcrop Brazilian aquifer systems
Source: ANA (2013a).

It is estimated that Brazil has 1.1 trillion m^3/year of groundwater reserves (ANA, 2020, p. 8). On this basis, availability would be approximately 14,650 m3/s, with the distribution and productivity of aquifers occurring unevenly across the territory (ANA, 2020, p. 23).

In the global context, Brazil is the 9th largest user of groundwater (Hirata et al., 2019, p. 47). The actual usage rates, however, are unknown, as most users are not regularized. ANA (2020) estimates that there are about 2.4 million wells in Brazil, however, the SGB-CPRM's Groundwater Information System (SIAGAS) recorded in October 2021 only 346,150 wells. The database fed by the Federative Units, in turn, recorded only 101,074 wells (ANA, 2020). To Hirata et al. (2019), this number would exceed 2.5 million driven wells, which would have an extraction capacity of about 17,580 Mm3/year (557 m3/s), whose volume would be able to supply the entire Brazilian population for a year. (Hirata *et al*., 2019). This driven well infrastructure represents an investment of approximately R$ 75 billion in drilling and complementation services and pumping equipment (HIRATA *et al*., 2019).

2.3.1 User profile and its role in water security

Groundwater is essential for domestic and public supply, industrial processes, the provision of various types of services and agricultural activity. Figure 5 shows the profile of users based on the following classifications: agriculture and livestock (wells dedicated to irrigation or watering animals); domestic supply (urban residences); public supply (water service providers); industrial (wells that supply industries); multiple use (they serve more than one purpose, being mostly the provision of urban services); and others (wells for purposes not listed in the other categories, such as leisure). Domestic supply is the main user (30%), followed by agricultural use (24%), urban public supply (18%), multiple supply (14%), industrial supply (10%) and others (4%) (HIRATA *et al*., 2019).

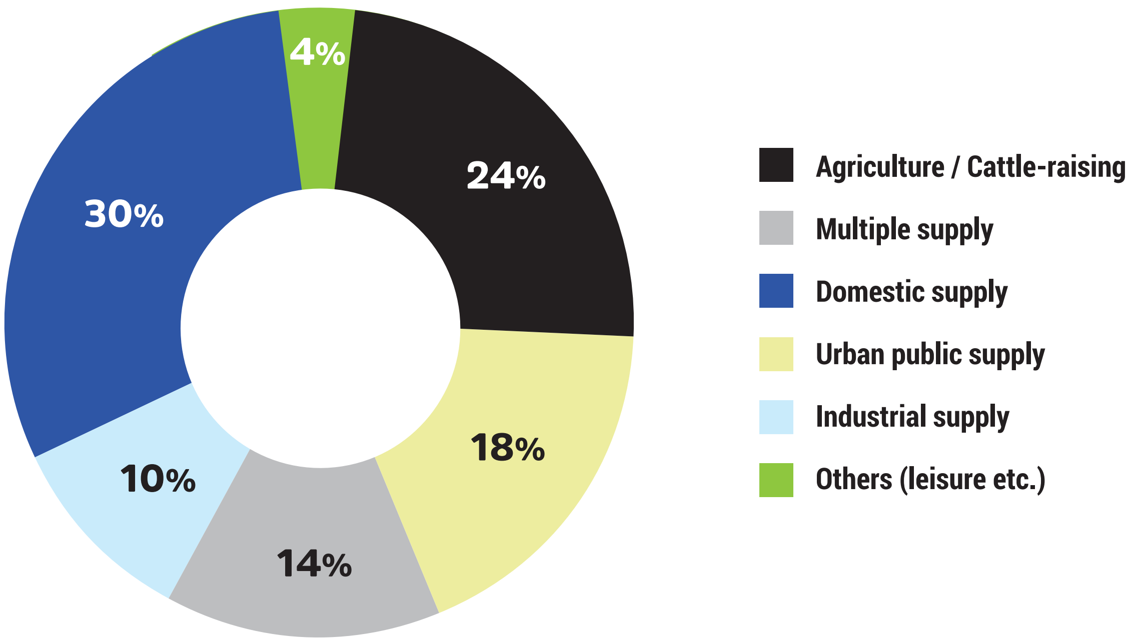


Figure 5 - Profile of groundwater users in Brazil
Source: Hirata *et al*. (2019, p. 15).

According to data from Hirata *et al*. (2019), of the total groundwater extracted in the country (557 m^3/s), only 10% (53 m^3/s) serve public supply of cities through public utility concession holders and municipal services. Although these flows are low, the resource is essential for public water supply in small (< 10,000 people) to medium- (< 100,000 people) sized cities. Almost half of the municipalities with a population less than 10 thousand are totally dependent on groundwater. They represent the only source in 36% of Brazilian municipalities and in a complementary way (mixed systems) in 16%. Therefore, 52% of municipal seats depend to some degree on this resource (Figure 6) (ANA, 2010).

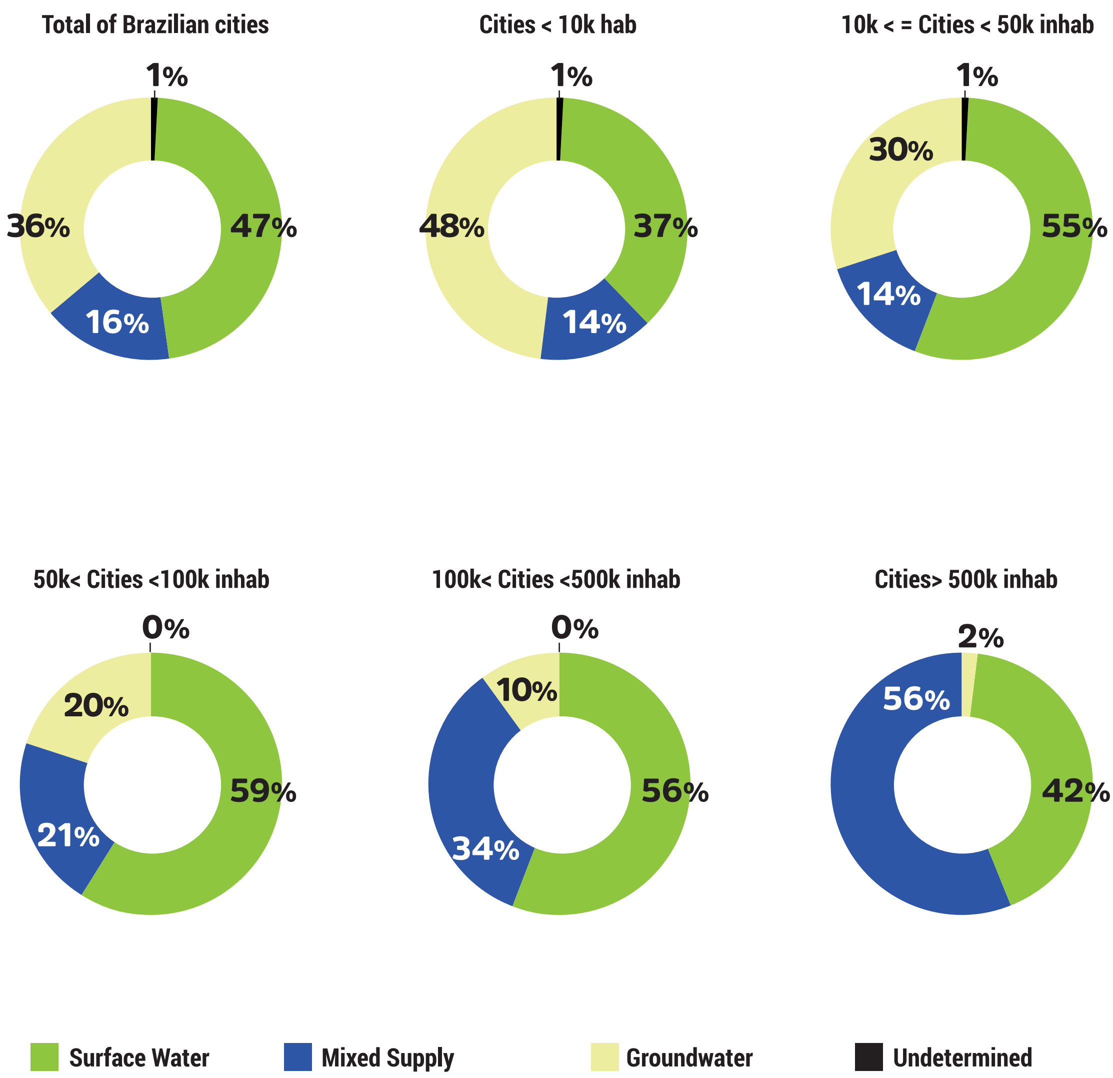


Figure 6 – Distribution of Brazilian municipalities (total and by population size), according to the type of supply source

Source: Hirata *et al.* (2019).

Regarding urban use, the most dependent states are: São Paulo, Piauí, Ceará, Rio Grande do Sul, Bahia and Paraná. As for rural use, the main user state is Minas Gerais, followed by São Paulo, Bahia, Tocantins and Rio Grande do Sul (Hirata *et al.*, 2019). Although the Northeast does not appear as a major rural user, groundwater is widely used by populations in the semiarid region, including those waters from brackish aquifers, turned potable through filtering technologies.

The importance of groundwater in rural areas is still poorly recognized (Aly JÚNIOR, 2019). According to the IBGE Agricultural Census (2017), there are approximately 3 million abstractions from excavated wells and springs, in addition to 1.03 million rural properties equipped with at least one driven well. Despite their low flow, dug wells and springs are the main source of water in peripheral regions that do not have a water network, such as villages in the mountains and small rural properties. Its use for irrigation should also increase due to its quality and lower susceptibility to climatic instability that threatens agricultural production (Hirata; Varnier, 1998). In 2015, the largest number of valid grants belonged to the urban and rural supply sector, followed by industry (ANA, 2016). However, when analyzing the average extraction flow among users (relative to the number of grants/flow), we note that the main user was the agribusiness (48.6 m^3/h), followed by manufacturing (20.86 m^3/h) and supply (17.89 m^3/h) (Figure 26 B) (ANA, 2016). Proportionally, rural users use greater amounts of groundwater compared to others, which demonstrates the need for more studies on this type of use (Aly JÚNIOR, 2019).

Groundwater is also essential for the industry because although in the set of wells of the Mineral Resources Research Company (CPRM) these wells represent only 10% of users. Within the scope of granted uses they constitute 25% and have an average flow slightly higher than the supply. Several industries use this source, even in areas equipped with water network infrastructure, given the cost advantage and the fact of having their own water source (Hirata *et al*., 2019). Moreover, we cannot forget the beverage industry and mineral and table drinking waters, which also use this resource.

2.3.2 The advantages of using groundwater

The use of groundwater has intensified due to growing demand for water resources, the degradation of surface water sources and the increase in drought periods. This increased use tends to affect surface waters more

(Hirata; Conicelli, 2012). The use of groundwater has several advantages over surface waters, such as:

- the good natural quality which, in most cases, requires only chlorination/fluoridation;
- lower costs related to obtaining water, extracting, maintaining and operating the extraction, compared to sources of surface water systems;
- the autonomy of the driven wells, which work in an automated way, requiring little maintenance;
- the exclusivity of owning a water source and controlling its use;
- the lowest environmental impact of underground extraction. The deep driven well is considered to have a low impact compared to surface capture, which involves treatment plants, distribution stations and dams;
- the ease and speed of the infrastructure necessary to enable the extraction. The execution time of a well is from days to weeks; on the other hand, dams and water treatment plants require years;
- implementation of the underground water extraction system can be carried out gradually, rationalizing investments in water capture;
- the lack of use of expropriation of large areas, which represent massive financial expenses;
- the possibility of a sector-based distribution, with exploration batteries, constituted of isolated or interconnected systems and, many times, close to the demand, reducing the construction of long pipelines;

- less susceptibility to climatic conditions, for the storage capacity of the aquifers makes the flow stable even during drought periods.

2.4 What are aquifers and how they work

The aquifer is a "geological formation capable of accumulating and transmitting water through its pores, fissures, or spaces resulting from the dissolution and transport of rocky materials" (article 2, I, Res. CNRH 202/2018). In practice, only those geological units capable of producing water through wells, under economically viable conditions, are considered aquifers. In Hydrogeology[3], geological formations can be classified according to their ability to store and transmit water into three categories: *aquifers*, *aquitards* or *aquicludes*: Aquicludes and aquitards can relate to aquifers as they delimit their top and/or base. However, they have little to no ability to transfer water and are considered impermeable or semi-permeable. Aquicludes are geological formations that contain water in their interior, however, without transmission capacity. Aquitardes are semi-permeable formations that may contain water, but their transmission occurs very slowly, rendering economic exploitation unfeasible.

The classification of formations in one of these categories is done through the evaluation of the rock's or sediment's ability to transmit water, represented by the hydraulic conductivity parameter (or proportionality coefficient of Darcy's Law[4]). Hydraulic conductivity in aquifers is equal or higher than 10^{-4} cm/s (or 8.64 cm/day), which represents the speed of the water flow.

3 Hydrogeology: is the area of geology that deals with the distribution and movement of groundwater in the soils and rocks of the earth's crust.

4 Darcy's Law is a phenomenological constitutive equation that describes the flow of a fluid through a porous medium (DARCY, 1856). Cabral (2008, p. 77) explains this equation in didactic terms.

Aquifers can be classified according to their rock types and the pressure to which they are subjected. These characteristics influence water storage capacity, flow speed, recharge rates and vulnerability to contamination.

Regarding the type of rock, aquifers can be classified into three simplified categories: a) *granular*; b) *fractured*; and c) *karsts*. This classification is related to the origin of the rock or sediment, its degree of consolidation and fracturing or dissolution.

- **Granular aquifers**: are composed of sediments or sedimentary rocks. Known as *primary porosity aquifers*, which are generated at the time of depositing of sediments and distributed uniformly, facilitating the extraction of water. The total porosity of unconsolidated sediments varies between 25 and 40% for gravel, 25 and 50% for sand and 35 and 50% for silt (Freeze; Cherry, 1979). The increase in granulometry tends to decrease the porosity of the rock. The degree of grain selection, its sphericity and the occurrence of cementation also influence porosity.

- **Fractured aquifers**: they are formed by intrusive crystalline, metamorphic and igneous rocks, which are geological materials of low primary permeability, however, when subjected to tectonic efforts, fracturing occurs. Known as secondary porosity aquifers, water is stored through the voids delimited by these fractures in the rock, which have various orientations and are connected to each other, forming a system or network of fractures. Its porosity is low, but the groundwater flow speed can be high, being restricted to a small percentage of fractures, but with good conduits. These aquifers can also be formed in sedimentary rocks of low primary permeability, such as shale, siltstones, mudstones, some limestones and cemented sandstones (FREEZE; CHERRY, 1979; SINGHAL; GUPTA, 2010).

Photo: Érico Hiller/ANA Image Database
Emergence of a fractured aquifer in the rural area of Guaribas - Piauí.

- **Karst aquifers**: are composed of karstified carbonate rocks that have generated networks of conduits/cavities through which water is transmitted and stored. Its origin results from the dissolution process of soluble rocks, such as limestone, dolomite, quartzite, sandstone with carbonate cementation etc. They are known as *tertiary porosity aquifers* due to *karstification*, a phenomenon that minimally requires the following conditions: i) rock with chemical capacity to dissolve; ii) acidic water (solvent), resulting from the contact of rainwater with carbon dioxide (CO2) in the atmosphere or in the soil, capturing CO2 from organic matter; iii) hydraulic gradient (differences in hydraulic loads that allow the flow of solvent; and iv) discontinuities in the rock (fault/fracture, bending, bedding plane or stratification) that allow the flow of water. Over time, the discontinuities in the rock widen and, progressively, a hierarchical structure develops, such as a system or network of karst conduits. If this karst structure is in the water-saturated zone, it will be considered the karst aquifer. Underground flow, therefore, determines the hydrogeological structure of the karst environment which, in turn, creates a feedback effect, modifying the conditions of this flow (GOLDSCHEIDER; DREW, 2007)

The formation of these aquifers is related to the geological and geomorphological processes that took place on the continent. According to ANA (2013b), aquifers and sedimentary aquifer systems outcrop in 53.8% of the national territory, fractured in 44.7% and karst in only 1.5% (Figure 7). Aquifers do not occur homogeneously or uniformly in the Brazilian territory. The rocks or sedimentary packages that compose them and their exposure to different climates mean that each one of them presents specific conditions of infiltration, percolation, flows, storage and water discharges, which impact their production and the quality of their waters.

Figure 7 - Distribution of fractured, sedimentary and karst aquifers in Brazil

Source: Diniz *et al*. (2014, p. 25).

Understanding the distribution of rock types in the Brazilian territory and the way in which their characteristics influence the flow of groundwater helps to distinguish the main aquifers in the country, *i.e.*, those with greater capacity for storage and transmission of water. The relevance of rock as an aquifer is defined through its physical-chemical properties, among them/-: porosity, permeability (or hydraulic conductivity), conditions of occurrence (extension, thickness and structure) and the technical and economic extraction possibility.

Concerning the water storage pressure to which they are submitted, aquifers are also classified as: a) *uncontained* and b) *contained* (Figura 8), although there are intermediary conditions between these two types, such as *semi-contained*, *covered* or *suspended* aquifers.

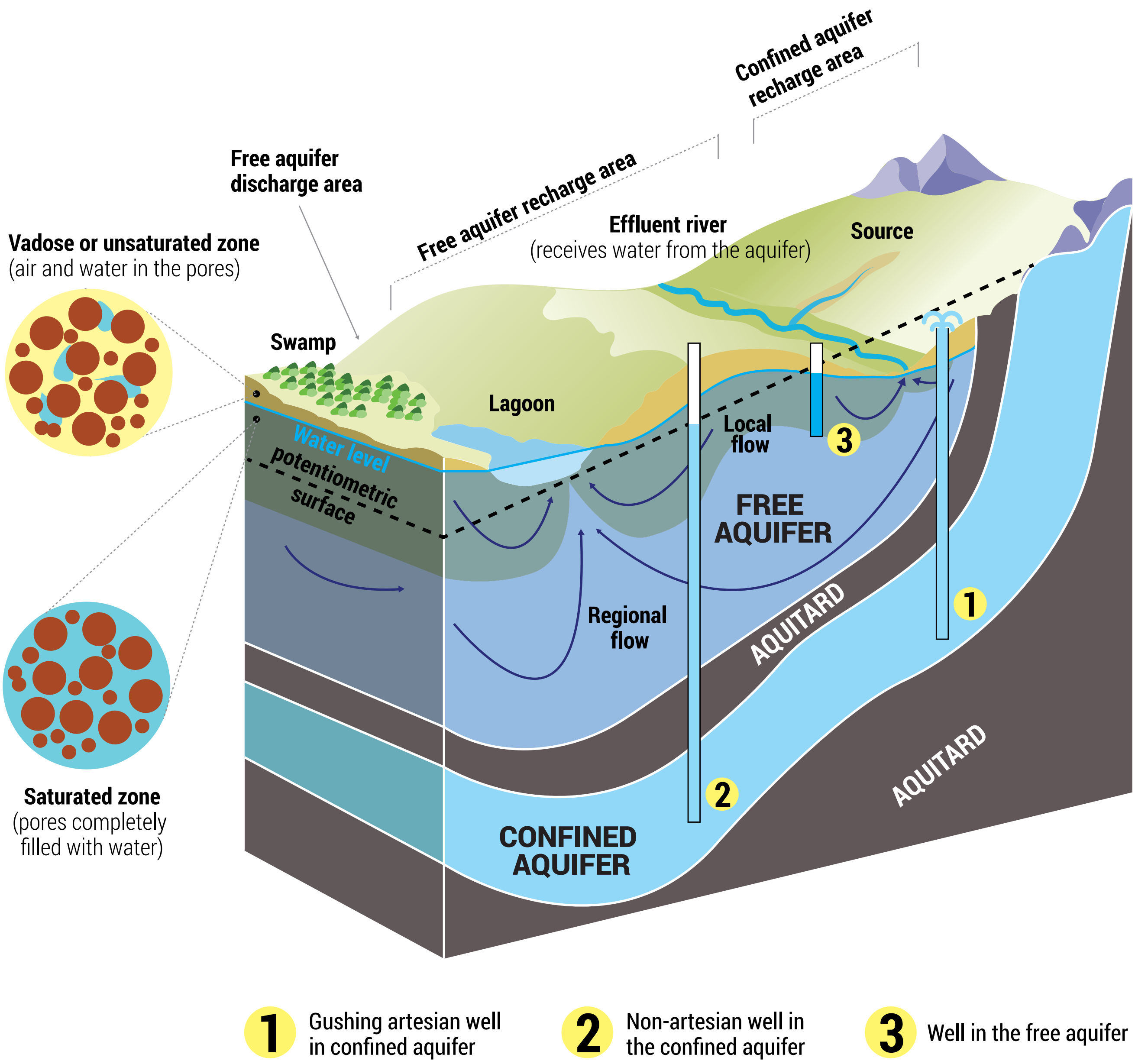


Figure 8 - Operation of an aquifer

Source: Cabral (2008), adapted by Dora Atman.

In uncontained aquifers the upper limit is formed by the water level, which corresponds to the top of the saturated zone (phreatic surface), in equilibrium and under the same atmospheric pressure conditions. Contained aquifers are bounded at the base and top by non-aquiferous units (aquicludes) or partially impermeable rocks (aquitards), with water stored under pressure. In the intermediate situation are semi-contained aquifers, whose layers that limit them have low permeability, causing water to pass through very slowly.

Since confined or semi-contained aquifers are under pressure, when drilled by the well, the water overflows and its equilibrium piezometric water level is above the top of the aquifer layer (reservoir) (Figure 8). In some cases, depending on the topography and pressure of the aquifer, this water may rise above the surface and form artesian (gushing) wells.

Groundwater flows slowly towards the lower *areas* as it percolates through the vadose zone (Figure 8). While the surface water flow moves for miles in a few days, the underground flow advances millimeters or inches per day. The movement of groundwater takes place through the filling of empty and connected spaces of the rocks and a slow displacement in the saturated zone. This difference in flow speed allows water that infiltrated tens, hundreds or even thousands of years ago to still be slowly moving in the underground environment. Therefore, the aquifer stands out more for its storage than for its high production when compared to rivers.

The volumes stored in uncontained aquifers fluctuate seasonally or over multi-annual cycles, demonstrating that part of the incident and infiltrated rainfall at the surface reaches the aquifer (recharge) and leaves it (discharge) over time. Due to their size and recharge dynamics, even small aquifers have waters that can be decades and even thousands of years old.

Photo: AdobeStock
Artesian well drilling.

Fluctuations in the volume stored in aquifers configure a dynamic equilibrium sustained by variations in precipitation along climatic seasonalities and by internal changes in recharge and discharge rates resulting from variations in the hydraulic gradient. When the water level of the aquifer rises over time as a result of increased recharge, there is a natural tendency for water outflow rates to increase by increasing discharge – for example, through increased groundwater flow. that reaches the rivers. On the other hand, when the water level of the aquifer decreases due to the decrease in recharge, there is a tendency for the discharge rates to decrease (e.g,. decrease in the base flow of rivers). Therefore, over geological time, the aquifer tends to a state of dynamic equilibrium, in which "tomorrow's" discharge rates will be set according to "today's" recharge rates.

Exploitation through wells, therefore, is a discharge imposed on a system that was considered to be in dynamic equilibrium. The intensity of pumping, the time of exploitation, the size and the hydraulic characteristics of the aquifer will define the consequences of this interference in the rates of recharge, discharge and storage.

The water dynamics of groundwater in the hydrographic basin

The adoption of the hydrographic basin by the management makes this space a reference for the analysis of the interactions between meteoric, underground, surface and coastal waters. The hydrographic basin is composed of a geological framework that provides the initial elements for its analysis, as well as directly influencing water availability. This geological framework is understood here as a mosaic and/or a succession of rocks and unconsolidated material that make up the floor and subsoil of a watershed, to which relief forms and topographic variations are associated, resulting from the action, in geological time, of internal (endogenous) and external (exogenous) dynamics.

The geological framework can consist of different types of rocks (igneous, metamorphic or sedimentary), with different ages, compositions and possibilities of spatial relationship (stratigraphy), as well as geological structures (fractures, faults, folds etc.). Older and deeper rocky packages due to uplift associated with weathering and erosion may end up outcropping or being buried by more recent sedimentary sequences formed in the most different geological environments. Rocks with or without cover, formed by unconsolidated material and soils, have characteristics of porosity and permeability (or hydraulic conductivity) that can facilitate or prevent the percolation of rainwater. The climate and its variations over geological time are equally determinant in the form of occurrence and dynamics of underground, surface and coastal bodies of water. It is what controls the characteristics of the cycle and hydrological balances that are established in a given hydrographic basin. In a hydrographic basin, therefore, the geological framework defines the geometry of the aquifers and their relationships with other bodies of surface water (Figure 9). Rainfall, in turn, influences the amount of water available to be stored in aquifers.

2 GROUNDWATER IN THE HYDROSOCIAL CYCLE

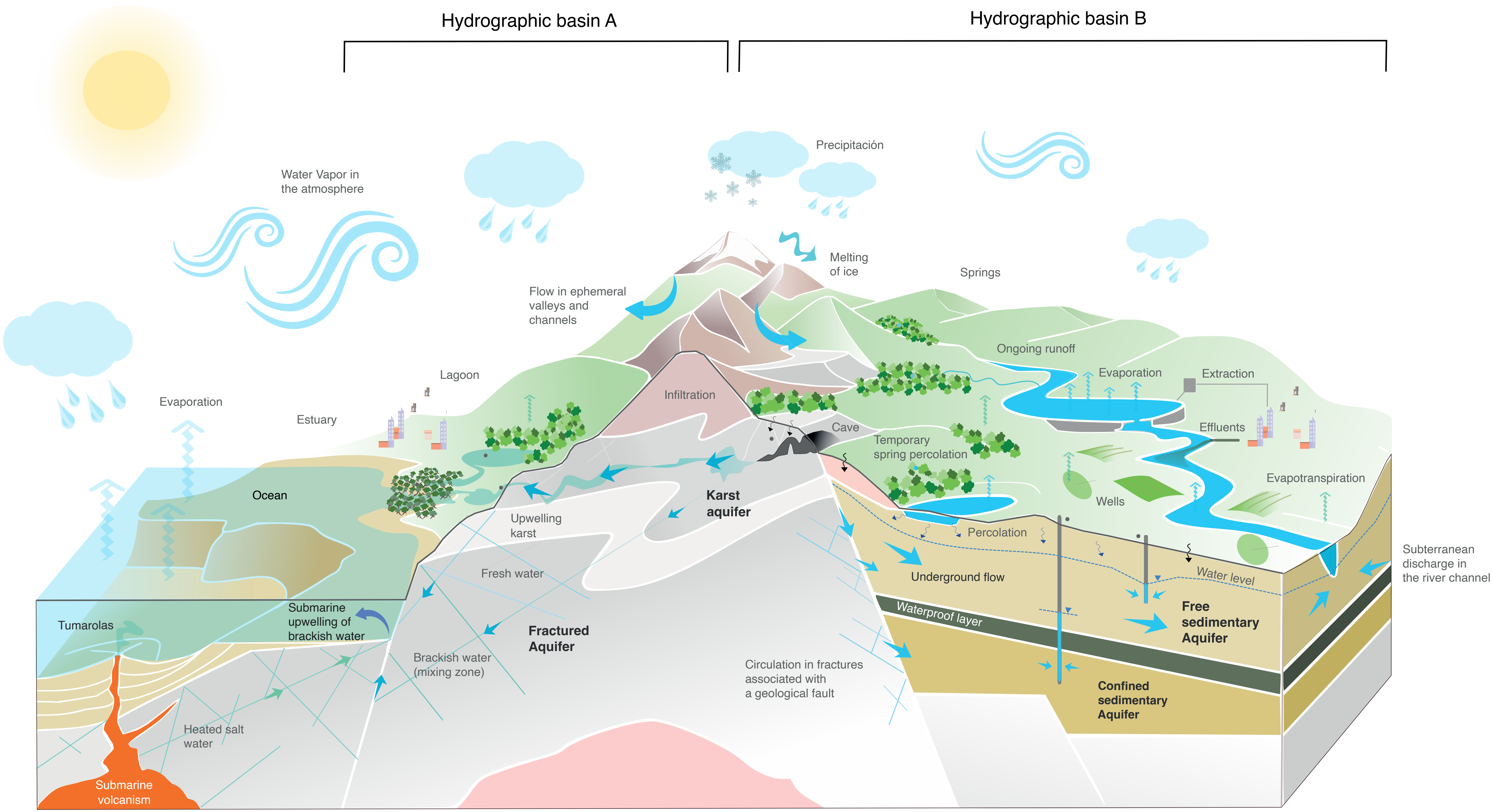


Figure 9 - The geological framework as a basic element for defining the territory of the basin and water storage
Source: prepared and provided by Dora Atman.

As shown in Figure 9, the interaction between climate and the geological framework determines the organization of water resources. Rain is the main mechanism for water entry into the basin, while rocks will form the different types of aquifer and, together with the topography, will be decisive in defining the behavior of water, which can run off superficially, infiltrate with subsurface outflow, vertical and lateral or water still to be absorbed by the plants and return to the system through evapotranspiration.

Vertical subsurface outflow supplies groundwater flows, and part of these flows generate springs and inputs into surface and/or coastal water drainages. Otherwise, the surface bodies of water generate the recharges for the underlying aquifers. Interactions between surface and groundwater occur both in the upstream and downstream parts of a watershed, depending on the geological framework, rainfall conditions and topography.

The river-aquifer interaction generally depends on the difference in elevation of water levels in these bodies of water. If the elevation of the water level in the aquifer is greater than the elevation of the water in the river, this river receives water from the aquifer and is therefore called an *effluent river* (Figures 10 A and D). In the reverse situation, i.e., when the elevation of the water level of the aquifer is lower than that of the river, this river supplies water to the aquifer, therefore, it will be an *influent river* (Figures 10 B and C). Therefore, two situations of hydraulic connection are observed in nature, mainly during the dry season: 1) a *Perennial River*, in which there is a connection between the water table and the river (Figures 10 A and D), which guarantees the flow throughout the year, regardless of the rainy or dry periods; and 2) an *Intermittent River*, in which the river is disconnected from this surface, becoming dry in the dry season (Figure 10 C) (HEALY, 2010; POETER *et al*., 2020; WINTER *et al*., 1999; WOESSNER, 2020).

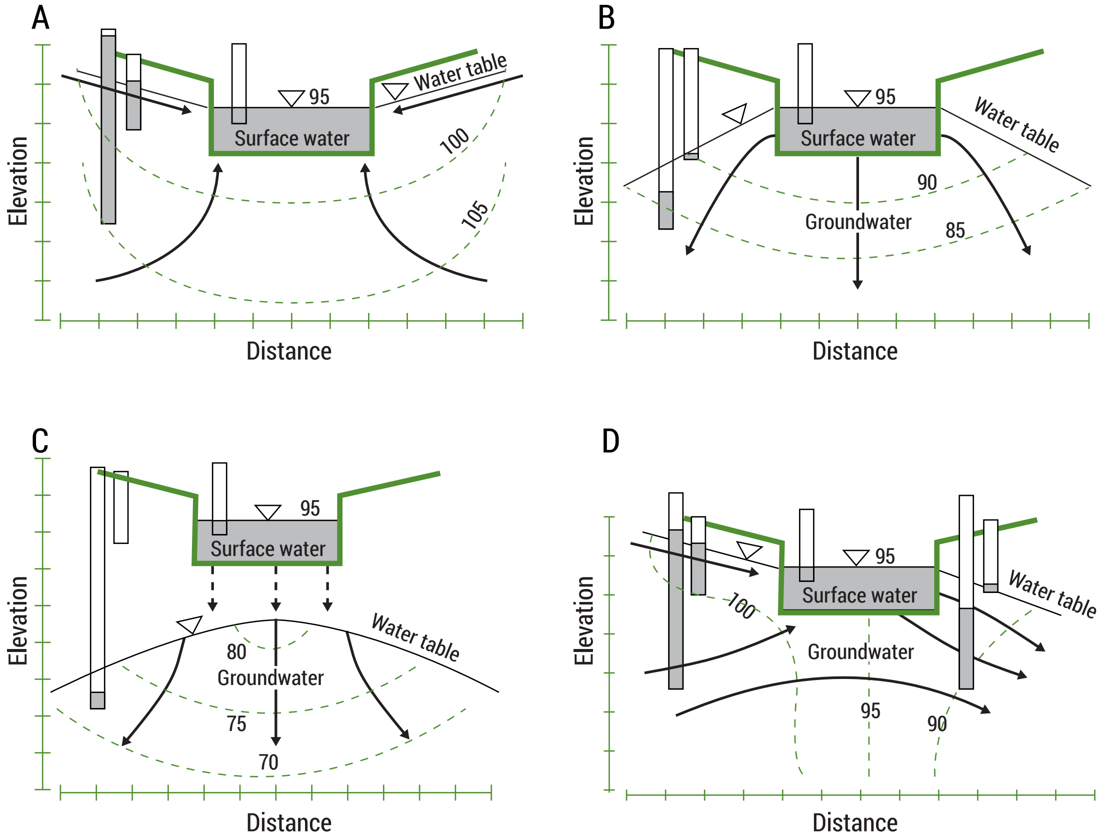


Figure 10 – (A) Conceptual model for effluent rivers; (B) Conceptual model for influent rivers1; (C) Conceptual model for influent rivers2; (D) Conceptual model of direct flow

Source: Woesner (2020), adapted by Didier Gastmans and Camila de Lima.

1 Scenario in which the water level rise that separates the saturated from the unsaturated zone is connected with the river; 2 Scenario in which the water level rise that separates the saturated from the unsaturated zone is disconnected from the river.

In crystalline terrains it is common for springs to appear to go in the higher portions of the relief and form small watercourses, which join others as they reach the lower portions of the drainages, composing streams, creeks or other larger bodies of water. Therefore, a hydrographic basin is constituted, whose drainage pattern is generally controlled by the structuring of the rocks of the geological substrate. Throughout this trajectory, underground discharges occur to surface water courses, which are responsible for their perpetuation. The basins, whose geological framework is formed by poorly permeable rocks and with pronounced topographic gradients, present a large part of the flow dependent on surface outflow. Although aquifer interactions with water courses are minor, they must be considered in the elaboration of the water balance and management plans since they can provide important contributions.

On the other hand, in watersheds that drain sedimentary terrain or alluvial plains, aquifer interactions are highly relevant, as rivers receive a large volume of underground discharges which makes them perennial during drought periods.

Between recharge and discharge, groundwater moves along several paths, forming what is called a flow network, whose lines can conform to three situations: *local, intermediate and regional* (Figure 8) (Tóth, 1963).

- **Local flow lines:** drain to discharge areas relatively close to the points where recharges took place, normally pointing to surface bodies of water (rivers and lakes). This is the case of flow lines originating in recharge areas of the Guarani Aquifer System (SAG).

- **Intermediate flow lines**: have one or more local flow systems between their recharge and discharge area.

- **Regional flow lines**: they are deeper inside the aquifers and have a transit of great distances with discharges to surface bodies of water, namely: rivers, large lake bodies or even the ocean. SAG discharges into the riverbed of the Uruguay and Paraná Rivers are concrete examples of regional flow lines.

Groundwater flows must be seen three-dimensionally, i.e., there may be superficial and local flows overlapping deeper ones, which are regional flows.

Therefore, it is possible that in the same aquifer there can be local, intermediate and regional flows (Figure 8). To quantify the integrated water availability of the basin, it is important to understand the dynamics of these flows and estimate their discharge rates.

Aquifer systems, incidentally, can even be larger than hydrographic basins. Their recharge areas located in a basin can favor discharges into rivers in other river basins (Figures 8 and 9). Therefore, the same aquifer can participate in flows from more than one surface watershed (Figures 8 and 9), as well as supply water to the sea. If the discharge takes place at sea, the flow of fresh water from the aquifer is opposed to the flow of salt water, establishing a dynamic boundary between these waters, which are separated by a mixing zone.

There is an intrinsic connection between surface and groundwater, therefore, assessment must be done from an integrated and joint approach. Surface water can become groundwater through infiltration, while groundwater can become surface water through discharge from aquifers. It is therefore necessary to understand, in space and time, how the transfer relationships that regulate the volumes and fluctuations of water available to ecosystems occur. This theme reinforces the idea of river-aquifer interactions, as in the Urucuia Aquifer System and the São Francisco River Basin (ANA, 2017a).

The extraction of groundwater through wells modifies the original hydraulic condition of the aquifer and the basin, which can generate positive and negative impacts. Overall, this extraction generates social benefits as it increases regional water availability, allowing the development and supply of communities that often do not have another water source or need to complement the surface source. Depending on the magnitude of the volumes withdrawn, however, overexploitation of the aquifer may occur, which generates a reduction in aquifer discharges to surface bodies of water or to the sea, culminating in negative environmental and economic effects.

2.5 Threats to Brazilian groundwater resources

Aquifers are also subject to impacts resulting from excessive use of water and human activities, which can cause problems of overexploitation, reduced recharge or groundwater contamination.

2.5.1 Overexploitation of aquifers

The removal of water from an aquifer generates its lowering and changes in the hydrodynamic flow of recharge and discharge and, in some cases, changes in the geochemistry of its waters. The consequences of overexploitation are not immediately noticeable, but increase over time, varying according to aquifer dimensions, storage capacity and usage scenario. Hydraulic and chemical changes in aquifers take years or decades to be noticed by users or the Government. Therefore, it is necessary to monitor extractions in order to prevent them from generating externalities, whose recovery is complex, costly and time-consuming to reverse.

Overexploitation comprises several phenomena and impacts generated by extraction or changes in recharge, which reduce water availability, harming users or the environmental and social roles of groundwater. The mere reduction of aquifer levels does not characterize a situation of overexploitation, but it materializes when the impacts of extraction cause financial, ecological or social losses that cannot be compensated by the benefits of exploitation.

Unlike surface waters, it is not possible to visually observe the processes that occur in the aquifer. Therefore, the challenge of the management of groundwater resources is to measure and establish when their exploitation will be considered harmful enough to place it in this situation. In general, overexploitation is understood as changes in the hydrological cycle that cause at least one or more of the following impacts:

a. reduction of aquifer levels through water extraction. The withdrawal of water can deplete the aquifer, that is, create such a pronounced reduction in potentiometric levels that it no longer allows its use, either because of the excessive hydraulic difference (head height) to be overcome by the well pumps, or because of the reduced saturated thickness of the aquifer, which prevents pumping, or even the elimination of natural sources and surges;

b. reduction in water contribution to base flows in surface bodies of water. The decrease in water input damages the availability of surface water and dependent ecosystems, such as rivers, lakes, swamps and mangroves;

c. increase in water exploitation costs due to the lowering of the dynamic levels of the wells and/or the readjustment of extraction infrastructure. In this case, the origin may be: a) the imbalance between aquifer recharge and its extraction in the long term (decades); or b) interference between wells, whose proximity causes hydraulic interference and strong drawdowns. Extraction costs are more associated with pumping, which requires energy to bring water from the aquifer to the surface, than with the infrastructure work itself;

d. loss of shallower wells or springs preventing equitable access to water. The use of groundwater through dug wells or even shallow tubes by poor and socially vulnerable populations is a common practice in rural areas or suburban regions. In many cases, these methods constitute the only source of water available to guarantee the water and food security of these populations. Depending on the hydraulics of the aquifer, the installation of high production deep wells can cause the water level to drop and dry out shallower wells and springs. In most cases, the deepest well is legalized, however, its use can generate a problem of social inequality and violate the principle of multiple uses of water. Owners of wells that have dried up often do not correlate well loss with overexploitation of the aquifer;

e. land subsidence. The use of some aquifers, such as those associated with multilayer karst or sedimentary systems, can create ground slump, which impacts civil works, causing social and economic losses, such as the collapse of buildings and modification of urban water flows;

f. Introduction of contaminated or saline waters into the aquifer due to excessive pumping or reduced recharge. The extraction of water from an aquifer or even human occupation of the surface changes the hydrological cycle, modifying recharge rates and subsurface flow directions. In some cases, these changes can bring low quality water to aquifer use areas. This occurs when pumping from wells induces contaminated water from groundwater aquifers or rivers to enter the aquifer. Contamination by the induction of low-quality water through pumping must be faced with the control of the operation and exploitation of wells;

g. Saline intrusion into coastal aquifers. In coastal aquifers, in equilibrium, there is a hydraulic gradient that conditions the flow of fresh water from the continent to the ocean. This flow can be reversed due to the characteristics of tidal and climate variations, for example, mixing fresh and salt waters. This water mixture is conditioned by hydrodynamic dispersion, with fresh water, less dense, tending to flow closer to the surface, while salt water, denser, advances towards the aquifer, forming a saline wedge (FEITOSA et al., 2008). Excessive extraction of coastal aquifers allows the advance of the saline wedge towards the continent, for the pumping reverses the flow directions of these waters, causing hydrodynamic imbalance in the system and compromising the quality of the aquifer waters.

Overexploitation can affect part of an aquifer or the entire system. Due to the low speed of the underground flow, the evaluation of its effects can take years to manifest, despite its causes having occurred a long time ago. In the case of fossil aquifers, i.e., those where water restitution in the exploited portion is greater than tens of thousands of years, overexploitation is inevitable, as the level loss is determined by the extraction rate. Therefore, it is necessary to plan its use, considering whether the socioeconomic gains of the extracted water compensate for the depletion of the aquifer in the long term and its loss for future generations.

In some cases, the recovery of the water table resulting from the abandonment of wells can also generate negative impacts. By decreasing groundwater extraction, water levels can recover to the original situation or even surpass it, as cities tend to increase recharge levels due to water losses from the water and sewage network. Many buildings, canals, tunnels, galleries and the subway network have underground structures that were built when those portions were dry (unsaturated zone), so returning to the original level will require draining water. If the foundations of buildings were built on dry ground, the resumption of the water table would cause their vertical movement, which would impact structural stability, generating social losses.

2.5.2 Reduction of aquifer recharge due to change in land use and occupation

Changes in urban and rural land cover patterns directly affect recharge, as they influence rainfall distribution, temperature, surface outflow, evapotranspiration and aquifer recharge (TANG *et al*., 2005). The main causes of these changes in aquifer recharge are related to the following aspects: a) sealing by impermeable surfaces (JACOBSON, 2011); b) compression (PITT *et al*., 2003); and c) reduction of tree cover (ANDJELKOVIC, 2001). Sealed areas are more present in urban areas and include all paved areas and buildings that prevent water infiltration. Compaction is the affectation of the physical properties of the soil, in order to reduce its porosity, being caused, for example, by the movement of earth or the passing of heavy machinery. The reduction of tree coverage causes impacts related to the loss of evapotranspiration, changes in the albedo of the land surface, the increase in temperatures and the intensification of erosion and desertification processes (TANG *et al*., 2005). Furthermore, forests prevent soil disturbances and their roots and associated ecosystems contribute to improving soil porosity (Artaxo, 2014; AZEVEDO, 2019). In cities, eventually, there may be compensation for the loss of natural recharge due to leaks in the water, sewage and rainwater drainage network (Hirata; Foster; Oliveira, 2015).

2.5.3 Contamination of soil and groundwater

Contamination of soil and aquifers occurs mainly through incorrect disposal of effluents and solid waste, handling and storage of hazardous substances or accidents. The unsaturated zone represents the first line of natural defense against pollution, and has a certain ability to attenuate and eliminate pollutants (FOSTER; HIRATA, 1988). Despite this fact, several activities generate contaminant loads that exceed the retention and degradation capacity of the unsaturated zone, causing soil and groundwater contamination. This contamination can be punctual or diffuse (Foster; Hirata, 1988):

a. **punctual**: when the source of contamination is restricted to a small area. This feature facilitates the identification, monitoring and remediation of impacts, as it generally causes plumes of reduced extension and high concentrations. These are the typical cases of areas of sanitary landfills and dumps, buried tanks, effluent ponds, piles and deposit of hazardous products, among others; and

b. **diffuse** or **multi-point**: when the source of contamination extends over the territory and the pollutants are released in a sparse way, which makes their identification difficult because well-defined plumes of contamination are not perceived. Examples of this type of contamination are: agricultural areas with excessive application of pesticides and fertilizers, or urban areas without a sewage system and the use of rudimentary and septic tanks, among others.

Potential sources of contamination may be related to activities in the urban, suburban or rural region, including those resulting from the urbanization process, the depositing of solid and liquid residues, industrial, mining, agriculture and livestock. In principle, all human activities that generate, handle or store hazardous products can contaminate groundwater. Within these activities, however, there are those that can cause greater impacts or occur more frequently (FOSTER; HIRATA, 1988; FOSTER *et al*., 2002). In groundwater management, it is important to identify, distinguish and classify these human activities, allowing public bodies and society to establish their policies.

Foster and Hirata (1988) and Foster *et al*. (2002) emphasize that polluting activities are not necessarily linked to large enterprises. In some cases, small enterprises can be a cause for even greater concern, as they handle dangerous products without the necessary controls, being responsible for major impacts, as occurred in the Industrial District of Jurubatuba (São Paulo). In this region, an enterprise with just over hundreds of square meters generated serious contamination because it handled, without proper care, chlorinated solvents as a degreasing agent for the production of batteries. Therefore, the contaminating potential of the activities must be analyzed mainly from two aspects: a) the type of product produced, handled and stored; and b) if the entry into the soil is made with some associated hydraulic load, as there is no way for a contaminant to enter the aquifer if it is not via a fluid.

Contaminants must be analyzed based on their toxicity, mobility and persistence in the subsurface. Chlorinated solvents have these characteristics and are therefore problematic. In turn, nitrogen, although it has low toxicity, has a wide occurrence, which makes it a challenge for management. It is present in fertilizers used in agriculture and in domestic effluents that seep into the aquifer, via septic or rudimentary tanks and via leaks from the sewage system.

Brazil has a particularly vulnerable situation in relation to the lack of sanitary sewage, as 39% of the sewage generated is not collected, with 12% destined for individual *in situ* treatment systems (septic tanks) and 27% released mainly into the soil through rudimentary pits and sinkholes (99%) or in surface waters (1%) (HIRATA *et al*., 2019, ANA, 2017b, IBGE, 2008). In areas with sanitary infrastructure, the maintenance of sewage networks is lacking, which allows the leakage of expressive volumes that can exceed 10% of the total sewage collected (Hirata *et al*., 2019).

Although Brazil is a country with thriving agricultural activity and uses large amounts of inorganic fertilizers and pesticides, there are no systematic studies, even in the academic environment, which evaluate the impacts or occurrence of this type of contamination The application of nitrogen fertilizers is the main cause of agricultural contamination in North America and Europe, whose data report extensive contaminated areas.

Another problem is that the construction of wells or abstractions ignores technical standards, their location is inadequate (close to potential sources of contamination) or they are not properly maintained, which can lead to aquifer contamination. Technical diligence prevents, for example, microbiological pollution, which is very common in wells installed close to pits. The well, therefore, must be far from potentially polluting sources, recommending the adoption of protection perimeters, as well as frequent chemical analyses.

In Brazil, information concerning the situation of contaminated areas is scarce. The National Database on Contaminated Areas (BDNAC)[5] only has information concerning the states of Minas Gerais, Rio de Janeiro and São Paulo.

5 BDNAC was implemented by Conama Resolution 420/2009. For more information, see: http://ibama.gov.br/ residuos/areas-contaminadas/banco-de-dados-nacional-sobre-areas-contaminadas-bdnac.

3

THE BUILDING OF GROUNDWATER GOVERNANCE AND MANAGEMENT

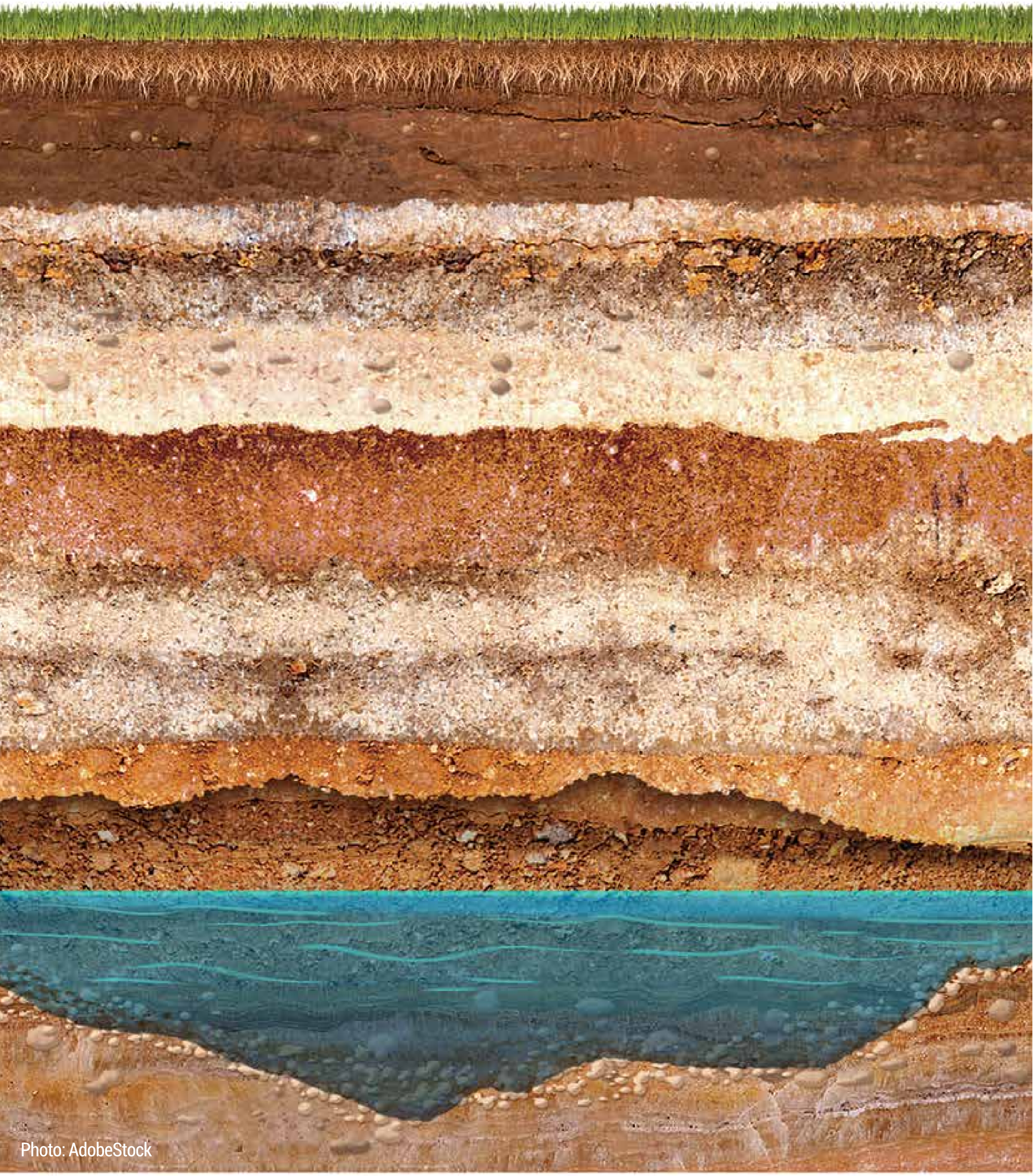


Photo: AdobeStock

3 THE BUILDING OF GROUNDWATER GOVERNANCE AND MANAGEMENT

Faced with the need to regulate the use and protect aquifers, the concepts of groundwater governance and management have gained prominence, especially since the late 2000s. One of the first and most cited definitions of water governance was established in a report by the *Global Water Partnership*, which defined it as "the set of political, social, economic and administrative systems that exist to develop and manage water resources and the provision of water services at different levels of society." (Rogers; Hall, 2003, p. 7).

Ever since, several concepts and approaches to water governance have emerged (RIBEIRO; JOHNSSON, 2018). In this profusion of literature, the idea of groundwater governance emerged as a specific and more restricted aspect of water governance which is justified by the following factors (Jarvis *et al*., 2005; Madani; Dinar, 2012; Villholth; Conti, 2018):

- ecosystem importance of groundwater, as the aspect which maintains the base flow of rivers, springs and wetlands;
- main reservoir of fresh water available to populations on the planet;
- most extracted natural resource from the subsoil in Brazil and in the world;

- extraction rates exceed replacement rates in many aquifers;
- contamination, which in many cases makes the aquifer unfeasible due to the technical complexity and costs of depollution;
- specific characteristics that make its management difficult, with emphasis on the following: a) natural and social invisibility of these waters; b) low ground flow speed; c) extension of aquifers; and d) difficulty in controlling access;
- cultural perception that these waters are linked to land ownership rights;
- public policies that neglect groundwater and its relationship with surface water;
- lack of knowledge about the status of these waters and aquifers.

Emphasizing groundwater governance contributes to improving resource management and seeking joint and specific strategies among social actors in view of the natural and social particularities of aquifers. There are several definitions for groundwater governance. Megdal *et al*. (2014, p. 678) define them as:

> the framework comprising the laws, regulations and customs on the use of groundwater, as well as the engagement processes of the public sector, private sector and civil society. It may involve coordinating administrative actions and decision-making processes between and among different jurisdictional levels. This structure fundamentally shapes how groundwater is managed and how aquifers are used.

Governance is not to be confused with governability, nor with management or management, although there is confusion between the terms. The distinctions between these concepts focus on the number of actors involved and the extension of their scope (Villholth; CONTI, 2018). Governability is part of governance, however, it is restricted to the "state dimension of the exercise of power" (Gonçalves, 2005, p. 3), focusing on the attributes of the government's exercise of power and its systemic conditions, such as: "the political regime (whether democratic or authoritarian), the form of government (whether parliamentary or presidential), the relations between powers (greater or lesser asymmetry, for example); party systems (whether multi-party or bipartisan)." (DINIZ, 1999, p. 196).

Management focuses on actors with jurisdiction to carry out routine actions aimed at diagnosing, monitoring and applying management instruments or laws. It focuses on the performance of technicians and water managers dedicated to implementing laws (policies) through specific actions. According to the *Food and Agriculture Organization of the United Nations* (FAO), the term groundwater management "comprises activities carried out by legitimate actors to develop, use and sustainably protect groundwater resources." (FAO, 2016, p. 17).

The management of water resources corresponds to the execution of structural and non-structural actions aimed at controlling water systems (natural or artificial), to ensure social benefits and comply with environmental requirements. Structural measures require the construction of structures, such as: dams, water mains, water and sewage treatment plants, soil erosion containment works, recovery of contaminated areas, and de-silting of bodies of water, among others. Non-structural measures are programs or activities that do not require works, such as zoning of land use and occupation, environmental education actions, campaigns for the legalization of wells etc. (GRIGG, 1996).

The scope of governance is more comprehensive and inclusive, as it incorporates the "set of mechanisms and procedures to deal with the participatory and plural dimension of society," considering the visions not only of the government (governability), but also scientists, users, non-governmental organizations, civil society and traditional communities (Villholth; CONTI, 2018). It presupposes, therefore: a) "to expand and improve the means of interfacing and administration of theplay of interests;" and b) to give the State greater flexibility of action, allowing the decentralization of functions, transfer of responsibilities and expansion of the "universe of participating actors, without giving up the instruments of control and supervision." (DINIZ, 1999, p. 196).

The strengthening of the idea of governance generates a change in the paradigm of water management, which is no longer an exclusive theme of governmental technical bodies and starts to seek partnerships with other actors, including different approaches, such as: a) social learning; b) negotiation and conflict mediation techniques; c) traditional knowledge; d) environmental education actions; e) creation or expansion of opportunities for user and civil society participation etc.

In this process, the idea of **Integrated Management of Water Resources (IWRM)** was established, defined by the Global Water Partnership (GWP, 2000, p. 22) as a "process that promotes the development and coordinated management of water, land and related resources," to maximize the resulting economic and social well-being in an equitable manner, without compromising the sustainability of vital ecosystems." This concept aims to promote the horizontal integration of multiple uses, as well as the vertical integration between the different institutional levels (local, state or provincial, national and transboudary).

International organizations such as the *Global Water Partnership*, the United Nations Environment Program (UNEP) and the United Nations Development Program (UNDP), in addition to international conferences and the editions of the World Water Forum, argue that this model is configured as the most efficient to guarantee sustainability in the use of water (VILLAR, 2015). Its supporters maintain that water problems could be solved by IWRM, irrespective of the differences in the physical, economic, social and environmental conditions of the countries (Biswas, 2008). However, they warn that its application requires an adequate governance context to effectively promote good water governance (VILLAR, 2015).

- Therefore, the processes for achieving good governance and implementing IWRM in practice are challenging and complementary. IWRM encourages water legislation and institutions to adopt the following principles: watershed as a spatial management unit; participation of social actors; funding mechanisms; monitoring; development of information systems. Moreover, it encourages the adoption of the following management strategies (Villar, 2015):

- determination of the states' roles in relation to other actors and regulation of the entitlements and responsibilities of water users and suppliers;

- building partnerships between government, business sector, community and voluntary organizations;

- legal prescription of governmental management institutions and their respective powers;

- search for ways to ensure the sustainable use of the resource;

- analysis of the situation of water resources;

- installation of a consortia of actors involved in the decision-making process, with representation of sectors of society and gender balance;

- organization of water allocation systems, water extraction, waste water disposal permits and databases;

- basin-based water resources management;
- organizational structures at basin and sub-basin levels to enable decision making at the lowest possible level;
- preparation of plans by IWRM based on a multi-sectoral approach and stakeholder participation.

In the specific case of groundwater, IWRM draws attention to the following points that need to be addressed by management:

- surface and groundwater cannot be managed separately from each other or independently of related ecosystems (KENNEDY *et al*., 2009);
- groundwater management requires observing the balance between groundwater extraction and recharge, and planning for medium and long-term use (Kennedy *et al*., 2009);
- groundwater management must monitor the impact of irrigation and subsidized charges for the use of water and power, which, whereas desirable from a socioeconomic standpoint, can encourage overexploitation of the aquifer (FOSTER; AIT-KADI, 2012);
- groundwater management must be included in urbanization policies due to the impact of land use and occupation and the absence or inadequacy of sanitation services (FOSTER; AIT-KADI, 2012);
- the spatial scale of the watershed needs adjustments to promote aquifer management (Foster; Ait-Kadi, 2012).

From the 1990s onwards, several countries, including Brazil, changed their legal and institutional milestones aiming to implement IWRM and incorporate its tools at the watershed scale (Miranda; Reynard, 2020). The following sections describe the Brazilian institutional policy framework that guides the implementation of this process and its relationship with groundwater.

3.1 Groundwater in the 1988 Federal Constitution

The 1988 Federal Constitution represents a milestone in the management of groundwater, as it radically transformed its legal nature. These waters were governed by the Water Code (Decree Nº. 24,643/1934) which, in general, classified them as private waters (Article 8), provided their use is free for the owners of the land where they were located (Article 96): The only exceptions to this treatment were the cases of springs that: a) formed the head of a river (*caput fluminis*) due to the abundance of its flow, as provided in article 2, item "e" of Decree Nº. 24,643/1934; or b) if were located on public land (TOVAR, 1955).

The 1946 Federal Constitution publicized surface waters, but did not mention groundwater. Only after the 1988 Federal Constitution was there the publication of all groundwater, which was expressly included in its Article 26, Part I. Therefore, the jurisdiction over water was divided as follows between the Federal Government and the states:

> Article 20. The following are assets of the Federal Government:
>
> III – lakes, rivers and any water currents on land under their domain, or that bathe more than one State, serve as boundaries with other countries, or extend to foreign territory or come from it, as well as marginal lands and river beaches;

> IX – mineral resources, including those in the subsoil;
>
> Article 26. The assets of the States include:
>
> I – surface or underground water, flowing, emerging and in deposit, except, in this case, as provided by law, those resulting from infrastructure work carried out by the Federal Government.

The waters attributed to the Federal Government, in part III of the Federal Constitution, are restricted to surface waters (lakes, rivers and water streams) that meet the following conditions: "bordering with States or with another country, or situated in more than one State or Country." (MILARÉ, 2020, p. 1154). To the States, in turn, Article 26 attributes surface waters not included in article 20, Part I, and groundwater, with no territorial constraints on the domain of groundwater resources (Milaré, 2020). Notwithstanding, some groundwater can also be classified as mineral resources and subject to the Federal Government's control pursuant to mineral legislation.

Groundwater belongs to the States (CAMARGO; RIBEIRO, 2009; FERNANDES, 2019; VILLAR; GRANZIERA, 2020). The Federal Constitution repealed the concept of municipal and private waters. This understanding was corroborated by Law Nº. 9,433/1997, which classified water as a public asset (article 1, part I), therefore, the property right to water resources, whose use is subject to state regulation, no longer applies. Most provisions of the Water Code became incompatible with the ownership regime established by the Federal Constitution and with the water regime of Law Nº. 9,433/1997.

A precedent of the Superior Court of Justice (STJ) indicated the possibility of federal groundwater (STJ, 2016a; 2016b). This interpretation took place in actions that discussed the legality of acts of the Government that, supported by state decrees or by article 45 of Law Nº. 11,445/2007, aimed to prohibit wells, without a grant, as an alternative source of water in areas equipped with a water supply network. This position does not rule out the state jurisdiction of groundwater because it was determined in actions that did not discuss the domain of these waters, nor did the actions have the participation of the States and the Federal Government.

The topic was widely debated in the discussion of the Draft Amendment to the Constitution (PEC) 43/2000, which aimed to transfer to the federal domain groundwater that exceeded state limits or that were shared with other countries. ANA and several Hydrographic Basin Committees were against the PEC because they understood that the management of aquifers should prioritize the local scale. PEC 43/2000 was shelved on merits, because according to the Constitution, Justice and Citizenship Commission, the proposal was contrary to the decentralized model and would not contribute to the improvement of the National Water Resources Policy (CASAGRANDE; ABREU, 2010, p. 4).

In addition to defining the jurisdiction over water, the 1988 Federal Constitution, in article 21, Part XIX, determined the duty by the Federal Government "to institute the national system for the management of water resources and to define the criteria for granting the right to use it." Article 22, Part IV, on its turn, gave the Federal Government the exclusive jurisdiction to legislate on water rights (VILLAR; GRANZIERA, 2020). These constitutional commands paved the way for the enactment of Law Nº. 9,433/1997, which establishes the foundations of water governance in the country. The state management of groundwater, therefore, is conditioned to the observance of the presuppositions contained in the federal water legislation. It is also worth noting that the state jurisdiction does not interfere with the Federal Government's ability to establish negotiations involving transboundary aquifers (article 21, part I, of 1988 Federal Constitution), so much so that Brazil signed, with Argentina, Paraguay and Uruguay, the Agreement on the Guarani Aquifer, whose assumptions must be respected by the States.

Roraima
Amapá
Amazonas
Pará
Maranhão
Ceará
Rio Grande do Norte
Paraíba
Piauí
Pernambuco
Alagoas
Acre
Tocantins
Sergipe
Rondônia
Mato Grosso
Bahia
Goiás
Distrito Federal
Minas Gerais
Mato Grosso do Sul
Espírito Santo
São Paulo
Rio de Janeiro
Paraguai
Paraná
Santa Catarina
Rio Grande do Sul
Aquifer Guarani
Argentina
Uruguai

3.2 The National Water Resources Policy: a new way of managing water

Law Nº. 9,433/1997, called National Policy on Water Resources, is composed of 57 articles divided into four titles: Title I – National Water Resources Policy; Title II – National Water Resources Management System (SINGREH); Title III – Offenses and Penalties; and Title IV – General and Transitory Provisions. Its provisions refer to water in general, without differentiating surface water from groundwater.

This law transformed the management of water resources until then governed by the Water Code (Decree Nº. 24,643/1934), which had a centralizing, privatizing and utilitarian vision, focused mainly on the use of hydraulic potential, without concern for water conservation (Pompeu , 2006; Milaré, 2020). Law Nº. 9,433/1997 created a governance model based on decentralized, integrated and participatory management (BARBI; JACOBI, 2007), which incorporated the main guidelines of the IWRM model.

The law adopted the watershed as a management unit, allowed the participation of social actors, attributed economic value to water, determined the organizations responsible for management and established instruments to guide the use, use and protection of water. Furthermore, it established that water management must comprehend aspects relative to quantity and quality, as well as take into account the multiple uses of water resources, environmental management, land use, territorial planning and the relationship with estuary systems and coastal regions. Figure 11 details its foundations, objectives, guidelines, management instruments and institutional framework.

GROUNDS (article 1)

- public asset;
- limited natural resource, endowed with economic value;
- priority use for human consumption and the watering of animals in situations of scarcity;
- multiple use of water;
- hydrographic basin as a territorial unit for the implementation of the PNRH and the operating framework of SINGREH;
- decentralized and participatory management (Government, users and communities).

OBJECTIVES (Article 2)

- ensuring the current and future generations the necessary water availability, in adequate quality standards for the respective uses;
- rational and integrated use of water resources;
- prevention and defense against critical hydrological events;
- encourage and promote the extraction, preservation and use of rainwater.

GENERAL GUIDELINES FOR ACTION (Article 3)

- systematic management of water resources, without decoupling the aspects of quantity and quality;
- adequacy of water resources management to the physical, biotic, demographic, economic, social and cultural diversities of the different regions of the country;
- integration of water and environmental management;
- articulation of water planning with that of user sectors and with regional, state and national planning;
- articulation of water management with land use;
- integration of watershed management with that of estuarine systems and coastal zones.

MANAGEMENT INSTRUMENTS (article 5)

- Water Resources plans;
- classification of bodies of water into classes, according to the predominant uses of water;
- granting rights to use water resources;
- charging for the use of water resources;
- Water Resources Information System.

SINGREH (article 33)

- National Water Resources Council.
- National Water and Sanitation Agency.
- State and Federal District Water Resources Councils;
- River Basin Committees;
- federal, state, DF and municipal public authorities whose powers are related to the management of water resources;
- Water Agencies.

Figure 11 – Fundamentals, objectives, guidelines, management instruments and institutional architecture of the National Water Resources Policy
Source: Brazil (Law N^{0}. 9,433/1997).

Law Nº. 9,433/1997 did not provide specific guidelines for groundwater, nor did it define the concept and scope of integrated management or the way of reconciling the territoriality of the hydrographic basin with that of the aquifers, nor did it specify how to apply management instruments to the particularities of the groundwater or how to build coordination with other managements, such as environmental, sanitation, territorial, coastal, municipal, state and national development. However, when SINGREH was established, an institutional apparatus was created capable of adapting and operationalizing management for the particularities of groundwater resources.

Despite its application having prioritized surface resources, an institutional effort is gradually being made to include groundwater. The National Water Resources Council (CNRH), in article 3 of Resolution 202/2018, defined that the integrated management of surface and groundwater must consider the following basic aspects:

i. delimitation of recharge and aquifer contribution areas for directly connected rivers;

ii. estimate of the contribution of aquifers to the base flow of rivers;

iii. estimate of recharge and exploitable and renewable reserves;

iv. estimate of integrated underground and surface water availability for different uses;

v. the necessary hydrometeorological and hydrogeological monitoring networks.

3.3 The institutional arrangement for the protection of groundwater: SINGREH

The application of the water policy is conducted by SINGREH, which is materialized through a set of bodies and entities that work in the management of water resources in Brazil, with specific hierarchies and attributions, according to their scale of action (Figure 12). Its objectives were set forth in Article 32 of Law Nº. 9,433/97:

- To coordinate integrated water management;
- To administratively arbitrate conflicts related to water resources;
- To implement the National Water Resources Policy;
- plan, regulate and control the use, preservation and recovery of water resources;
- To promote charging for the use of water resources.

Due to the division of water domain, SINGREH is divided into two levels of jurisdiction: federal and state. This political-administrative architecture is composed of three categories of bodies that are divided according to their nature and performance (Granziera, 2015):

- *Panel-based organs:* National Water Resources Council (CNRH); State and Federal District Water Resources Councils and Hydrographic Basin Committees;

- *management and control organs and entities:* the National Water and Sanitation Agency – Brazil (ANA), Water Agencies, agencies and entities of federal, state, Federal Distict and municipal governments, whose powers are related to the management and control of water resources;

- *civil water resource organizations:* (a) inter-municipal watershed joint-ventures and associations; (b) regional, local or sectoral water resource user associations; (c) technical, teaching and research organizations interested in the area of water resources; (d) nongovernmental organizations with the objective of defending the diffuse and collective interests of society; (e) other organizations recognized by the National Council or State Water Resources Councils.

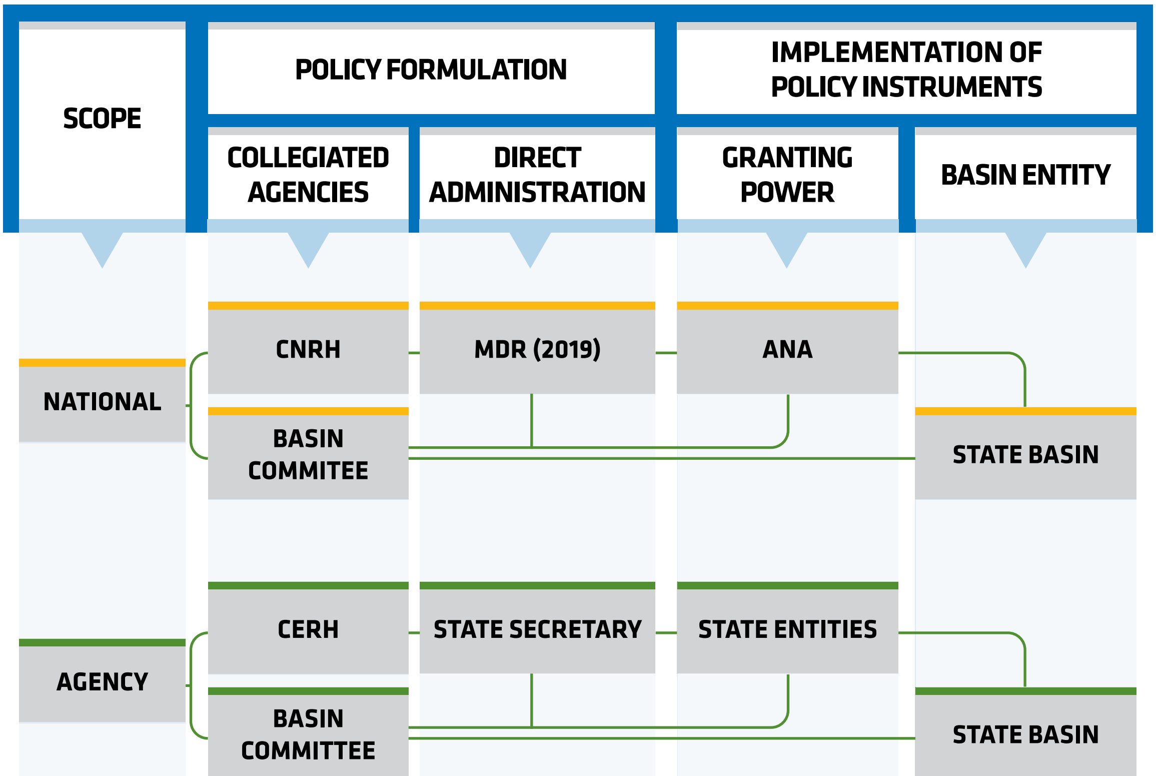


Figure 12 - SINGREH matrix and functioning*

Source: Villar e Granziera (2020, p. 48).

(*) Composition, legal nature and specific attributions of each body or entity will be detailed in the following items.

These organs are responsible for promoting integrated water management and reconciling the territoriality of aquifers and the hydrographic basin. If the aquifers exceed the limits of the basin, these organs will promote "the standardization of guidelines and criteria for data collection and preparation of the hydrogeological studies necessary for the identification and characterization of the hydrogeological basin" (article 4 15, of January 11, 2001). The Hydrographic Basin Committees "shall seek to exchange and systematize the data generated for the perfect characterization of the hydrogeological basin" (Article 4, sole paragraph).

In the case of transboundary or interstate aquifers, SINGREH is responsible for promoting the integration of "federal, state and Federal District government agencies that have jurisdiction concerning groundwater management." If there are conflicts in this process, the Water Resources Councils of the States and the Federal District are responsible for resolving them in the first instance, and the CNRH in the last instance (Article 5, § 1 of Res. CNRH 15/2001). In the case of transboundary aquifers, the agreements concluded between the Federal Government and the countries of the aquifer must be taken into account.

Moreover, the National System and the State and Federal District Water Resources Management Systems must guide municipalities to: i) promote the integrated management of groundwater in order to follow the water resources plans; ii) protect aquifer recharge areas; and iii) encourage the adoption of reuse and artificial recharge practices (Res. CNRH 15/2001).

Groundwater is managed by state water resources systems which, in turn, are part of a national system equipped with institutional and regulatory infrastructure that guides state management. States are responsible for organizing the management of groundwater, as well as controlling and inspecting its use and quality. Its policies, however, must be aligned with the national water policy and its regulations. Traditionally, the management of use (quantity) is carried out by state water resources agencies, while quality aspects are analyzed by state environmental agencies, established by the National Environment System (Sisnama). The organs that make up SINGREH's national structure play an important role in guiding and coordinating this management, as will be seen below.

3.3.1 The Ministry of Regional Development (MDR)

Based on Law Nº.13,844/2019, the Ministry of Regional Development (MDR) is responsible for the national policy on water resources, with jurisdiction concerning the following national policies: a) regional development; b) urban development; c) civil protection and defense; d) water security; e) irrigation; f) sanitation; and g) territorial planning. Therefore, it became responsible for the preparation of plans, programs, projects and actions for water resources management, infrastructure and guarantee of water security, irrigation, protection and civil defense and risk and disaster management, housing, sanitation, mobility and urban services (Article 29).

The National Water Security Department (SNSH) is primarily responsible for the water policy and has the following powers: a) to coordinate the formulation, review, implementation, monitoring and evaluation of the National Water Security Policy of the National Policy on Water Resources and its instruments; b) formulate policies, plans and norms and define strategies on integrated management of water resources, including border and transboundary waters; c) coordinate the preparation and review of national plans, programs and projects related to groundwater and monitor the development of their actions, in accordance with the principle of integrated management of water resources; and d) perform the function of Executive Secretary of the National Water Resources Council (article 19, of Decree 10,773/2021). The SNSH is composed of the Department of Water Works and Support for Studies on Water Security (Department of Strategic Projects and Department of Water Resources and Revitalization of Hydrographic Basins) (Article 2, II, b of Decree 10,773/2021), whose jurisdictions are provided, respectively, in Articles 20, 21 and 22 of Decree 10,773/2021.

In the specific case of aquifers, the Department of Water Infrastructure and Support for Water Safety Studies is responsible for supporting the execution of well drilling works and monitoring the implementation of project actions aimed at expanding the water supply. The Strategic Projects Department, in turn, should encourage the preparation of studies and proposals for the National Water Security Policy and its instruments, and monitor, supervise and inspect actions aimed at the strategic use of water and soil resources. The Department of Water Resources and Revitalization of Hydrographic Basins is responsible for: a) coordinating, supporting and monitoring the implementation of Law Nº. 9,433/1997 and the National Plan for Water Resources; b) support the States and the Distrito Federal in the implementation of state management policies and systems; c) technically support the constitution and operation of hydrographic basin committees; d) propose guidelines for the management of border and transboundary aquifers; e) prepare plans, programs and projects related to water resources, including groundwater; f) to exercise the Executive Department of the CNRH; and g) link the management of water resources with that of land use.

3.3.2 The National Water Resources Council (CNRH)

Linked to the MDR structure, the National Water Resources Council (CNRH) is SINGREH's national consultative and deliberative body. Its role is to "promote the articulation of national, regional, state and user sector planning prepared by the entities" that are part of SINGREH and "to formulate the National Water Resources Policy", under the terms of Law Nº. 9,433/1997 (Article 2 of Law Nº. 9,984/2000). Its powers are set by article 1 of Decree 10,000/2019 and in its Internal Regulations, approved by CNRH Resolution 215, of June 30, 2020. CNRH is responsible for establishing complementary guidelines for the implementation of Law Nº. 9,433/1997, having edited several resolutions that aim to guide the application of management groundwater instruments (Table 1).

Resolution CNRH 15/2001	Sets the general guidelines for groundwater management
Resolution CNRH 16/2001	Regulates the granting of the right to use water resources
Resolution CNRH 22/2002	Sets the guidelines for including groundwater in the instruments of the Water Resources Plans
Resolution CNRH 29/2002	Sets guidelines for granting the use of water resources for the use of mineral resources
Resolution CNRH 48/2005	Sets the general criteria for charging for the use of water resources
Resolution CNRH 76/2007	Sets general guidelines for the integration between the management of water resources and the management of mineral, thermal, aerated, drinking water or water intended for spa purposes
Resolution CNRH 91/2008	Provides for general procedures for the classification of bodies of surface and groundwater
Resolution CNRH 92/2008	Sets the general criteria and procedures for the protection and conservation of groundwater in the Brazilian territory
Resolution CNRH 107/2010	Sets the guidelines and criteria to be adopted for the planning, implementation and operation of the National Network for Integrated Qualitative and Quantitative Groundwater Monitoring
Resolution CNRH 126/2011	Approves guidelines for the registration of users of water resources and for the integration of databases referring to the use of surface and underground water resources
Resolution CNRH 153/2013	Sets the criteria and guidelines for implementation of Artificial Aquifer Recharge in the Brazilian territory
Resolution CNRH 184/2016	Sets general guidelines and criteria for the definition of derivations and abstractions of surface and underground water resources, and releases of effluents into bodies of water and accumulations of small volumes of water, considered insignificant, which do not depend on the granting of the right to use resources water resources, and other provisions.
Resolution CNRH 202/2018	Sets guidelines for the integrated management of surface and underground water resources that contemplate the articulation between the Federal Government, the states and the Federal District focused on strengthening this management.

Table 1 – Main Resolutions issued by the CNRH directly related to groundwater
Source: Villar and Granziera (2020).

These national normative acts guide states and Hydrographic Basin Committees (CBHs) in the process of applying water management instruments for groundwater and establish management guidelines and actions. This is the case with the implementation of the integrated monitoring network or the general guidelines for artificial recharge and data exchange between state water resources agencies and the National Mining Agency. The CNRH has the Technical Chamber for Integration with Environmental and Territorial Management (Article 9, part IV of Decree 10,000/2019), which is responsible for proposing actions for the inclusion of groundwater in water management and replaced the Technical Groundwater Chamber.

The CNRH also has jurisdiction act in the resolution of conflicts between states over surface and groundwater. This mediation role stands out in the case of conflicts over the use of interstate or transboundary aquifers, or even involving the relationship of aquifers with federal rivers.

3.3.3 ANA's operation in groundwater and the integrated management of water resources

The National Water and Sanitation Agency – Brazil (ANA), originally called the National Water Agency, was created by Federal Law Nº. 14,026, of July 15, 2020, changed its original name and expanded its list of powers, which are addressed by Articles 4 and 4-A of Law Nº. 9,984/2000. Article 1 of Law Nº. 9,984/2000 defines ANA in the following terms:

> a federal entity for the implementation of the National Water Resources Policy, part of the National Water Resources Management System (SINGREH) and responsible for the establishment of reference standards for the regulation of public sanitation services, and establishes rules for its performance, its administrative structure and its funding sources.

A member of SINGREH, ANA is an agency under a special regime, with administrative and financial autonomy. In 2019, it was linked to the MDR [Ministry of Regional Development] (Decree Nº. 9,666/2019). Its duties are to implement, within the scope of its competences, the National Policy on Water Resources and to institute reference norms for the regulation of public sanitation services, as well as to promote the management of waters in the domain of the Federal Government.

Concerning groundwater, ANA seeks to support state management and strengthen the integrated management of surface and groundwater resources with an emphasis on the river-aquifer relationship. Its performance in the area of groundwater takes place mainly through the implementation of the Agenda of Actions for the Integrated Management of Surface and Underground Water Resources, hereinafter called the Groundwater Agenda, whose attributions are provided in the National Groundwater Program, (PNAS), included in the National Water Resources Plan. This agenda aims to "propose and execute a set of actions that will strengthen the implementation of integrated management of surface and groundwater resources in Brazil." It is structured into five main actions that are divided into several activities, as shown in Figure 13:

ACTIONS	ACTIVITIES
Promotion of the integrated management of aquifers connected to federal rivers	Diagnosis of the aquifers connected to federal rivers
	Preparation of assessments for integrated management
	Proposition of regulatory frameworks and allocations
Preparations of hydrogeological assessments	Identify and carry out studies on aquifers in urban areas supplied by AS
	Identify and develop hydrogeological assessments in interstate and transboundary aquifers
	Develop a portfolio for supply solutions with AS in areas with water vulnerability due to critical events

ACTIONS	ACTIVITIES
Data systematization and AS monitoring	Operate and maintain the SAS/SHRH Groundwater System
	Plan and coordinate the National Integrated Monitoring Network
	Qualitative and Quantitative of Groundwater
Support for the elaboration of water resources plans in the AS theme	Prepare the diagnosis of Groundwater in the water resources plans
	Implement actions provided in water resources plans for AS
Training	Planning of specific training in integrated management
	Implementation of specific training in integrated management

Figure 13 – ANA'S Groundwater Agenda
Source: ANA (2015a, p. 12).

ANA has excelled in expanding hydrogeological knowledge through aquifer mapping and carrying out hydrological studies or pilot projects aimed at promoting integrated river-aquifer management. Moreover, it promoted studies on aquifers that are vital for the supply of the following Metropolitan Regions (MR): Maceió, Natal, Belém, Ilha de São Luís, and Manaus.

According to its operations in the elaboration of water resources plans in hydrographic basins within the domain of the Federal Government, ANA included, in a pioneering way, the integrated river-aquifer water approach in the plans of the Rio Doce, Rio Grande, Rio Paranapanema river basins and the Paraguai River. The Agency works closely with state water resource management organs, basin committees and basin agencies, focused on preparing these plans.

ANA is also empowered to organize, implement and manage the National Water Resources Information System (SNIRH) (Article 4, XIV of Law Nº. 9,984/2000). It also acts in the coordination and planning of the National Network for Integrated Qualitative and Quantitative Monitoring of Groundwater, in accordance with CNRH Resolution 107/2010.

In 2019 in partnership with the SGB-CPRM, ANA started a pilot project on aquifers with high baseflow, focused on jointly operating monitoring points of the Integrated Groundwater Monitoring Network (RIMAS), in an integrated manner with the National Hydrometeorological Network (RHN). The first pilot includes the Urucuia Aquifer System, with around 75 points operating together. Currently, RIMAS has approximately 400 monitoring points, distributed through 24 aquifers and 20 states (GENARO; PEIXINHO; MOURÃO, 2019).

Another ANA contribution to groundwater is related to the creation of the Water Producer Program[6]. This program takes place in partnership with several institutions where local Payments for Environmental Services (PES) projects are carried out, which adopt reforestation and conservationist planting practices to increase soil permeability and recover or increase water flow from springs. ANA even developed a methodology (OLIVEIRA et al., 2021) to identify the most favorable areas in the hydrographic basins in order to implement conservation practices focused on maximizing recharge.

The Geological Service of Brazil (SGB-CPRM) is a public company linked to the Ministry of Mines and Energy, with attributions of geological service (see Federal Law Nº. 8,970/1994). Although it is not a member of SINGREH, SGB-CPRM is an important partner of ANA in the survey of geological data on groundwater. The institution has the largest collection of geological, hydrological and hydrogeological data in the country. Moreover, it operates part of the National Hydrometeorological Network (RHN) for ANA and the Integrated Groundwater Monitoring Network (RIMAS). It is also responsible for the Groundwater Information System (SIAGAS), which has an extensive record of wells in Brazil. This collection consists of information cataloged through well registration cards provided by public and private institutions, managers and users of groundwater. It is a registry that is not valid for the purpose of verifying the regularity of water use.

6 For more information, see the Water Producer Program website: https://www.gov.br/ana/pt-br/acesso-a-informacao/ acoes-e-programas/programa-produtor-de-agua.

3.3.4 Hydrographic Basin Committees and inclusion of aquifers in management

The Hydrographic Basin Committees (CBHs) are panel-based organs with normative, deliberative and consultative attributions, linked to the Government and subordinated to the respective Water Resources Councils (CNRH Resolution 5/2000), and are part of the national and state water resources management systems. If their area of operation is a federal river, they are linked to the National Water Resources Council; and in the case of state rivers, they are linked to the State Water Resources Council.

The CBH is a political body that materializes through the construction of a discussion forum between the Government, users and civil society; therefore, it is not a legally independent entity. These panel-based bodies are characterized as the most important instance of local participation, integration of water planning and management (Villar; Granziera, 2020). Law Nº. 9,433/1997, in article 38, and CNRH Resolution 5/2000 defines its main attributions:

- promote the debate on issues related to water resources and articulate the action of the intervening entities;
- arbitrate, in the first administrative instance, conflicts related to water resources;
- to approve the Basin's Water Resources Plan;
- monitor the execution of the Basin's Water Resources Plan and suggest the necessary measures to fulfill its goals;
- proposing to the CNRH and to the State Councils of Water Resources the accumulations, derivations, captures and releases of little

expression, for the purpose of exemption from the obligation to grant rights to use water resources, according to their jurisdictions;

- establish charging mechanisms for the use of water resources and suggest the amounts to be charged;
- make watershed plans for tributary watercourses compatible with the Water Resources Plan of the Hydrographic Basin (Watershed) under their jurisdiction;
- approving the Water Agency's proposals submitted to it;
- submitting, necessarily, the water resources plans of the hydrographic basin to the public hearing;
- developing and support initiatives in environmental education;
- approving its bylaws.

The CBH is empowered to approve and monitor the implementation of basin plans. It must, therefore, verify if the planning instrument incorporated groundwater, observing the CNRH guidelines, with emphasis on Resolutions 22/2002, 92/2008 and 202/2018. Furthermore, CBH is responsible for determining the volumes considered insignificant and establishing the values for charging for groundwater resources.

Law Nº. 9,433/1997, in its Article 37, establishes that the CBHs can have as areas of action: a) "the entirety of a watershed" (part I); b) "watershed sub-basin of a tributary of the main watercourse of the basin, or of a tributary of that tributary" (part II); or c) "group of contiguous river basins or sub-basins" (part III). The hydrographic basin refers precisely to the "geographic space delimited by the respective watershed, whose surface outflow converges to its interior, being captured by the drainage network that concerns it." (ANA, 2015, p. 7). Although this territorial unit focuses on surface waters, this does not make the management of aquifers unfeasible, especially due to the idea of integrated management of water resources and the contribution of aquifers to surface bodies of water.

As the shape of the hydrographic basin does not always converge with that of the aquifers, the CBHs must elaborate inter-institutional cooperation arrangements in order to build the integrated management of surface and groundwater. Therefore, CNRH Resolution 15/2001, in Article 4, sole paragraph, determined that in the case of aquifers underlying two or more hydrographic basins, it is up to the CBHs to seek the exchange and systematization of the data generated for the perfect characterization of the hydrogeological basin.

Overall, CBHs face difficulties in including groundwater in their discussions. This, in large part, is due to a more focused action on surface water resources, lack of knowledge about groundwater and specialized personnel, or low social engagement. Environmental education and technical training programs and initiatives focused on groundwater can help to transform this reality.

3.4 States and groundwater management

The states and Federal District are responsible for: a) defining state policies for water resources that include groundwater; b) establish the institutional infrastructure of the State Water Resources Management Systems; c) lead the implementation of water management instruments provided in Law 9,433/1997; and d) promote studies on aquifers (Fernandes, 2019).

State water management must comply with national rules relative to Water Law, which is under the exclusive jurisdiction of the Federal Government (Article 22, part IV, of the 1988 Federal Constitution) (FERNANDES, 2019; VILLAR; GRANZIERA, 2020). Law Nº. 9,433/1997, CNRH and CONAMA resolutions established or regulated management instruments applicable to groundwater that must be incorporated into state policies, as well as recommending the performance of various technical studies within the scope of hydrographic basins.

Figure 14 shows that water management instruments can be divided into two categories: those dedicated to water in general, and those specific to groundwater. In addition to these, water management is also influenced by the application of instruments from other public policies that can contribute to the management of aquifers. The states and the Federal District have a fundamental role in the application of these instruments, as well as encouraging municipalities to consider aquifers in municipal territorial planning.

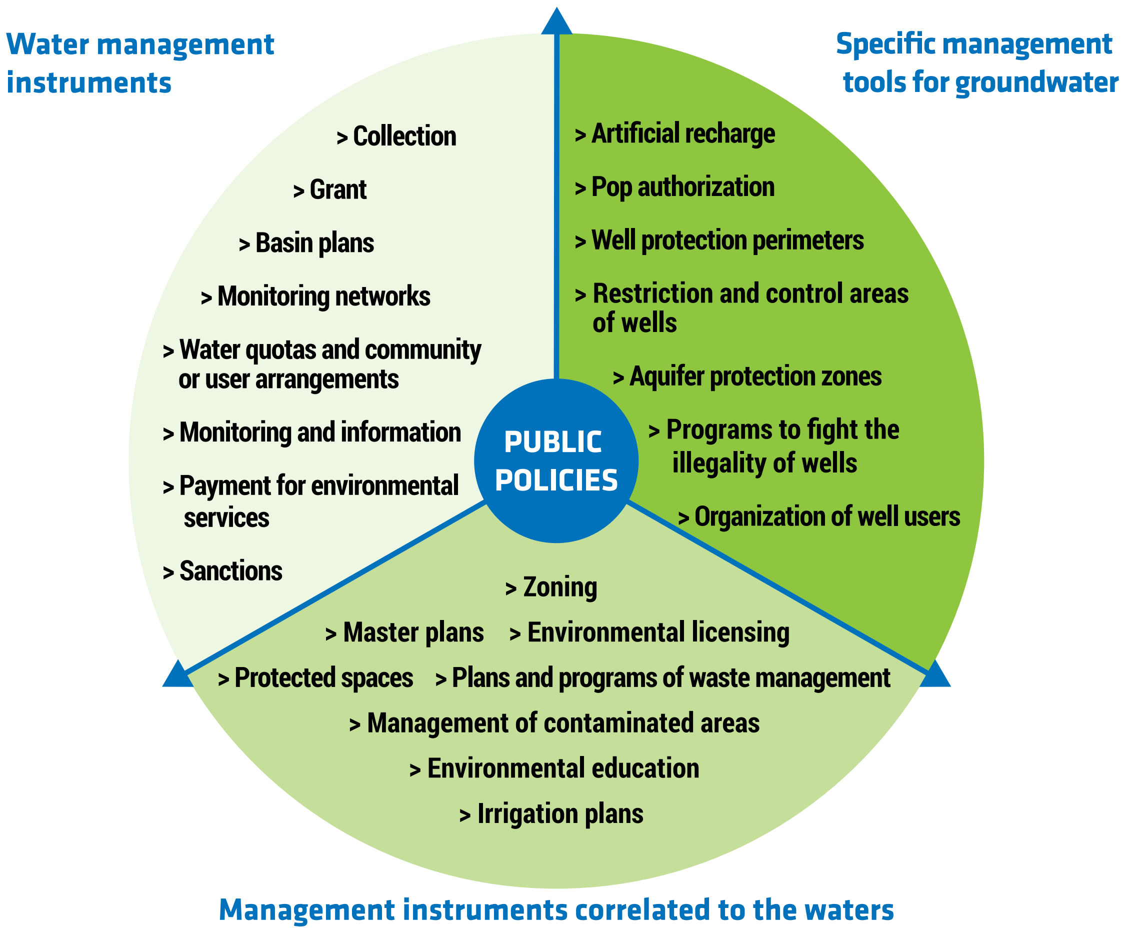


Figure 14 - Direct and indirect groundwater management instruments
Source: Villar and Hirata (2022, p. 5).

The states and the Federal District are responsible for the management of groundwater, even in the case of interstate and transboundary aquifers. This fact highlights the importance of state water resources policies and systems working together, especially to promote aquifer monitoring, information exchange and management measures that protect recharge areas and groundwater flow, when shared.

There is also a need for greater coordination between the federal and state systems, something that is already happening in the case of surface waters through the National Water Quality Monitoring Network (RNQA) and the Program to Stimulate the Dissemination of Water Quality Data – Qualiágua Program (ANA Resolution 643/2016).

3.5 Municipalities and their role in aquifer management

Although there are no municipal waters, municipal entities are important social actors in water management, as they are part of the CBHs and have specific competences for topics directly related to water management. Therefore, municipalities have exclusive administrative jurisdiction to provide public services of local interest (Article 30, V, of CF/88), which includes the organization and provision of sanitation, either directly or under a concession or permission regime. Moreover, they have exclusive jurisdiction to promote territorial planning through planning and control of the use, subdivision and occupation of urban land (Article 30, VIII, of CF/88) and exclusive legislative jurisdiction in matters of local interest (Article 30, I, of CF/88).

The municipality can set several restrictions on the use and occupation of the soil to protect the aquifers based on the instruments provided in Article 4 of the City Statute (Law Nº.10,257/2001), with special emphasis on the master plan, municipal zoning and the creation of protected territorial spaces. Examples of this type of administrative restriction are: a) adoption of stricter environmental parameters for the occupation of recharge areas; b) prohibition of the installation of potentially polluting activities or undertakings in recharge areas; c) imposition of higher percentages of green areas or technologies that contribute to ensuring soil permeability; d) encouraging the adoption of reuse practices; or e) creation of conservation units in recharge areas.

Thus, CNRH Resolution 15/2001 determines that SINGREH bodies must propose mechanisms to encourage municipalities to protect aquifers and adopt practices of artificial water reuse and recharge (Article 6, sole paragraph). Moreover, municipal territorial planning must observe the guidelines contained in the hydrographic basin plans in order to contribute to the integrated management of water and soil (Article 6).

Art. 23 of the 1988 Federal Constitution attributes common administrative jurisdiction in environmental matters to municipalities, which allows them to take actions aimed at protecting the environment and combat pollution in any of its forms; preserve forests, fauna and flora; promote the improvement of sanitation conditions; register, monitor and inspect the concessions of rights to research and exploit water and mineral resources in their territories (see Article 23 of the 1988 Federal Constitution). Complementary Law (LC) Nº. 140/2011, in Article 9, XIV, "a" and "b", regulated the municipal jurisdiction for the environmental licensing of activities that cause or may cause environmental impact at a local level. Without the support of these administrative entities, however, there will hardly be good aquifer management.

3.6 Users of underground water and water management

Groundwater is used through wells or springs. The main users of groundwater (larger volumes extracted) use driven wells[7], benefiting exclusively from these waters, whose use is under the users control. Without the participation of these users, it is not possible to achieve the rational and integrated use of water resources or guarantee the availability of water for present and future generations.

Groundwater users are responsible for: a) obtaining the necessary permits to drill the well and use the groundwater (for example, the well drilling permit, the grant of right to use or other documents attesting to a use considered exempt or insignificant); b) hiring reputable drilling companies that follow the technical standards; c) registering in the wells registry ; d) operating and maintaining the well in accordance with technical standards to protect it from contaminants; e) monitoring the quality and quantity of water, keeping pumping within the recommended technical parameters and the terms of the grant; f) storing the necessary information concerning well profile and operation; g) providing groundwater extraction with devices that allow water collection, level measurements, flow and volume withdrawn to carry out quantitative and qualitative monitoring; h) collecting the amounts owed for the use of water in cases where the charge is implemented in the basin; and i) plugging abandoned or unproductive wells, as instructed by the state management agency. Moreover, users can adopt technological solutions that allow savings or optimization of the use of water resources, as well as contribute to the inspection process, by reporting or advising non-regularized landowners (VILLAR; GRANZIERA, 2020).

7 The wells are divided into two main categories: i) driven wells, popularly called artesian or semi--artesian, and ii) excavated wells, which receive different names, depending on the region of Brazil. The driven well is a cylindric and vertical drilling performed using machines, lined with additive-PVC material or steel in the form of tubes and filters. An artesian well is a driven well in which water flows naturally above the surface of the ground without the aid of pumps.

In the case of groundwater classified as mineral, thermal, drinking or for bathing purposes, the following obligations are highlighted: a) obtaining an authorization for research and a mining ordinance with the ANM in order to exploit the potential of the waters underground related to the characteristics of mineral, thermal, drinking water or for bathing purposes; b) complying with the terms contained in the research authorization and in the mining ordinance issued by the ANM; c) protecting and conserving mineral water sources and using them in accordance with technical precepts; d) establishing mineral water protection perimeters; e) observing the requirements of the state water resources management agency for this type of enterprise in relation to grants, registration or drilling authorizations (Villar; Granziera, 2020, p. 129).

Unfortunately, most groundwater users are clandestine, i.e., they fail to comply with legal and technical obligations related to the drilling, construction and operation of wells. Failure to comply with legal obligations for the use of water resources can generate civil, criminal and administrative liability, under the terms of Article 14, § 1 of Law Nº. 6,938/81 and Article 225, § 3 of the Federal Constitution. There is a great deal of case law from state courts that: a) authorizes the plugging of wells that do not have the right of use or proof of exemption; b) obliges polluters or landowners to remedy contaminated areas; and c) condemns irregular users of mineral waters to pay an indemnity to the Federal Government, as financial compensation for the unauthorized use of a federal resource (Villar; Hirata, 2022; Villar; Granziera, 2020).

3.7 Groundwater and mineral waters of Brazil

Mineral and drinking waters are extracted from natural or underground sources (Assirati, 2018). They are characterized by being “special groundwater” and “distinct from common water by different stages of mineralization” (Queiroz;

Pontes, 2015, p. 15). All mineral water exists underground, however, not all groundwater is mineral water (HIRATA *et al*., 2019). Its extraction is intense, being classified as the most explored mineral resource in the Brazilian subsoil (HIRATA *et al*., 2019).

Brazil is the 5th largest global market for bottled water (ASSIRATI, 2018). In 2017, the use for beverage composition was 21.9 billion liters, while bathing uses consumed 82.2 billion liters in the 83 existing concessions distributed in the "states of Goiás (with 92.7% of the declared volume used) , Santa Catarina (2.5%), São Paulo (2.0%), Mato Grosso do Sul (1.4%), Paraná (1.3%), Rio Grande do Sul and Pernambuco (with less than 1% each)." (ASSIRATI, 2018, p. 2). In all, there are more than a thousand areas of mineral and drinking water mining, of which 48% are located in the Southeast region (Queiroz; Pontes, 2015). These waters are also closely linked to tourism, whether for medicinal purposes or resorts. Although studies on its economic role are lacking, important tourist complexes were built based on its exploitation, as in the case of Araxá (MG), Poços de Caldas (MG), Rio Quente (GO), Caldas Novas (GO), Olimpia (SP), Águas de Lindoia (SP), Santo Amaro da Imperatriz (SC), and Gramado (RS), among others. Figure 15 shows the concessions for mining mineral or drinking water in Brazil.

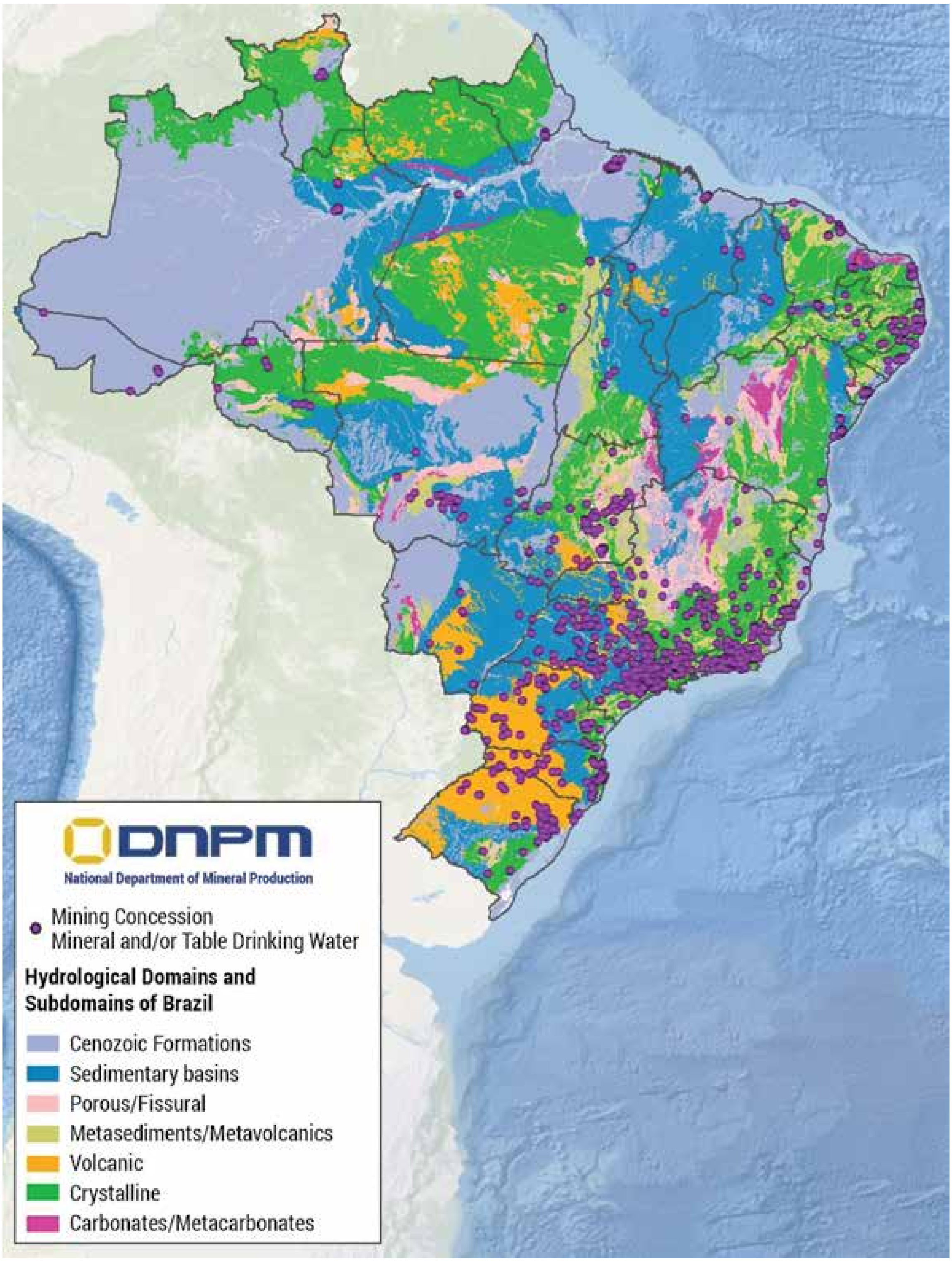


Figure 15 - Map of mineral and drinking water mining concessions in the Brazilian territory
Source: Queiroz and Pontes (2015, p. 27).

The definition of mineral and drinking water is found, respectively, in Articles 1 and 3 of the Mineral Waters Code (Decree-Law Nº. 7,841, of August 8, 1945):

> Art. 1. Mineral waters are those from natural sources or artificially captured sources that have chemical composition or physical or physical-chemical properties different from common waters, with characteristics that give them medicinal properties.
>
> Art. 3 "Drinking water" will be defined as water of normal composition from natural sources or artificially extracted sources that only meet the drinking conditions for the region.

Mineral water has medicinal properties, while drinking water only meets potability requirements. Mineral waters are classified into 12 groups, according to their chemical composition (Table 2). Mineral sources are classified according to the gases present and the temperature (Table 3).

Classification	Characterization according to chemical composition
Radifers	Dissolved radioactive substances, which gives them permanent radioactivity
Alkaline-bicarbonated	Alkaline compounds equivalent to at least 0.200 grams of sodium bicarbonate per liter
Alkaline-earthy	Alkaline earth compounds equivalent to at least 0.120 grams of calcium carbonate per liter
a) alkaline-earth calcium	At least 0.048 g of Ca cation in the form of calcium bicarbonate per liter
b) magnesium alkaline-earth	At least 0.30 g of Mg cation in the form of magnesium bicarbonate per liter

Classification	Characterization according to chemical composition
Sulfated	At least 0.100 grams per liter of the sulfate anion (SO42-) combined with sodium (Na1+), potassium (K1+) and magnesium (Mg2+) cations
Sulphurous	At least 0.001 gram of the sulfur anion (S) per liter
Nitrated	At least 0.100 grams per liter of the nitrate anion (NO31-) of mineral origin
Chlorinated	At least 0.500 grams of sodium chloride per liter
Ferruginous	At least 0.005 grams of the iron (Fe) cation per liter
Radioactive	Radon (Rd) dissolved
a) weakly radioactive	Radon content between five and ten Mache units, per liter, at 20° C and 760 mm of Hg pressure
b) radioactive	Radon content between 10 and 50 Mache units per 1 liter, at 20° C and 760 mm of Hg pressure
c) strongly radioactive	Radon content greater than 50 Mache units per liter at 20° C and 760 mm Hg pressure
Thoronactive	Content of thoron (an isotope of radon) in dissolution, equivalent in electrostatic units to at least two Mache units per liter
Carbogaseous	200 milliliters of dissolved free carbon dioxide (CO2) at 20°C and 760 mm of Hg pressure per liter
Oligominerals	They do not reach the limits established in the legislation, but they have proven medicinal action attested by studies subject to inspection and approval by the Permanent Committee on Crenology.

Table 2 - Classification of mineral waters, according to their chemical characteristics

Source: Brazil (Decree-Law Nº. 7,841/1945).

Classification of sources regarding gases		Description
Radioactive sources	a) weakly radioactive	A gas flow of at least one liter per minute (l.p.m.) with a radon content between five and 10 Mache units, per liter of spontaneous gas, at 20° C and 760 mm of Hg pressure
	b) radioactive	A gas flow of at least 1 l.p.m., with a content between 10 and 50 Mache units, per liter of spontaneous gas, at 20° C and 760 mm Hg of pressure
	c) strongly radioactive	A gas flow of at least 1 l.p.m., with a radon content greater than 50 Mache units, per liter of spontaneous gas, at 20° C and 760 mm of Hg pressure
Thorium sources		At a minimum, a gaseous flow rate of 1 1.p.m., with a thoron content in emergence equivalent in electrostatic units to two Mache units per liter
Sulfur sources		Those that have a defined release of hydrogen sulphide in emergency status.
Classification of sources according to temperature		**Description**
Cold springs		temperature below 25°C
Hypothermal sources		temperature between 25 and 33°C
Mesothermal sources		temperature between 33 and 36°C
Isothermal sources		temperature between 36 and 38°C
Hyperthermal sources		temperature above 38°C

Table 3 - Classification of mineral sources in terms of gases and temperature

Source: Brazil (Decree-Law Nº. 7,841/1945).

Although mineral and drinking waters are all underground, they are classified as mineral resources under the Mineral Water Code. When classified as mineral resources, their domain was attributed to the Federal Government, based on Article 20, Part IX, of the 1988 Federal Constitution[8]. Thus, Decree Nº. 9,406,

8 Art. 20. The following are assets of the Federal Government: IX - mineral resources, including those underground.

of June 12, 2018, determines that the Federal Government is responsible for "organizing the administration of mineral resources, the mineral production industry and the distribution, trade and consumption of mineral products", as well as formulating "public policies for the research, mining, processing, marketing and use of mineral resources" (Article 3). The commercial use of these resources requires a regime of successive authorizations for exploration and mining concessions, established by the Mining Code (Decree-Law Nº. 227/1967, which reworded Decree-Law Nº. 1,985/1940).

The authorization for research and mining, inspection and regulation of the trade in these waters is carried out through the National Mining Agency (ANM), established by Federal Law Nº. 13,575/2017 and linked to the Ministry of Mines and Energy (MME). ANM assumed all the attributions of the defunct National Department of Mineral Production (DNPM) (see article 32).

The Mineral Water Code allows any groundwater to be classified as a mineral resource, as long as the rules imposed by the ANM and the potability requirements of the National Health Surveillance Agency (Anvisa) are complied with. Therefore, the use of the properties of mineral, thermal and aerated waters for the purpose of bottling or bathing use, or even the bottling of drinking water, are under the protection of the Federal Government.

Groundwater is classified as mineral water deposits if it meets the following requirements: a) it is used for the special purposes provided in mineral legislation; b) it fulfills the necessary quality requirements; and c) it carries out the administrative procedure with the ANM, requesting the authorization of research and a mining concession, which are mandatory for those who wish to exploit this bathing and bottling potential (BOSON, 2002; CAUBET, 2009; Queiroz; Pontes, 2015) .

The research authorization is the moment when the first contact occurs between the applicant and the ANM, being defined as "the execution of the works necessary for the definition of the deposit, its evaluation and the determination of the feasibility of its economic use." (Article 2, part V, of Resolution 76/2007). In turn, the concession of a mining ordinance for mineral, thermal, aerated, table water or for bathing purposes is defined as the "administrative act through which the interested party is granted the right to industrial use of mineral water deposits, thermal, aerated, drinking or intended for bathing purposes" (Article 2, part VI, of CNRH Resolution 76/2007).

On the other hand, if the use of groundwater is intended for general purposes, such as supply, irrigation or industrial use, it is subject to the legal regime of state water resources, which requires the following formalities: a) the granting of the right to use the resources water resources or proof of their waiver (*e.g.,* declaration of insignificant use); b) registration in the user registry; and c) charging for the use of water, if implemented in the basin. The granting of rights to use groundwater must comply with the priorities of the water resources plans and this extraction is accounted for in the water balance of the basin.

The exploitation a of mineral water deposits can impact the management of water resources, interfering with the availability of groundwater and surface water; however, this is not usually accounted for in the water balance of the basin. To circumvent this problem, Resolution CNRH 76/2007 was issued, which "establishes general guidelines for the integration between the management of water resources and the management of mineral, thermal, aerated, table or drinking waters intended for bathing purposes". This resolution recognized "the need for integration and coordinated action between organs and entities, whose powers refer to water resources, mining and the environment." To facilitate this procedure, Article 3 of CNRH Resolution 76/2007 recommends that water and mineral management organs share information and jointly define the content and technical studies of the administrative procedures involved. The information to be shared refers, at a minimum, to:

i. titles of mining rights for research or mining of mineral, thermal, gaseous, drinking waters or intended for bathing purposes for inclusion in the Water Resources Information System and consideration by water resource management organs;

ii. administrative acts related to the use of water resources, such as: granting the right of use, prior statements and authorizations for the construction of wells for their inclusion in the mineral resources information system and consideration by the mineral resources management organ;

iii. to the area object of research request for mineral, thermal, aerated water, drinking water or intended for bathing purposes;

iv. the area or perimeter of source protection established by the mineral resources management organ, in order to be considered by the water resources management organs;

v. restriction and control areas established by the competent water resource management organ or provided in the water resources plans, so that the information will be considered by the mineral resources management organ;

vi. the quantitative and qualitative monitoring available in management organs;

vii. those necessary for the formulation of water resources plans and for the performance of hydrographic basin committees (Article 3, sole paragraph).

Moreover, the mineral resources management organ must observe the authorization acts and uses registered with the water resources management organ at the time of analysis of the "authorization application for the research of mineral, thermal, aerated, drinking water or intended for bathing purposes." (Article 6). The water resources management organ, on the other hand, at the time of analyzing the application for granting the right to use water resources, must observe "the existing information in the research requests, research permits and mining ordinances for mineral, thermal, aerated water, tableware or intended for bathing purposes." (Article 7).

Despite representing a positive step, its operationalization faces limitations in promoting the coordination of the federal management of mineral waters with the state management of groundwater (SERRA, 2009; SCALON, 2011; VILLAR; GRANZIERA, 2020). CNRH Resolution CNRH 76/2007 determines that the information provided by management organs be observed; however, this information is not linked to their decision. This represents a problem because as Villar and Granziera (2020, p. 115) explain:

> Mineral, thermal, aerated, drinking water and intended for bathing purposes are mineral resources, but they are also water resources that integrate the water balance of the basin and constitute one of the multiple uses of water. In fact, these waters have a special legal nature, since they are part of the field of operation of two legal systems, mineral and water resources.

Ideally, these users would submit to both mining and water resources regulations since they have complementary natures (FERREIRA JÚNIOR, 2007). The mining ordinance guarantees the exploiter of the deposit the right of access to the mineral resource (mineral, thermal, carbonated water, drinking water or intended for bathing purposes). The granting of the right to use water resources, in turn, guarantees that this exploitation is subject to socioenvironmental control (FERREIRA JÚNIOR, 2007).

Photo: AdobeStock
Parque das Águas, located in the city of Caxambu - MG

Based on the state jurisdiction over groundwater and on competing and common jurisdictions, states may set rules that require the granting of the right to use groundwater classified as mineral, thermal, gaseous, drinking water and those intended for bathing purposes (FERREIRA JÚNIOR, 2007). Moreover, they can subject extraction to a charge, something that happens, for example, in the state of Ceará. This requirement is justified by article 12, Part II of Law Nº. 9,433/1997, which conditions all “extraction of water from underground aquifers” to the granting of the right of use. The law uses the generic term *water* and not *groundwater resources*.

In Brazil, although the topic is still little explored, there are already conflicts related to the use of groundwater and mineral waters, as is the case of Caldas Novas and Rio Quente in the state of Goiás (ANDRADE; ALMEIDA, 2012) or even in the hydromineral resorts of the Circuito das Águas, in Minas Gerais (Caxambu, São Lourenço, Cambuquira and Lambari) (BORGES, 2006).

4

GROUNDWATER MANAGEMENT: FROM THEORY TO PRACTICE

Photo: Eduardo Gomes de Assis/ANA Database
Emergence of a karst aquifer in the Pacuí Basin on the border between Montes Claros and Coração de Jesus – MG.

4 GROUNDWATER MANAGEMENT: FROM THEORY TO PRACTICE

The National Water Resources Policy established several instruments for the management of fresh water. The purpose of this chapter is to present them and demonstrate how they are applied to groundwater.

4.1 Water Resource Plans

The water resources plans were provided in Law Nº. 9,433/1997 and constitute the main instrument for "building consensus in the river basin" (Porto; Porto, 2008, p. 51). Its application goes beyond traditional planning, as it incorporates participatory processes that bring together government, civil society and economic agents (Porto; Porto, 2008). The law defines them as master plans that aim to "establish and guide the implementation of the National Water Resources Policy and the management of water resources" (Article 6 of Law Nº. 9,433/1997).

The application of these plans takes place at three levels of action: national, state and hydrographic basin (Article 8 of Law Nº. 9,433/1997). Figure 16 summarizes the types of plans according to the policy (national or state), their geographic scope and the board-based entities responsible for approving water resources planning in Brazil.

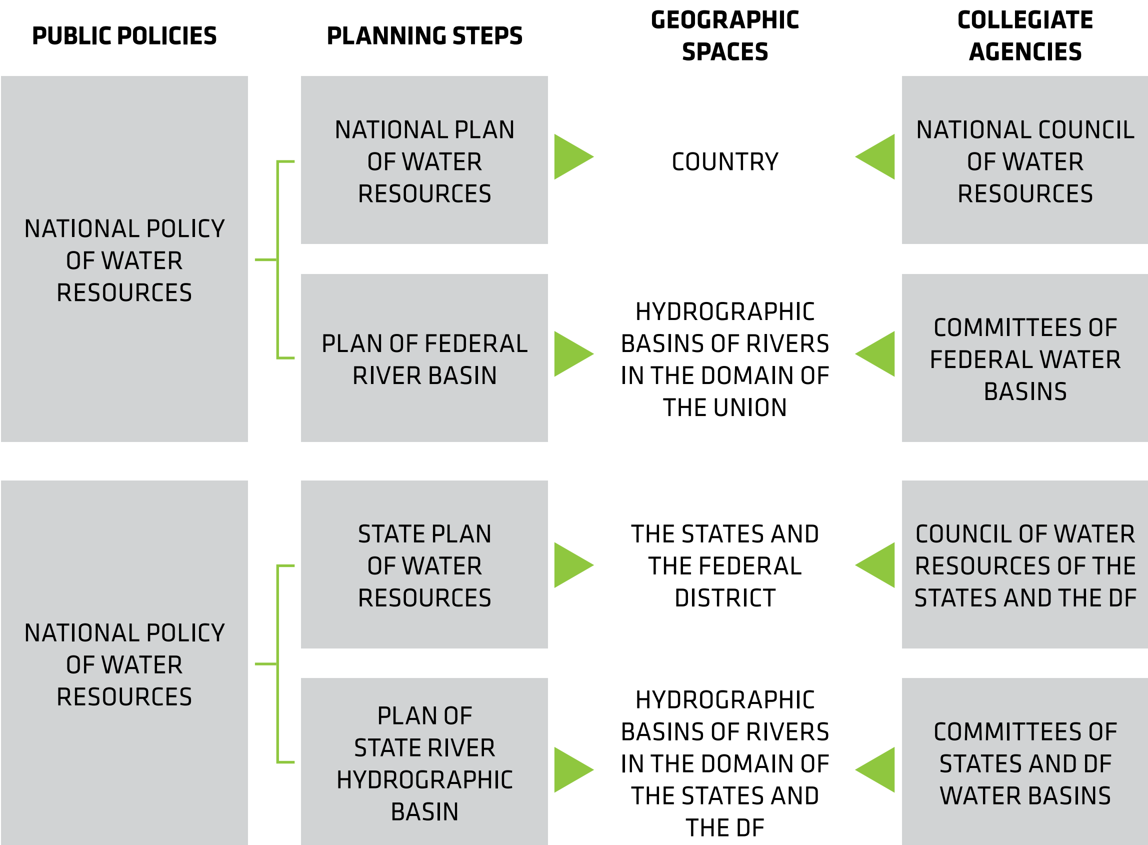


Figure 16 - Public policies, types of plans, geographic scopes and coordinating entities in the water resources planning process in Brazil
Source: Lanna, Pereira and Hubert (2002, p. 110).

In the same hydrographic basin, different scales of water resources plans can coexist: federal, state, of state basins or of interstate basins. Therefore, we have: a) the National Water Resources Plan; b) State Water Resources Plans; and c) Hydrographic Basin Plans, which are subdivided into two categories according to the type of basin: a) River Hydrographic Basin Plans, under federal jurisdiction; and b) River Basin Plans, under state ownership (LANNA; PEREIRA; HUBERT, 2002). Each of these plans incorporates the aquifers correlated to their scale of action in the basin.

4.1.1 National Water Resources Plan (PNRH)

The first National Water Resources Plan (PNRH) was approved in 2006 (CNRH Resolution 58, of January 30, 2006), effective until 2020 and periodic reviews every four years, hereinafter referred to as PNRH 2006-2020. Since its conception, two reviews have been carried out to set priorities for the 2012-2015 and 2016-2020 cycles. The term of this last cycle was postponed to December 2021 (Res. 216, of September 11, 2020). The National Water Security Department (SNSH), linked to the MDR, with the technical support of ANA and in articulation with the CNRH, has been debating the new National Water Resources Plan (PNRH 2022-2040), whose role is to guide the preparation of the federal, state or district multi-annual plans (PPAs) and their respective annual budgets.

The structure of the PNRH 2006-2020 is composed of four volumes: i) Overview and state of water resources in Brazil (v. 1), which deals with the diagnosis of water; ii) Waters for the future: scenarios for 2020 (v. 2), which outlines reference scenarios for planning; iii) Guidelines (v. 3); and iv) the national programs and goals (v. 4) (Article 1 of CNRH Resolution 58/2006).

In parallel with PNRH 2006-2020, ANA prepares, on an annual basis, the report named *Situation of Water Resources in Brazil*. This report serves as a base for various government actions that include monitoring the PNRH 2006-2020, monitoring the federal government's multi-annual plan or analyzing the Environmental Economic Water Accounts System. The report also summarizes the main data on surface and groundwater in the country.

The 2006-2020 PNRH has several programs and subprograms that are detailed in volume 4. In total, seven national programs are planned: Program I – Strategic Studies of Water Resources; Program II – Institutional Development Program for IWRM in Brazil; Program III – Development and Implementation of Water Resources Management Instruments; Program IV – Technological development, training, communication and dissemination of information in IWRM; Program V – Inter-Sector, Inter-Institutional and Intra-Institutional Articulation Program for Water Resources Management; Program VI – Multiple Uses and Integrated Management of Water Resources Program; Program VII – Sector-BAsed Programs focused on Water Resources, in addition to six regional programs. Groundwater is included in the subprograms and priority actions of these programs and is part of the National Groundwater Program (Program VIII) which, although it has national and transboundary scope, was included in the component of regional water resources programs.

Program VIII was divided into three sub-programs: i) Expansion of Basic Hydrogeological Knowledge; ii) Development of Institutional and Legal Aspects; and iii) Training, Communication and Social Mobilization (CARDOSO, 2009). According to the National Water Resources Plan: priorities 2012-2015, each hydrographic region defined priority actions for groundwater, such as the implementation of monitoring networks, preparation of hydrogeological maps, user registration, protection of recharge areas, development of studies technicians etc. (BRAZIL, 2011). It is expected that the actions established as priorities in the PNRH 2006-2020 will be maintained in the PNRH 2022-2040. An example is the case of the expansion of the Integrated Groundwater Monitoring Network, whose goal was a 100% expansion, which was not possible due to budgetary limitations. Notwithstanding, the Network was expanded from 369 to 409 wells. Part of these monitoring wells started to be operated jointly between SGB-CPRM and ANA, with the inclusion of this piezometric data in the National Hydrometeorological Network (RHN), which contributes to promoting the integrated management of surface and groundwater, allowing analysis of the aquifer and river, as was the case of the Urucuia Aquifer System and the São Francisco River.

4.1.2 State Water Resources Plans (PERHs)

The State Water Resources Plans (PERHs) have jurisdiction limited to the scope of each member state and the Federal District, and the plans are responsible for portraying the situation of water resources in the state or district domain. Its main objective is to guide water management through guidelines and criteria at the state or district scale, in order to address the needs expressed in the basin plans. Its preparation, updating and implementation is the responsibility of the organs that make up the State Water Resources Management Systems, as provided by state legislation.

Each state, based on its state policy on water resources, establishes the guidelines and criteria for the preparation of the PERH, in order to contemplate the following aspects:

- guidelines, objectives, criteria and goals of state water management;
- financial priorities in the promotion of regional programs for the management of water resources;
- strategies for coordinating interbasin issues;
- diagnosis and monitoring of the macro situation of water resources in the state (availability, quality, demand, uses and conflicts);
- state programs, projects and actions for water resources;
- guidelines for the application of water resources management instruments within the scope of state hydrographic basins.

Due to the state jurisdiction of groundwater, PERHs are key elements in stimulating the management of aquifers. Among the information that should be covered by the instrument is: a) data on the availability, demand and quality of groundwater; b) proposal of areas for the exploitation of these waters or protective measures, such as areas of restriction to the use of groundwater; c) identification of priority points for monitoring; d) stimulation of coordination mechanisms between CBHs that share the same aquifer; and e) definition of specific state programs for groundwater etc.

4.1.3 Water Resources Plans for Hydrographic Basins

This is the main management instrument provided by water resources policies, applied to small, medium and large hydrographic basins. It is also called the *Water Master Plan*, the *Water Resources Master Plan*, the *Integrated Water Resources Plan* and the *Hydrographic Basin Plan* – the most common denomination after the implementation of the State Water Resources Policies that began in 1991 (São Paulo, 1991), as well as the issuance of the National Water Resources Policy.

The Water Resources Plans of Hydrographic Basins can be defined as:

> [...] instruments for long-term management of water resources, provided by Law Nº. 9,433, of 1997, with a planning horizon compatible with the period of implementation of its programs and projects, whose objective is supporting and guiding the implementation of the National, State and District Water Resources Policies and the management of water resources within the scope of the respective hydrographic basins. (Article 2 of CNRH Resolution 145/2012).

This document sets the strategic planning of water management, and its legal provision and regulation is found in Law Nº.9,433/1997 and in several CNRH Resolutions, with emphasis on Articles 10 to 13 of CNRH Resolution 145/2012, which establish their steps and minimum content: i) Diagnosis of the water resources situation; ii) Prognosis; and iii) Action plan (Figure 17). The planning process must consider the guidelines of other water resources plans (national, state or other river basin plans which may eventually overlap). CNRH Resolution 145/2012 presents the minimum structure of the plans, however, in the scope of the complementary and common jurisdiction, the states can incorporate additional elements.

The Water Resources Plan for Hydrographic Basins must contain the multi-annual action program, whose term usually is 12 years. This document sets the investment program (short, medium and long term), which must contain: i) the name of the planned action; ii) the framing in programmatic lines of the managing collegiate board; iii) the established goal; iv) the term (year) of execution; v) the area covered by the action; vi) the priority of execution; vii) the forecast of the person responsible for the execution; viii) the executor of the action; ix) the estimated cost of the action; and x) the sources of the necessary financial resources. CNRH Resolutions 15/2001, 22/2002, 92/2008, 145/2012 and 202/2018 determine the basic information that basin plans must incorporate on aquifers (Figure 18). Without these analyses, the exploration of aquifers puts surface and underground water availability at risk, causing damage to the environment and users.

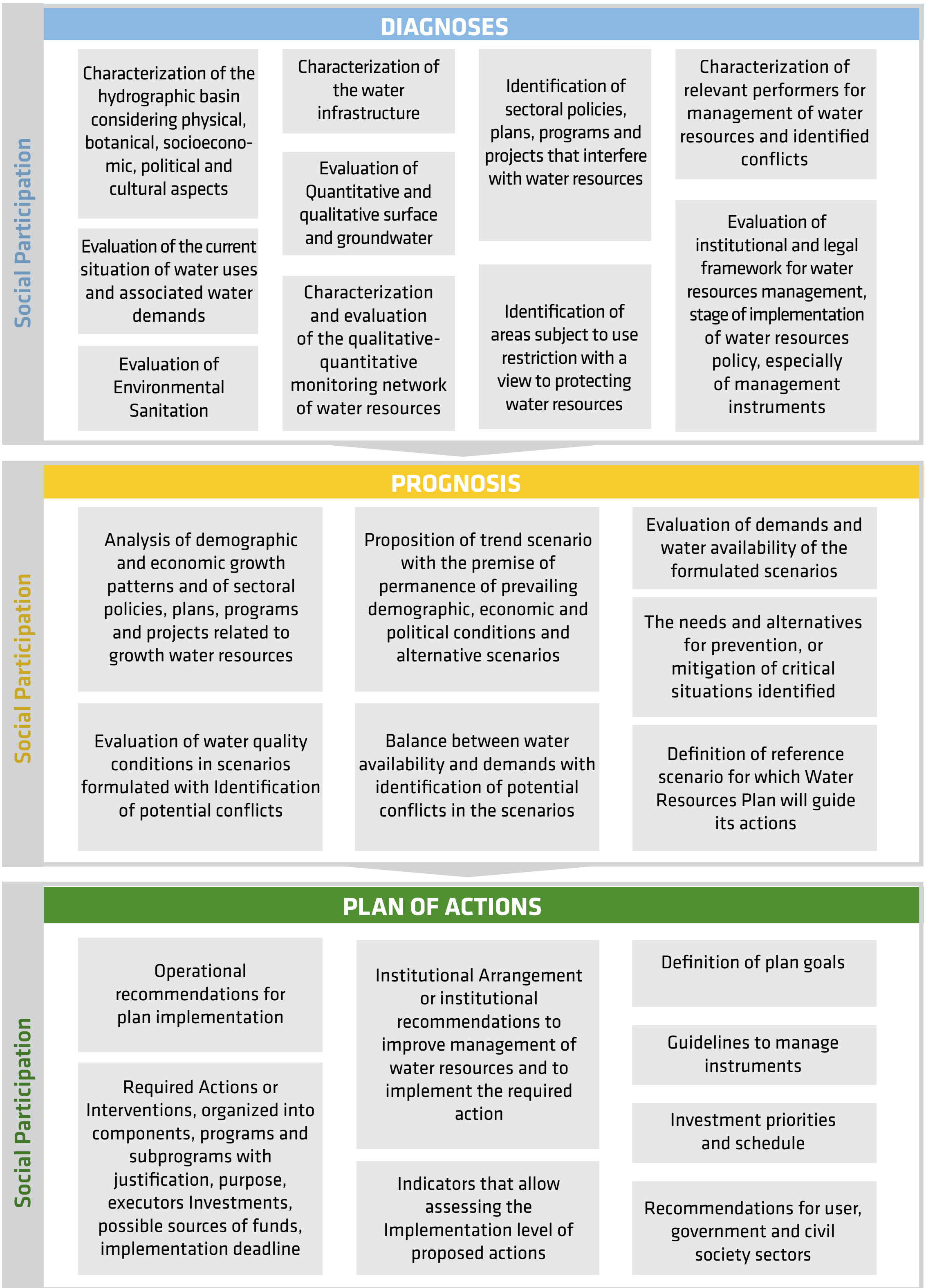


Figure 17 – Guidelines for preparation of the Water Resources Plans for Hydrographic Basins
Source: CNRH (Resolution 145/20120).

Minimum Content of Basin Plans for Groundwater (AS)	▸ Space characterization. ▸ Computation of AS in water balance. ▸ Estimate of recharges and discharges and exploitable reserves. ▸ Physical, chemical and biological characterization of AS. ▸ Measures for use and protection of aquifers.
Monitoring of quantity and quality, with results presented in maps	▸ Monitoring network of aquifer water levels and their quality. ▸ Density of monitoring points. ▸ Parameter monitoring frequency.
Potentially impacting actions and protection or mitigation, including emergency measures	▸ Description and forecast of estimated socioeconomic and environmental pressures on availability. ▸ Estimate of point and diffuse sources of pollution. ▸ Evaluation of soil characteristics and use. ▸ Analysis of other human activity impacts related to AS.

Potentially impacting actions and protection or mitigation, including emergency measures	▸ Maximum Protection Areas.
	▸ Well Protection Perimeters.
	▸ Restriction areas and AS use control.
	    ▪ HR availability considering the base discharge of rivers.
	    ▪ Risk of geometric instability and soil use and occupation.
	    ▪ Sustainability of exploitation in coastal areas.

Integrated hydrological evaluations	▸ Delimitation of recharge and contribution areas of aquifers to directly connected nodes. ▸ Contribution of aquifers to the rivers base flow. ▸ Recharge and exploitable and renewable reserves. ▸ Integrated underground and surface water availability for different uses.

Figure 18 - Groundwater in Basin Plans, with grounds on CNRH Resolutions

Source: CNRH (Resolutions 15/2001, 22/2002, 92/2008, 145/2012 and 202/2018).

Basin Plans are fundamental instruments for inserting aquifers in the management and allowing the conjunctive use of groundwater and surface waters. The joint use of these waters optimizes the water reserves due to the storage capacity of the aquifers that can provide water in the dry season and save water in the rainy season to allow its recharge or even encourage saving through recharge mechanisms (Foster; Steenbergen, 2011). The Interstate Basin Plans have sought the interaction of waters through the Integrated Water Resources Plans, however, there is still a long way to go in view of the lack of data or problems related to the implementation of management instruments.

4.2 Specific management instruments for groundwater

Conama Resolution 396/2008 determines that environmental agencies, in conjunction with water resources management agencies, establish Aquifer Protection Areas, Supply Wells Protection Perimeters and Groundwater Use Restriction and Control Areas (Articles 20 and 21). CNRH Resolution 22/2002 states that Basin Plans must provide for measures for the use and protection of aquifers (Article 3, VI). CNRH Resolution CNRH 92/2008, in turn, provides for the definition of aquifer protection zones, restriction and control areas, and well protection perimeters based on hydrogeological studies (Article 2, I, II and III).

4.2.1 Aquifer Protection Areas (APA)

Aquifer Protection Areas (APA) are intended to protect aquifer recharge zones; however, since they presuppose restrictions on land use and occupation, the instrument has not been used. Incidentally, it is questioned whether it could be applied without the support of municipalities which have exclusive jurisdiction for municipal territorial planning.

4.2.2 Restriction Areas for Groundwater Use Control

Groundwater Use Restriction and Control Areas are exceptional and temporary measures aimed at restricting the use or extraction of water in situations where the quality or quantity of groundwater is compromised. According to CNRH Resolution 92/2008 (Article 4), the state water resources management organ, in articulation with the environmental organ, may establish these areas with the approval of the CBH and the State Water Resources Council, provided that the measure is technically justified by the need for protection, conservation and recovery of: i) supply sources; ii) ecosystems threatened by groundwater degradation; iii) areas vulnerable to contamination; iv) contaminated areas; or v) areas subject to or with identified overexploitation.

The main objective of these measures is to correct distortions in the use of aquifers that may compromise the quality or quantity of water. Its implementation is a complex process that demands the articulation of the government, collegiate bodies, managers and users, as well as the monitoring of the evolution of the aquifer situation. Several states have regulated and implemented this instrument, such as the State of São Paulo which, through Deliberation CRH 052, of April 15, 2002, set the guidelines and procedures for the definition of these areas.

4.2.3 Well Protection Perimeters (PPP)

Well Protection Perimeters (PPP) are intended to protect groundwater extraction and have been regulated by several states. Mineral legislation requires water classified as mineral or drinking water to establish protection areas or perimeters, as provided by Articles 12 and 13 of the Mineral Water Code and DNPM Ordinance 231/1998.

To protect the well surroundings of public supply is an efficient strategy to minimize the danger of contamination of groundwater supplied to the population (NAVARRETE; GARCÍA, 2003). This protection is based on controlling activities that have contaminating potential and applying restrictions on land use in aquifer recharge areas that contribute to the well. The closer to the extraction, the more restrictive are the measures adopted, and this protected area is called the Perimeter of Protection of Wells (PPP) (Figure 19).

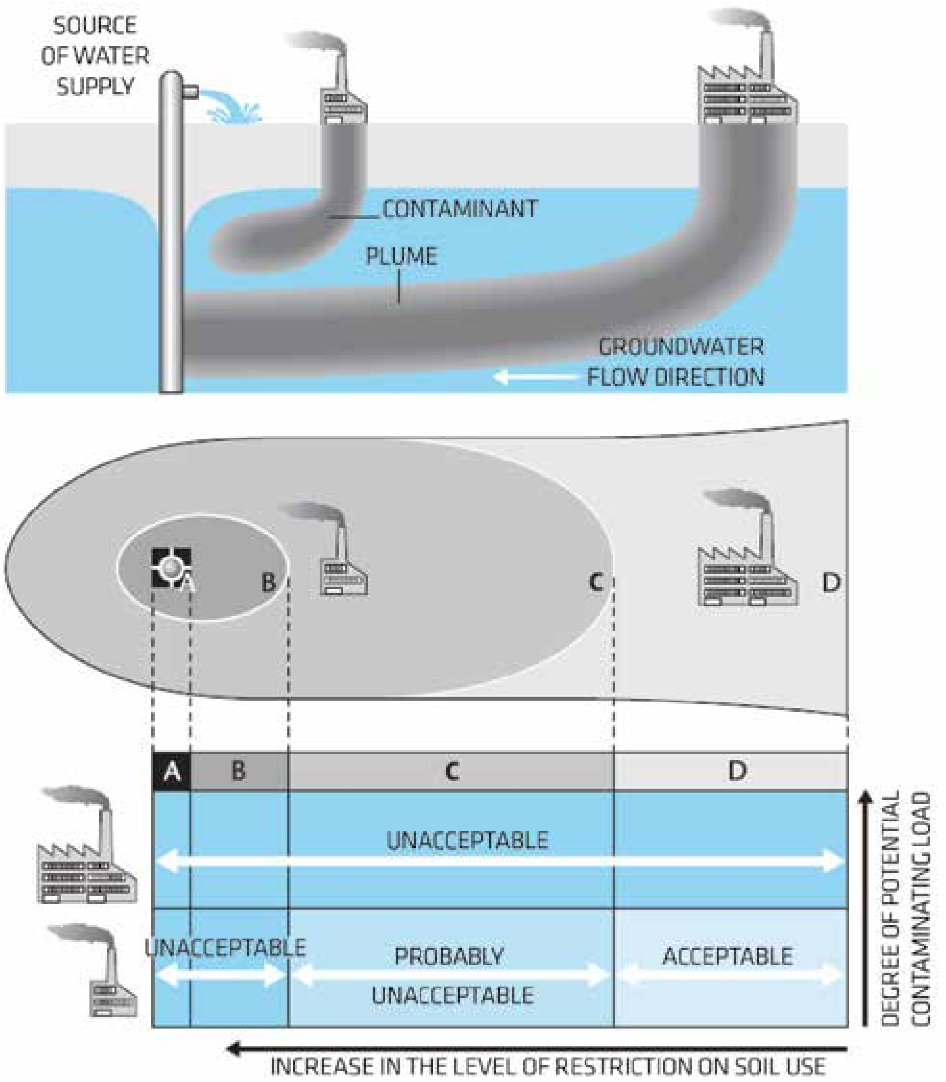


Figure 19 – Well Protection Perimeter Concept

Source: Foster *et al*. (2006, p. 9).

Each well drilled defines a specific Contribution Zone (ZC), which is the area in which all aquifer recharge contributes to the well, based on the different characteristics of the aquifer (permeability, porosity, thickness and recharge) and the constructive and operational conditions of the well (depth of penetration into the aquifer, flow and operating time). PPPs, therefore, are established in the ZC of the well (FOSTER *et al.*, 2006).

The delimitation of protection perimeters is based on different criteria, the most used being: a) longitudinal distance from the well; or b) time traveled by the water in the aquifer until it reaches the well (called transit time). There are several methodologies for delimiting protection perimeters, the choice of which also depends on the quantity and quality of the existing data, the importance of withdrawal to supply the population served and the financial resources available. In addition to the technical foundations, the implementation of well protection areas needs to be a participatory process with users and society in general. For example, in the State of São Paulo, legislation requires PPPs to be supported by studies and approved by the State Council for Water Resources.

4.3 Classification of underground bodies of water, according to predominant uses

The classification of bodies of water into groups, according to the predominant uses of water for aquifers, is regulated by Conama Resolution 396/2008 and CNRH Resolution 91/2008. Art. 29 of CONAMA Resolution 396/2008 determines that the classification of groundwater bodies must consider, at least, the following aspects:

I. hydrogeological and hydrogeochemical characterization;
II. characterization of vulnerability and pollution risks;
III. the registration of existing and operating wells;
IV. land use and occupation and its history;

V. the technical and economic feasibility of the framework;
VI. the location of potential sources of pollution;
VII. natural quality and groundwater quality condition.

Based on these criteria, groundwater is grouped into classes, as defined in article 3 of CONAMA Resolution 396/2008 (Table 4).

Classes	Uses
Class Limit	Aquifer waters, a set of aquifers or a portion thereof intended for the preservation of ecosystems in integral protection conservation units and those that directly contribute to the stretches of surface bodies of water classified as a special class.
1	Water from aquifers, a set of aquifers or portions thereof, without changes in quality due to human activities, and that do not require treatment for any predominant uses due to their natural hydrogeochemical characteristics.
2	Water from aquifers, a set of aquifers or a portion thereof, without changes in quality due to human activities, and which may require adequate treatment, depending on the predominant use, due to their natural hydrogeochemical characteristics.
3	Water from aquifers, a set of aquifers or a portion thereof, with changes in quality due to human activities, for which treatment is not necessary due to these changes, but which may require adequate treatment, depending on the predominant use, due to their natural hydrogeochemical characteristics.
4	Water from aquifers, a set of aquifers or a portion thereof, whose quality has been altered due to human activities, and which can only be used, without treatment for the predominantly less restrictive use.
5	Water from aquifers, a set of aquifers or portions thereof, which may have its quality changed due to human activity, intended for activities that do not have quality requirements for use.

Table 4 – Classes for groundwater classification, according to predominant uses

Source: CONAMA (Resolution 396, of April 3, 2008).

According to CONAMA Resolution 396/2008, groundwater classified in the Special Class must "have its natural quality conditions maintained" (Article 5). The standards of Classes 1 to 4, in turn, are based on the Quality Reference Values (VRQ) and the Maximum Allowed Values (MPVs) for each predominant use (Article 4), observing the Practical Quantification Limits (LQPs) presented in Appendix I of CONAMA Resolution 396/2008. VRQs must be defined by the empowered body, which could be CONAMA or state agencies, however, these standards have still not been defined. Table 5 presents the standards for each class:

Classes	Uses
Special Class	It must maintain its natural quality conditions.
1	It presents, for all parameters, VRQs below or equal to the Most Restrictive Maximum Allowed Values (VMPr+) of the predominant uses (Article 7 of CONAMA Resolution 396/2008).
2	It presents, in at least one of the parameters, a Quality Reference Value (VRQ) higher than its respective Maximum Allowed Value (Most Restrictive) (VMPr+) of the predominant uses (Article 8 of CONAMA Resolution 396/2008).
3	It must meet the Most Restrictive Maximum Allowed Value (VMPr+) among the preponderant uses for each of the parameters, except when it is a natural condition of the water (Article 9 of CONAMA Resolution 396/2008).
4	It must meet the Less Restrictive Maximum Allowed Values (VMPr-) among the preponderant uses for each of the parameters, except when it is a natural condition of the water (Article 10 of CONAMA Resolution 396/2008).
5	It will not have quality conditions aAd standards, according to the criteria used in CONAMA Resolution 396/2008 (Article 11).

Table 5 - Standards for groundwater classification

Source: Conama (Resolution 396, of April 3, 2008).

The procedure for classifying surface and underground bodies of water is defined by CNRH Resolution 91/2008 and is divided into the following steps: i) diagnosis; ii) prognosis; iii) proposal of goals related to the framing alternatives; iv) deliberation by the Water Resources Committee and Council; and v) implementation of the framework program (Figure 20).

The first three stages are technical in nature, which requires social participation through public consultations, technical meetings, workshops and others (article 3, § 2, of CNRH Resolution 91/2008). The process of issuing the deliberations and implementation of the classification program, in turn, have a more political/ decisional nature, and should be conducted by CBH in conjunction with its Technical Agency (COSTA *et al.*, 2019, p. 45). So far, this instrument has not been used for groundwater.


Photo: AdobeStock

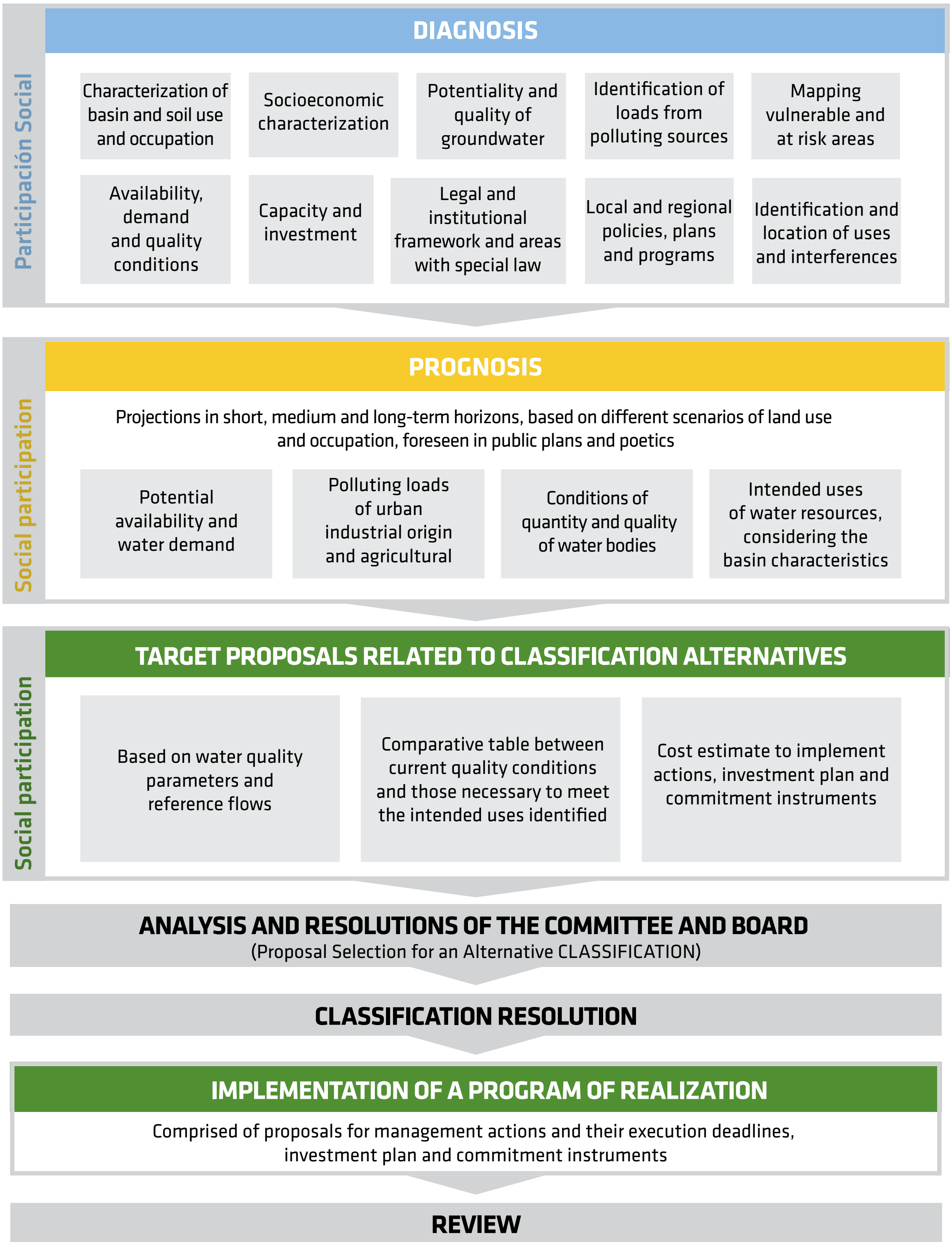


Figure 20 - Steps of the procedure for classifying surface and underground bodies of water, defined by Resolution 91/2008

Source: CNRH (Resolution 91, of November 5, 2008).

4.4 Granting the right to use groundwater resources

The granting of the right to use water resources was defined as “the administrative act through which the granting authority grants the grantee previously or through the right to use water resources, for a determined period, under the terms and conditions expressed in the respective act, considering the specific legislation in force.” (Article 1 of CNRH Resolution 16/2001). This instrument makes it possible to reconcile the public nature of water with its private use, through the role of the State manager (ANA, 2007).

“The role of the grant will be to apportion the available water between existing or potential demands so that the best results are generated for society” (LANNA, 2000, p. 89). The use priorities for granting the concession must be included in the Hydrographic Basin Plans (Article 7, VIII, of Law Nº. 9,433/1997), approved by the CBHs.

This instrument is a reflection of the State’s police powers, as it regulates the use of water resources through the granting of formal authorization to the user who intends to use them privately, for a specified period and in accordance with the established conditions (PORTO; PORTO, 2008). Its maximum term is 35 years from the date of publication of the respective administrative act (Article 16 of Law Nº. 9,433/1997). That term, however, may be extended by the granting authority as long as the priorities established in the hydrographic basin plans are respected (Article 6, § 1 of CNRH Resolution 16/2001).

Its concession does not imply the alienation of water, but rather a right of use (Article 18 of Law Nº. 9,433/1997). The grant aims to balance water availability with demand, allowing the Government to control the use of water in order to guarantee the management objectives and, at the same time, guarantee the user access to water (LEAL, 1998). It is an instrument of “quantitative and qualitative control of water uses” and a condition for the “exercise of rights of access to water" (Law Nº. 9,433/1997, Article 11). The uses that depend on the grant were listed in article 12 of the same federal law:

> Article 12. The rights of the following uses of water resources are subject to granting by the Government:
>
> I. derivation or extraction of a portion of the existing water in a water body for final consumption, including public supply, or production process input;
>
> II. **extraction of water from underground aquifer for final consumption or production process input;**
>
> III. release of sewage and other waste into a body of water, whether liquids or gases, treated or not, for the purpose of their dilution, transport or final disposal;
>
> IV. use of hydroelectric potential;
>
> V. other uses that alter the regime, quantity or quality of water in a body of water. (BRASIL, 1997).

The law expressly included the need to grant the right of use to extract water from aquifers (Article 12, part II). Due to the state jurisdiction of groundwater, the states and the Federal District will be responsible for regulating this instrument, always observing national standards. In addition to extracting water from wells, some states, based on Article 12, part V, require this instrument for cases of lowering of the water table in buildings and civil construction or for lowering the water level in mining activities (in this case, see CNRH Resolution 29/2002). In these situations, the focus is not on use, but on the effects that these activities may have on the aquifer or water in general.

Due to the exclusive jurisdiction of the federal government to legislate on water matters, this instrument can only be waived in the cases provided in Article 12, paragraph 1 of Law Nº. 9,433/1997:

> § 1. Do not require granting by the Public Power, as defined in regulation:
>
> I. the use of water resources to satisfy the needs of small population centers distributed in rural areas;
>
> II. derivations, extractions and ejections considered insignificant;
>
> III. accumulations of water volumes considered insignificant. (BRASIL, 1997).

In these cases, the request for granting the right of use is waived, however, the states impose other administrative conditions, such as: registration in the register of wells or users and obtaining a document attesting to the character of exempt or insignificant use. It is incumbent on the state CBHs to propose guidelines and criteria to establish the uses considered insignificant for groundwater and, then, the CERHs to approve them. In the event of absence of determination of these criteria by the CBH or the absence of this entity, the state granting authority makes the definition on a provisional basis (see CNRH Resolution 184/2016).

The volumes considered insignificant may vary between basins or in specific regions of a basin. Its definition must analyze the following criteria: a) the "percentage of the volumetric reference of a certain portion of the aquifer as an individual limit of catchment"; b) the "percentage limit of quantitative collective commitment of aquifer portions"; and c) the "cumulative effect, in the same water body, of all derivations, abstractions, releases or accumulations of small volumes of water, considered insignificant." (Article 6 of CNRH Resolution 184/2016).

The granting of the right to use groundwater must "avoid the qualitative and quantitative compromise of aquifers and surface bodies of water connected to them." (Article 3, part III of CNRH Resolution 15/2001). To that effect, the decision must be based on the hydrogeological studies described in CNRH Resolution 92/2008 (Article 2) (Figure 21).

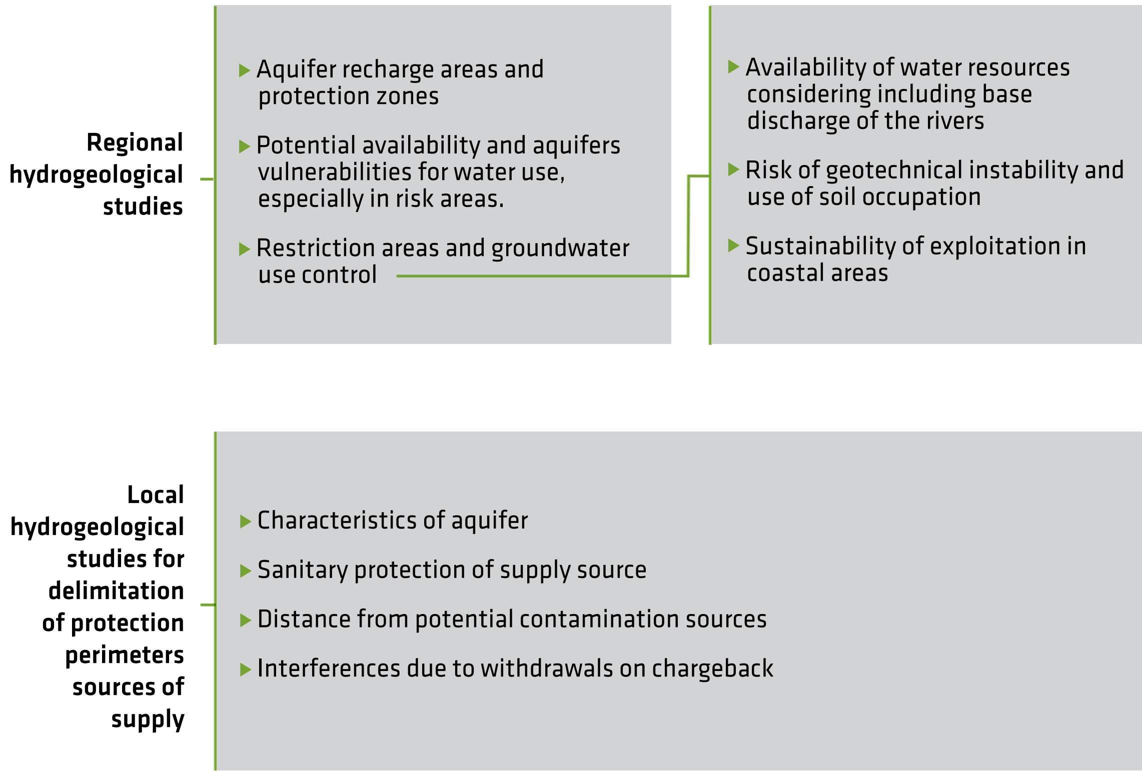


Figure 21 - Hydrogeological studies and granting of right to use groundwater

Source: CNRH (Resolution 92/2008), adapted by the authors.

The granting of the right to use groundwater must take into account the following criteria: a) characteristics of the aquifers; b) user needs; c) possibility of interference between wells and maximum levels of drawdowns allowed; d) risk of saline intrusion; e) demand management among users of groundwater and surface water; and f) articulation with soil management (COSTA et al., 2011).

The main challenge for its implementation, however, refers to the low adherence of users to the instrument. The absolute majority of wells are illegal or irregular. Illegal wells "are those whose drilling and use of groundwater are not supported by law, therefore their existence is prohibited and, consequently, if the interested party requested a grant, it would be denied." (VILLAR; HIRATA, 2021). In turn, irregular wells "are those whose drilling and use of groundwater are supported by law, but which require compliance with certain procedures or impose restrictions or conditions for this use, which were not met by the owner of the well." (VILLAR; HIRATA, 2021).

The clandestine use impairs the application of other instruments, such as the preparation of basin plans and charging for their use. Unfortunately, in the case of legal uses, most of the grants are issued without the necessary hydrological assessments or are not based on appropriate methodologies. ANA (2013b, p. 64) recommends that the calculation of underground water availability be guided by the concepts of:

- **Direct Potential Recharge (RPD)**: it is "the portion of the average annual rainfall that infiltrates and effectively reaches the uncontained aquifers, thus constituting the renewable or regulatory reserve.

- **Sustainability Coefficient (CS)**: maximum percentage recommended to exploit the RPD, in order to avoid adverse effects on the aquifer or decrease in base flows of interconnected rivers;

- **Estimated Exploitable Potential Reserve (RPE)**: corresponds to the portion of the RPD indicated by the CS.

The state of Mato Grosso do Sul uses this methodology to delimit the volumes available for the grant. There are, however, other ways to determine these values, such as: a) average aquifer flow; b) percentage of well flow; c) base flow


Photo: AdobeStock

of surface drainage; d) safety flow; e) available drawdown; and f) qualitative analysis of pumping test data (CAMPOS; CORREA, 2013).

The precariousness of the implementation of this instrument puts the objectives of the water policy at risk. Without control of use, there is no way to ensure water availability for present and future generations or rational and integrated use, much less prevent and mitigate critical hydrological events resulting from inappropriate water use (VILLAR, 2016). Table 6 summarizes the main reasons for the illegality of wells and proposes actions to fight this practice.

Social Actors	Facilitating factors	Mitigating actions
Users	• Lack of knowledge about groundwater in terms of technical and legal aspects; • They see no problems or consequences in using the waters clandestinely; • They do not know the benefits of having the well regulated; • There are no financial or service incentives or compensation that make the regularization of the well attractive for the user; • There is no willingness on the part of the user to pay withdrawal fees without seeing a return on that payment. • Resistance to accept payment of the sewage fee proportional to the volume of water withdrawn from the well; • There is an understanding that having an unregulated well is a minor offense and does not harm society or the environment.	• Make users aware of the need and benefits of regulating wells. • Provide consistent technical and groundwater availability information to assist the user in prospecting and withdrawing the resource. • Offer compensation for regularized use. For example, through technical operational guidance on pump and energy efficiency, water quality etc. • Look for ways to include the well owner as a partner in groundwater management.
Managing Organs	• Lack of political will to inspect and control the wells; • Lack of institutional tradition and organizational stability; • Limited knowledge and data on aquifer behavior; • Inconsistent well records and insufficient groundwater availability information to help users or promote good management; • Low field operational capacity, which hinders effective inspection; • Sanctions are rarely applied to irregular wells, in many cases it is only required to carry out regularization; • Groundwater is not seen as a priority by managers or society; • Grant processes are often complex, bureaucratic and time-consuming.	• Carry out effective inspection, identifying irregular wells, promoting regularization and applying the law and its penalties; • Use supervision and the application of penalties in an exemplary way, including publicising these actions to demonstrate state action; Create programs to regularize wells, especially in areas with intense use, signs of overexploitation and conflicts between neighboring users.

Social Actors	Facilitating factors	Mitigating actions
Drillers	Omission about the obligation of the grant and the risks and consequences arising from the lack of authorization; Limited knowledge of hydrogeology to understand the impacts of irregular use; There are drillers working without registration with the activity control organ (CREA) or whose technical manager spends less time than the established minimum; Lack of cooperation between the management organs and those controlling the drilling activity.	Establish a relationship between the water resources management body and CREA, including data exchange. Carry out the effective inspection and control of the well-drilling activity. Make drillers aware to perform only authorized drilling and in accordance with technical standards.

Table 6 – Why do we have so many irregular wells and how can we change this situation? Source: FOSTER, HIRATA AND CUSTODIO (2021), adaped by Antonio Luiz Pinhatti.

4.5 Charging for the use of water resources: means to promote groundwater management

The charge for the use of water resources is provided for in Article 5, Part IV of Law Nº. 9,433/1997. Art. 19 of the aforementioned law and CNRH Resolution 48/2005 define that its objectives are to:

I. recognize water as a limited public good, with economic value, and give the user an indication of its real value;

II. encourage the rationalization of water use and its conservation, recovery and sustainable management;

III. obtain financial resources to finance studies, projects, programs, works and interventions, included in the Water Resources Plans, promoting direct and indirect benefits to society;

IV. encourage investment in depollution, reuse, protection and conservation, as well as the use of clean technologies that save water resources, according to the classification of bodies of water in classes of predominant uses; and,

V. to induce and encourage conservation, integrated management, protection and recovery of water resources, with emphasis on areas subject to flooding and recharge of aquifers, springs and riparian forests' through compensation and incentives to users. (CNRH, Resolution 48/2005, article 2).

This economic and control instrument is based on the polluter-payer and user-payer principles, and the amounts collected have a public price nature, as it is a consideration paid for the use of public assets (GRANZIERA, 2015; VILLAR; GRANZIERA) , 2020). The charge can be federal or state, depending on the domain over the water resource and the area of the committee in question. In the case of interstate CBHs, the charge was applied to the following basins: the Paraíba do Sul river; the Piracicaba, Capivari and Jundiaí rivers; of the São Francisco River; from the Rio Doce; of the Paranaíba River; and the Verde Grande River (ANA, 2019).

Due to the state jurisdiction of groundwater, the federative units are responsible for regulating and enforcing the charge. Based on the legislation, in a participatory way, the CBHs establish the charging mechanisms and suggest the values to be approved by the state council for water resources (CERH). In some states, in addition to this approval, a government decree is required to allow effective charging, which is restricted to the uses granted (VILLAR; GRANZIERA, 2020).

Most states, unfortunately, have not fully implemented charging (Figure 22). States with a high rate of exploitation of groundwater and equipped with CBHs face difficulties in applying the charge, as is the case of Rio Grande do Sul, Santa

Catarina, Paraná, Mato Grosso, Mato Grosso do Sul and Goiás. Moreover, when applied, the situation of non-regularity of wells impairs effectiveness.

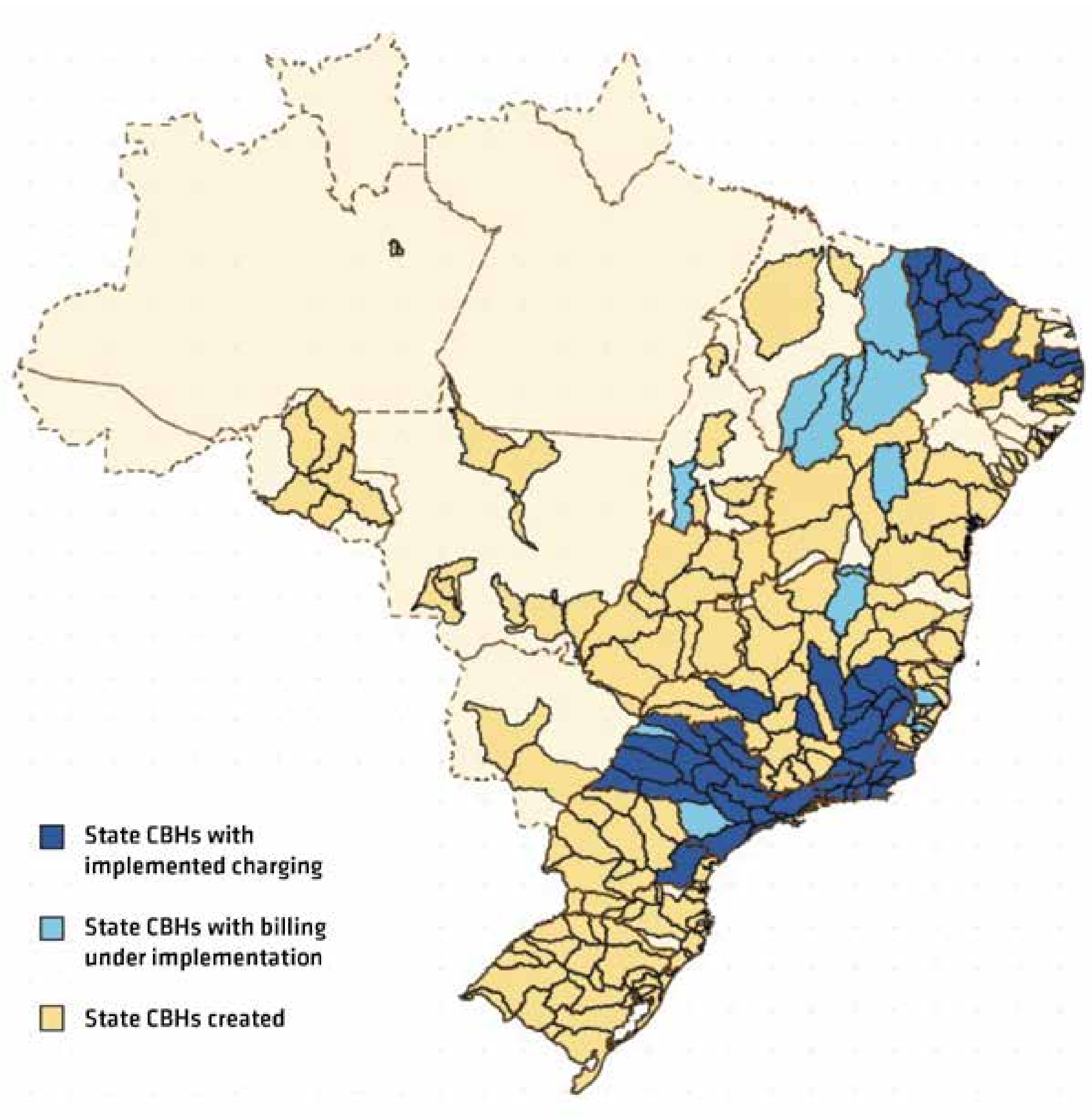


Figure 22 – Charge for the use of water resources in Brazil – State Water Committees
Source: ANA (2019, p. 26).

The Basic Unit Price (PUB) applied to the collection of groundwater collection varies, on average, between R$ 0.01 and R$ 0.02 per cubic meter, depending on the type of use and charge. The case of Ceará stands out, which charges a specific amount of R$ 0.85 per cubic meter for the extraction of mineral waters (see Notice 01/2021/GECOM/DIAFI/COGERH, of 02/16/2021). The PUB is not the final price paid by the user, which is obtained from mathematical formulas that apply different weighting coefficients to this value. Despite the application of these coefficients, the prices charged are low and do not necessarily encourage the rational use of water resources (OECD, 2015). The application of charging is fundamental to water management, as it contributes to the implementation of various programs and projects aimed at improving water management, in addition to strengthening integrated water management.

4.6 Information Systems and groundwater

Information Systems are essential to inform the decision-making process. The application of water resources management instruments, provided by Law Nº. 9,433/1997, depends on the availability of data that allow the assessment of the conditions of hydrographic basins and their respective aquifers (PORTO; PORTO, 2008). Water resources information systems can be national or statewide. In the case of groundwater, three information systems can be highlighted: the National System of Information on Water Resources (SNIRH), the National Registry of Users of Water Resources (CNARH), which is a subsystem of the SNIRH, and the Groundwater Information System (SIAGAS). The first two are under the the attributions of ANA, with the SNIRH seeking to gather general information on water resources, while the CNARH focuses on the use of water resources. SIAGAS, on the other hand, operates independently of the systems coordinated by ANA and is characterized as a well database gathering information on the constructive, geological and hydrogeological aspects.

CNRH Motion 38, of December 7, 2006, recommended the adoption of SIAGAS by ANA and by state management bodies, state government secretariats and users of groundwater resources, as a shared national basis for storage, handling, exchange and dissemination of groundwater information. In addition to these water-related information systems, one stresses the National Environmental Information System (SINIMA) and the National Sanitation Information System (SNIS). Motion CNRH 39, of December 7, 2006 recommended the integration between all these systems.

4.6.1 National Water Resources Information System (SNIRH)

SNIRH is provided in Articles 5, Part VI, and 25 to 27 of Law Nº. 9,433/1997, and aims at the "collection, treatment, storage and retrieval of information on water resources and factors involved in their management" (article 25). ANA is responsible for the organization, implementation and management of this system, which is intended for SINGREH entities, users, the scientific community and society in general[9]. The stored data provide the basis for the preparation of Water Resources Plans and include information on: hydrographic division, water quantity and quality, water uses, water availability, critical hydrological events, water resources plans, regulation and supervision of water resources and programs aimed at the conservation and management of water resources.

4.6.2 National Register of Users of Water Resources (CNARH)

CNARH was established by ANA Resolution 317, of August 26, 2003, with the objective of "learning the demand for water use in the country to provide support for the implementation of the instruments of national and state policies on water resources, and for the supervision of uses and interference in water resources" (Article 1, § 2). The registry materializes a "record of users of water resources, uses and interference regularized by the states and the federal government" (Article 1, § 1), which is part of the SNIRH. Developed by ANA, together with water resources management authorities, CNARH allows states to insert their databases related to the uses of water resources in order to establish users and uses, based on different territorialities (local, regional or

9 This system can be accessed on the website: https://www.snirh.gov.br/.

national). The bodies or entities that manage water resources and state and federal granting-authorities are responsible for inserting the register of users, uses and interferences, in addition to regularization acts.

CNRH Resolution 126/2011 set guidelines for the registration of users of water resources and for the integration of databases referring to the use of surface and underground water resources. For this registry, users are classified as "individuals or legal entities, of public or private law, using or interfering with water resources, whether or not subject to grant, under the terms of Article 12, of Law No. 9,433, of 1997, and of the current state norms" (Article 3, part III, of CNRH Resolution 126/2011).

4.6.3 Groundwater Information System (SIAGAS)

SIAGAS was created before the water policy, in 1996, by the SGB-CPRM, and constitutes the main collection of information on wells in Brazil. Its database is built from information provided by water resource management bodies, drilling companies and groundwater users. Its main objectives are: to collect, store and make available georeferenced hydrogeological data and information in order to support the preparation of hydrogeological maps and contribute to meeting the demands for data from users and managers of water resources or related areas. The system provides a database that contributes to: a) providing technical data to research, studies and hydrology and hydrogeology projects developed by the Geological Survey of Brazil; b) store the national well database available to the general public; and c) support water management through technical information on the use and characteristics of groundwater and registered wells. The system is equipped with mechanisms that facilitate the collection, consistency and storage of hydrogeological data, working in coordination with state management bodies and partner companies (public and private)[10].

10 The system can be accessed on the website: http://siagasweb.cprm.gov.br/layout/.

4.7 Other instruments that contribute to water governance

The idea of integrated management of water resources presupposes not only specific policies for the use and exploitation of water resources, but also the coordination of policies related to the use and occupation of the territory and environmental protection. The centrality of water for economic activities, ecosystems and the quality of human life makes this substance (or should be) an important variable in the application of management instruments for other public policies, especially those related to the environment, sanitation, agriculture and urban development.

The National Environmental Policy (Federal Law Nº. 6,938/1981), the Agricultural Policy (Federal Law Nº. 8,171/1991), the National System of Nature Conservation Units (Federal Law Nº. 9,985/2000), the Urban Policy (Federal Law Nº.10,257/2001), the National Sanitation Policy (Federal Law Nº.11,445/2007), the National Policy on Climate Change (Law Nº. 12,187/2009), the National Solid Waste Policy (Federal Law Nº.12,305/2010), CONAMA Resolution 420/2009 (contaminated areas), the “New Forest Code” (Federal Law Nº.12,651/2012) and the National Irrigation Policy (Federal Law Nº.12,787 /2013) are examples of national laws that provide for instruments management related to water management.

States and municipalities, to the extent of their powers, must regulate and implement these instruments, to include aspects related to water (surface and groundwater) and the promotion of water security. According to VILLAR AND HIRATA (2022), the main management instruments that can positively or negatively influence water are:

- the master plan;
- the legislation related to the subdivision, use and occupation of land;
- the environmental zoning;
- the environmental licensing of potentially polluting activities;
- the licensing or administrative authorization for probing and drilling of wells;
- the ecological economic zoning (ZEE);
- the conservation units;
- the state environmental regularization program (PRAs);
- the areas of permanent preservation and legal reserve;
- the environmental information system;
- the climate change plans;
- the solid waste plans;
- the solid waste management plans;
- the management of contaminated areas;
- the report of contaminated areas;

- the sanitation plans;
- the information systems on public sanitation services;
- the spring recovery programs;
- the program for the proper management of animal waste;
- the irrigation plans (PEI);
- the agroecological zoning (ZA);
- the irrigation information system.

These instruments have the potential to promote groundwater management insofar as they guide and optimize the performance of users, protect water or elements related to the hydrological cycle, impose restrictions or limit the use and occupation of land or condition the implementation of activities potentially polluters or users of natural resources. The government, however, has difficulties in elaborating or implementing these planning instruments effectively and efficiently. This is the case of the state plans for irrigation, agroecological zoning and ecological economic zoning. The situation is particularly worrysome as Brazil is among the ten countries with the largest area equipped for irrigation, with agriculture being the main user in quantitative terms (ANA, 2021). Another problem is the relationship between aquifers and municipal land use planning because it is not usual for municipalities to incorporate the protection of recharge areas or consider the vulnerability of aquifers in the application of urban policy instruments.

5

GROUNDWATER GOVERNANCE AND THE STRENGTHENING OF INTEGRATED MANAGEMENT OF WATER RESOURCES


Photo: AdobeStock

5 GROUNDWATER GOVERNANCE AND THE STRENGTHENING OF INTEGRATED MANAGEMENT OF WATER RESOURCES

Groundwater governance and the strengthening of integrated management presuppose the involvement of different actors, the overcoming of legal and institutional bottlenecks, as well as the adoption of strategies to protect its quantity and quality. Therefore, this chapter intends to present the main recommended actions for the construction of this groundwater governance process and the effective implementation of the integrated management of water resources.

5.1 Strategies to protect the quantity and overexploitation of aquifers

The main characteristic of aquifers is the large storage of water, thus, withdrawals of volumes greater than the recharge can be allowed as long as they are compensated in the future. Aquifers, therefore, are able to be used as a "savings account", which requires long-term planning, with clear rules for exploitation, based on technical studies and monitoring through an integrated monitoring network, in addition to the user engagement to fulfill agreed upon commitments. The extractions in aquifers should not be reduced to a simple arithmetic of inputs and outputs, which disregard the storage capacity of the aquifer or the fact that the extractions can induce greater availability of groundwater (FOSTER *et al.*, 2006). Ignoring these considerations means losing the opportunity offered by aquifers to provide more water or to regulate the balance between production and demand, especially in dry periods and prolonged droughts.

The preparation of a long-term planning is hampered by the low investment in studies, which would make it possible to accurately assess the potential of aquifers. Furthermore, the problem of overexploitation is associated with the high number of irregular or unknown wells, which makes it difficult to establish a realistic program for the management of water resources.

The proper management of extractions and the use of an aquifer, an aquifer system or a specific part of an aquifer must be composed, first of all, by the identification of critical areas, i.e., those in which the use of groundwater is more intense or the performance of its ecosystem services are essential. This will make it possible to plan groundwater use actions and, above all, enable managers to identify priorities among critical areas.

The identification methods of critical areas must be based on: a) hydrogeological cartography to recognize aquifers and their hydraulic characteristics, supported by a register of wells, with tests and hydraulic data; b) identification of ecologically fragile areas (swamps, rivers and mangroves) of the underground flow; c) registering of urban centers dependent on underground water for public and private supply; d) records of conflicts between users; e) inventory of areas with a record of large losses of potentiometric levels of the aquifer, reported by well drilling companies, users or operators of water supply systems; and f) history of flow reduction in rivers, drainages and dry swamps or loss of springs and lakes.

From the identification and characterization of critical areas, it is necessary to transform this knowledge into institutional, political and legal actions. Usually, the most frequent action is the creation of groundwater restriction and control areas, whose objective is to limit the volumes withdrawn or new drilling. This strategy is foreseen in the legislation of several Brazilian states and abroad, having been used, for example, in the case of Ribeirão Preto (SP).

The success of this measure depends on the involvement of the government and users. Management bodies need to monitor the evolution of aquifer water levels, engage users in the process of defining goals and ways of allocating water and monitoring compliance. To fulfill these obligations it is necessary to build partnerships between the various levels of government (local, state and federal). Users, in turn, need to commit to reducing abstractions to achieve goals, monitor their wells and work together with the government to recover the aquifer. Another measure to recover an aquifer is the adoption of mechanisms for the artificial recharge of the aquifer.

5.1.1 Artificial recharge and maintenance of aquifers

In Brazil artificial recharge is not used as a public policy although it is provided in CNRH Resolution CNRH 153/2013. This regulation defines recharge as the "unnatural introduction of water into an aquifer, by planned human intervention, through the construction of structures designed for this purpose." (Article 2). The structure of recharge mechanisms can be built either by the government or by users or by mixed models between government and users. Its main objectives are: storing water, stabilizing or raising water levels in aquifers, compensating for the effects of overexploitation of aquifers, controlling saline intrusion, or controlling soil subsidence (Article 4).

In Article 3, CNRH Resolution 153/2013 determines that artificial recharge can be deployed from the surface or at a' depth. At the surface, infiltration occurs through dams, water sprinkling, canals, ditches, or a combination of these methods. At a depth, water is injected directly through wells. The literature also points out the possibility of deep recharge in the unsaturated zone through infiltration boxes (filled or coated), recharge trenches, subsurface drains or drainage galleries (SEWRPC, 2006).

According to the literature, the water injected into the aquifer can be the result of rain, surface bodies of water, other aquifers or reuse. It is important to ensure that these waters do not jeopardize the water quality of the aquifer. Therefore, any artificial recharge scheme must be preceded by technical studies, as well as the construction of small-scale pilot systems and qualitative-quantitative monitoring. The state water resources management body is responsible for authorizing the artificial recharge of aquifers, which will be conditioned to the "carrying out of studies that prove their technical, economic, sanitary and environmental feasibility" (CNRH, Resolution 153/2013, Article 5).

5.2 Strategies for protecting the quality of aquifers

Strategies for the protection of aquifer water quality should not be dissociated from those that aim at their quantity. The water use concession programs must consider the quality of the resource and the danger of pollution to avoid problems and risks to the users' health or to facilitate the identification of contaminated areas in the aquifer. Generally, prevention against the loss of quality of water resources focuses on two distinct strategies: a) actions aimed at protecting the aquifer as a whole; and b) actions to protect water sources for public supply (Foster *et al*., 2002).

The protection of the aquifer takes place, mainly, through the control of the use and occupation of the soil, in order to avoid that contaminating loads are generated or that reach the aquifer (saturated zone). It is therefore required the application of instruments that restrict certain uses in recharge areas or even authorizations and permissions for use that consider vulnerability to aquifer contamination, as well as the approval of hazard management procedures to avoid or mitigate accidents that can generate contamination. Brazilian legislation has established several instruments for this, such as environmental licensing, environmental zoning and municipal land use and occupation laws.

The prevention of contamination can be achieved by reducing the danger of contamination of an area (FOSTER; HIRATA, 1988; FOSTER *et al*., 2002). Hazard is defined as the interaction between the contaminating load and the vulnerability of the aquifer to its degradation. Therefore, the greatest danger occurs when there are high contaminant loads in areas of high vulnerability, such as, for example, the outcrops of a free, sedimentary, sandy and permeable aquifer. In contrast, the lowest danger is associated with the case where there is a reduced or non-existent contaminant load, located in an area of low vulnerability (FOSTER; HIRATA, 1988; FOSTER *et al*., 2002).

Aquifer vulnerability mapping is a management strategy that allows prioritizing resources for the most vulnerable aquifers. Another management approach is the protection of the most important water sources, such as those used for public supply or users who are more sensitive to the issue of quality, such as hospitals, health clinics and schools. In this case, the main strategies are: a) to define the Protection Perimeters of Wells or Springs (PPP), and b) to prevent potential sources of contamination from being installed in the surroundings (CARVALHO; HIRATA, 2012; FOSTER *et al*., 2002).

5.2.1 Management of contaminated areas and groundwater

In the case of groundwater contamination, it is necessary to resort to the Management of Contaminated Areas (GAC), which is a procedure regulated by CONAMA Resolution 420/2009 and by state legislation. The term contamination is defined in article 6, Part V, of CONAMA Resolution 420/2009 as:

> the presence of chemical substance(s) in the air, water or soil, resulting from human activities, in concentrations that restrict the use of this environmental resource for current or intended uses, defined based on a risk assessment to human health, as well as the assets to be protected, in a standardized or specific exposure scenario; [...].

From the perspective of the GAC, degradation becomes legally relevant when it exceeds contamination parameters previously set by legislation. According to CONAMA Resolution 420/2009, this procedure is guided by the Guiding Values (VOs), which are subdivided into the following categories:

> **Quality Reference Value (VRQ)**: is the concentration of a certain substance that defines the natural quality of the soil, being determined based on statistical interpretation of physicochemical analyzes of samples of different types of soil (Article 6, XXII);
>
> **Prevention Value (VP)**: is the limit value concentration of a given substance in the soil, such that it is capable of sustaining its main functions, in accordance with Article 3 (Article 6, XXIII);
>
> **Investigation Value (VI)**: is the concentration of a certain substance in the soil or underground water above which there are potential risks, direct or indirect, to human health, considering a standardized exposure scenario (Article 6, XXIV).

The characterization of contamination, therefore, presupposes the existence of certain concentrations in the soil or groundwater that, according to the legislation, would generate a potential or effective risk to human health or ecosystems. Once this situation is verified, it becomes mandatory to adopt a series of measures to restrict the use of soil and groundwater, as well as to recover and remedy the contaminated area. CONAMA Resolution 420/2009 regulates the VOs, however, the states must regulate the GAC, defining its procedures, the competent body to carry it out and the Quality Reference Values (VRQ), in addition to being able to establish more restrictive VOs.

The protection of groundwater must be guided by prevention, as the damage is usually irreversible and can make the use of water unfeasible. Moreover, the cost of recovery or remediation is greater than the cost of actions to prevent it. In the State of São Paulo, several lawsuits have discussed whether the recovery of contaminated areas should be guided by the criteria of the VOs or by the duty of integral environmental repair. The substantive issues of this legal debate center on the cost-benefit analysis promoted by the GAC in the face of environmental damage and the technical capacity to decontaminate an aquifer, i.e., what would be an accepted recovery from an environmental, economic and social point of view? Unfortunately, there are technological and/or economic limitations that prevent the full repair of the damage, i.e., the restoration of the natural geochemical characteristics of the aquifer. In many cases, even with high investments and application of the best available techniques, contamination levels can only be reduced.

The GAC's priority focus in Brazil is: a) identification of the contaminated area; b) assessment of the risk to human and environmental health; and c) carrying out the rehabilitation process. The logic of this procedure is to establish goals for cleaning the soil or aquifer and carry out its rehabilitation in order to return to society an environment that offers a tolerable level of risk. Therefore, a contaminated area is understood to be one that offers a level of risk above the tolerated level and not just a physical-chemical or biological alteration of the environment compared to the original natural qualities.

Given the environmental and social costs of contaminated areas, environmental agencies must seek preventive protection of soil and aquifers through the following actions:

- establishment of environmental quality standards for soil, air and water, as well as for pollutant emissions;
- licensing and inspection of potential sources of contamination, based on pre-established legal norms;
- incentives for the development and application of best technological practices aimed at reducing or eliminating pollutant emissions.

From the identification of areas with probability of contamination, the GAC imposes a sequence of procedures and studies in order to characterize and prove this situation and act in the remediation of the problem. This procedure begins with a preliminary assessment. The study aims to "find evidence, indications or facts that make it possible to suspect the existence of contamination in the area" through the collection of historical information and site visits (Article 6, part II, CONAMA Resolution 420/2009). Based on it, the confirmatory investigation plan is elaborated.

Confirmatory investigation, unlike preliminary investigation, requires sampling of soil and groundwater, and other invasive or non-invasive techniques (such as geophysics). The purpose of this investigation is to confirm or not the existence of contamination. This recognition is made by comparing the results of chemical analyses of soils and water with the VOs and quality reference, established by the environmental agency.

Once the contamination is confirmed, a detailed investigation is carried out, the objective of which is to "understand the dynamics of contamination in the affected physical environments and the identification of specific scenarios for land use and occupation, existing risk receptors, exposure paths and entry pathways". (Article 6, part IX of CNRH Resolution 420/2009). In this step the level and limits of degradation are established (mapping of the extensions of the contaminant plume), in addition to the quantification of the mass present and the transport dynamics of these substances. This activity will make it possible to assess the degree of risk to which people and the environment are exposed. Once the contaminated area and the existing risks are defined, the process of rehabilitation of the area begins, which must include an intervention plan. With the approval of the environmental agency, the execution of the soil and aquifer remediation begins. If the remediation fulfills its objectives, the monitoring program begins, the objective of which is to ensure that the agreed targets are actually achieved. If the monitoring report confirms that the targets have been met, the area will be declared by the environmental agency as rehabilitated for its declared use.

5.3 Groundwater governance as a means of ensuring socioeconomic development

The extraction of groundwater has contributed to social and economic development, in addition to ensuring water and food security in various parts of the planet over the centuries. The use of groundwater dates back to ancient peoples, who developed techniques for its use and guaranteeing a source of quality supply. Ancient civilizations built aqueduct systems to transport water from springs to villages (DEMING, 2020). The oldest well record is found in the *Atlit Yam* region of Israel (8000 BC) (GALILI; NIR, 1993). Since 5000 BC the Chinese had already drilled deep wells with bamboo poles (REBOUÇAS, 2006), while the Persians developed systems of underground horizontal tunnels, called canates, which spread through the countries participating in the old trade routes (VILLAR, 2015). Upon the Spanish colonization, the *canates* system was brought to Hispanic America, being used to this day in countries such as Chile, Mexico and Peru (PALERM, 2002; 2004 and 2020).

Population and consumption growth, the degradation of surface reserves, advances in the field of knowledge of hydrogeology and well drilling techniques encouraged and expanded the use of these waters from the 1950s and on (UN/

WWAP, 2003; VILLAR, 2015). Groundwater, therefore, was, is and will always be an important source of water for humanity. Despite its importance, the perception of population dependence and the benefits resulting from its exploitation were only highlighted in the literature from the 2000s onwards (VILLHOLTH; CONTI, 2018).

Groundwater was considered by the Millennium Development Goals (MDGs) as the fastest and cheapest way to achieve the goals of access to water and win the fight against hunger (LLAMAS; MARTINEZ-CORTINA, 2002). Its importance was reaffirmed in the Sustainable Development Goals (SDGs) (GUPPY *et al*., 2018). These resources are essential to ensure the goals set out in the SDGs, especially in SDG-6, which deals with universal access to drinking water, sanitation and hygiene. Due to the transversality of water, underground reserves are fundamental for all SDGs, especially SDG-1, SDG-2, SDG-3, SDG-5, SDG-8, SDG-9, SDG-10, SDG- 11, ODS 12 ODS-13 and ODS-15 (Figure 23). These waters contribute to the fight against poverty and to food, water and health security for thousands of people, mainly in rural and arid and semi-arid areas. Moreover, they are less susceptible to climate variability, allowing for strategies to mitigate and adapt to climate change and may even generate geothermal energy in some regions.

Figure 23 – Sustainable Development Goals (SDG)
Source: United Nations Brazil (2021).

SDG-6 highlights the need to meet international goals related to expanding access to water and sanitation. In the case of Brazil, the Água Doce Program (PAD) can be highlighted, which promotes socioeconomic development and access to water for the most vulnerable populations in the semi-arid region through the use of brackish aquifers. This Program corrected the management errors of its predecessor, the Água Boa Program (PAB) and sought to reuse abandoned brackish wells.

The PAB was implemented by the Ministry of the Environment/Department of Water Resources and Urban Environment (MMA/SRHU) in the late 1990s, with the aim of installing desalinators in brackish or saline wells in areas considered critical. The Program, however, faced several implementation problems, such as failures in the destination of saline effluents, which contributed to desertification and soil erosion in areas close to the extractions, and caused closure of the program. Moreover, the lack of preventive maintenance or poor management of desalination systems led to the loss of water quality, causing the deactivation of part of the equipment (Azevêdo, 2015).

In turn, the PAD is an initiative of the Federal Government, promoted by the MDR in partnership with various governmental and social actors, which aims to promote water security through the installation and management of small desalination plants in the Northeast Semiarid region, allowing the use of brackish or saline aquifers. The effluents generated are discarded in containment tanks or reused in other uses, such as irrigation in biosaline agriculture. The Program counts on the effective participation of communities and municipalities through "shared management agreements," which establish the rights and duties of social actors and the different government bodies involved in management. The PAB and PAD prove that even brackish groundwater and aquifers with low flows can help compose strategies to guarantee the water security of populations, especially in the context of scarcity in semi-arid regions. The desalination process of these waters is simpler than that applied to marine waters and does not require major infrastructure. Moreover, they can contribute to food security, either by maintaining subsistence crops or by reusing their effluents.

5.3.1 The need to know the socioeconomic role of groundwater

In Brazil, there is a lack of studies that analyze the social dimension of groundwater, such as its role in socioeconomic development, especially for vulnerable groups or related to gender relations. Governance needs to include in the management, this mass of people who use springs, excavated wells or small-flow wells. Most of the time, these uses are not regularized although they can be legalized and classified as exempt or insignificant. Water management needs to create spaces for these social users, provided in Article 12, § 1 of Law Nº. 9,433/1997, as it is a completely unknown contingent whose subsistence depends on groundwater.

Groundwater can and should be used as a way of guaranteeing supply, however, its exploitation must be guided by the maximization of the social benefits generated and by sustainability, either through extractions compatible with recharge, through the preparation of long-term extraction plans or adoption of mechanisms that contribute to promoting recharge. Uncontrolled exploitation can cause damage, even culminating in the depletion of the aquifer. In general, most Brazilian aquifers have adequate exploitation conditions, however, there are already records of worrysome national situations, such as the case of Ribeirão Preto (SP), Recife (PETELET-GIRAUD *et al*., 2017), São José do Rio Preto (SP) (HIRATA; FOSTER; OLIVEIRA, 2015) and the Urucuia Aquifer. The international literature brings several cases of warning about the economic losses caused by the unsustainable exploitation of this resource.

The loss of the aquifer harms the quality of life and the livelihood of an entire community, however, the effects of falling hydraulic levels do not affect users on an egalitarian basis. Large users are more resilient as they can drill deeper wells or seek other water sources. Small users, on the other hand, are the first to lose their access to water and their financial capacity to obtain another source is limited and may even compromise their permanence in the place.

The effects of overexploitation can generate impacts that go far beyond water users. The city of Jakarta, in Indonesia, is one of the most emblematic examples of the negative consequences of uncontrolled exploitation. The lowering of the aquifer and subsidence, allied to the regime of motions and the rise of the sea level, threaten the viability of a world megalopolis. Due to the city's sinking rates, the president of Indonesia has determined a plan to transfer infrastructure from the country's capital to the city of Penajam on Kalimantan Island. This process will generate billions in economic losses, estimated at around US$ 32.7 billion, and incalculable socio-environmental losses. (KLAAS *et al*., 2018).

Therefore, groundwater governance must include actions to recognize that: a) it is not possible to think about groundwater management without taking into account the management of surface water and soil; b) the profile of groundwater users is very varied since it includes a range from large economic users to subsistence uses; c) social users need to be incorporated into the management process, since they are the first to be harmed by degradation; d) groundwater management, especially in critical areas, requires planning that seeks economic alternatives for lower water consumption; e) there are no quick solutions to the problems associated with the degradation or depletion of aquifers, and the recovery process can take many decades and demand high costs; and f) the prevention of aquifer degradation is always the best alternative.

5.4 Integrating society in groundwater management: the importance of social participation

Social participation is a central element of water governance and integrated management of water resources. In addition to being a way to increase efficiency, it can be classified as a fundamental right, provided in the Brazilian constitutional order (PRETTY, 1995; MELO; SCHIER, 2017). There are several definitions for the process related to the ability of social actors to interact with government agencies, political leaders and organizations responsible for creating or implementing public policies, as well as their engagement in these policies. Participation can presuppose the direct or indirect involvement (representation) of stakeholders in the decision-making process on policies, plans or programs related to the multiple dimensions of water (QUICK; BRYSON, 2016).

Water management brings together a representative number of stakeholders or social actors, which are all those people, groups or organizations that can influence or be affected by political decisions involving the protection or use of water (QUICK; BRYSON, 2016). Among the actors involved in the management of aquifers, the following stand out: well drilling companies; deep well users; communities or individuals who are totally dependent on the well or spring for their livelihood; universities and research institutes; the Public Ministry; technical professional associations, mainly those related to engineering and g'eology, and non-governmental organizations related to water resources, especially the Brazilian Association of Underground Waters (ABAS). Social participation in groundwater management promotes the following benefits:

- it fosters understanding and encourages the adoption of good practices in the management of groundwater management (for example, adequate techniques to construct the well and define its location, adoption of PPPs, etc.) (GARDUÑO; VAN STEENBERGEN; FOSTER, 2010);

- it contributes to the implementation of management actions, as decisions that do not include the owners of the wells will hardly be implemented, especially with the government's limitations to promote inspection (GARDUÑO, VAN STEENBERGEN; FOSTER, 2010);

- it creates the opportunity for users to negotiate with each other and with the government management goals that take into account the socio-environmental impacts of aquifer protection (EMERSON; NABATCHI; BALOGH, 2012);

- it allows the construction of cooperative agreements for the execution of activities related to management, such as monitoring, inspection and inspection (GARDUÑO, VAN STEENBERGEN; FOSTER, 2010);

- it facilitates the coordination of decisions related to water and land use planning, even helping to reduce contradictions between policies (GARDUÑO, VAN STEENBERGEN; FOSTER, 2010);

- it contributes for individuals, groups and local communities to have a voice in the design of water management to protect its groundwater supply, which in many cases is the most vulnerable because it involves excavated springs and wells (QUEVAUVILLER, 2016).

Brazilian legislation incorporates different levels of participation in the exercise of water governance, such as consultation processes in the preparation of the National Water Resources Plan 2022-2040, discussions held within the scope of CBHs or, even, the Shared Management Agreements of the Ãgua Doce Program. Despite that fact, public policies face difficulties in promoting the participation of society and users of groundwater, for the public policies cannot motivate them to participate in the process of obtaining information, developing policies and strategies for the management or implementation of these policies. (PIYAPONG *et al*., 2019). This is largely due to the following aspects: a) lack of information and technical and social knowledge on the subject; b) the extremely technical nature of the groundwater debate; and c) non-regulation of use.

This scenario makes groundwater considered a topic restricted to technicians and of lesser importance in water management. It also favors clandestine exploitation, which "takes place without regard to the availability of local water, disrespects the right to use of third parties and inhibits arbitration of their impacts on public supply, authorized users and owners of exempt wells". (VILLAR, 2016, p. 92). The execution of environmental education and training programs for groundwater are essential to change this reality.

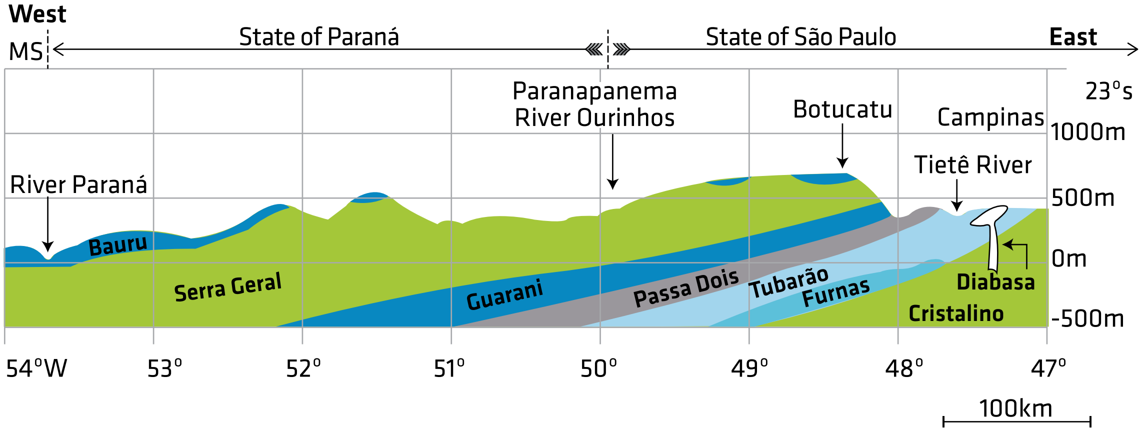
Unfortunately, social participation related to groundwater is a subject little explored in Brazil. Approaches from the social sciences could contribute to fostering the debate on the development and application of methodologies and tools aimed at promoting the dissemination of knowledge, social engagement or mediation and negotiation in the aquifer management process.

5.5 Cooperation between the various administrative entities and the focus on local management of groundwater

Brazil is a federative country that "institutes the division of responsibilities and autonomy between the federal, state and municipal governments." (GRANJA; WARNER, 2006, p. 1101). The existence of common and competing competences points to a federalism of cooperation and integration, which is reflected in the water policy and in the organization of the National System of Water Resources, formed by national, state, regional and local systems. Law Nº. 9,433/1997 also adopts participatory and decentralized management through the hydrographic basin and operated by the CBHs. Therefore, the water management model in Brazil is guided by federalism and the principle of subsidiarity, which determines that legislative or administrative decisions must be taken at the lowest possible political level, i.e., by those who are close to the decisions defined, enforced and executed (GRANJA; WARNER, 2006).

The hydrographic basin as a water management territory is not to be confused with the classic division of administrative entities: federal government, states, Federal District and municipalities, but transcends the classic administrative limits, as its territoriality is based on physical-natural aspects. Although legal limits are established, subdividing them into smaller portions as a way of facilitating management, it cannot be ignored that the water system is one. Therefore, a territoriality of decision was created that requires the construction of cooperative and integrative arrangements between all these administrative entities and, in some cases, even with other countries, according to the scale of the basin or aquifer, or due to the correlation between these bodies of water (GRANJA; WARNER, 2006).

Aquifers were included in this management by basins although their territoriality does not always converge with it. Despite this, the basin is still the best territory to manage them, as their main ecosystem services and the impacts of the use of their waters or soil occur in the territoriality of the hydrographic basin. As we see in Figure 24, in the same basin there are several overlapping aquifers, which have completely different territorialities although they may interact with each other and with the basin. Given the scenario of application of Law Nº. 9,433/1997, thinking about creating a specific territoriality for each aquifer would be a complicated management challenge for a country that has not even managed to fully implement watershed management.



Made by Geraldo H. Oda based on IGG (1974), IPT (1981). DNPM/CPRM (1983)

Figure 24 – Schematic geological section of the State of São Paulo with the sequence of aquifer systems
Source: São Paulo (2014, p. 29).

CNRH set the main guidelines to guide the performance of federative units, municipalities and CBHs in the joint management of basins and aquifers; however, there is a lack of studies that analyze how or if this was done. Moreover, it would be important for the CNHR and the state councils to determine an area of priority for the control of aquifer extractions that may have effects beyond the basin in which the management takes place. This definition would help to stimulate cooperation between administrative entities and SINGREH organs. These cooperative actions could include: a) carrying out joint studies and monitoring; b) adoption of joint methodologies to determine water availability and control extractions; c) creation of situation rooms for aquifers; or d) idealization of inter-basin or international agreements. The experience of the Guarani Aquifer System is quite an example of the importance of coordinating actions at different levels of management.


Photo: AdobeStock

5.5.1 Transboundary and interstate aquifers: the case of the Guarani Aquifer

CNRH Resolution CNRH 202/2018, in Article 2, defines transboundary and interstate aquifers as follows:

> III - interstate aquifer: aquifer distributed in the territories of at least two states, or between a state and the Federal District;
>
> IV - transboundary aquifer: aquifer shared by Brazil with at least one neighboring border country.

Brazil has several interstate and/or transboundary aquifers. In all, the country has 11 transboundary aquifers (Figure 25): Amazonas, Aquidauana, Boa Vista, Bauru-Caiuá, Roraima, Pantanal, Permo-Carbonífero, Costeiro, Litorâneo, Serra Geral and Guarani.

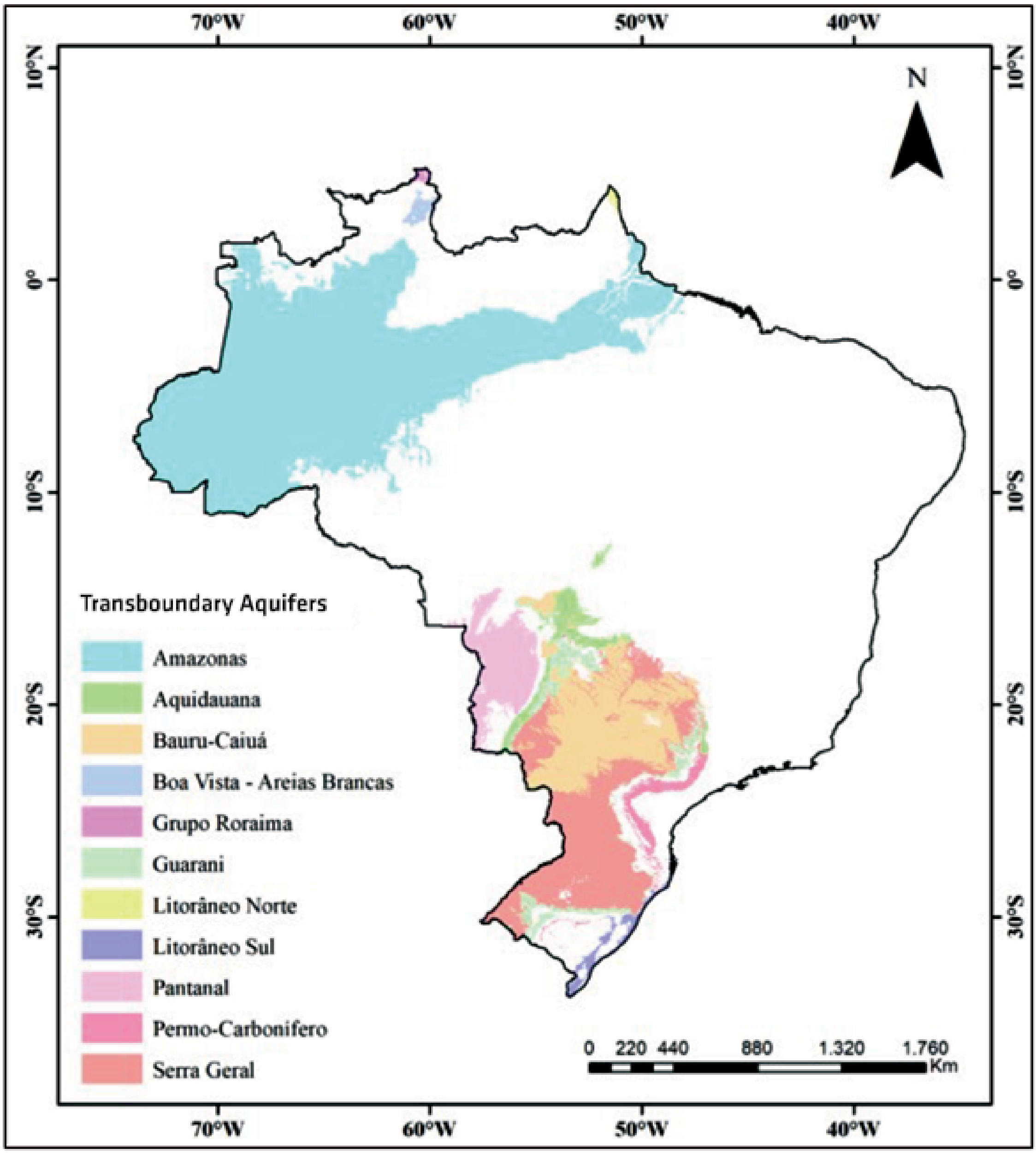


Figure 25 – Transboundary aquifers in the Brazilian territory
Source: ANA (2017, p. 1), adapted and provided by Felipe Nincao.

Photo: Roberto Eduardo Kirchheim/ANA Image Database

Among these aquifers, the best known is the Guarani Aquifer System (SAG), which is overlapped by two other transboundary aquifers: the Serra Geral and the Bauru-Caiuá. The total area of the SAG is 1,087,879 km^2, and comprises the territory of Argentina (225,500 km2), Brazil (735,918 km^2), Paraguay (71,700 km^2) and Uruguay (45,000 km2) (OAS, 2009, p. 62) (OAS, 2009, p. 62) (Figures 25 and 26). Brazil holds the largest portion of the aquifer (61.65%), where it can also be classified as an interstate aquifer because it spans eight states: Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Rio Grande do Sul, Santa Catarina and São Paulo (OAS, 2009). It is a sedimentary aquifer and confined to 90% of the territory, and the outcrop zones correspond to only 124,650 km2 (LEBAC/UNESP, 2008).

Contrary to popular imagination, the SAG is not a uniform structure, like a sponge or an underground lake/river. On the contrary, the geological and hydrogeological characteristics of the aquifer are quite heterogeneous (Figure 26), presenting upwelling areas and regions covered by basalts of different thicknesses (OAS, 2009; BORGHETTI; BORGHETTI; ROSA FILHO, 2011). The permanence time of waters can be months or more than hundreds of thousands of years. The presence of old and recent waters demonstrates differences in the inflow of recharge and impacts the geochemical characteristics of the water, which has areas of excellent quality and others with high-salinity or natural anomalies (OAS, 2009, p. 66; BORGHETTI; BORGHETTI; ROSA FILHO, 2011).

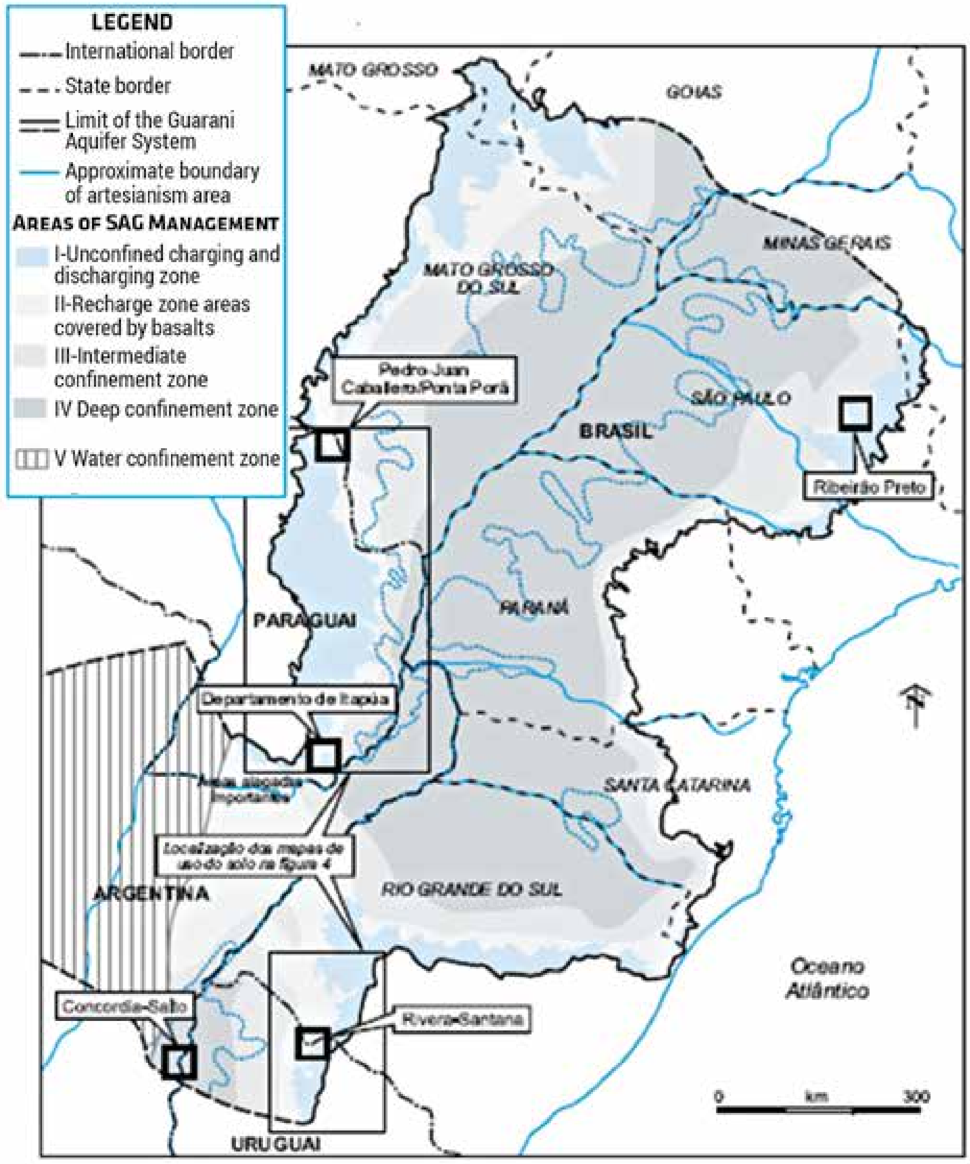


Figure 26 - The Guarani Aquifer System and its management zones

Source: FOSTER *et al*. (2009, p. 11), adapted by Tito Lívio Barcellos Pereira.

Figure 26 illustrates this heterogeneity, proposing five management zones that show the need for different planning approaches (FOSTER *et al*., 2009):

i. **unconfined recharge and discharge zone**: the aquifer rises to the surface, so the waters are continually replenished, contributing to surface water resources. On the other hand, contamination is fragile;

ii. **recharge zone in an area covered by basalts**: recharge occurs through basalt fractures, being considerably lower than in the outcrop zone. The connection with surface resources needs to be further studied;

iii. **intermediate confinement zone**: the area is covered by the basalts of the Serra Geral formation, therefore, there is no significant recharge. The waters have a residence time of over 10,000 years and their extraction would be equivalent to mining the aquifer. The risk of human contamination is very low. There is the possibility of water quality problems arising from residence time and lack of renewal. In some areas, the content of dissolved salts, including fluorine and arsenic, can compromise its potability;

iv. **deep confinement zone**: similar to zone III, however, the basalt layer that confines the aquifer exceeds 400 meters. The cost of extraction renders exploration unfeasible, except for hydrogeothermal use;

v. **confinement zones with high salinity**: in addition to confinement, the waters in this region have high salinity, and can be used for hydrogeothermal purposes or after treatments if economically viable.

Although this division suggests a certain homogeneity, there are heterogeneities that can only be assessed on the local level. In the city of Ribeirão Preto (SP), for example, it is possible to find zones I, II and III with distances that vary by a few kilometers. Moreover, considering the water residence time, most impacts end up having local effects. The overexploitation of Ribeirão Preto can compromise the aquifer in the cities around it; however, it does not influence the exploitation of other Brazilian states.

This situation illustrates that, although geological formations extend beyond national boundaries, groundwater flow has local characteristics, therefore, “the current and potential transboundary effects of SAG are restricted to a narrow range of no more than a few tens of kilometers, depending on local and specific hydrodynamic conditions” (OAS, 2009, p. 18). Therefore, there would only be transboundary problems in the SAG if there were intense and extensive exploitation of groundwater in the border areas.

The logic of local flows is maintained in Brazilian states. Therefore, from the point of view of interstate cooperation, it is important to delimit areas with extensive and intense exploration close to interstate boundaries. The definition of areas where damage to interstate or inter-basin underground flows may occur would contribute to promoting joint actions between basins and states. The National Water Resources Plan and the State Water Resources Plans play an important role in promoting this cooperation.

SAG achieved the remarkable feat of making itself known by society and encouraging actions for groundwater despite the fact that there were no problems with border crossings and overexploitation is restricted to specific points (HIRATA; FOSTER, 2020; Hirata; KIRCHHEIM; MANGANELLI, 2020). In large part, this was justified by the implementation of the Environmental Protection and Integrated Sustainable Management Project of the Guarani Aquifer System (also known as the Guarani Aquifer System Project - PSAG), between 2003 and 2009. This international project had the participation of the aquifer countries and the support of several organizations, notably the World Bank, the Organization of American States (OAS) and the Global Environment Facility (GEF) (VILLAR, 2015; SINDICO; HIRATA; MANGANELI, 2018). The SAG will be the target of a new medium-sized international project called the Strategic Action Program for the Guarani Aquifer: Rendering Regional Actions Feasible, organized by the states, the GEF and the **Latin America Development Bank** (CAF).

The end of the PSAG stimulated the signing of the Agreement on the Guarani Aquifer and the creation of the Regional Center for Groundwater Management

(CeReGAS). The Guarani Aquifer Agreement was signed by Argentina, Brazil, Paraguay and Uruguay on August 2, 2010, and entered into force in November 2020. This Agreement was the first specifically designed for an aquifer in Latin America and an example of preventive diplomacy because there were no conflicts over the use of groundwater (VILLAR; RIBEIRO, 2011). The entry into force of the Agreement allows the states to deepen the cooperation process, as well as draws attention to the need to establish the Commission for the Guarani Aquifer, determining its powers and competences to fulfill the principles and objectives of the agreement (VILLAR, 2020).

CeReGAs arose from the need to establish a regional articulation office dedicated to promoting cooperation in the field of groundwater in the face of the dismantling of the PSAG's institutional infrastructure. In 2014, an agreement was signed between the government of the Oriental Republic of Uruguay and UNESCO, aiming at its creation as a UNESCO Category II Center. Its purpose is to promote scientific and technical capabilities that contribute to the governance of aquifers.

5.6 Monitoring of groundwater resources

Groundwater monitoring is carried out by monitoring hydraulic and/or biophysical-chemical parameters in time and space with different objectives, which may include the initial characterization of an aquifer or the design of strategies for its protection or remediation. Therefore, different objectives will impose different monitoring programs, which must consider: i) location of the point to be monitored; ii) densities of monitored points and constructive profile of wells or hydrogeological characteristics of the water point; iii) measurement frequency; iv) analysis parameters; v) data to be collected and vi) definition regarding its form of organization and verification, among others.

In order to assess aspects of quantity (availability of the resource) or quality (natural and anthropic pollution), the monitoring of groundwater presents a fundamental constraint: the low capacity of monitoring wells or water production wells (used for the monitoring) in characterizing the phenomena that occur in the aquifer.

Phenomena that act on an aquifer, such as pollution, generate specific plumes that hardly reach more than 1-2 km from the source causing it. On the other hand, static monitoring wells (as opposed to pumping wells) can only identify the plume that reaches them if it passes within a few meters of the well, otherwise it will not be identified. For this reason, studies of contaminated areas have a high density of wells (between tens to hundreds of wells per hectare). Another characteristic of polluting plumes is that they are three-dimensional entities, i.e., it is almost certain that there is stratification of the aquifer water quality, i.e., if the well filter is not located in front of the plume, it will not be detected.

Monitoring associated with the characterization of point source contamination events is well developed in Brazil. And while it requires a large number of wells to determine the limits of contaminant plumes, there are several standardized procedures to do so, such as well drilling technologies, installation of multilevel wells and installation of water sampling equipment.

However, when water quality monitoring involves diffuse and multipoint sources, the affected area is very large, requiring a high density of wells to recognize the extent of damage to the aquifer. In practice, this monitoring becomes less assertive or generates very high costs. Generally, contaminations of this type cause very heterogeneous plumes in terms of concentration, which makes data interpretation difficult.

In many regional studies, the characterization of aquifer contamination is made trough tubular water production wells, i.e., those in which the positioning of the filters takes into account only the production of the aquifer. Driven wells are vertical structures that connect different levels of water in the same aquifer, mixing waters of different ages and chemical quality inside. Often, this mixture of water ends up masking the more superficial contamination of the aquifer, leaving important plumes undetectable.

Quantity monitoring presents the same problems, and it is important to follow the potentiometric level over time, which requires periodic and systematic measurements to assess long-term variations, such as changes in recharge due to climate change or to identify problems relative to overexploitation. In the latter case, monitoring wells would have to be installed in the areas where the water extraction wells are located. In this way, the interpretation of data needs to isolate those arising from hydraulic interference from a nearby extraction or from regional drawdown, which must be quantified. This quantification is not obtained by monthly or even semi-annual measurements, common to regional monitoring programs, but requires hourly or at least daily piezometric monitoring, forcing the installation of pressure transducers and several wells in the same region.

The greateste limitation of monitoring is in the regional characterization, when the objective is to identify overexploitation or contamination of a dispersed nature arising from agricultural and urban activity. Some states have implemented regional quality monitoring networks with biannual monitoring of their waters. The São Paulo network, for example, monitors the geochemistry of 316 active groundwater quality monitoring points (CETESB, 2020). Considering that each well monitors what happens in a 200m radius, the total area assessed by each well is 0.13 km^2. Therefore, the network is only monitoring 0.02% of the state's area (~41 km^2). It was found that there is a relationship between the concentrations of nitrate in groundwater and the occupation of land within one km of the well, indicating that the well network, instead of monitoring the state of São Paulo, analyzes the situation close to the 316 wells located in different urbanization contexts (PILEGGI *et al.*, 2021). These numbers give the dimension of the low assertiveness of regional water quality networks and the need to rethink regional networks of this type and with this approach.

To overcome the limitations in regional monitoring, it is necessary to have clarity of the intended objectives. The São Paulo network is efficient in the sense of showing how cities modify water quality over time, in long historical series, but limited in verifying the impacts on aquifer units as a whole.

The Integrated Groundwater Monitoring Network (RIMAS) of the Geological Service of Brazil is more regional and broader, as it aims to monitor the evolution of levels in natural areas far from human occupation, in conjunction with Meteorological Stations. It intends to trace the evolution of potentiometric levels over time, indicating, for example, the variations expected by global climate change. Therefore, even with far fewer wells, the characterization of the background and the evolution of hydraulic levels over a long period determines the right scale and technique for the intended objective.

RIMAS is an automatic network of hourly records of water levels that checks their natural variations in order to estimate recharge, hydraulic parameters and the calculation of the water balance, as well as follow the water level variation caused by exploitation. of water or land occupation (MOURÃO; PEIXINHO, 2012). Its operation and maintenance are carried out by the Brazilian Geological Service/Mineral Resources Research Company (SGB/CPRM). Part of RIMAS is operated in an integrated manner with the National Hydrometeorological Network (RHN), in partnership with ANA, and occurs, for example, in the Urucuia aquifer area (west of Bahia) and in the basins of the Verde Grande and Carinhanha rivers (border between Bahia and Minas Gerais).

Overcoming the low assertiveness of monitoring wells in regional networks is a challenge, especially when there are few investments. There are alternatives that use different strategies. One of them is to complement the regional quality network with the results of the sanitary surveillance network in cities supplied by underground water. The legislation requires that points in a city's water network be periodically monitored and the information forwarded to health agencies. If the parameters indicating regional contamination (including electrical conductivity, chloride, ammonium and nitrate) were systematically analyzed and the sampling points associated with the producing wells identified, there would be an extensive network of thousands of points, in which variations of concentration of the elements through time could indicate the degradation of the aquifer or a part thereof.

The data contained in the tubular well construction reports could help with monitoring. For that reason, well drilling companies should be required to deliver this information, as well as the date of drilling, the terrain quota, the static and dynamic level, in addition to the well flow and its total depth.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6
LESSONS LEARNED AND CHALLENGES

Photo: AdobeStock
Lagoa da Serra, city of Rio da Conceição – Tocantins.

6 LESSONS LEARNED AND CHALLENGES

Water governance in Brazil has focused its efforts on one component of the hydrological cycle: surface waters. The Government faces difficulties in including groundwater and aquifers in the management, while the integration with estuarine and coastal waters remains in the debate, and that of meteoric waters is not even discussed. The integration of surface and groundwater is the first step towards the integrated management of water resources. This type of management demands joint actions that contemplate this cyclical movement of water, in addition to specific actions that consider the particularities of each dimension, otherwise society will lose social, ecological and economic opportunities. Table 7 presents the main distinctions between surface and groundwater.

ASPECT	GROUNDWATER AND AQUIFERS	SURFACE WATERS AND RESERVOIRS
Storage	Great	Small and medium
Resource area	Relatively unrestricted	Restricted to bodies of water
Flow speed	Very low	Medium and high
Permanence time	Usually decades/centuries	Usually weeks/months
Prone to droughts	Low	High

Table 7 - Main distinctions between surface and groundwater
Source: Tuinhof *et al*. (2006, p. 2).

ASPECT	GROUNDWATER AND AQUIFERS	SURFACE WATERS AND RESERVOIRS
Evaporation losses	Low and located	High
Resource evaluation	High cost and uncertain	Low cost and certain
Impacts of extraction	Long and scattered	Immediate
Water quality	Generally good	Variable

Table 7 (Continued) – Main distinctions between surface and groundwater
Source: TUINHOF *et al*. (2006, p. 2).

Groundwater is not an accessory resource to surface water, on the contrary, it maintains surface water availability. Moreover, the scenario of climate change or water crises intensifies the use of these waters, which are already essential for public supply, economic uses and vulnerable groups. Finally, their residence time means that part of them is not considered a renewable resource, which requires debate about the priority of their use, and how to maximize and guarantee future generations.

The lack of knowledge about groundwater and aquifers or about their uses and strategic role is a threat to water resources (both underground and surface), ecosystems, human beings and future generations. Moreover, the opportunity to stimulate the development of areas that could benefit from this water potential is lost. Brazil faces increasingly frequent periods of drought, reduced river flow and water availability from reservoirs, which can compromise water, energy, food and economic security. This scenario causes an increase in the use of aquifers, whether for animal and human, industrial or irrigation purposes. In this context, there are three central problems that threaten groundwater (CONTI, 2017):

a. **Lack or inefficiency in the management and control of aquifer extractions**. Disorderly extractions generate socio-environmental damage and can compromise the only source of water available, especially in the case of vulnerable populations.

b. **Lack or inefficiency of actions to maintain the quality of the aquifer or restore it**. Human activities can contaminate aquifers and render important water reserves unfeasible.

c. **Lack of strategic planning in the management of aquifers that incorporates the pressures arising from the global-local and local-global relationship.** Climate change, the loss of large forests and the international market build new realities of supply and demand for groundwater that need to be faced. According to the structuring of this plan, groundwater can be used as a strategy for adaptation and mitigation or degradation.

These problems are solved through knowledge-based governance, inter-institutional coordination and the participation of multiple actors (institutional and social) involved in the use and management of water resources and in territorial, environmental and socioeconomic planning. The particularities of groundwater reinforce the importance of governance, especially in view of the need to move beyond sectoral management and user engagement actions.

The existing hydrogeological knowledge in Brazil is incipient in view of the needs imposed by the management of water resources; however, only through hydrological knowledge is it possible to visualize the aquifers. Groundwater moves through heterogeneous and complex geological structures, which makes access to information and the formation of participatory and informed decision-making processes difficult. Invisibility and ignorance also result from conflicts between users and between the water resources, environment, agriculture, sanitation, and mining and economic development sectors. Users do not correlate that well productivity losses or contamination may be caused by third parties using the wells incorrectly (or irregularly) or by the proximity of activities capable of contaminating the soil and aquifers. Without understanding the causes of these problems, there is no social pressure on the managing Government (VILLAR, 2016; CONICELLI *et al*., 2021).

In Brazil, command and control instruments are the basis of water management, however, they show limitations in the case of groundwater resources. The overwhelming evidence is the high degree of unregulated wells. If noncompliance with the law, in itself, is a problem, another is the lack of knowledge of the existence of the real number of wells. In Brazil, 90% of abstractions are private and only 10% supply urban public networks (HIRATA *et al.*, 2019). Most abstractions are invisible to public policies and states have no idea of the economic dimension and socio-environmental role of these waters.

This source becomes increasingly popular for supplying various activities in the countryside and in the city due to the ease of exploitation, which is based on the following points: low cost of exploitation; speed in drilling wells (in some cases in less than a week); new technologies associated with the operation of wells, allowing collections to function almost autonomously; and availability in practically the entire Brazilian territory. The well is the solution where the problem exists, and there are no water distribution stations.

In this context, governance needs to jointly build the answers to the following questions: How can we protect an invisible resource that is unknown to society? Who extracts these waters and how can we control this extraction in order to make individual use compatible with collective interests? How can we encourage aquifer protection actions? How can we reveal and equate existing conflicts over use? There are no right answers to these questions because in each aquifer, within the context of the hydrographic basin itself, there is a need for a governance process that defines the way in which it will be used in relation to the socioeconomic and ecosystem services performed.

The government and water resources management organs have a fundamental role in this process; however, it is necessary to mobilize other actors and stakeholders. Good governance makes it possible to move more holistically towards the challenges faced by groundwater management. Much more than surface water, the use of groundwater is spread across hundreds to thousands of extraction points in just one location. Therefore, adequate management will not exist if users are not aware of their responsibilities and rights and, above all, if they do not participate in this process. Thus, groundwater governance needs to overcome the following weaknesses:

- **Lack of hydrogeological knowledge and/or difficulty in incorporating this knowledge into the application of water governance.** Hydrogeology plays a fundamental role in the governance of aquifers insofar as this science is responsible for spatializing aquifers and determining the central aspects of management, such as: a) how much water can be provided; b) how extraction impacts the aquifer and dependent water resources; c) what the quality of the water is; d) how can we conserve the aquifer; and e) how can we recover an aquifer. In many cases, even with the existence of data demonstrating risk situations, it is difficult to incorporate aquifers into public policies and management instruments.

- **Lack of studies on the social, economic and political dimensions of governance, management, appropriation, use and importance of groundwater.** The debate must go beyond the technical issues of geology and engineering and include topics such as: institutional and legal architecture of groundwater governance; value of these waters; social relations and power structures behind the logic of clandestineness, ignorance and invisibility; processes of social participation in relation to these waters; social conflicts and unequal resource appropriation; environmental education strategies etc.

- **Institutional and legal weaknesses to promote groundwater governance.** The institutions responsible for organizing the management of water resources face problems related to the lack of resources to promote technical studies and institutional campaigns, as well as operational and technical difficulties to implement management instruments or inspection actions. At the same time, the lack of regulation or its limitations make it difficult to implement management and its instruments, creating legal conflicts or simply preventing its operationalization.

- **Lack of horizontal and vertical[11] coordination between managing organs for the implementation of public policies related to groundwater.** Brazilian federalism and the division of powers in matters of water, soil, mineral exploitation and economic development require coordination between different sectors and levels of government to promote effective policies for the management of groundwater. Notwithstanding, there is a lack of initiatives that promote this coordination between the federal government, states, the Federal District and municipalities, as well as correlation of groundwater resources, environment, territorial planning, mineral waters and sectoral policies, such as sanitation, agriculture and development.

- **Lack of user engagement and participation in groundwater management.** Groundwater users are not proactively involved in the management and monitoring of the aquifer; on the contrary, the vast majority of the users are on the sidelines of this management because they use water in an unregulated way. Brazilian legislation does not encourage the formation of user organizations as in other countries, and thus restricts the role of users to participation in collegiate organs (CBH, CERH and CNRH). Most of the time these users do not participate or are underrepresented.

11 Horizontal coordination takes place between "organizations and political and bureaucratic actors that make up the same level of government", while the vertical coordination is composed of "different levels of government" (SOUZA, 2018, p. 16).

- **Social ignorance about aquifers and groundwater.** Civil society, users and even the government do not promote the debate on aquifers. In collegiate organs, discussions and investments prioritize surface water resources. Most nongovernmental organizations operating in the sector focus on surface water. The lack of knowledge about groundwater prevents participation, for social actors do not understand the importance of managing the resource or the consequences of not doing so. Ignorance does not allow a sense of relevance, urgency or priority for these waters to be established in the community.

Thus, the governance, governability and management of groundwater resources goes through the following minimum agenda:

- regional recognition of potential aquifers and their main ecosystem functions through studies that go beyond the obvious and incorporate the various roles that groundwater plays, including its economic importance (quantifying it) and ecological importance (recognizing it);

- study on the relationship of aquifers with other bodies of water, quantifying groundwater discharges in the perenniality of rivers, lakes, mangroves and swamps from analysis of hydrographic basins and regional numerical modeling;

- identification of critical areas of groundwater resources, i.e., those with greater use of water, both for public and private supply, or those where greater danger of contamination is identified (in the sense of FOSTER; HIRATA, 1988), from the registration of potential sources of contamination and vulnerability of aquifers to contamination;

- identification of actors involved in the use and management of water resources, both territorial and environmental;

- identification of vulnerable communities and groups that depend on groundwater;

- creation of specific hydrogeology groups in hydrographic basin committees and other instances that contribute to reflect on the use of water in the basins, especially in critical areas. These groups must define a particular investment agenda to identify priority areas and studies that seek solutions;

- once the basic hydrogeological studies have been carried out, the water resources management organs, especially the collegiate ones, should establish interdisciplinary groups to think of strategic actions for a management committed to the needs of society and the environment, which also considers topics such as equity and social responsibility;

- creation of interdisciplinary research lines to promote groundwater in universities and research centers, private and consulting companies, in addition to organized civil society groups;

- realization of technical training at various levels for different audiences, always in line with groundwater resources management and governance policies;

- promotion of Environmental Education and Social Communication initiatives on groundwater and aquifers in schools, unions, neighborhood associations, etc., prioritizing critical areas, to reduce the irregularity of abstractions and the risk the use of contaminated groundwater.

Entities such as CREA and the Health Surveillance should be involved in these initiatives;

- inclusion of contractual clauses addressing sanitation service providers, providing for Environmental Education actions related to groundwater, especially seeking to identify irregular private users, making them aware of the importance of good use, protection and maintenance of extraction;

- search for incentive mechanisms to promote the regularization of wells;

- promotion of user organizations that help the Government in the monitoring and inspection of water;

- promotion of partnerships with universities and research centers, OAB [Brazilian Bar Association] and the prosecutors' offices in order to monitor the progress of state public policy relative to groundwater;

- integration of information systems related to water, environment and user sectors, giving more visibility to groundwater;

- inclusion of groundwater in urban policies, sanitation, irrigation, solid waste management and irrigation plans;

- production of groundwater indicators that feed a process of communication with society on advances and failures in water management, as well as actions taken, considering what is planned, executed and long-term courses to improve the use of water resources, including groundwater.

7 FINAL CONSIDERATIONS

Photo: AdobeStock
Fervedouro Rio Sono - Jalapao - Tocantins.

7 FINAL CONSIDERATIONS

After more than two decades since its implementation, the National Water Resources Policy (PNRH) is yet to become fully operational from an institutional point of view or from the standpoint of application of management instruments in several basins in the Brazilian territory. This scenario impacts the management of water. Groundwater assumed a supporting role in said management despite its importance in maintaining surface water and ecosystems and despite its strategic nature in public and private supply, including water security for vulnerable social groups.

Gradually, SINGREH organs seek to encourage the inclusion of aquifers and provide guidelines for water management. However, there is still not sufficient data and monitoring as to the way the states – who have jurisdiction over this resource – have promoted said management. The application of water management instruments at the state level faces serious difficulties in the inclusion of groundwater. In many cases, the approach to aquifers in basin plans is superficial, without defining priority management areas. Granted wells are the exception, as the vast majority of users are unregulated and do not see any benefit from legalization. On the other hand, there is tolerance by the Government relative to this situation, in light of the difficulty faced by management agencies in carrying out inspection. In many cases, concessions have been granted without the necessary hydrogeological assessments to determine the exploitable flow of aquifers, for the purposes of protecting them from overexploitation. The classification of groundwater bodies has not left the drawing board, especially given the lack of state regulations for the applicability thereof. The charge, on the other hand, when applied, is not very effective in view of the scenario of non-regulation of the wells.

Overall, the country has a legal and institutional framework capable of promoting the integrated management of water resources; however, it is necessary to improve the water governance environment in order to improve: i) coordination between different administrative and management entities sectored (environment, sanitation, economic development, and territorial planning etc.); ii) the involvement and support of social actors, especially well owners and drilling companies; iii) the training of technicians who work in management; iv) the promotion of technical and social knowledge on the subject; and v) the effective inclusion of these waters in management instruments. Based on the foregoing governance, it will be possible to encourage strategic planning of groundwater taking into account the relations between society and aquifer, and aquifer and river and ecosystem.

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