Analysis of environmental liabilities and water resources management for the development of the hydraulic fracturing activity in the Paraná Basin, Brazil

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Abstract

Brazil has great potential to produce unconventional reservoirs. However, the demand for water resources for the exploration of these reservoirs is also great and may even make the development of projects unfeasible if water management is not properly carried out. In this context, this article aims to analyze the relationship of hydraulic fracturing with the water resources of the Paraná Basin, as well as to identify the environmental liabilities in this basin. To this end, a vast bibliographic review was carried out and a survey of the history of environmental liabilities in the states of São Paulo and Paraná was carried out, as well as an analysis of the Brazilian legislation on hydraulic fracturing and other countries. It can be concluded that to minimize the impact of fracking activities on water resources, it is necessary to establish clear, objective rules that are easy to follow by the authorities to ensure their development in suitable regions.

Keywords: hydraulic fracturing, water resources, unconventional reservoirs

Introduction

The exploration of unconventional resources using the technique of hydraulic fracturing was the key to the success of countries like Argentina and the United States in increasing their hydrocarbon production and reducing their energy dependence. However, fracking is a subject that is still much debated, given that, no matter how small, there is the possibility of environmental disasters.

Hydraulic fracturing is an oil and gas well stimulation technique that has been used in the world for over 60 years. This technique basically consists of injecting a mixture of water, chemical additives and a supporting agent (sand, ceramic or bauxite), from the surface to the formation of interest, through the well. Due to the high pressures reached during injection, a fracture is induced in the rock and filled with the supporting agent. With the relief of pressure, the fracture closes around the support agent, expelling most of the fluid towards the surface and, consequently, maintaining a preferential channel of high conductivity, through which the oil or gas will flow.

As fossil resources have become scarcer around the planet, new technologies have emerged over time, with the aim of extracting these resources at depths that were previously unreachable, both onshore and offshore. A more classic example is the so-called Pre-Salt Layer, which a short time ago had not even been discovered and today is already responsible for 73.1% of Brazilian oil and gas production (ANP, 2021). Currently, Brazil is a pioneer and world leader in ultra-deep water extraction technology thanks to the discovery of huge accumulations in the pre-salt carbonate reservoirs. By the way, the permeability of these carbonates is so low that these formations also need to be stimulated, but through the acidification technique, since these carbonate formations are soluble in hydrochloric acid. Otherwise, hydrocarbons would simply not flow towards the surface.

All these innovations make a large area of the field to be explored with fewer resources, greatly increasing efficiency and, consequently, economic viability. However, the demand for water resources to be used in the exploration of these unconventional reservoirs is also great and may even make the development of projects unfeasible if water management is not well done.

Although water use in the oil and gas industry is considerably less than in sectors such as agriculture, electricity and others, water management is a key component of oil and gas operations. The sector can, indeed, use fresh water significantly, not only on a local scale, but also regionally. Operations may also involve large-scale handling and management of produced water and water to be disposed of. Therefore, the efficient use of water resources is a fundamental part of the processes in the oil and gas industry as a whole, but mainly in the development of non-conventional resources.

In this context, this article aims to analyze the relationship between fracturing and the environment, especially with the water resources available in the Paraná Basin. To this end, a vast bibliographic review was carried out with the intention of providing and developing the theoretical foundation necessary to enrich the discussion on non-conventional reservoirs. In addition, a survey was carried out on the history of environmental liabilities in the states of São Paulo and Paraná that may be associated with natural gas exploration activities in this basin, as well as an analysis of Brazilian legislation on hydraulic fracturing and other countries, such as, for example, USA and Argentina.

Mapping of permanent protection areas, conservation units and other environmentally sensitive areas

For the economic exploration of any mineral resource, a better understanding of how the activity should impact the environment in which it will be carried out is necessary. For this, this topic aims to carry out a brief survey of environmentally sensitive areas for both the state of Paraná and the state of São Paulo.

In this section of the work, data will be collected on environmentally sensitive areas according to the National System of Nature Conservation Units (SNUC), established through Law No. 9,985/2000 (BRASIL, 2000). SNUC's role is to assist in the maintenance of Brazilian natural ecosystems, whether at the federal, state or municipal level, encouraging sustainable development. The bodies responsible for managing the SNUC are the National Council for the Environment (CONAMA), Chico Mendes Institute for Biodiversity Conservation (ICMBio), Ministry of the Environment (MMA), Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) and bodies responsible for managing state and municipal conservation units, at the discretion of CONAMA.

As for the divisions of the Conservation Units (UCs) of the SNUC system, there are two large groups: the Integral Protection Units and the Sustainable Use Units. Within these two areas, there are its subdivisions and the definitions for each are referred to in Chapter III, Articles 8 to 21 of L9985/00.

State of Paraná

As mentioned, UCs can be of federal, state and municipal domain. In this topic, we will present data on the UCs surveyed for the state of Paraná and their particularities.

Taking data from the Ministry of the Environment (MMA, 2021), which consider the units specified only in the SNUC system, the state of Paraná has 97 conservation units (data from the 2nd half of 2020), among which are 35 federal domain (36.08%), 57 state domain (58.76%) and 5 municipal domain (5.15%). It is noteworthy that 3 of these 97 UCs are shared with other states, namely: Mata Preta Ecological Station (Paraná and Santa Catarina), Ilha Grande National Park (Paraná and Mato Grosso do Sul) and Ilhas e Várzeas do Environmental Protection Area Paraná River (Paraná, Mato Grosso do Sul and São Paulo), all under Federal administration.

Other important data regarding these 97 UCs are: 72 do not have a management plan (74.23%) and 25 have one (25.77%); 80 are under public management (82.47%) and 17 under private management (17.53%).

Table 1

Consolidated data on areas of strict protection and sustainable use in the state of Paraná

		Paraná		
		Federal Domain	*State Domain*	*Municipal Domain*
Full Protection	Ecological Station	2	5	0
	Biological Reserves	3	2	0
	Park	7	30	4
	Natural Monument	0	1	0

	Wildlife Refuge	1	1	0
Sustainable Use	Environmental Protection area	2	9	1
	Area of Relevant Ecological Interest	0	4	0
	Forest	3	5	0
	Extractive Reserves	0	0	0
	Fauna Reserve	0	0	0
	Sustainable Development Reserve	0	0	0
	Natural Heritage Reserve	17	0	0
	Total	35	57	5

Source: Panel of Brazilian Conservation Units, MMA.

State of São Paulo

Considering the data from the Ministry of the Environment (MMA, 2021), which take into account the units explained only in the SNUC system, the state of Paraná has 256 conservation units (data from the 2nd semester of 2020), among which are 64 in federal domain (25%), 152 in state domain (59.38%) and 40 in municipal domain (15.63%). It is noteworthy that 3 of these 256 UCs are shared with other states, namely: Serra da Mantiqueira Environmental Protection Area (São Paulo, Minas Gerais and Rio de Janeiro), Ilhas and Várzea do Rio Paraná Environmental Protection Area (São Paulo, Mato Grosso do Sul and Paraná) and Serra da Bocaina National Park (São Paulo and Rio de Janeiro), all under Federal administration.

Other important data regarding these 256 UCs are: 184 do not have a management plan (71.88%) and 72 have it (28.13%); 180 are under public management (70.31%) and 76 under private management (29.69%).

In Table 2 there are data on the quantities of strict protection and sustainable use conservation units according to the SNUC with data from the MMA.

Table 2

Consolidated data on areas of strict protection and sustainable use in the state of São Paulo

		São Paulo		
		Federal Domain	*State Domain*	*Municipal Domain*
Full Protection	Ecological Station	3	26	4
	Biological Reserves	0	1	2
	Park	1	36	25

	Natural Monument	0	2	1
	Wildlife Refuge	1	1	0
Sustainable Use	Environmental Protection area	4	36	8
	Area of Relevant Ecological Interest	6	5	0
	Forest	3	6	0
	Extractive Reserves	1	2	0
	Fauna Reserve	0	0	0
	Sustainable Development Reserve	0	7	0
	Natural Heritage Reserve	45	30	1
	Total	64	152	41

Source: Panel of Brazilian Conservation Units, MMA

Mapping surface and subsurface water

In this section, we will present a water resource mapping for the states of São Paulo and Paraná.

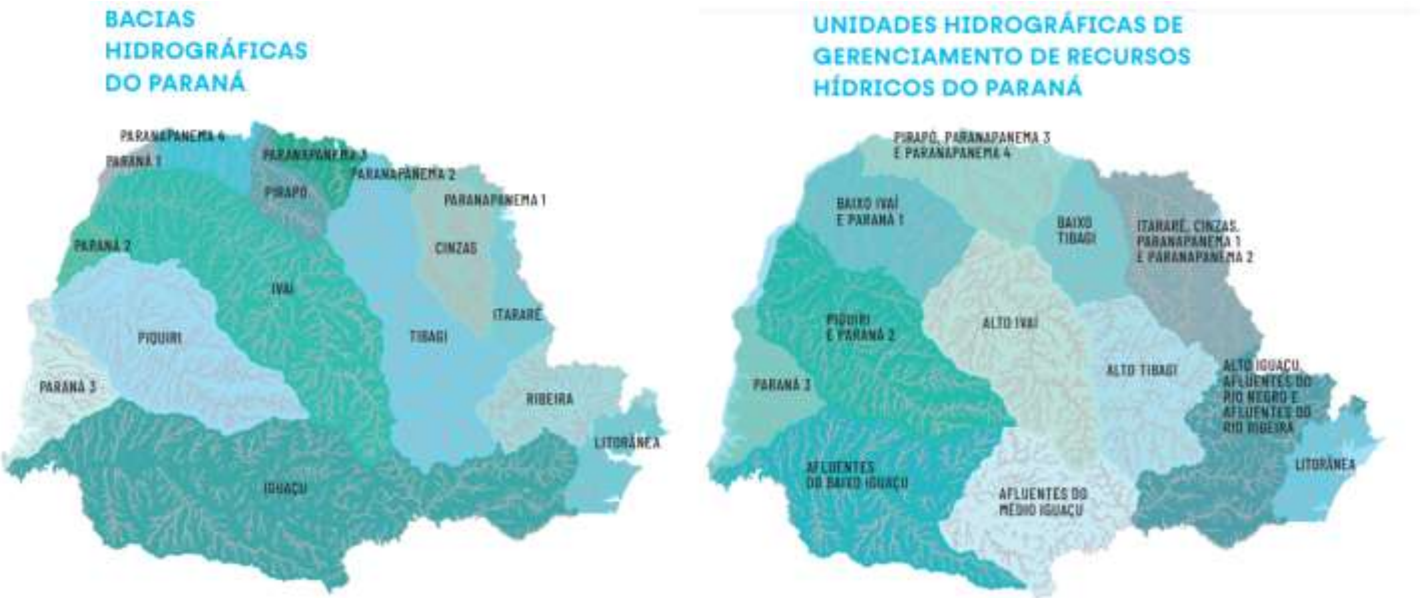
State of Paraná

In 2006, the State of Paraná instituted, through Resolution of the State Secretariat for the Environment and Water Resources of Paraná nº 24 of 2006 and Resolution nº 49 of 2006 of the State Council of Water Resources, its 12 Hydrographic Units for Management of Water Resources (UHGRH), in the same way that it delimited the coverage area of its 16 hydrographic basins, as shown in Figure 1.

As for the hydrogeographic units, according to SEMA-PR Resolution nº 24/2006, the motivation for their creation, in short, was the greater facility in improving the processes of environmental management and water resources.

Figure 1

Paraná Hydrographic Basins and Its Hydrographic Units for Water Resource Management



Source: Paraná State Water Resources Conjuncture Report (IAT 2020)

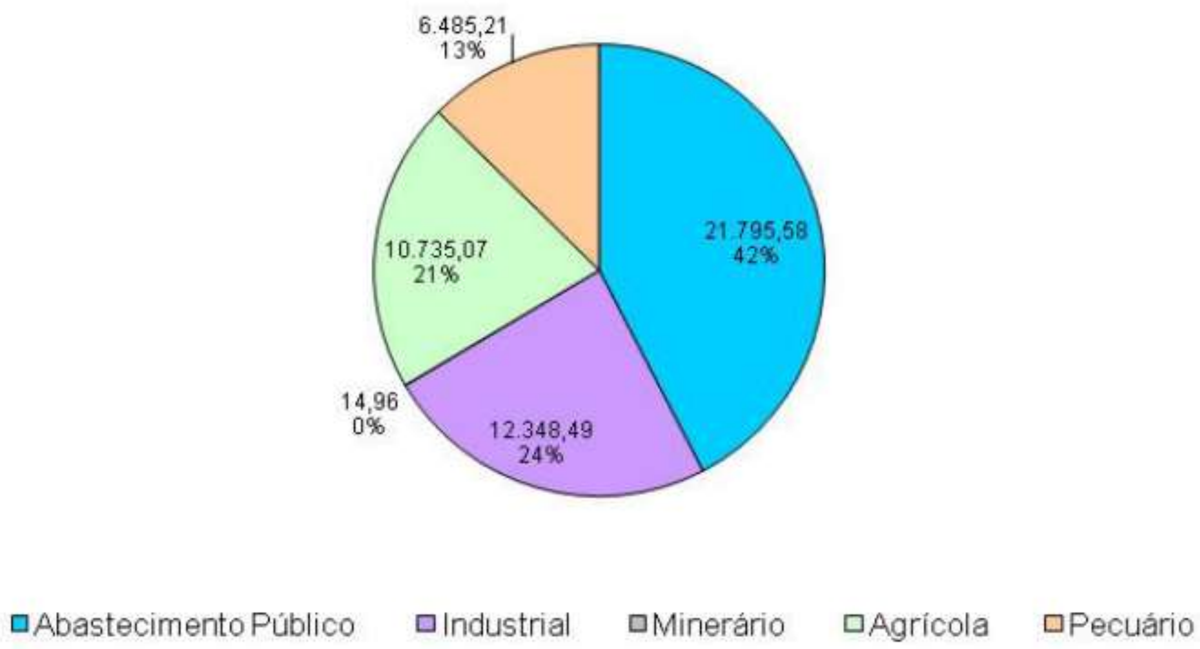
In 1997, the National Water Resources Policy (PNRH) was instituted through Law No. 9433/1997, and the state of Paraná, in agreement, in 1999 instituted its State Water Resources Policy (PERH).

PERH established the structuring of the management and inspection system, thus instituting the State Water Resources Management System (SEGRH). The State Water Resources Management System (SEGRH/PR): the State Water Resources Council (CERH/PR), the Hydrographic Basin Committees (CBHs), the State Secretariat for Sustainable Development and Tourism (SEDEST/PR) and the Instituto Água e Terra (IAT).

One of the most interesting data when it comes to the non-conventional industry is the availability of water to carry out the hydraulic fracturing operation, since large volumes of water are needed in order to be pumped. In Figure 2 we have the characterization for the entire state of Paraná. It can be seen that the most prominent sector is public supply (42%), followed by industrial (24%), agriculture (21%), livestock (13%) and mining (~0%).

Figure 2

Water demand by use for the entire state of Paraná

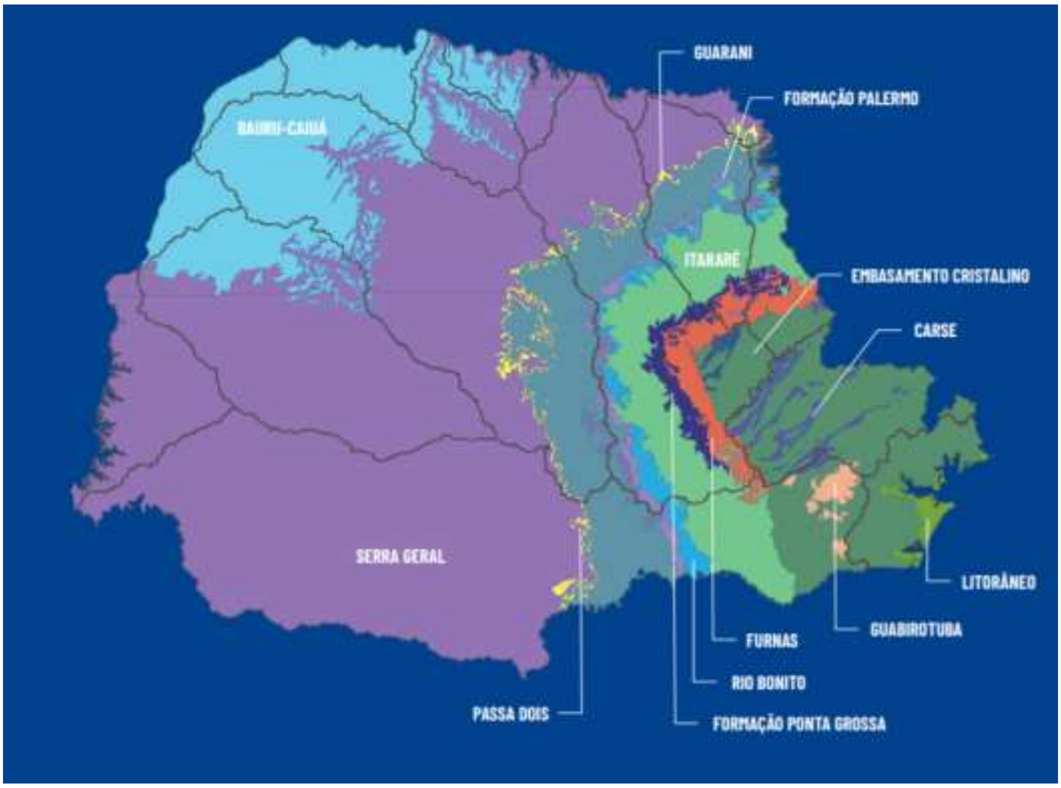


Source: IAT (2021)

In the territory of Paraná, there are eleven underground aquifers, namely the aquifers: Crystalline Basement, Karst, Furnas, Itararé, Rio Bonito, Passo Dois, Guarani, Serra Geral, Caiuá, Guabirotuba and Litorâneo, as shown in Figure 3. Information that will be covered in this subtopics is based on the Paraná Groundwater Charter, where a wide range of professionals from multiple institutions were involved in the preparation of the document, namely: Secretariat of Water Resources and Urban Environment, Ministry of the Environment Environment (MMA/SRHU), Geological Survey of Brazil (CPRM), Sanepar, Mineropar, Environmental Institute of Paraná, Secretariat of Environment and Water Resources, Hydrogeological Research Laboratory of the Federal University of Paraná (LPH/UFPR) and the Institute of Earths, Cartography and Geosciences.

Figure 3

Paraná State with emphasis on the multiple underground aquifer units



Source: Paraná State Water Resources Conjuncture Report (IAT 2020)

The motivation that made us emphasize groundwater mapping in this work is associated with possible accidents when it comes to the use of hydraulic fracturing in unconventional reservoirs, since there was already a case in which a migration of natural gas from fractured wells was found. hydraulically to adjacent aquifers.

Thus, knowledge of the depth of aquifers is of paramount importance so that, in simulations of propagation of fractures from reservoirs, it is possible to know whether these fractures will be able to reach the aquifers listed here. To this end, studies were sought about deep tabular wells in all aquifer units in the state of Paraná, as shown in Table 3. This table contains statistical data on the number of deep tabular wells drilled as well as the medians of their depth in meters. If deemed necessary, the well-to-well depths can be consulted in the Paraná Sanitation Company (SANEPAR) database.

Table 3

List of underground aquifer units in the state of Paraná with their number of deep tabular wells drilled as well as the medians of their depth in meters

Aquifer	Number of Drilled Wells	Depth Median (m)
Embasamento Cristalino	236	90,00
Carste	109	50,70
Furnas	36	136,00
Itararé	169	150,00
Rio Bonito	61	174,00
Passa Dois	95	114,00
Guarani	80	201,50
Serra Geral	1626	120,00
Caiuá	404	102,00
Guabirotuba	13	55,00
Litorâneo	6	15,00

Source: Paraná Groundwater Charter (2018)

State of São Paulo

The hydrographic units present in the 645 municipalities of the state of São Paulo are grouped into 22 hydrographic basins, listed in Table 4 (GOVERNMENT OF THE STATE OF SÃO PAULO, 2021a).

The use of water in the state of São Paulo has gradually increased in recent decades, becoming a critical issue for the management of São Paulo. In this context, it is important to know the use of water resources to enable better management. The main categories of water use as well as their respective flows by river basin are presented in Table 4 (COBRAPE, 2020).

Table 4

Water flows (m3/s) granted in the state by hydrographic basins in the State of São Paulo

Hydrographic Basin	Public Supply	Industry	Rural	Alternative Solutions and Other Uses	Total Demand/Use
Mantiqueira	0,35	0	0,74	0,03	1,12
Paraíba do Sul	12,19	5,67	5,55	0,79	24,20
Litoral Norte	2,29	0,02	0,5	0,19	3,00
Pardo	6,08	3,7	6,07	1,45	17,30
Piracicaba/Capivari/Jundiaí	56,55	14,71	2,81	3,62	77,69

Alto Tietê	46,34	6,89	0,98	3,33	57,54
Baixada Santista	11,09	8,82	0	1,13	21,04
Sapucaí Mirim/Grande	3,07	2,23	7,17	0,29	12,77
Mogi Guaçu	6,32	13,36	15,64	2,45	37,77
Sorocaba/Médio Tietê	6,25	2,85	4,18	2,53	15,81
Ribeira do Iguape/Litoral Sul	0,89	1,39	0,91	0,3	3,49
Baixo Pardo/Grande	3,54	2,28	15,9	1	22,72
Tietê/Jacaré	3,23	8,72	6,45	1,34	19,74
Alto Paranapanema	1,95	2,08	12,6	0,2	16,84
Turvo/Grande	4,26	3,9	10,12	0,93	19,20
Tietê/Batalha	1,67	1,34	8,36	0,75	12,12
Médio do Paranapanema	1,99	5,01	8,17	0,36	15,53
São José dos Dourados	0,48	1,36	2,67	0,05	4,56
Baixo Tietê	1,98	2,82	4,08	0,35	9,22
Aguapeí	0,76	4,01	1,84	0,85	7,46
Peixe	1,12	0,71	0,75	0,13	2,71
Pontal do Paranapanema	0,86	1,03	1,62	0,15	3,66
TOTAL	173,24	92,90	117,11	22,23	405,48

Source: Adapted from COBRAPE (2020)

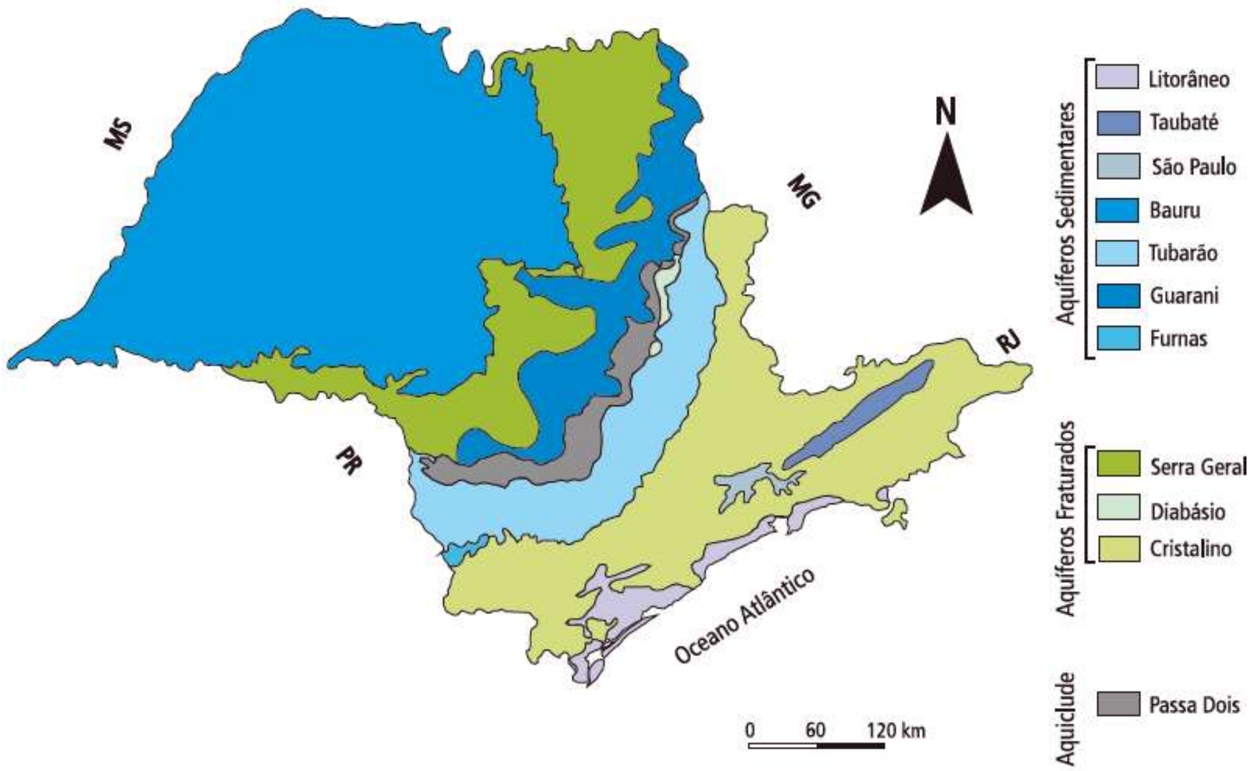
The situation in which the demand for water is greater than the availability and capacity for renewal is called water stress or physical water scarcity. Forecasts say that more than 40% of the world's population will live in the short term in regions affected by increasing water stress (JACOBI; EMPIOTTI; SCHMIDT, 2016).

Water availability can be given in two ways: using a reference flow or using a series of historical monthly flows. Demands, on the other hand, can be determined using granted flows or specific demand determination methodologies (COBRAPE, 2020).

Aquifers in the state of São Paulo are divided into two large groups: Sedimentary and Fractured Aquifers, as can be seen in Figure 4. The first group comprises those constituted by sediments deposited by the action of rivers, wind and sea, where the water circulates through the pores between the mineral grains. The main aquifers in São Paulo that fall into this category are the Guarani, Bauru, Taubaté, São Paulo and Tubarão aquifers. Fractured aquifers are those formed by igneous and metamorphic rocks. The main examples are the Serra Geral and Cristalino aquifers (GOVERNMENT OF THE STATE OF SÃO PAULO, 2014).

Figure 4

Aquifers of the State of São Paulo.



Source: Government of the State of São Paulo (2014)

Through a study carried out by the Department of Water and Electric Energy (DAEE), the Geological Institute (IG), the Technological Research Institute of the State of São Paulo (IPT) and the Geological Service of Brazil (CPRM), the Map was drawn up. of Underground Waters of the State of São Paulo. This publication is a synthesis of groundwater knowledge in the State of São Paulo, providing an overview of the main hydrogeological characteristics and potential of aquifers in the territory of São Paulo.

The Map is made up of thematic segments, including a base of wells made up of selected wells and representative wells, belonging to the well register of DAEE and, subordinately, to the IG. The base of those selected comprises 3539 wells with reliable hydrogeological information and distributed as homogeneously as possible, according to the aquifers, while the base of representatives comprises 195 wells with the most complete information and pumping tests (see Figure 5).

Figure 5

Number of wells used in the Groundwater Map of the State of São Paulo

Aqüífero	Poços selecionados	Poços Representativos
Bauru	676	69
Guarani	111	34
Tubarão	853	09
São Paulo	172	06
Taubaté	130	04
Litorâneo	60	04
Furnas	01	01
Serra Geral (basalto)	285	24
Serra Geral (diabásio)	49	-
Pré-Cambriano	1202	44
Total	**3539**	**195**

Source: Groundwater map of the State of São Paulo (2005)

The distribution map of registered wells was prepared from the SIDAS – Groundwater Information System of the Directorate of Granting Procedures and Inspection (DPO) of the Department of Water and Electric Energy (DAEE). In the entire state of São Paulo, 17,822 wells registered in SIDAS were located, 62% of which are located in the Paraná Basin, 26% in the Crystalline Basement, 9% in the São Paulo Basin and the remainder (3%) in the Basin of Taubaté (SÃO PAULO, 2005). In about 290 municipalities in the state, a density greater than 1 well/km2 was identified. Among these municipalities, the following stand out: Araraquara, Campinas, Presidente Prudente, Ribeirão Preto, São Carlos, São José do Rio Preto, São Paulo, Sorocaba, among others.

Water resources legislation in Brazil

In the Federal Constitution (CF) of 1988, the theme of water resources can be found. According to the regulation, the Union's assets are “lakes, rivers and any water streams on land under its domain, or that bathe more than one State, serve as boundaries with other countries, or extend to or come from foreign territory” (art. 20, III), all other surface water resources being underground state goods (art. 26, I).

Its management is the responsibility of the Union (art. 21, XIX) and the States. However, it is the common competence of the Union, the States, the Federal District and the Municipalities, to protect the environment and register, monitor and inspect the concessions of rights to research and explore water and mineral resources in their territories (art. 23 , VI and XI).

According to the Federal Constitution, it is the competence of the Union to legislate on water (art. 22, IV) and the Union's competitor with the States to legislate on "conservation of nature, defense of the soil and natural resources, protection of the environment and pollution control" (art. 24, VI). Furthermore, in the third and fourth paragraphs of art. 24 of the normative contains the supplementary competence, which authorizes the States to complement the federal legislation of concurrent competence, or even to discipline the entire matter, in the absence of a federal law.

In 1997, Law No. 9,433 was enacted in the country, establishing the National Water Resources Policy, and creating the National Water Resources Management System. This standard provides the foundations that serve as a basic conceptual framework for formulators of public policies, the objectives, and general guidelines for action for the implementation of the National Water Resources Policy. The Law also addresses the need for the Union to liaise with the States, with a view to managing water resources of common interest (Art. 4).

The National Agency for Water and Basic Sanitation (ANA) is primarily responsible for water management at the federal level. Created by Law 9,984/00, it is responsible both for meeting the objectives and guidelines of Law 9,433/97, and for complying with important stages of the new legal framework for basic sanitation, Law 14,026/20, including water supply.

Thus, the management of water resources must be carried out in a decentralized manner, contemplating the various spheres of government involved in the water resources and environment system (JUNIOR, 2021; XAVIER E BEZERRA, 2005).

In this context, the topics of this work below examine the legislation of the states of São Paulo and Paraná, to finally make considerations about the legislation and use of water for unconventional gas exploration.

Water resources legislation in the state of São Paulo

The State Policy on water resources for São Paulo was established by Law 7.663/1991, which sets forth as guidelines the priority use for the supply of populations, protection of water against actions that could compromise its current and future use, and conservation and protection of water against pollution and overexploitation (art. 4, I, III and VI).

This Law also determines that the use of water resources, surface or underground, and the execution of works or services that change their regime, quality, or quantity, will depend on the prior manifestation, authorization or license of the competent bodies and entities (art. 9º), the grant being applicable for the derivation or use of water resources (art. 10). The grant is regulated by Decree 63.262/18.

In the state of São Paulo, the agency responsible for planning the management of water resources and issuing permits is the Department of Water and Electric Energy – DAEE.

The State Water Resources Plan is established by Law 16,337/16, which divided the State of São Paulo into 22 (twenty-two) hydrographic units called Water Resources Management Units – UGRHIs.

The Hydrographic Basin Committees, collegiate bodies (with representatives of the public power and society), consultative and deliberative at the regional level (art. 37 and ss of Federal Law 9,433/97) are of paramount importance for water management. In the state of São Paulo, it is incumbent upon the Committees, among other attributions, to approve the proposed plan for the use, conservation, protection and recovery of water resources of the water resources management unit, in particular the classification of water bodies into classes of preponderant use (art. 26).

Among other norms of interest to the subject of study, we can mention State Law 12,183/05, which regulates the charge for the use of water resources in the domain of the State of São Paulo, as well as Resolution SIMA 86/20, which regulates the procedures for the integration of authorizations, permits, licenses and environmental licenses with grants, declarations and records of use and interference in water resources.

Water resources legislation in the state of Paraná

In the State of Paraná, the State Water Resources Policy was instituted by Law 12,726/99, which establishes the multiple use of water as an objective of water resources management (art. 2, IV).

This Law determines the granting of rights to use water resources applicable to the capture or extraction of surface or underground water for input to the production process and other uses and actions that change the regime, quantity or quality of water or the bed and margin of bodies of water (art. 13, I, II and VI). The grant is detailed and regulated by Decree 9,957/14 (SUDERHSA, 2006).

The Instituto Água e Terra (Law 20.070/19) is the agency responsible for planning the management of water resources and issuing grants in the state of Paraná.

Law 12,726/99 brings a Chapter for the protection of underground water deposits (Chapter VII – art. 26 et seq.). This regulation expressly provides that the implementation of irrigation projects or others, which depend on the use of groundwater, or which may have a relevant impact on them, must be preceded by hydrogeological studies to assess the potential of its water reserves and for the correct dimensioning of the flows to be extracted. subject to prior approval by the competent bodies (art. 28).

In this system of water resources management in the state of Paraná, as prominent bodies we can mention the State Water Resources Council (CERH/PR) and the Hydrographic Basin Committees (CBH).

Water management in countries that produce from unconventional reservoirs

In this item, we will present how water management is done in some countries that produce shale gas using hydraulic fracturing. To do so, we are going to discuss the experiences of the United States and Argentina, countries where the exploration of non-conventional reservoirs is more developed.

United States

With the oil crisis of the 70s, the American government encouraged research in the development of technological advances in the exploration of shale gas (TAIOLI, 2013). This initiative enabled the availability of horizontal drilling and hydrofracturing, among other techniques. But it was only at the beginning of the 21st century that there was a vertiginous growth in the application of hydraulic fracturing in the USA. The production of shale gas corresponded to 1% of the total national production of natural gas in the USA in 2000. In 2010, this share rose to 20% (STEVENS, 2012).

Several sedimentary basins in the US are recognized as sources of shale gas, as shown in Figure 6. The technically recoverable US shale gas resources are estimated to be on the order of 10 trillion m3 (353 trillion ft3) in December 2019, reaching almost 70% of total natural gas (US EIA, 2021a).

Currently, there are 13 US states that produce shale gas using hydraulic fracturing (US EIA, 2021b). The total production of natural gas in the US reached 1,158 billion m3 in 2019. The shale gas accounted for 786.4 billion m3, approximately 68% of the total (US EIA, 2021c). These include: Texas, Pennsylvania, Ohio, Louisiana, West Virginia, Oklahoma, New Mexico, North Dakota, and Arkansas as the top shale gas producing states in the United States. Thus, the water management analysis will focus on the states of Texas and Pennsylvania, the largest producers of natural gas from unconventional reservoirs in the US.

Figure 6

US shale gas basins, with numbers of wells and platforms

Source: Goodman (2018).

Most of the risks associated with shale gas exploration are non-specific and are an integral part of any oil and gas well drilling operation. However, the greater diversity of chemical products, the considerably higher volume of water abstracted, and the greater pressure exerted on the well casing tube, give the shale gas operation a more accurate risk management (KANSAL, 2012; ARAÚJO, 2016).

The water cycle used in hydraulic fracturing comprises its removal from a surface or underground source. Then there is the process of mixing with proppant (usually sand) and chemical compounds. This mixture is then injected into the well at high pressure (between 2,000 and 12,000 psi) when the target rock fractures. The oil and gas released from the formation are brought to the surface with a liquid effluent (mixture of hydraulic fracturing fluid with formation water and chemical transformation products), which is called return water, also known as flowback. The next step is to dispose of this liquid effluent (US ENVIRONMENTAL PROTECTION AGENCY, 2016).

The three main sources of water for hydraulic fracturing in the US are surface water (ie, rivers, streams, lakes and reservoirs), groundwater and reused hydraulic fracturing wastewater. The water collection option will depend on its availability around the location and relevant federal and state laws and regulations. In 2010, 58% of American drinking water consumption came from surface water sources and 42% from underground resources. According to 2010 data, the majority of the population (86%) in the USA depends on drinking water supply from public systems (MAUPIN et al., 2014).

There is a large federal legal framework that impacts water management in the activity of shale gas exploration, which includes the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act – RCRA, among others.

The Drinking Water Act (SDWA), enacted in 1974, aims to protect the quality of drinking water in the US. It establishes maximum levels of contaminants in drinking water and their respective control and supervision. It also includes underground water resources, which has an influence on the hydraulic fracturing operation, when considering the disposal of water produced in underground injection wells.

The Clean Water Act (CWA), created in 1970, regulates the discharge of pollutants into surface waters in the US and sets its quality standards. It authorizes the US Environmental Control Agency (US ENVIRONMENTAL PROTECTION AGENCY - US EPA) to implement pollution control programs to set wastewater standards for the industry and establish water quality standards for all contaminants in water bodies of surface. The CWA also provides for the management of the disposal of effluents generated during the construction and operation of oil and gas wells and requires licenses from operators. It prohibits the discharge of pollutants into water bodies without obtaining a permit, which may include the disposal of return water (KANSAL, 2012; ARAÚJO, 2016).

In many American states there are regulations restricting the location where wells will be installed and requirements for analysis of the groundwater that is influencing the drilling operation before it starts. The distance of the unconventional gas well in relation to water bodies is widely regulated (ARAÚJO, 2016).

In the state of Pennsylvania, Law 58, section 3215, established that unconventional gas wells cannot be drilled less than 500 feet (152.4 meters) away from a building or artesian water well, measured horizontally from of the vertical well without the written consent of the respective owners. However, there are limitations, such as not allowing the drilling of an unconventional well within 300 feet (91.44 meters) of any wetland area larger than an acre in size. For wetlands less than one acre, the boundary of the area disturbed by the drilling location must maintain a setback of at least 100 feet (30.48 meters) from the wetland boundary (Pennsylvania General Assembly, 2021). The state of Texas, on the other hand, does not regulate the retreat of the unconventional gas well in relation to any source of water resource (ARAÚJO, 2016).

In most American states, except in a few cases, the volume of water used in hydraulic fracturing is relatively small compared to the total use and availability (US ENVIRONMENTAL PROTECTION AGENCY, 2016). According to the US EPA (2016), the American east is more dependent on surface water sources than the arid and semi-arid west, where the water supply comes from both underground and surface water sources.

According to Scanlon et al. (2020), the projections for the main unconventional reservoirs located in semi-arid climates of the United States, it is estimated the generation of larger volumes of return water than those that could be necessary to be reused in new fracturing stages or for the development of new unconventional wells. Therefore, it is highly necessary to analyze the reuse in other productive sectors and not just in the energy sector, also considering that injection in wells has a limitation of time and space.

The municipalities most directly impacted by the benefits and risks of water billing activities have limited local regulatory authority. They are confined to the federal and state regulatory framework for the development of unconventional gas production activities (ARAÚJO, 2016). We can say that states play a key role in regulating the development of shale gas exploration and production in the United States. Araújo's (2016) thesis presents a broad picture of the federal, state, and municipal regulatory framework linked to the development of unconventional gas in the United States.

The set of investigations carried out in the USA on fracking shows which are the points of greatest environmental risk, but the conclusion has prevailed that the damage depends more on human negligence than on the technique itself. If the drilling is well conducted and there is a correct handling of fluids and residues, there should be no more risk in this activity than in any other, such as agriculture or urban industry (VILLENA, 2020).

Argentina

In Argentina, there are 24 sedimentary basins, 5 of which produce oil and natural gas: Noroeste, Cuyana, Neuquina, Golfo San Jorge and Austral (Figure 7). In 2018, the Neuquina Basin became the main producer of natural gas in Argentina, surpassing the Northwest Basin (EPE, 2020).

Figure 7

Argentine sedimentary basins producing oil and natural gas

Source: EPE (2020)

Argentina's proven natural gas reserves are in the order of 346 billion cubic meters (BP, 2019). Natural gas is the main source of primary energy in Argentina, accounting for 58% of the supply in 2019. Electricity generation in the country has natural gas as its main fuel, responsible for 67% of total consumption in power plants, in 2018 (EPE, 2020).

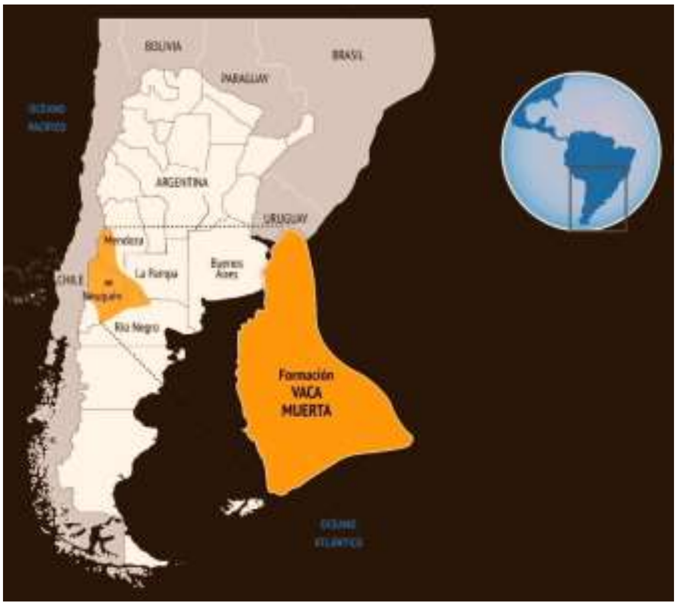
The total production of natural gas in Argentina in 2020 was 45,096 million m3, a decrease of 8.6% compared to the previous year. Unconventional natural gas, which comprises shale and tight gas, had a 4.8% drop in production compared to 2019, reaching 19,331 million m3 (42.8% of the total). The average annual growth rate of unconventional gas production was 23.4% between 2015 and 2020 (SWISSINFO, 2021; IAE GENERAL MOSCONI, 2021).

The shale gas is mainly found in the following formations: Los Monos (Northwest Basin); Vaca Muerta and Los Moles (Neuquina Basin); Cacheuta (Cuyana Basin); D-129 and Aguada Bandera (Gulfo San Jorge Basin) and Inoceramus (Austral Basin) (IAPG, 2020). Due to the preponderance of the province of Neuquén in the development of unconventional resources in Argentina, this report will focus on the management of water resources only in that province, basically on the formation of Vaca Muerta, whose daily production reached 35 million m3 in 2019 (NEWBERY, 2019).

The Vaca Muerta formation is found predominantly in the province of Neuquén, but it also extends to the provinces of Río Negro, La Pampa and Mendoza, with an extension of about 30,000 square kilometers (Figure 8). It contains the second unconventional gas resource in the world.

Figure 8

Argentine Map of the Vaca Muerta Formation



Source: https://www.argentina.gob.ar/economia/energia/vaca-muerta/mapas

The province of Neuquén has an important hydrographic network. Most of the surface is arid, with average annual precipitation of less than 200 mm (SECRETARIA DE MINERÍA DE LA NACIÓN DE LA ARGENTINA, 2015), allochthonous rivers, which feed in the mountain range, with a long channel without tributaries until it flows into the ocean. Due to the magnitude of the flows and the quality of its waters, the province's hydrographic basins can be considered the most important in the country, with entirely national waters.

The province of Neuquén enacted the Water Code (Law No. 899) in 1975, which established that the province's waters are public goods, whether the rivers that originate and die within the provinces' boundaries, the navigable lakes and their beds, among other categories. It also establishes that no one can use water from the public network for special uses, without holding a license or concession. It is understood by "special uses" and in order of importance - which are also of priority for its concession: (a) supplying populations; (b) irrigation; (c) therapeutic and thermal uses; (d) industrial uses; (e) hydraulic power; (f) lagoons and swimming pools. The water that flows through natural and public channels is in common use, for normal domestic uses. When the use is for economic purposes, they will be subject to prior authorizations or authorizations from the Water Board of the Province of Neuquén (GOBIERNO DA LA REPÚBLICA ARGENTINA, 2021a).

In 2008, Law 2600 of the province of Neuquén establishes that companies operating in the Province, whether or not headquartered in its territory, that carry out investigation, exploration, drilling, exploitation, storage and/or transport activities of liquid or gaseous hydrocarbons must obtain the "Certificate of Environmental Aptitude for the Activity of Hydrocarbons". The law seeks to maximize environmental safeguards and protection measures in the field of its own and/or related hydrocarbon activities. The certificate is renewed annually (DUFILHO E SAMARUGA, 2021). An "Annual Environmental Monitoring Report" must also be prepared, and an "Annual Environmental Management Plan" and a

"Basic Environmental Study of the Concession Area" must be presented, the latter similar to the Environmental Impact Study (EIA) and its respective Environmental Impact Report (RIMA) of Brazil. The Environmental Baseline Studies must include all physical, biological and socioeconomic aspects of the concession area together with the assessment of water and wind erosion of the soils, alluvial risk, aquifer vulnerability, environmental sensitivity and mitigation and contingencies monitoring plan (DUFILHO E SAMARUGA, 2021).

For the extraction of unconventional hydrocarbons in Neuquén, Decree 1483/12 establishes the mandatory use of water consumption from surface sources - lakes, rivers, streams and/or canals, duly authorized by the Sub-secretariat of Water Resources, prohibiting the use of water which will be preserved for human consumption and irrigation. In all cases, water withdrawals are limited, and the flow captured cannot exceed 50% of the total flow of the surface water body.

The average volume of water required for billing is relatively high, around 1,000 to 1,500 m3 per billing, and ranging from 30,000 to 70,000 m3 per well. In 2017, there were around 400 wells exploring shale gas operating in the province of Neuquén (DUFILHO E SAMARUGA, 2021).

Decree No. 1.483/12 of the province does not permit, under any conditions, the discharge of return water from the hydraulic fracturing activity in surface water bodies. It also establishes that the flowback must be submitted, in its entirety, to a treatment system that fits its discharge parameters in accordance with what is established by local and federal legislation. Treated water can be: (a) reused in the oil and gas industry; (b) reused in production or environmental restoration projects; or (c) disposed in disposal wells. (Tenth, 2020).

According to the Department of Territorial Development and Environment of the province of Neuquén, 1,288,304 m3 of return water (flowback) were generated throughout the province in 2018 (MÁS ENERGÍA, 2020).

In early 2020, there were 57 discharge wells in operation in the province of Neuquén, out of a total of 155 drilled for this purpose. Regulation 12/29 of the province of Neuquén establishes how a disposal well must be built (MÁS ENERGÍA, 2020).

The minimum requirements required by the authorities of the province of Neuquén for issuing an authorization to inject return water into wells are as follows (GOBIERNO DE LA PROVINCIA DEL NEUQUÉN, 2018): (a) Physical integrity of the well; (b) Geological characteristics: characteristics of the injection formation (lithology, porosity, permeability, allowable pressures – step rate test, thickness, fracture gradient, etc.); characteristics of the formation of the seal that hydraulically isolates the level to be used as a reservoir (lithology, porosity, permeability, admissible pressures, thickness, etc.); isopachic map of injection formation and seal formation; seismic profile that demonstrates the lateral continuity of the injection and seal formations: depth of the Neuquén Group or aquifer, of the injection and seal formations and the levels to be injected.; (c) Fluid to be injected; (d) Construction design of the well.

The well injection authorization issued must include: quality of the fluid to be injected; execution of a monitoring well within the invasion radius of the overlying aquifer at the injection level; installation of real-time Q and P instrumentation; installation of automatic stop instruments; installation of device for sampling; install treatment equipment for reuse; increase hydrogeological knowledge (GOBIERNO DE LA PROVINCIA DEL NEUQUÉN, 2018).

In Neuquén Province, the depth of unconventional reservoirs is much greater than in Marcellus (USA), in the order of 3,000 meters, which increases the degree of safety in exploration activities. The greater distance from the communities also contributes to a lower environmental risk.

A very important initiative of the Argentine government to manage the development of the Vaca Muerta resources, which has also shown very good results in terms of public perception regarding the production of shale gas in the province of Neuquén, was the creation of a permanent forum. of discussions called “Mesa de Vaca Muerta”. The forum involves the federal and provincial governments, companies and civil society, to address topics of interest for the development of non-conventional activities (infrastructure, value chain, technology, etc.) and reduction of social and environmental impacts. To date, there have been six face-to-face meetings of the forum, in 2018 and 2019, and the forum was interrupted in 2020 due to the Covid-19 pandemic (GOBIERNO DA LA REPÚBLICA ARGENTINA, 2021).

The main tool to prevent the impact on water resources of the hydraulic fracturing activity is the evaluation and monitoring carried out on the mechanical integrity of wells through specific tests, such as cement profile, corrosion profile, leak tests, among others. Either in wells in production (secondary recovery) or in old conventional wells that are already exhausted and that are converted into drainage wells (DÉCIMA, 2020).

Conclusion

As pointed out in this document, addressing the environmental issue, there is great complexity regarding conservation units. In view of this scenario, a case-by-case analysis is necessary in order to grant environmental licenses for the execution of a hydraulic fracturing project, and it is essential to understand how the operation will affect, directly and indirectly, the conservation unit or indigenous land in question, whether for the state of São Paulo or Paraná.

With regard to the water issue, extremely important parameters were raised in this study, such as the supply versus demand relationship for the hydrographic basins in Paraná and São Paulo, as well as the median depths of their aquifers. Such information is essential to be able to draw a relationship between the use of water and the fracturing operation, given that fracking is an activity with intensive use of this resource. Another fact that may occur that is linked to the data collected here is the migration of fluids from the well to adjacent formations, where it is necessary to know the depth of the aquifers so that the risks can be measured.

Regarding the experiences of developing this activity in other countries, the extensive fracking operations for the exploitation of unconventional resources in the United States and Argentina offer an extensive and important source of information about the management of the water resources used in these operations. In fact, the experience of these countries allows us to assess the interrelationship of this activity in environments as diverse as densely populated urban centers and rural regions, temperate and arid climates, and limited and abundant water supply.

Thus, it can be concluded that the impact of fracking activities on water resources is quantitatively reduced in general and qualitatively well known, making it possible to establish clear, objective and easy-to-follow rules by the authorities to ensure their development in regions adequate, limiting the occurrence and scope of any negative events up to limits compatible with the benefits generated by the activity.

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