HANDBOOK of CONSUMPTIVE WATER USE in BRAZIL

ANA

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Handbook of Consumptive Water Use in Brazil

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PRESENTATION

Dam System Canal - Pedra do Cavalo - BA
Eraldo Peres – Image Bank/ANA

Brazil is a privileged country when it comes to total water availability. However, water occurrence is unequal throughout the territory and depends on the season, and so is the demand for its use and the proper hydric infrastructure for its enjoyment and conservation. The water abundance culture has been progressively replaced with the idea that water is a finite resource that has economic value, which gives increasing importance to analyses that examine the balance between water offer and water uses, revealing regions that have water access deficits and risks to productive sectors.

The Brazilian National Water and Sanitation Agency - ANA -, in the fulfillment of its institutional mission to guarantee water security for the country's sustainable development, and as the agency responsible for implementing the National Water Resources Policy - PNHRH and the coordination of the shared and integrated management of the National Water Resources Management System - SINGREH, is permanently seeking to increase knowledge on water balance in the national territory.

This knowledge increase occurs through studies that result in methodological advances, primary data collection, technological development, and partnerships with renowned institutions. Information on the national quantitative water balance (that is, the relationship between water offer and demand) that is consistent, updated and scalable is fundamental for the decision-making necessary to guarantee water security to the population and for the development of economic activities.

The Handbook of Consumptive Water Use in Brazil is part of a comprehensive study that included the definition of methods, the elaboration of databases and the production, storage and provision of estimates for consumptive water uses in all Brazilian municipalities, following the evolution of the territories ever since 1931 (1,365 municipalities) until present day (5,570 municipalities). Projections for the demand up to 2030 were also carried out, totaling 100 years of research on water uses.

The water use categories considered consist of: human supply (urban and rural), animal supply, processing industry, mining industry, thermoelectricity and irrigation. A diagnosis of the liquid evaporation of artificial reservoirs was also carried out for reservoirs that may be individually associated for a specific water use (irrigation, aquaculture, public supply, power generation etc.) or that supply water for multiple uses.

Methods and databases from previous works were used in the development of this study, with the incorporation of procedures considered relevant and the proposing of advances considering the availability of new databases and the technological progress in information processing. Among these previous studies the most relevant at a national scale are: research carried out for the National Water Resources Plan (ANA, 2005; Brasil, 2006) and for the first Water Resources Situation Report for Brazil (ANA, 2009) in addition to important efforts in the production of estimates by the National Electric System Operator - ONS (2003; 2005) and by the Ministry of the Environment - MMA (Brasil, 2011).

As for the methods, the technical coefficients available in the literature and their adherence to the available data were investigated, resulting in expressive revisions of previously adopted coefficients. The study contains highly detailed and unprecedented coefficients in the case of industry, urban supply, and irrigation, which account for over 80% of water use in the country.

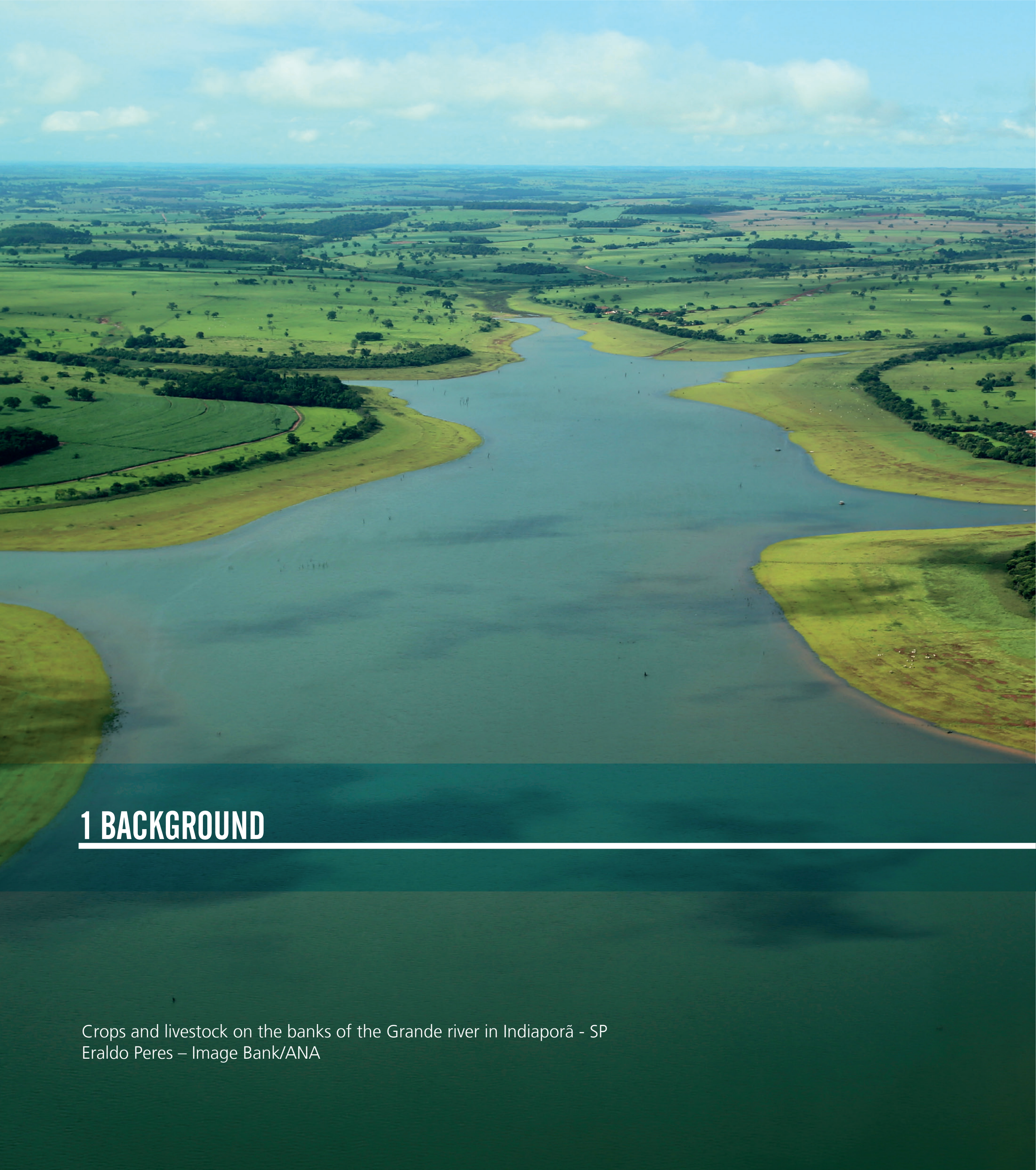
As for the databases in which the coefficients are applied, new sources and types of data were also researched and adopted, always seeking to improve the final results, which depict the human actions involved in water demand and, consequently, in the national water balance. Historical databases have also been recovered in similar documents, these databases were revised and completed using current technical criteria. The criteria included greater precision in the aggregation and disaggregation of municipal data, following the evolution of the network of the Brazilian territory, and which went through extensive changes during the period of analysis.

For the purpose of presenting the results, the diagnosis adopts 2017 as a baseline and the 2030 horizon as a prognosis. The consumptive uses flow series were generated in line with the evolution of the national territory and the variables that influence demand, selected based on availability and representativity, as well as the technical coefficients matrices and other associated information. The territorial basis for most of the information is the municipality.

The first chapter contextualizes the main concepts associated with the estimates for water demand, as well as the main figures and trends observed in the global and sectoral results. The other chapters detail the methodologies, databases and main results, divided by use, starting with human supply (urban and rural), followed by animal supply, processing industry, mining industry, irrigated agriculture, thermoelectricity and the liquid evaporation of artificial reservoirs. For the latter, the series were estimated only for the most recent period, due to the unavailability of historical data on occupied area and construction and filling dates.

Therefore, the Handbook provides a new technical basis for water uses in Brazil, both in methodological terms and in terms of the results generated and their applications. It represents the Brazilian reference on the theme and must be the starting point for continuous improvement on a national scale, as well as for initiatives related to the detailing and adaptation of the methods and consumptive water uses estimate flows to regional, seasonal and sectoral specificities.

Results of the series of consumptive uses, disaggregated by municipality, as well as interactive maps and indicator panels, can be accessed in the National Water Resources Information System – SNIRH website, at www.snirh.gov.br > *Usos da Água*.



1 BACKGROUND

Crops and livestock on the banks of the Grande river in Indiaporã - SP
Eraldo Peres – Image Bank/ANA

A use is considered as consumptive when the water withdrawn is partially or totally consumed in the process for which it is intended and does not directly return to the water body. Consumption can occur by evaporation, transpiration, incorporation in products, consumption by humans and animals, among others. The definition and estimate of consumption may be subjective and vary depending on the different applications of estimates.

Water uses such as navigation, fishing, tourism and leisure do not directly affect the amount of local water, despite depending on that water, and are considered as non-consumptive uses, which thus are not encompassed in the scope of this study.

The main consumptive water uses in Brazil are human supply (urban and rural), animal supply, the processing industry, the mining industry, thermoelectricity, irrigation and liquid evaporation of artificial reservoirs. For each use, the withdrawal (amount withdrawn from the water body), consumption (fraction of withdrawal that does not return to the water body) and return (fraction of withdrawal that returns to the water body) flows are characterized (Figure 1).

Water use estimates are a challenge, especially considering the spatial (national and municipal) and temporal (monthly, from 1931 to 2030) scales. Measurement inventories are scarce in Brazil, even when regarding a single municipality or a small hydrographic basin.

The inventory of land registers and water use grants (permits) is useful for several applications, but it does not guarantee accuracy as to the volumes really used, since the value granted tends to correspond to a maximum supply limit, with the industry operating at 100% of its installed capacity or a municipality that aims to supply its growing population in a future horizon. Average effective flows tend to be lower, especially for large users.

Furthermore, most grants are issued by the states, which are in different stages of implementation of water resource management instruments, i.e. with different levels of coverage and consistency of grants considering the universe of users.

Indirect methodologies arise as a necessary alternative for the calculation of water use, guiding sectoral and water resources planning and management. These methodologies generally use technical coefficients that associate inventory variables (e.g. population) with an average water demand (liters per inhabitant per year, for example).

The technical coefficients are usually calculated based on highly precise measurements, and their application in the estimates is a spatial and temporal extrapolation. The application of these coefficients is common in national and international reference studies.

The present study investigated the methods and databases adopted in Brazil and internationally so far, and proposes expressive changes in order to detail water demand in all its uses. The next chapters describe the steps and criteria used for measuring current water use estimates for each use.

The general numbers and the main trends and patterns observed in consumptive water uses are presented below. Detailed results can be accessed at www.snirh.gov.br/usos-da-agua.

Figure 1 shows the estimates for the country (withdrawal, consumption and return). Currently, disregarding liquid evaporation in artificial reservoirs (multiple use), irrigation accounts for 52% of water withdrawals, followed by urban supply (23.8%), the processing industry (9.1%) and animal supply (8%). As for consumption, due to the different proportions of average return to the water bodies, the proportion of uses in totalconsumption has changed, with an increase in the relevance of

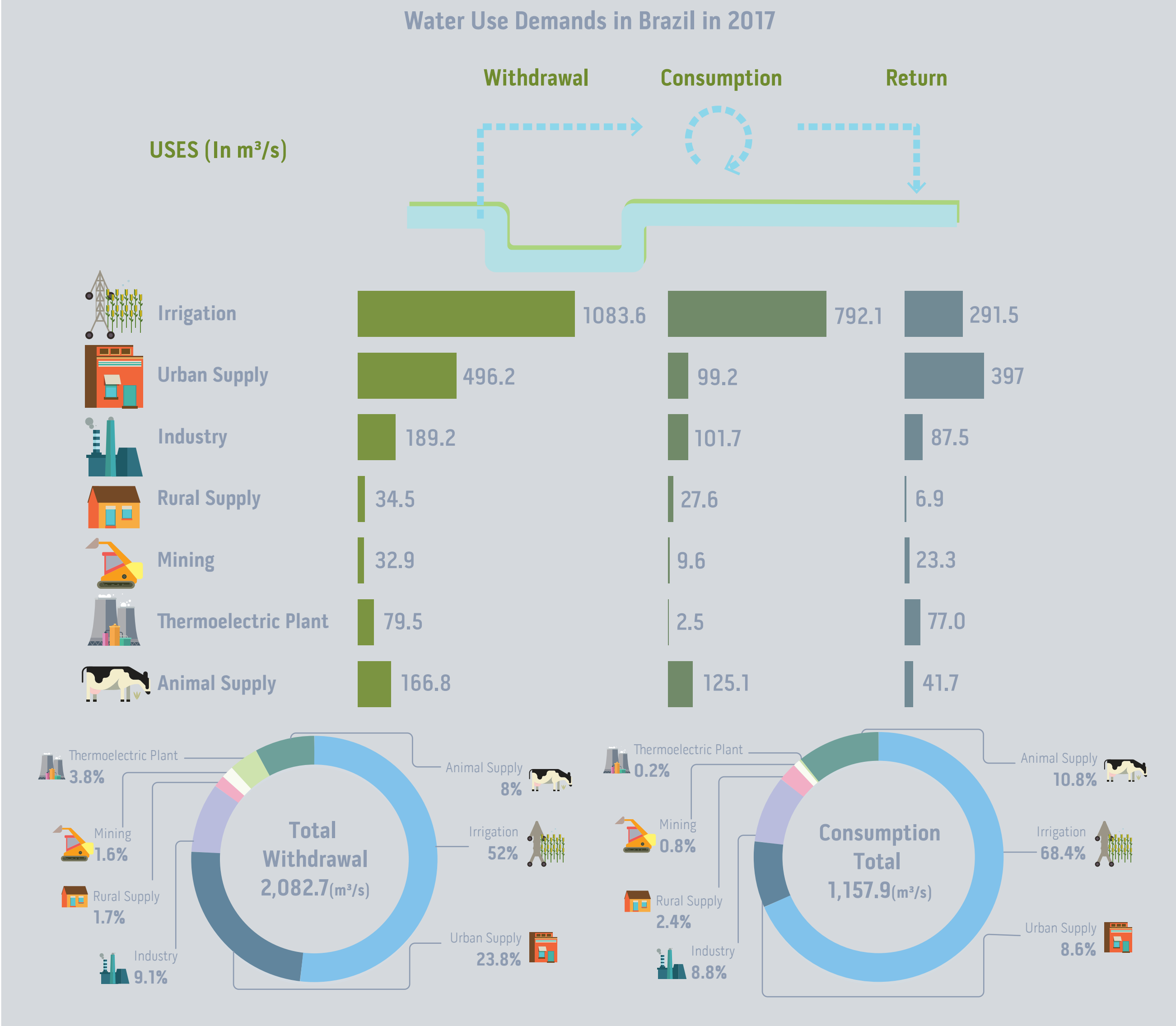


Figure 1 - Water use demands in Brazil in 2017, by purpose of use.
Source: modified from Situation Report 2017 (ANA, 2017).

irrigation and a drop in urban supply (Figure 1). The unprecedented estimate for thermoelectric power generation - a use that has become increasingly relevant today – should be highlighted.

Water demand in Brazil is currently growing, with an estimated increase of approximately 80% in the total withdrawal in the last two decades (Figure 2). The forecast is that there will be a 24% increase in demand by 2030.

The history of evolution of water uses is directly related to the country's economic development and the urbanization process. In the 1940s, the predominant water use in Brazilian municipalities was for rural human and animal supply. With the economic development and the advance of urbanization, the current situation reveals a greater diversity of uses, with increases in urban use and a relevant expansion of industrial uses and irrigated agriculture (Figures 2 and 3).

In the recent period, there was a slight reduction in growth from 2012 onwards (Figure 2), a fact related to the water crisis occurring in several regions of the country, as well as to the deceleration of Brazilian economic growth. The negative impact is more expressive in the industrial sector. An increase in the use of water for thermoelectric power generation is also observed as of 2012, due to the necessity of activating this complementary energy source, caused by the reduction in water volume availability for hydroelectric power generation.

Water withdrawals for thermoelectric plants and urban human supply are currently the leading water uses in the Northern Region of Brazil (Figure 3). Urban supply is the most relevant use in the Southeast Region, and the use of water for irrigated agriculture prevails in the other regions.

Irrigated agriculture has been the predominant use in the Southern Region since the 1930s, reflecting the pioneering nature of the state of Rio Grande do Sul in this practice, notably in the production of flooded rice. In the Northeast Region, irrigated agriculture became the main use in the second half of the 1990s, surpassing urban supply - a reflection of large public investments in

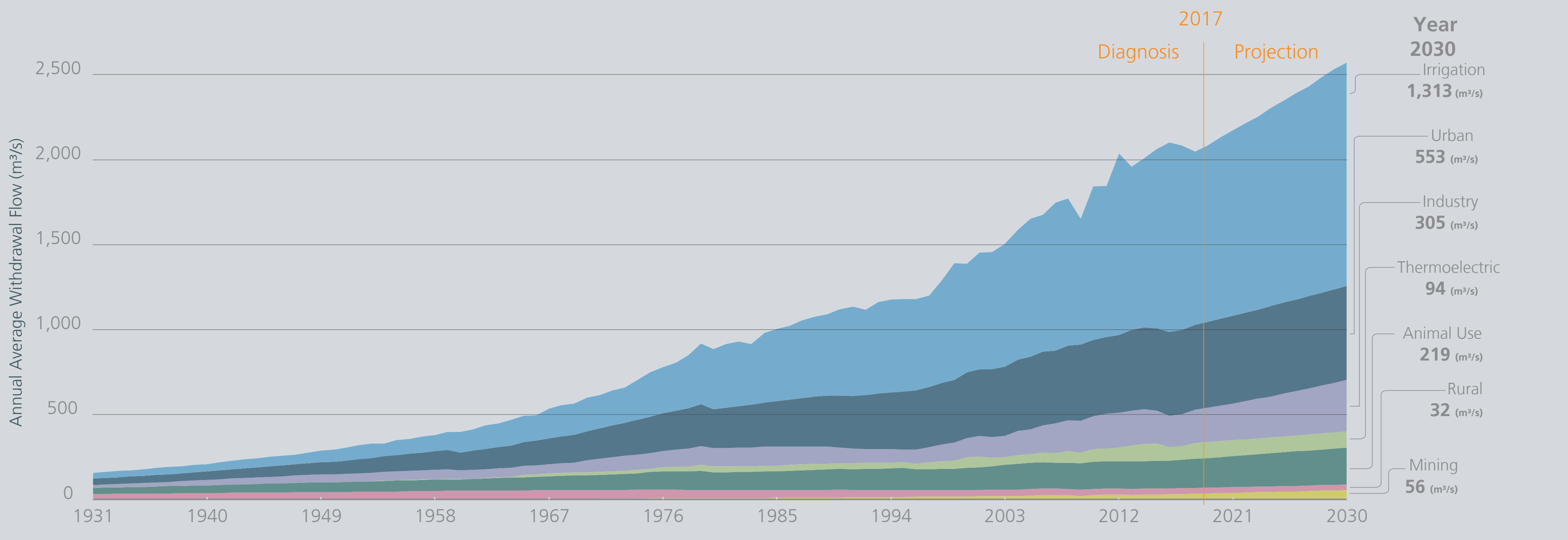


Figure 2 - Evolution of water withdrawal in Brazil (1931- 2030)

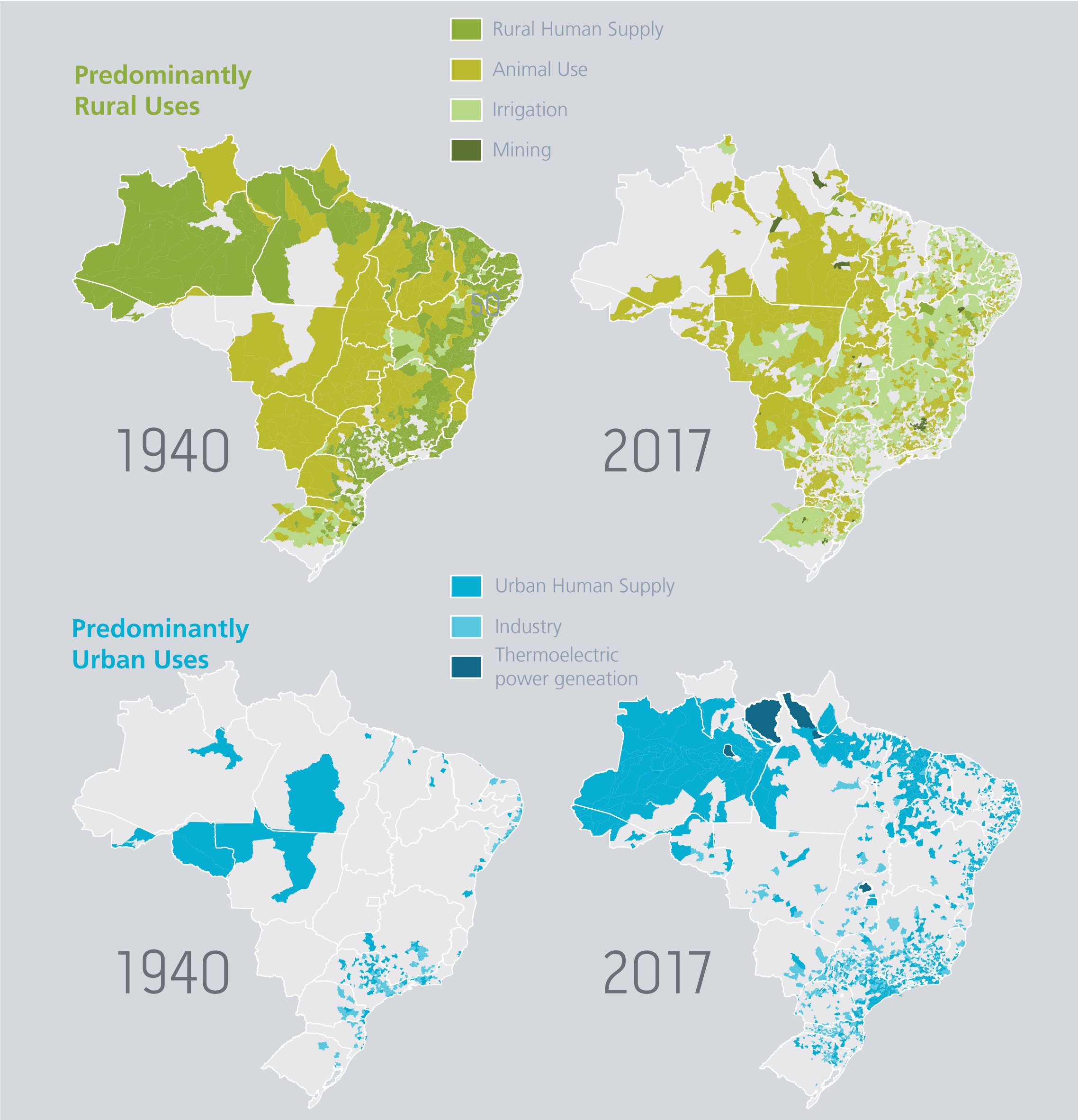


Figure 3 - Predominant water uses by urban and rural typology - 1940 and 2017
Source: adapted from the Situation Report 2017 (ANA, 2017).

water infrastructure and financing. In the Midwest Region, the predominance of the use for irrigated agriculture is even more recent, dating back to the mid-200s and surpassing the use for animal supply. For the Southeast region, projections point that irrigation will overcome urban supply in 2020 – leaving the North as the only region where this use will not be predominant.

Figure 4 presents a summary of the total water use demands by Hydrographic Region (withdrawal), also highlighting the proportions among the different sectors. Figure 5 presents a summary of the results for Brazil.

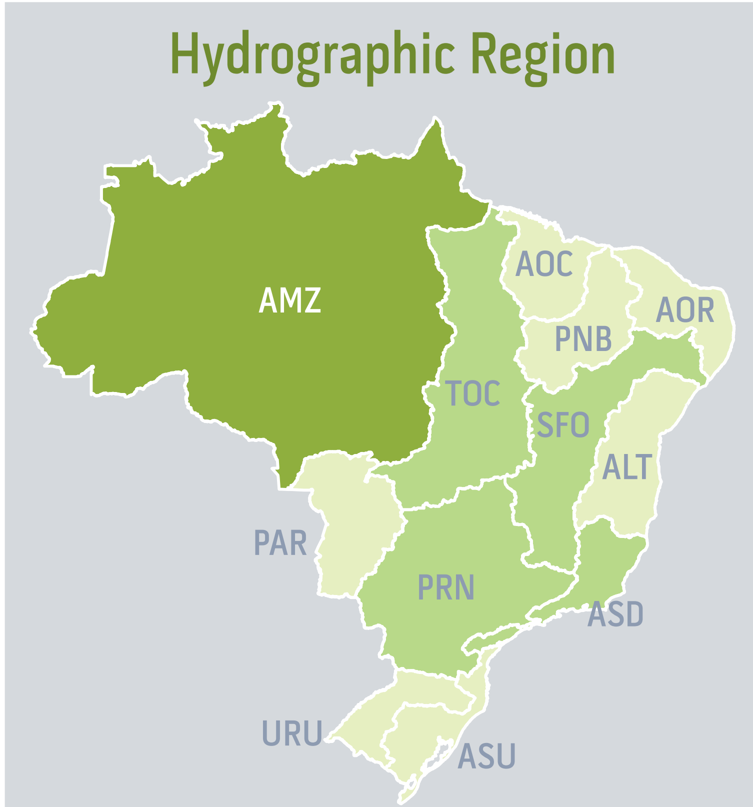


Figure 4 - water withdrawal demands in by Hydrographic Region (continues)
Source: adapted from the Situation Report 2017 (ANA, 2017).

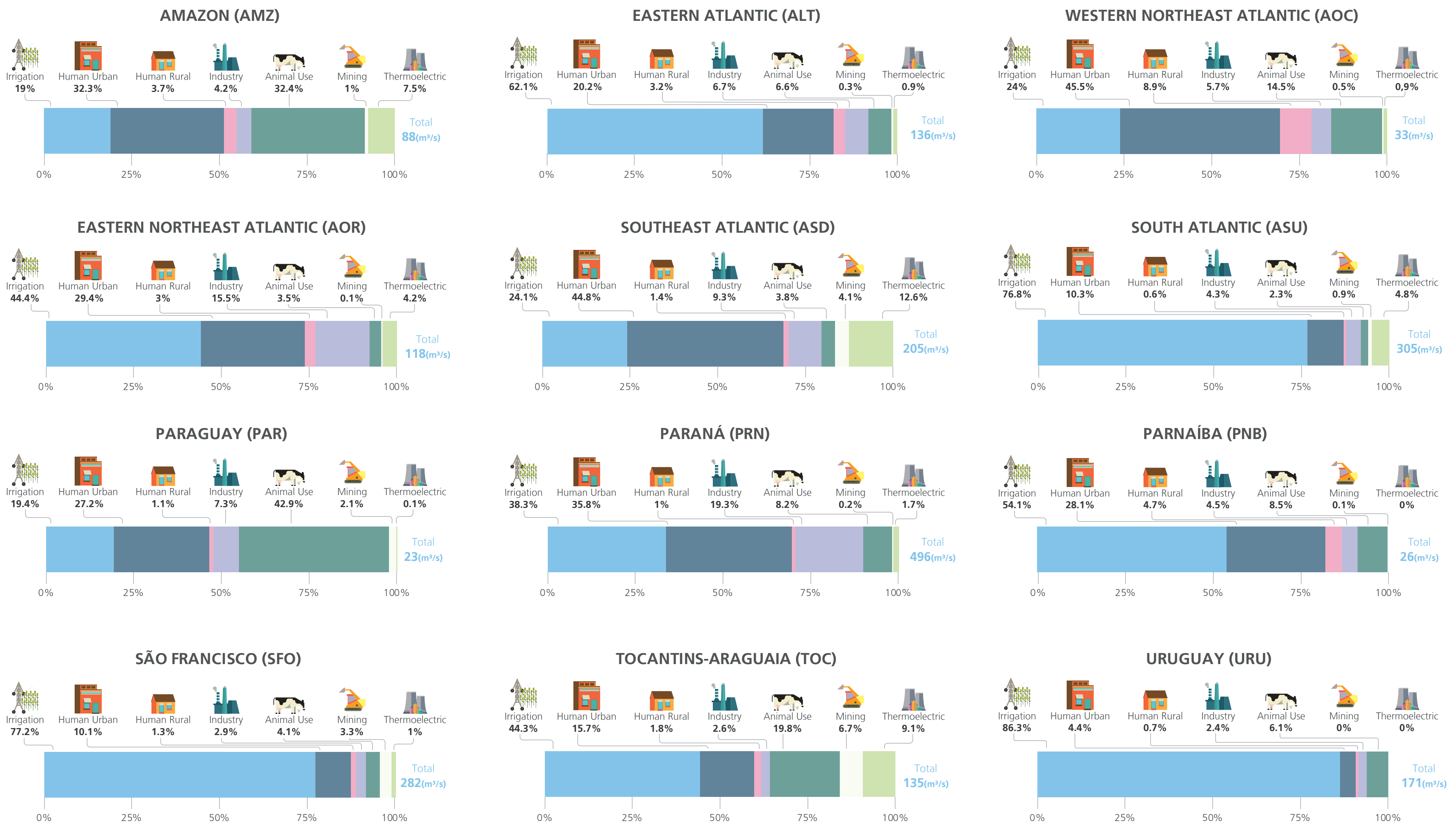
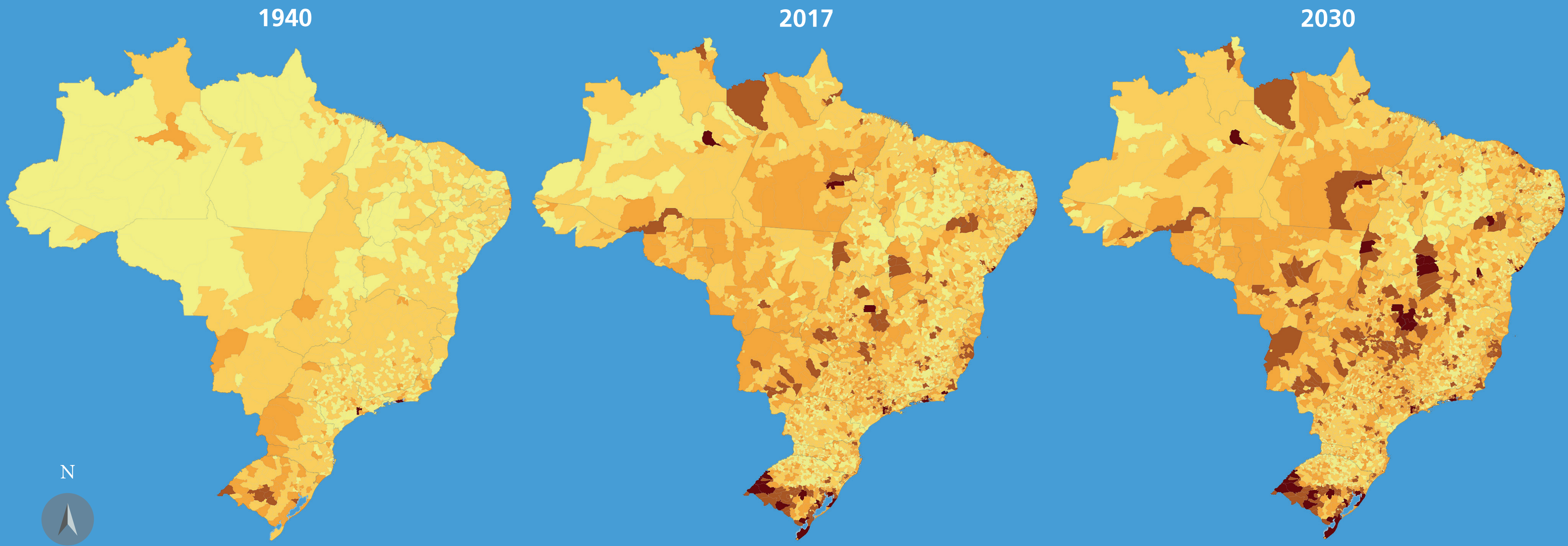


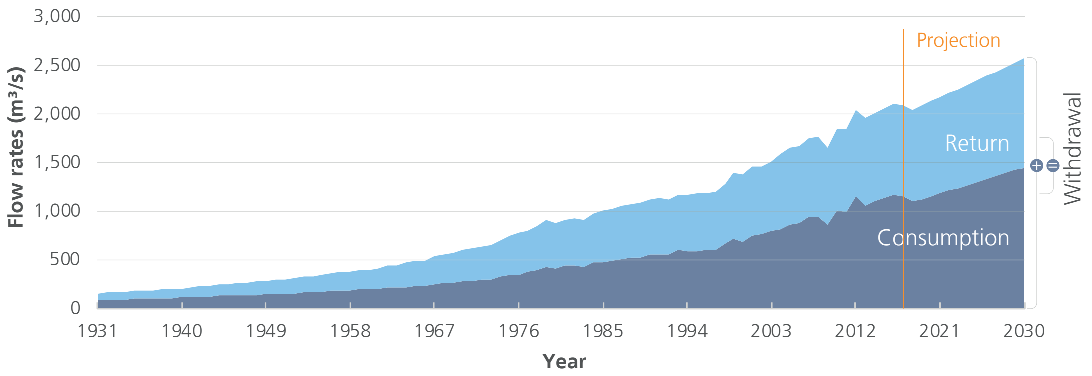
Figure 4 - Water use demands in the Hydrographic Regions - 2017 (continued)

Figure 5 - Flow series 1931 to 2030 – Results of Consumptive Uses in Brazil



Withdrawal Flows by Municipality (m³/s)

- 0.002 - 0.04
- 0.04 - 0.2
- 0.2 - 1.7
- 1.7 - 10.0
- 10.0 - 58.3



Largest withdrawal flows (m³/s) per municipality (2017) - Consumptive Uses in Brazil				
Ranking	**FU**	**Municipality**	**Withdrawal Flow (m³/s)**	**Predominant Use**
1st	SP	São Paulo	46.026	Urban Human Supply
2nd	RJ	Rio de Janeiro	45.283	Urban Human Supply
3rd	RS	Uruguaiana	24.405	Irrigation
4th	RS	Santa Vitória do Palmar	24.376	Irrigation
5th	RS	Alegrete	22.030	Irrigation
6th	RS	Itaqui	20.874	Irrigation
7th	BA	Juazeiro	18.261	Irrigation
8th	RS	São Borja	16.771	Irrigation
9th	PE	Petrolina	16.009	Irrigation
10th	RS	Mostardas	15.794	Irrigation

Among the ten Brazilian municipalities with the highest water withdrawal levels, the supply to the largest capitals in the country (Rio de Janeiro and São Paulo) is noted, and the municipalities have urban human supply as the predominant use. The other municipalities have irrigation as the predominant use, since they are areas of intensive use for the production of flooded rice (municipalities of the state of Rio Grande do Sul) or for the production of fruits and sugarcane in the Semi-Arid region (Petrolina and Juazeiro).
Detailed results for the historical series of consumptive uses for all municipalities can be accessed at www.snirh.gov.br/usos-da-agua

2 HUMAN SUPPLY

Water Treatment Plant (WTP) - Santa Bárbara - SP
Tomás May – Image Bank/ANA

2.1 Introduction

The Water Law (No. 9,433/1997) recognizes human supply and animal supply as the priority water uses in water scarcity situations. Supply encompasses domestic and residential uses (urban and rural) and uses in the trade and services sectors.

In addition to its importance as the second largest use in the country, urban supply is concentrated in the territory, resulting in increasing pressure on the water producing systems. The recent water crises in supply springs, such as the ones faced by the metropolitan regions of São Paulo, Rio de Janeiro and Belo Horizonte and the Federal District, have disseminated the discussion on water security in densely populated areas supplied by complex systems.

On the other hand, the rural supply demand has nationally dropped due to the smaller rural population. However, it still answers for the supply of 30 million people, often concentrated in regions with low water availability.

Ideally, the values for the volumes withdrawn and consumed must be based on the inventory and historical series measured, however, due to the unavailability and lack of consistence in the data, indirect estimates are usually used to evaluate and project demands.

Therefore, the studies previously carried out were generally developed based on similar methods, which varied according to data availability. Most methods use the population contingent and the per capita use coefficients (liters per inhabitant per day) as an explanatory variable for the estimates.

The National Sanitation Information System - SNIS is an important annual data source implemented in 1995. It is a system for collecting, treating, consolidating and providing information on operational water, sewage and rainwater systems. The SNIS has evolved in coverage and currently covers about 90% of the Brazilian municipalities and 95% of the urban population. It provides information about water and its methodology is similar to a census.

This chapter presents the method and explanatory variables used for the generation of the water demand series related to urban and rural human supply (1931-2030). Considering the methodological framework of the studies already developed in Brazil and in the world, the guideline presented for this study was based on municipal technical coefficients based on SNIS data, in addition to official counts and estimates published by the Brazilian Institute of Geography and Statistics - IBGE.

It is considered that the methodological advance resulting from the use of these databases provides a new technical reference on the human supply demands of the Brazilian municipalities, better depicting the country's current situation and its growth perspectives.

Considering large water use volumes account for human supply, it is estimated that 496.2 m³/s of water were withdrawn for urban supply and 34.5 m³/s for rural use in 2017. These values represent 23.8% and 1.7% of the total consumptive use of the country, excluding the liquid evaporation of artificial reservoirs.

Figures 6 and 7 illustrate the variation in withdrawal flows for urban and rural supply in the federation units. The state of São Paulo stands out, with withdrawal flows of the order of 135 m³/s for urban supply, which corresponds to almost four times the water withdrawal for rural supply in the country.

As a reference of the variations in the Brazilian regions, Figure 8 presents the percentages of the variations relating to total withdrawal and reflecting the population distribution and the patterns of use. The concentration of the rural population in the Northeast region - with its strong participation in continuous water scarcity areas in the Semi-Arid region is noted.

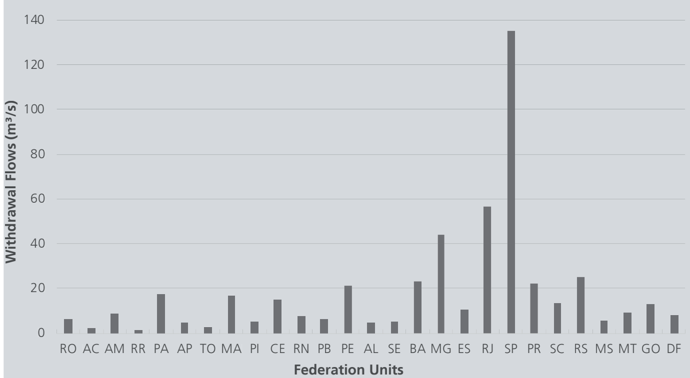


*Figure 6 – Withdrawal Flows (m³/s) for **Urban** Supply in the FUs*

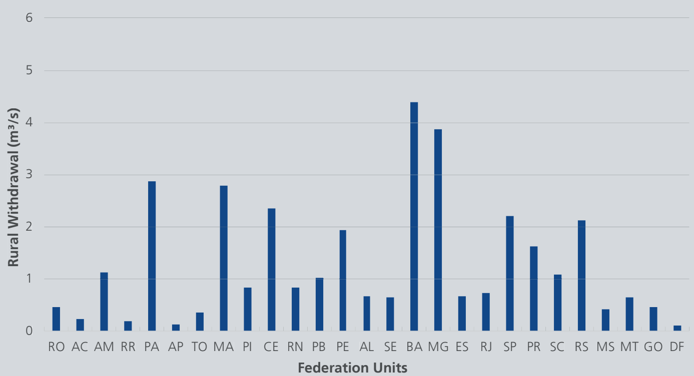


*Figure 7 - Withdrawal Flows (m³/s) for **Rural** Supply in the FUs*

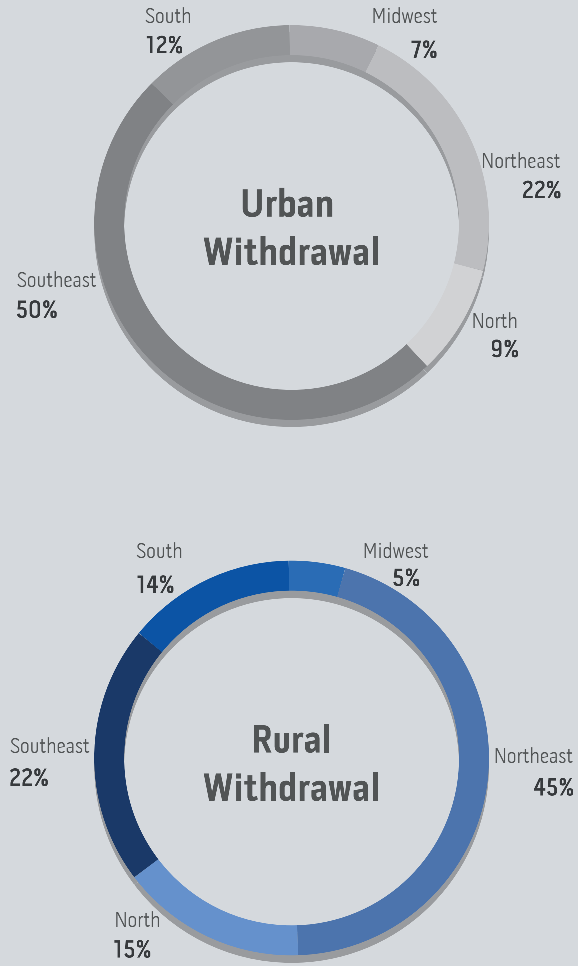
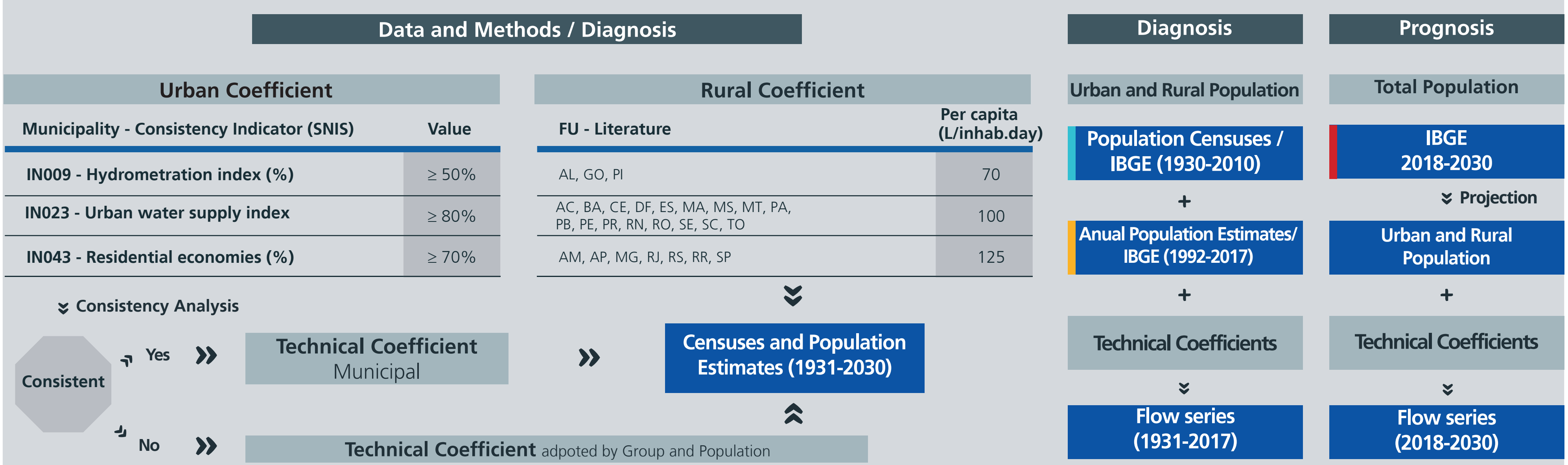


Figure 8 - Urban and Rural Supply in the Geographic Regions

2.2 Method and Database

The flowchart (Figure 9) provides a synthesis of the method for estimating flows associated with urban and rural human supply.



Municipality - Consistency Indicator (SNIS)	Value
IN009 - Hydrometration index (%)	≥ 50%
IN023 - Urban water supply index	≥ 80%
IN043 - Residential economies (%)	≥ 70%

FU - Literature	Per capita (L/inhab.day)
AL, GO, PI	70
AC, BA, CE, DF, ES, MA, MS, MT, PA, PB, PE, PR, RN, RO, SE, SC, TO	100
AM, AP, MG, RJ, RS, RR, SP	125

Group	Average per capita use (L/inhab.day) Faixa populacional (mil habitantes)				Loss (%) Faixa populacional (mil habitantes)			
	≤ 5	> 5 e ≤ 35	> 35 e ≤ 75	> 75	≤ 5	> 5 e ≤ 35	> 35 e ≤ 75	> 75
1	165	134	143	88	47%	46%	56%	58%
2	87	87	95	112	37%	36%	39%	50%
3	151	159	165	191	26%	33%	29%	34%
4	130	139	158	158	22%	26%	31%	39%
5	108	119	122	137	28%	31%	33%	37%
6	129	130	124	154	28%	30%	33%	32%

Group 1: AC, AM, AP, MA, PA, RO e RR | Group 2: AL, BA, CE, PB, PE, PI, RN, e SE | Group 3: ES e RJ | Group 4: MG e SP | Group 5: PR, RS e SC | Group 6: DF, GO, MS, MT e TO

Caption

- Source/Data base
- Variable
- Step

Municipal scale data = interpolation between census years without data
Annual municipal scale data = subdivision of the total population into urban/rural
State scale data = fragmentation for the municipal basis and subdivision into urban/rural

SNIS - National Sanitation Information System
IBGE - Brazilian Institute of Geography and Statistics

Figure 9 - Summary of the Method for Estimating Flows Associated with Human Supply

The method for estimating urban and rural supply is based on the application of **technical coefficients** to **population counts and estimates**. This study presents a new urban coefficients basis, further exploring the SNIS databases. As for the population data, the information provided by IBGE has been fully applied, and estimates were made for years without information or without distinction between urban and rural population.

The use of disaggregated SNIS information to define urban coefficients *per capita* is equally applicable and reliable for water use estimates.

Every year the SNIS provides general information on water and sewage, as well as operational indicators (Brasil, 2018). The general information relates to gross values obtained in the operations of the suppliers. The "AG" prefix was added to water operation information, these values are combined to obtain operational indicators ("OI"). Table 1 presents some information and indicators used for the generation or consistency analysis of the municipal water use coefficients and their descriptions. Figure 10 describes the criterion for the consistency analysis and for obtaining the urban coefficients.

Unlike other uses, in urban human supply the withdrawal values are estimated from two other indicators: the **per capita use** (water that may reach users) and the **losses** in the distribution networks (water lost between the withdrawal and the final user). The use corresponds to the distributed volumes that are really made available to the inhabitants (hydrometrated volumes in the residences + estimated volumes for inhabitants without water meters). The loss is equal to the part of the withdrawal volume which is not converted into use, potentially resulting from failures and leaks in the distribution network (physical loss), but which can also incorporate apparent loss (water used but not accounted for due to measuring failures or clandestine connections).

In order to obtain the indicators for municipal use and losses, the first SNIS data verification intends to ensure the representativeness of the sample: the hydrometration (IN009) must be greater than 50%, guaranteeing that the data presented by the provider accounts for a greater measurement percentage than the estimate; urban water supply (IN023). The data must cover over 80% of the municipality's population, guaranteeing a good representativeness of the coefficient; and the participation of residential savings (IN0430 must be over 70%, decreasing the influence of the trade and services sectors and of some of the smaller industries, which may have more expressive impact on the municipal values.

The per capita use and loss values are calculated for municipalities that meet the criterion (equations 1 and 2), verifying that the values are consistent with the minimum and maximum limits established (Figure 10).

For municipalities that did not meet the criteria, the use of IN022 is evaluated as a per capita use indicator (average water consumption per capita calculated by the SNIS).

After these analysis stages, municipality indicators were obtained for 85% of the Brazilian municipalities, covering about 95% of the urban population, without the need to adopt theoretical or average coefficients (provided by the State or by service providers).

In order to inform the *per capita* use and/or average loss for municipalities that did not provide data to the SNIS or that did not meet the consistency criteria, a table of reference was elaborated based on the municipalities that did provide the data. This matrix groups the Indicators by population range and federal units with similar use and loss characteristics (Figure 9). However, only 15% of the municipalities that correspond to 5% of the urban population had to use this table.

It should be noted that the coefficients are representative of the populations served by the public water distribution network. However, the total urban population was considered in order to estimate demand. One assumed that per capita demand and losses for the populations not served by the network are the same as for the population served. Furthermore, it is registered that 93% of the Brazilian urban population was served by the network in 2016 (Brasil, 2018).

With regard to the **consumption and return coefficients**, in this publication return corresponds to 80% of the withdrawal, based on ABNT recommendation NBR 9649. Thus, consumption corresponds to 20% of the withdrawal.

On the other hand, it should be noted that the breakdown of municipal coefficients into use and losses allows different **consumption/return** percentages to be adopted for different applications. In the generation of effluents, for example, the losses in the distribution network have no significant impact on the quality of the water and the consumption can be calculated only for the water that reaches the users and, therefore, is only partially converted into effluent.

With the *per capita* use and loss indicators calculated (Equations 1 and 2) or informed for all municipalities, the per capita withdrawal, consumption and return coefficients were calculated in accordance with Equations 3 to 5.

Table 1 - Information and indicators provided by SNIS, relevant for the estimation of per capita coefficients		
Item	**Name**	**Description**
AG001	Total population receiving water supply (Inhabitants)	Value of the total population receiving water supply by the service provider on the last day of the reference year. Corresponds to the urban population that effectively receives the services, in addition to other populations served located in non-urban areas. These populations may be rural or even urban provided they are located in areas considered rural by IBGE. Should the service provider not have its own procedures to precisely define that population, this number may be estimated using the product of the amount of active residential water savings multiplied by the average resident rate per household of the respective municipality.
AG002	Amount of active water connections (Connections)	Amount of active water connections to the public network (provided with hydrometer or not), which were in full operation on the last day of the reference year.
AG003	Amount of active water savings (Savings)	Amount of active water savings that were fully operational on the last day of the reference year.
AG004	Amount of active micro measured water connections (Connections)	Amount of active water connections provided with hydrometer that were in full operation on the last day of the reference year.
AG006	Water volume produced (1,000 m^3/year)	Annual water volume available for consumption, measured or estimated at the outlet(s) of the STS or STU. Also includes the volume of water collected by the service provider or gross imported water (AG016), which is made available for consumption without treatment, measured at the respective inlet(s) of the distribution system. This volume may be partly exported to another municipality (or municipalities) served or not by the same service provider.
AG008	Micro measured water volume (1,000 m^3/year)	Annual water volume measured by hydrometers installed on the active water connections. Not to be confused with the volume of water consumed, identified by the AG010 code, since the latter includes estimates for users of non-measured connections in addition to the measured volumes.
AG010	Water volume consumed (1,000 m^3/year)	Annual water volume consumed by all users, encompassing the micro measured volume (AG008), the estimated consumption volume for connections without hydrometer or with stationary hydrometer, plus the volume of treated water exported (AG019) to another service provider.
AG013	Amount of active residential water savings (Savings)	Amount of active residential water savings that were fully operational on the last day of the reference year.
AG014	Amount of micro measured active water savings (Savings)	Amount of active water savings whose connections are provided with hydrometer that were in full operation on the last day of the reference year.
AG018	Volume of treated water imported (1,000 m^3/year)	Annual volume of drinking water received from other providers, previously treated in STS or STU. Should not be computed in the water volumes produced (AG006).
AG019	Volume of treated water exported (1,000 m^3/year)	Annual volume of drinking water transferred to other distributors, previously treated in STS or STU. Should be computed in the consumed water volumes (AG010).
IN009	Hydrometration index (%)	(AG004 / AG002) x 100
IN022	Average *per capita* water consumption (L/Inhab./day)	((AG010 - AG019) / AG001) x 106) / 365
IN023	Urban water supply index (%)	(Urban population supplied (AG026) / total urban population) x 100
IN043	Participation of residential water savings in total water savings (%)	(AG013 / AG003) x 100

Source: BRASIL (2018)

Equation 1

$$Use_{percapita} = \{AG_{008} \cdot [AG_{014} \cdot (AG_{001} \div AG_{013})]\} \cdot 10^{6} \div 365$$

Equation 2

$$Loss_{average} = [(AG_{006} + AG_{018}) - AG_{010}] / (AG_{006} + AG_{018} - AG_{019})$$

Equation 3

$$Withdrawal_{percapita} = USE_{percapita} \cdot (1 - Perda_{média})^{-1}$$

Where:

$Use_{per\ capita}$ = coefficient defining the average use *per capita* in L/Inhab./day

$Loss_{average}$ = proportion that represents the portion withdrawn but not used by a percentage

$Withdrawal_{per\ capita}$ = coefficient defining the average withdrawal *per capita* in L/Inhab./day

Equation 4

$$Consumption_{percapita} = Use_{percapita} \cdot (1 - C) + (Withdrawal_{percapita} - Use_{percapita}) \cdot (1 - C)$$

Where:

$Consumption_{per\ capita}$ = average use *per capita* consumption in L/Inhab./day

$Use_{percapita}$ = average *per capita* use in L/inhab./day

$Withdrawal_{per\ capita}$ = average *per capita* withdrawal in L/Inhab./day

C = coefficient (C = 0.8 adopted for flows associated with urban and rural populations)

Equation 5

$$Return_{percapita} = (Withdrawal_{percapita} - Use_{percapita}) \cdot C + (Use_{percapita} \cdot C)$$

Where:

$Return_{percapita}$ = return *per capita* in L/Inhab./day

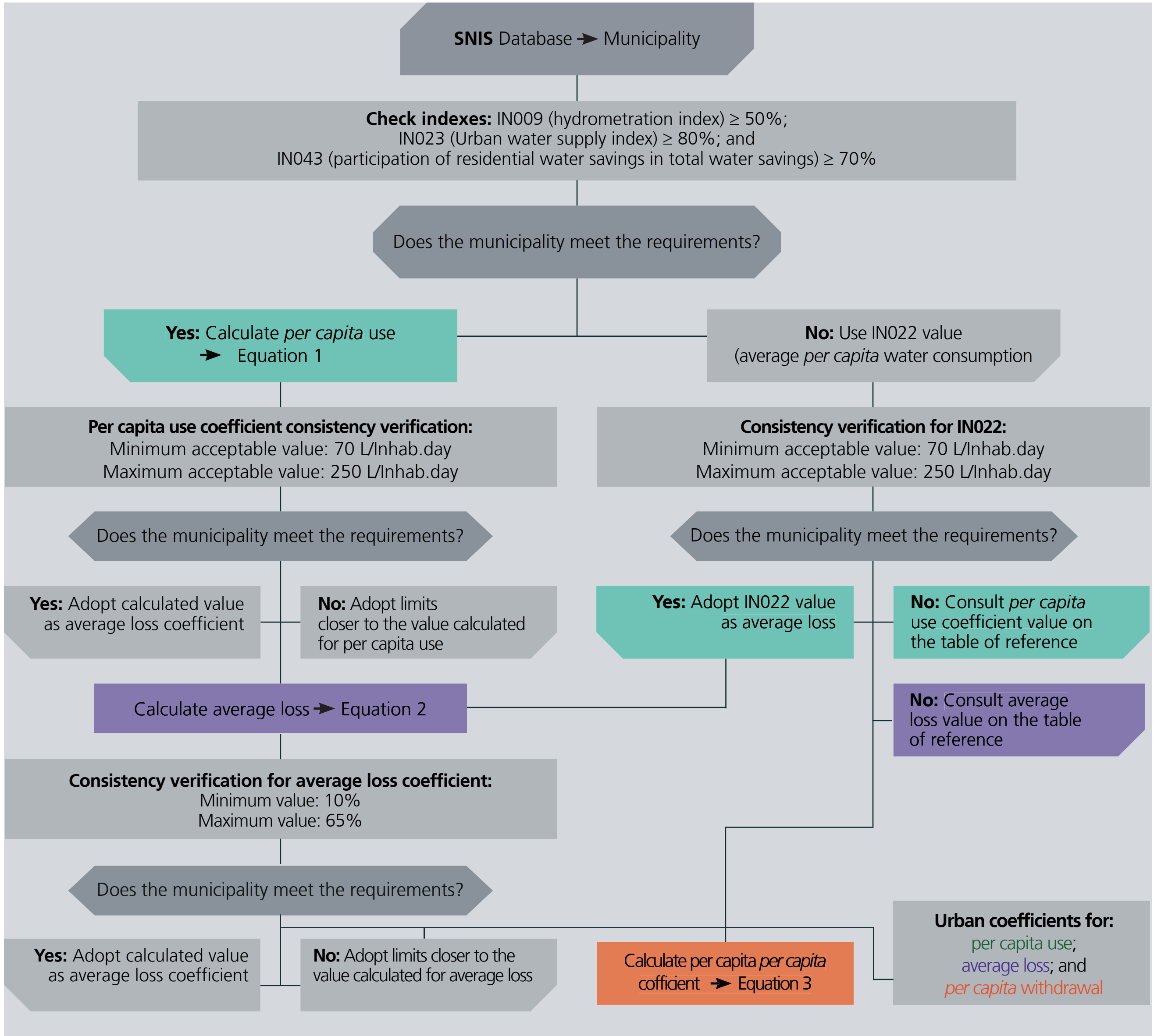


Figure 10 - Flowchart: method for obtaining average per capita use, loss and withdrawal coefficients for urban populations

With regard to the rural population, the withdrawal coefficients used were the ones adopted in previous studies (ONS, 2003; 2005), which vary from 75 to 125 liters per inhabitant per day, according to the FU (Figure 9). Consumption was also estimated at 20% of withdrawal (80% return)

Due to the unavailability of data on a national scale and the uncertainty of regression models related to use of water by populations, the per capita values obtained for the diagnosis were used for past and future scenarios. Even though increases in per capita water use are expected due to modernization and increased income for example, other factors also influence this process, such as increased efficiency (decrease in losses), water scarcity, impact of public policies, and changes in consumption habits.

When it comes to the quantification of the municipal populations considered in the calculation of human water supply demand, the information for the analyzed period was drawn from census surveys, counts and population estimates published by IBGE, mainly through the IBGE Automatic Recovery System - SIDRA (http://sidra.ibge.gov.br).

The main data sources between 1930 and 1991 are the Ten-Year Demographic Censuses. Information for urban and rural municipal populations in years without census data was collected from the available records.

Annual data is available from 1992 onwards: population counts in 1996 and 2007; population censuses in 2000 and 2010; and population estimates for the other years. IBGE only informs the total municipal population for part of the data in population counts and estimates, and a breakdown into urban and rural population was required to fill the gaps. For this purpose, the trends observed in the municipality between census years were applied, it being necessary to disaggregate the population into urban and rural.

With regard to the future population projection, it is estimated there will be a progressive reduction of the total Brazilian population by 2030.

IBGE provides annual estimates per federation unit with the 2030 horizon (IBGE, 2013). The future municipal population (total, urban and rural) was estimated based on a logistic method whose mathematic function accurately depicts the growth process that is decelerating as it approaches a saturation point. The method adequately portrays the predominant trend of the Brazilian municipalities to decrease in population growth. The municipal trends observed between 2000 and 2010 determined the calculation parameters.

The population per federation unit estimated by IBGE in the 2030 horizon was used as a control variable for evaluation and adjustment of the estimate, that is, the total population of the municipalities must be close to the official population estimated by IBGE in each FU (with a variation of up to 5%).

For the purposes of applying the logistic method to the 63 municipalities created after the year 2000, their populations were estimated in 2000 and 2010 using the census data from the municipalities of origin.

The logistic model was used to estimate total and urban populations, the rural population was determined by the difference between the two.

2.3 Results

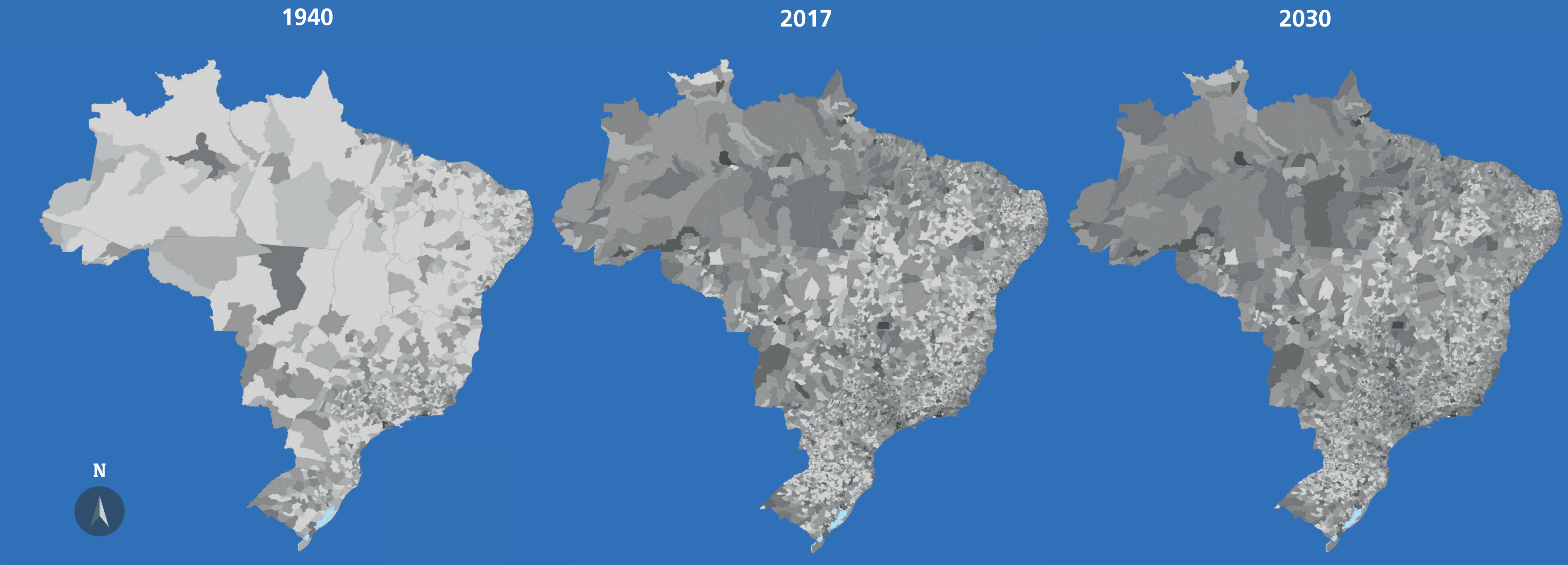
The infographics (Figures 11 and 12) provide a spatial and graphic summary of the results obtained for urban and rural human supply (1931 - 2030), respectively. The associated graph presents the historical series of withdrawals, consumption and return for the entire country. Tables containing the municipalities with the ten largest withdrawals in 2017 are also presented.

The impact of population variations on water demand is observed, notably due to the strong growth of the urban population and the drop in rural population numbers since the 1970s. The stabilization perspective is noted for the recent period and for future projections, when water demand will tend to be more affected by changes in the supply systems and by the consumption pattern of households than by population increase or migratory flows.

The 2030 scenario shows a total population of 226.4 million - 18.75 million more than 2017. The 9% growth in this period is driven by an increase of 21 million people in cities (+11.7%), while the population is expected to fluctuate negatively by 2.25 million (-7.9%).

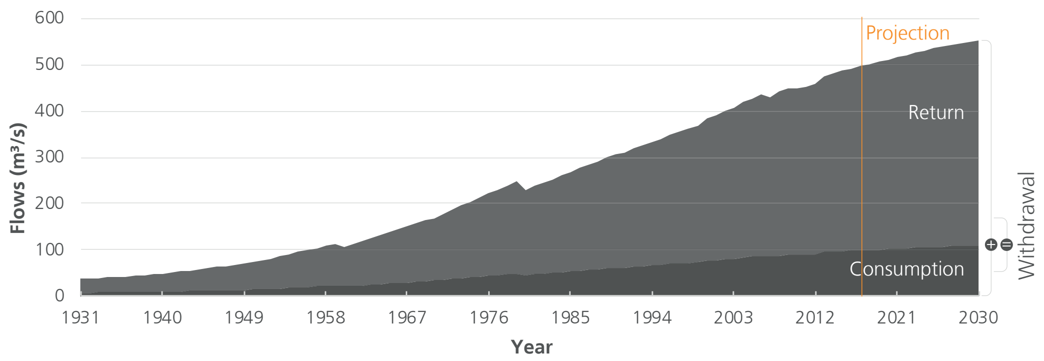
Detailed results can be accessed at www.snirh.gov.br and at metadados.ana.gov.br/.

Figure 11 – Withdrawal Flows 1931-2030 – Human Urban Supply



Withdrawal Flows by Municipality (m³/s)

- 0.000 - 0.012
- 0.012 - 0.015
- 0.015 - 0.027
- 0.027 - 0.086
- 0.086 - 0.354



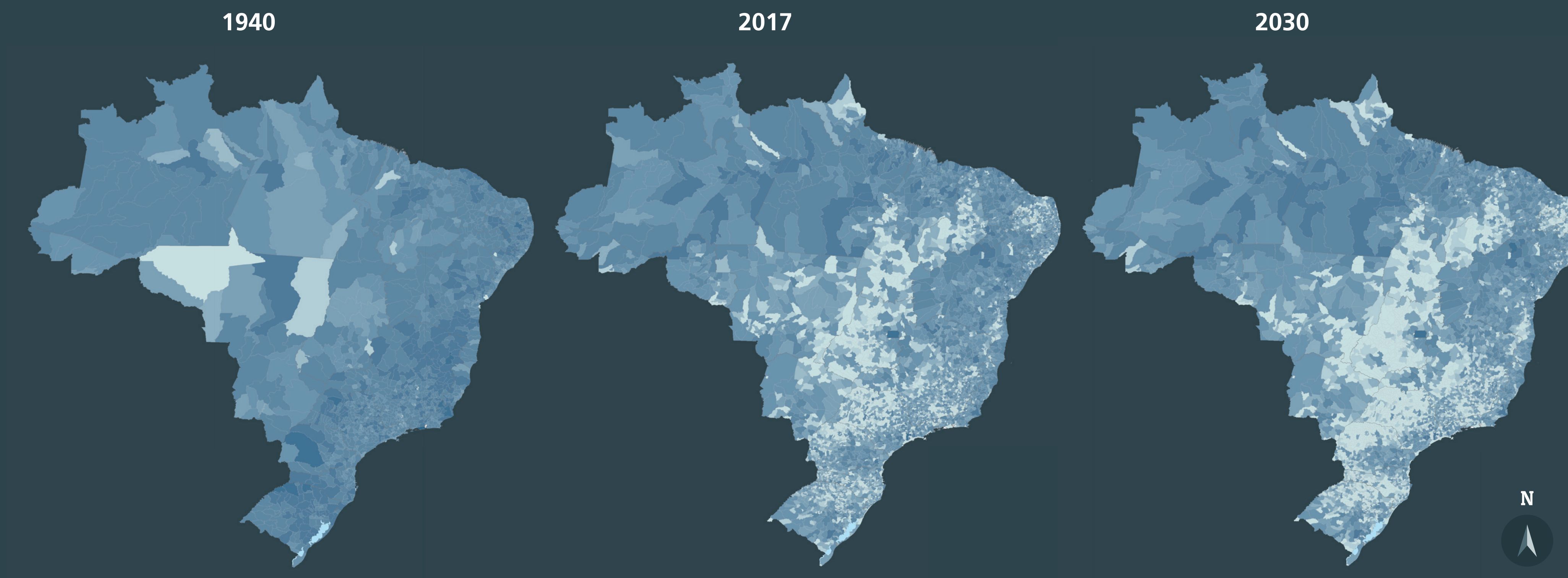
Largest Withdrawal Flows (m³/s) by Municipality (2017) - Human Urban

Ranking	FU	Municipality	Withdrawal Flow (m³/s)
1st	SP	São Paulo	40.254
2nd	RJ	Rio de Janeiro	24.049
3rd	BA	Salvador	8.357
4th	DF	Brasília	8.157
5th	MG	Belo Horizonte	7.110
6th	CE	Fortaleza	6.890
7th	PE	Recife	5.955
8th	PR	Curitiba	5.369
9th	RS	Porto Alegre	5.007
10th	PA	Belém	4.915

Some of our largest state capitals are among the largest withdrawal flows for urban supply. The ranking does not exactly reflect the population. Fortaleza, for example, has an urban population that is larger than Belo Horizonte, but the lower consumption standard reflects a lower demand if compared to the capital of Minas Gerais. The same logic applies to Recife and Curitiba. Belém is another example: with the 12nd largest urban population and the 10th largest water withdrawal.

Detailed results for the historical series of consumptive can be accessed at www.snirh.gov.br/usos-da-agua

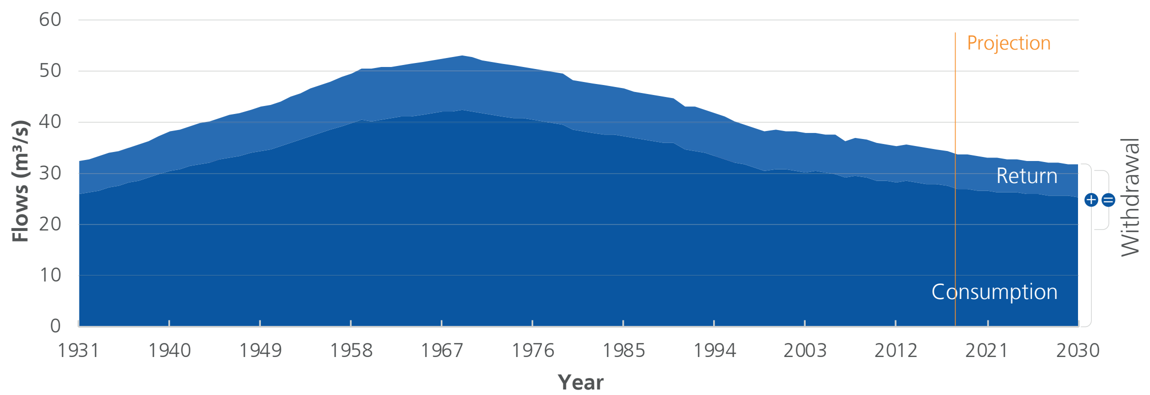
Figure 12 – Flow Series 1931 to 2030 – Rural Human Supply



Largest Withdrawal Flows (m³/s) by Municipality (2017) - Human Rural			
Ranking	FU	Municipality	Withdrawal Flow (m³/s)
1st	MA	São José de Ribamar	0.157
2nd	PE	Petrolina	0.101
3rd	DF	Brasília	0.100
4th	PA	Barcarena	0.089
5th	PA	Santarém	0.085
6th	PA	Cametá	0.084
7th	RJ	Cabo Frio	0.076
8th	PA	Abaetetuba	0.073
9th	SP	Ibiúna	0.070
10th	MA	São Luís	0.070

The largest withdrawal flow values for human rural supply are represented by municipalities with a considerable rural population, especially in the North and Northeast regions. The decreasing trend of the rural population will continue up until 2030, even though some municipalities show a grow in population due to the implementation or expansion of agribusiness, which has been observed in more recent historical series.

Detailed results of historical series of consumptive uses for all municipalities may be found at www.snirh.gov.br/usos-da-agua.



3 ANIMAL SUPPLY

Araguaia River - GO
Rui Faquini - Image Bank/ANA

3.1 Introduction

Agricultural uses are the largest consumptive uses of water on a global scale. In Brazil, a country which has some of the largest herds in the world, the water demand for animal consumption, breeding, and ambience is high.

Daily water consumption may significantly vary depending on the animal species since most of the demand is related to the physiological needs of the animals. The size and stage of development are determinant factors in water demand per capita and are also influenced by environmental and handling conditions (Ward & McKague, 2007).

The globally applied methodologies employ information from herd counts and technical coefficients per capita to estimate water demand. The level of detail of the coefficients is a function of the availability of information about the herds such as species, typology, size, developmental stage, and use of confinement.

In addition to specific animal needs (watering), disaggregated by type of herd, the current animal supply demands consider the use of water in a broader sense, such as for dairy operations, the cleaning of the animals and facilities, and the maintenance of rural structures.

Figure 13 illustrates the current withdrawal flow variation in the Brazilian federation units. Minas Gerais, Goiás, Mato Grosso, Mato Grosso do Sul, Pará and Rio Grande do Sul stand out, mainly reflecting the concentration of cattle herds in these municipalities. The current withdrawal demand is 166.8 m³/s (8% of the total). As a reference of the variations in the Brazilian regions, Figure 14 shows the percentages of these variations in relation to the global withdrawal.

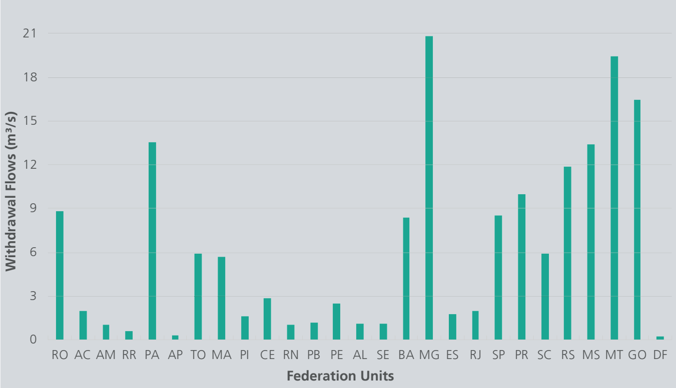


Figure 13 - Withdrawal Flows (m³/s) for Animal Supply in the FUs

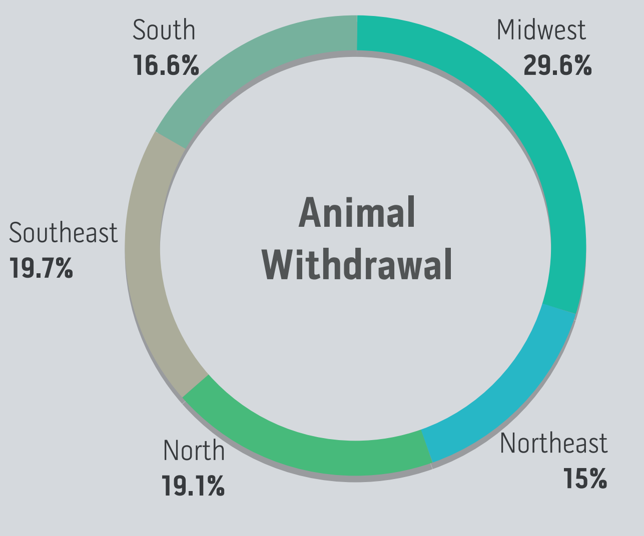


Figure 14 - Withdrawal Percentage for Animal Supply in Relation to Total Withdrawal in Each Region

3.2 Method and Database

The flowchart (Figure 15) provides a summary of the method and databases for estimating the flows associated with animal supply.

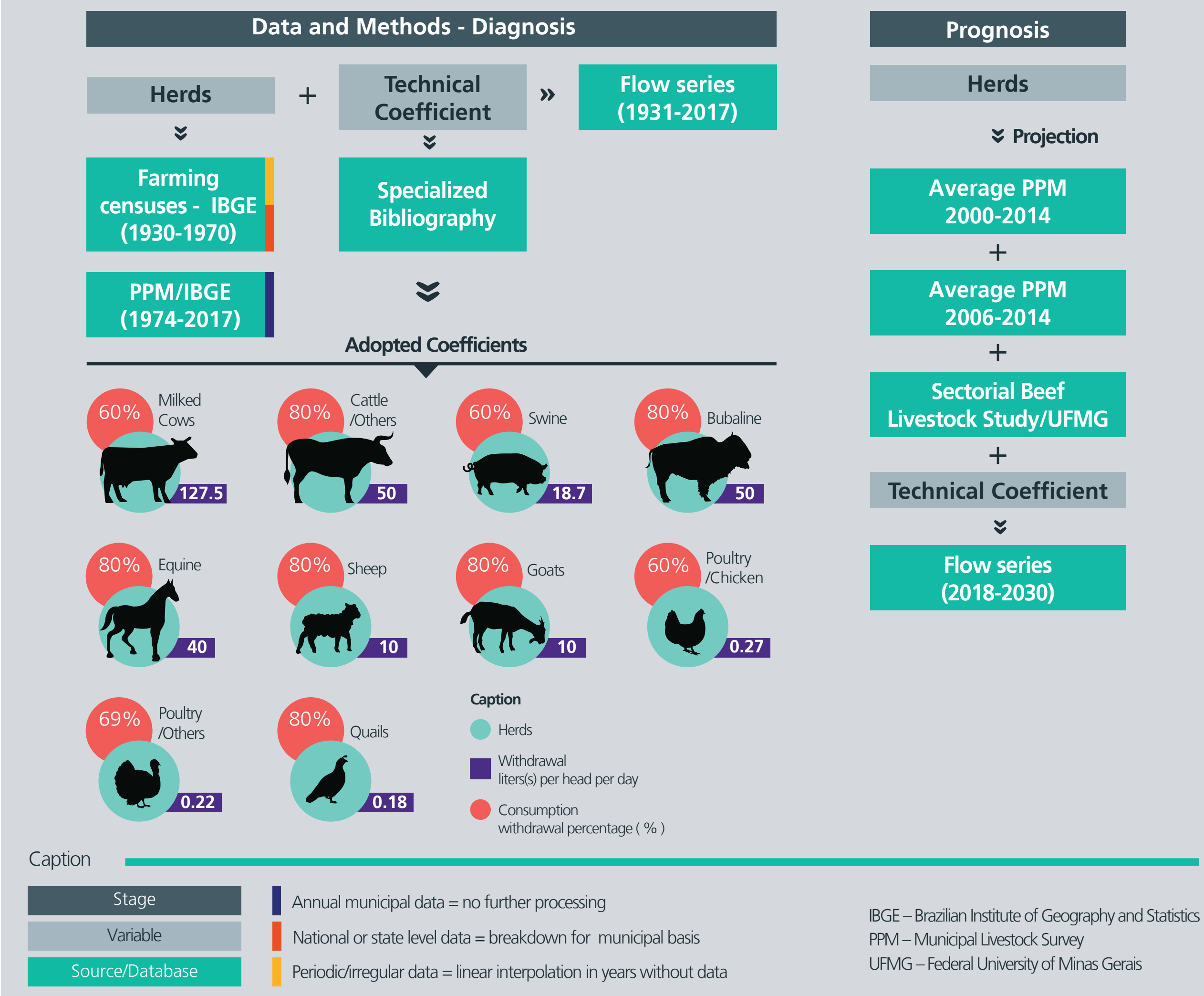


Figure 15 - Summary of the Method for Estimating Flows Associated with Animal Supply

The method adopted is similar to the one used by national and international reference studies. It consists of the application of **technical per capita coefficients** (liters per day per head), by **type of herd**, to the **number of heads** registered or estimated in the reference year. The conceptualization of the herds (IBGE, 2013; 2017) is presented in Table 2.

Two important characteristics related to the method and the databases differentiate this study from previous approaches.

The first consists of a new revision of the **technical coefficients** contained in the available literature, with the analysis of 12 national and international reference studies. Table 2 contains the minimum and maximum values observed, as well as the values adopted. There was no specific criterion for the choice of the coefficient; the case-by-case analysis took into account the depth, representativeness and data sources used by the authors, as well as the coherence of the coefficients with the data provided by IBGE. Tables 3 and 4 provide a detailed description of the main sources of animal consumption coefficients related to cattle (milked cows and others) and poultry (chickens and others), which categories showed greater discrepancy in their values.

The definition of coefficients by type of herd results not only in the full use of the data collected by IBGE, but also allows the sectorial analysis of the situation, the prognosis of water use by the different herds, and their association with the agro-industrial chain (processing industry).

In addition to detailed and more up-dated figures on animal consumption (physiological needs of the animals) (Table 2), there was an incorporation of values for other animal breeding needs (such as washing, cleaning, and maintenance of facilities and structures).

Table 2 - Herds: conceptualization and technical coefficients (minimum, maximum, and coefficient adopted)

Species	Conceptualization	Minimum Coefficient (liter (s) per head per day)	Maximum Coefficient (liter (s) per head per day)	Coefficient Adopted (liter (s) per head per day)	Consumption (%)	Source(s) Adopted
Cattle	Total mammals of the Bos indicus (Indian bull) or Bos taurus (European bull) species, irrespective of sex, age, breed or purpose (beef, milk or work).	20.0	80.00	50.0	80	ANA (2013)
Milked Cows	Mixed or breed cows (beef, milk or double-aptitude cows) existing in the municipality and which have been milked at some point in the reference year of the survey, whether for self-consumption, processing into cheeses, butter etc. or for sale.	20.0	150.0	85.0 (127.5)	60	ANA (2013) SUDERHSA (2006)
Swine	Total mammals of the Sus scrofa species (pigs and sows), regardless of sex, age or purpose of production.	5.0	30.00	12,5 (18,7)	60	ONS (2003; 2005) SUDERHSA (2006)
Bubaline	Total mammals of the Buballus buballis species, regardless of sex, age or purpose (meat or milk).	30.0	90.00	50.0	80	ONS (2003; 2005)
Equine	Total mammals of the Equus caballus species (horses, mares, foals).	20.0	60.00	40.0	80	ANA (2013) / SUDENE (1980)
Ovine	Total mammals of the Ovis Aries species (sheep, lambs and rams), irrespective of sex, age or purpose (wool, meat or milk).	5.0	30.00	10.0	80	ONS (2003; 2005)
Caprine	Total mammals of the Capra aegagrus hircus species (goat), regardless of sex, age or purpose (meat or milk).	4.0	30.00	10.0	80	ONS (2003; 2005)
Poultry	Total birds of the Gallus gallus species (fowls, chickens, pullets and chicks).	0.10	0.50	0.18 (0.22)	69	EMBRAPA (2005) SUDERHSA (2006)
Poultry - chicken	Total female birds of the Gallus gallus species intended for egg production, irrespective of the destination of the production (consumption, industrialization or incubation). Includes layers and matrices.	0.10	0.32	0.18 (0.27)	60	EMBRAPA (2005) SUDERHSA (2006)
Quail	Total birds of the Coturnix coturnix species intended for egg production and slaughter, irrespective of sex or age.	-	-	0.18	80	EMBRAPA (2005)

* The technical coefficient presented in brackets considers the adoption of a percentage destined for other animal breeding needs.

These values were taken into account in herds where this additional water use is more relevant, such as in the case of confinement or semi-confinement of chickens, pigs and milked cows. The withdrawal value for animal consumption adding 50% for swine, milked cows and chicken; and 20% for other types of poultry was based on SUDERHSA (2016), the current Water Institute of Paraná.

The second important refinement adopted in the method used for animal supply estimates refers to the extension of the **herd** databases, using not only Census data (five-year or ten-year) but also Municipal Livestock Survey data, including the breakdown of cattle into milked and others.

Table 5 presents a synthesis of the databases used and their temporal and spatial reference. Before 1974, the year when the availability of records becomes annual and municipal, the herds in years without data were estimated by linear interpolation. The breakdown into the municipalities was also necessary because these figures are only released for the country as a whole or by FU.

The breakdown of the data at the municipal level (pre-1973) was carried out considering the same proportions as in 1974, by type of herd, also considering the evolution of the territories over the years (dismemberment or grouping of municipalities).

A synthetic data series on milked cattle was also created for the period before 1974, taking into account the average proportion of this species in the total cattle of the country (12%), a step forward if compared to previous studies, the importance of which is visible in Figure 16. Milked cows account for about 12% of cattle but account for over 25% of the demand.

Table 3 - Comparison of technical coefficient values for bovine animals

Species	EMBRAPA (2005)	NIEA (2009)	DWAF (1996)	OMAFRA (2009)	UKEA (2007)	USGS (2009)	IMASUL (2010)	SUDERHSA (2006)	ANA (2013)
Bovine cattle	34.3 [1]	20	17 to 41	25 to 41	20	45 [2]	55	45	50 [3]
Milked Cows	62	92	38 to 95	115	92	132 [2]	62	53	85 [3]

[1] Average value for beef cattle (up to 250 kg, up to 410 kg and up to 566 kg), cows with calves, dried up cows, and calves.
[2] Average of the observed values.
[3] Average between minimum and maximum value.

Table 4 - Comparison of technical coefficients values for poultry

Species	ÁGUAS-PR (2010)	EMBRAPA (2005)	NIEA (2009)	FAO (2006)	USGS (2009)	ONS (2003)	IMASUL (2010)	ANA (2013)
Poultry - General	0.16	-	0.19 - 1.22	-	-	0.36	0.32	-
Poultry - Chickens	-	0.18	0.20 - 0.22	0.25	0.22	0.36	0.32	0.1 - 0.2
Poultry - Others	-	0.16 - 0.321	0.09 - 0.21	0.33	0.22	0.36	0.32	0.15 - 0.50

[1] Considering the following coefficients: Chickens (0.16), Laying Hens (0.25) and Breeders (0.32)

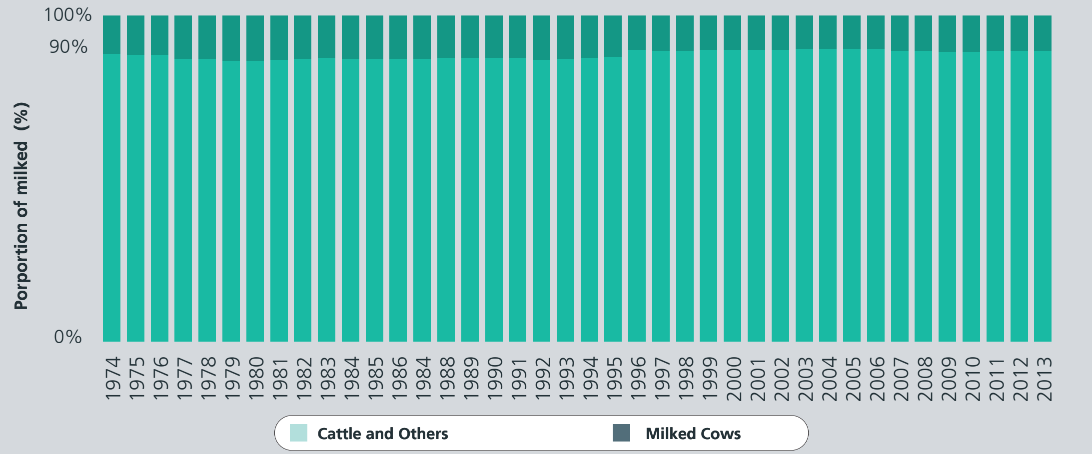


Figure 16 - Proportion of milked cows in the total bovine herd (1974 to 2013)

Table 5 - Database Available referring to the effective herds

Source (IBGE)	Variables[1]	Territorial Unit	Available Period	Period Used
Municipal Survey	(73) Effective of herds, by type of herd	Municipality	1974-2016 (annual)	1974-2016 (annual)
Municipal Survey	(94) Milked Cows	Municipality	1974-2016 (annual)	1974-2016 (annual)
Cattle Census	(281) Number of animals in farming facilities by species of herd	FU	1970, 1975, 1980, 1985, 1995, 2006	1970
Cattle Census	(281) Number of animals in farming facilities by type of herd	Brazil	1920, 1930, 1940, 1950, 1960, 1970, 1975, 1980, 1985, 1995, 2006	1930, 1940, 1950, 1960

[1] Number in brackets indicates the reference of the table in the IBGE Auto Recovery System - SIDRA/IBGE (http://sidra.ibge.gov.br/).

With regard to animal consumption (by drinking), due to the unavailability of other references, it is proposed that the 80% rate adopted in other studies (ANA, 2017; ONS, 2003) be considered. As a result, the return via solid and liquid excrement or via animal perspiration is 20%.

In the case of additional water volumes intended for other animal breeding needs, the consumption x return relationship is reverse (20% x 80%), with the adoption of values typically considered for supply in general (80% return as effluent). Thus, in herds where these volumes are taken into account, the average consumption percentage (drinking+ other needs), is 60% for milked cows, swine, and herd animals and chickens and 69% for other poultry.

Once in possession of the technical coefficients adopted and informed, the withdrawal, consumption and return flows for animal supply were calculated in accordance with equations 6, 7 and 8. The total animal supply flow in the municipality corresponds to the sum of the flows needed by the different herds.

For the projection of municipal herds (2030 horizon), the average rates observed in the short (2006-2014) and medium-term (2000-2014) were initially determined for the 137 mesoregions of Brazil, which were grouped into four types of herds (bovine, swine, poultry and other). Sector and government documents were consulted in the definition of periods and search for additional information (MAPA, 2011; UFMG, 2015; FIESP, 2015).

In relation to livestock specifically (cattle group - others), the trend projections were adjusted to the result of the Amazonian Beef Livestock Scenarios study, carried out by UFMG (2015). The study of water use for animal supply encompasses all the states of the Legal Amazon (AM, PA, RO, TO, MT, AC, AP, MA, RR) - main areas of recent and future expansion of livestock activity and consequently, expansion of water use for animal supply.

Equation 6

$$Q_d = \sum (Herd_{(herd,\ animals)} \bullet q_{\ (herd,\ animals)})$$

Where:

Q_d = animal withdrawal flow for a given municipality (liters.day-1);

Reb = number of animals per species for a given municipality (number of heads);

q = is the animal withdrawal coefficient per day obtained from the matrix of technical coefficients (litres.day-1 per animal species).

Equation 7

$$Q_r = \sum (Q_{d\ (herd,\ animals)} \bullet C_{r\ (herd,\ animals)})$$

Where:

Q_r = animal return flow for a given municipality (liters.day-1);

Q_d = animal withdrawal flow for a given municipality, per herd (liters.day-1);

C_r = coefficient of return for a given animal herd (%).

Equation 8

$$Q_c = Q_d - Q_r$$

Where:

Q_c = consumption flow for animal raising for a given municipality (liters.day-1);

Q_d = animal withdrawal flow for a given municipality (liters.day-1);

Q_r = animal return flow for a given municipality (liters.day-1).

Equation 9

$$Herd_{2030\ (species,\ animals)} = Herd_{year\ 1\ (species,\ animals)} \bullet (tx_{group,\ mesoregion})^{x\ years}$$

Where:

$Herd_{2030}$ = number of animals of a given species in the municipality in 2030 (number of heads);

$Herd_{year\ 1}$ = number of animals per given species in the municipality in the reference year for the diagnosis (number of heads);

tx = average growth rate of the mesoregion by 4 large groups of herds (bovine, poul try, swine and others) (%).

With a broad and profound approach, the UFMG study drew up three future scenarios for the expansion of herds in the FUs. In order to estimate future water demands, the scenario of higher growth was adopted in each FU. The breakdown of information into mesoregions and municipalities followed the growth trends shown in the PPM/IBGE data.

Following the definition of the rates by mesoregion, the projection of the herds was carried out by corresponding municipality and for each of the four groups of herds, as presented in Equation 9.

3.3 Results

Figure 17 presents the intensity of water use for animal supply in the Brazilian municipalities, and illustrates in which regions the withdrawals predominate by type of herd. One notes the importance of goats and sheep in the Brazilian Semi-Arid region; of poultry and swine in the Central -South region (often under confinement); and of bovines in the states of Rio Grande do Sul, Minas Gerais, Midwestern states and on the agribusiness border in the North region (Pará and Rondônia). In the Southern region and the *Triângulo Mineiro*[1] regions there is greater coexistence of different classes of herds.

Figure 17 also illustrates the current proportion of cattle in total animal supply in the country, where one observes the preponderance of bovine herds in the composition of the demand (88%), followed by swine (5%) and poultry (2%).

The infographic (Figure 18) presents a spatial and graphic synthesis of the results obtained for animal supply (1931-2030). Prospects of herd expansion are observed between 2017 and 2030, causing increased water use in the Legal Amazon region, while the use tends to decrease in several municipalities of the Centre-South region.

The graph (Figure 18) presents the historical withdrawal series, consumption and return flows for the country as a whole. A table presenting the ten municipalities with most relevant withdrawals in 2017 is also presented.

Detailed results can be accessed at www.snirh.gov.br and metadados.ana.gov.br/.

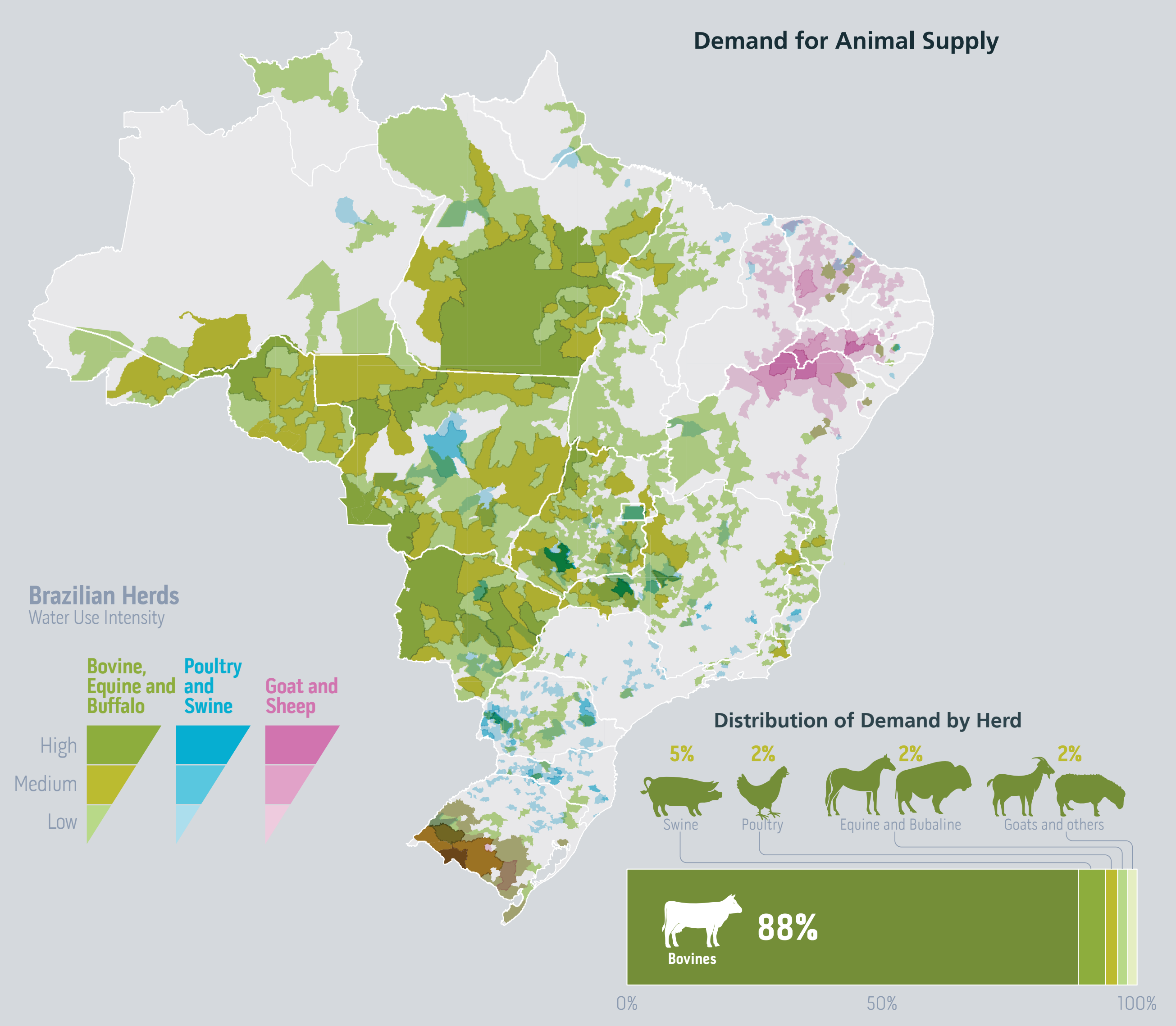
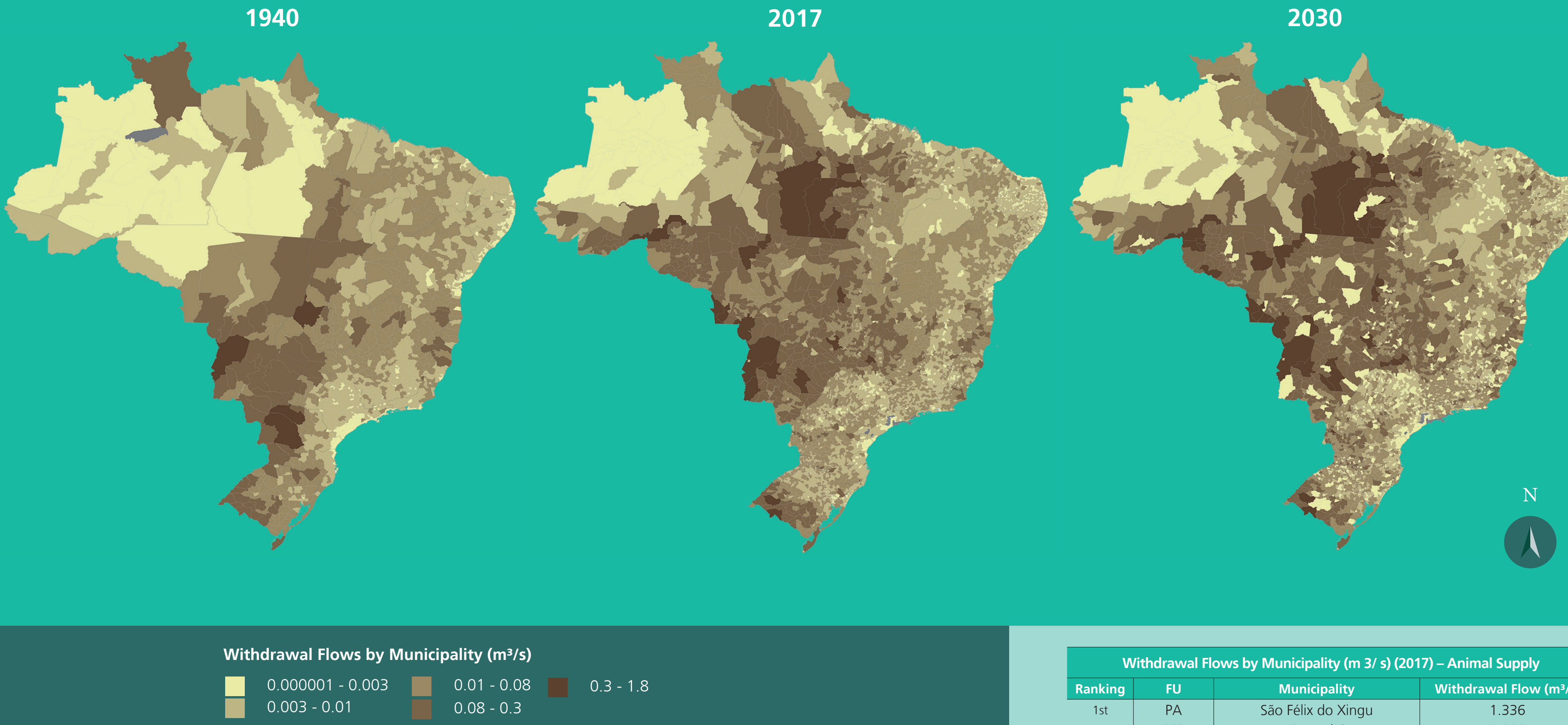


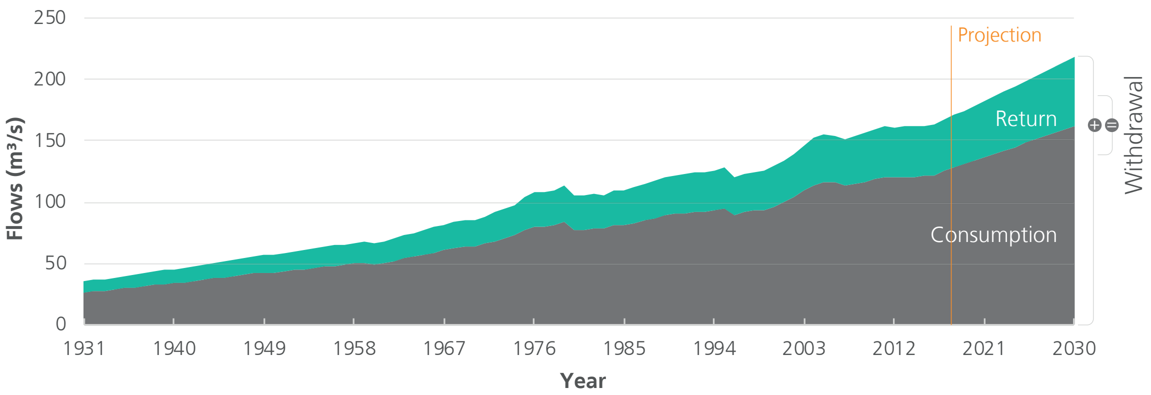
Figure 17 - Intensity of water use by herd group in the municipalities; and proportion of use by herd in Brazil.

Source: adapted from the Situation Report 2017 (ANA, 2017)

1. *The Triângulo Mineiro is one of the three planning regions of the state of Minas Gerais, in the Southeast of Brazil.*

Figure 18 - Synthesis of the Flow Series 1931 to 2030 – Animal Supply





Withdrawal Flows by Municipality (m 3/ s) (2017) – Animal Supply			
Ranking	FU	Municipality	Withdrawal Flow (m³/s)
1st	PA	São Félix do Xingu	1.336
2nd	MS	Corumbá	1.080
3rd	MT	Cáceres	0.679
4th	PA	Marabá	0.674
5th	MS	Ribas do Rio Pardo	0.666
6th	MT	Vila Bela da Santíssima Trindade	0.619
7th	PA	Novo Repartimento	0.608
8th	MT	Juara	0.592
9th	RO	Porto Velho	0.575
10th	PA	Cumaru do Norte	0.487

Even though Corumbá/MS and Félix do Xingu/PA stand out with the highest demands, reflecting the high concentration of bovine herds in these areas, the use of water for animal supply is dispersed throughout the national territory. However, the concentration in Mato Grosso, Mato Grosso do Sul, Rondônia and Pará is noticed, as well as in the traditional production pole of the state of Rio Grande do Sul.

Detailed results of the historical series of consumptive uses for all municipalities can be accessed at www.snirh.gov.br/usos-da-agua.

4 PROCESSING INDUSTRY

Paper industry in Mogi Guaçu (SP)
Raylton Alves / ANA Image Bank

4.1 Introduction

Brazil is one of the most industrialized countries in the world. The industry sector was responsible for the generation of 1.3 trillion BRL in foreign currency (22.7% of the Brazilian GDP), 40% of exports and 10 million jobs in 512,436 companies in 2015 (CNI, 2017). The intensification and maturity of the sector means that Brazil has a huge and varied industrial park that produces from consumer goods (such as food and clothing) to state-of-the-art technology.

Water has a wide variety of applications in the industrial sector, depending on the type of product or service, and the associated processes. It can be applied as a raw material; as solid, liquid and gaseous reagent and solvent; for washing and retaining materials contained in mixtures; as a suspension vehicle; and for operations involving cooling and heat transmission.

Historically, great effort has been made in estimating water use in the industrial sector. With the scarcity of measurement inventories, indirect estimates appear as a necessary alternative. In this study, the availability of microdata on workers in the industry motivated the construction of a matrix of technical coefficients that expresses the water use relations in the different typologies analyzed.

ANA has focused on analyses related to the processing industry, aware of the challenge related to the characterization of demand in the sector. The recent document *Water in Industry: Use and Technical Coefficients* (ANA, 2017), available at http://goo.gl/LtuwxL, details the methodology employed and the results achieved, which are the same applied in this study. This chapter presents an overview and a summary of the main aspects considered in the retrospective, current, and future analyses.

Considering the large volumes of water used in industrial activity, Figure 19 illustrates the variations in withdrawal flows between federal units in 2017. The state of São Paulo stands out, with withdrawal flows of 57.9 m³/s, which corresponds to about 30% of the country total (189.2 m³/s).

As a reference for the withdrawal variations in the Brazilian regions, Figure 20 presents the participation of these regions in the whole country.

4.2 Method and Database

The flowchart (Figure 21) provides a synthesis of the method and the databases used for estimating water use in the processing industry.

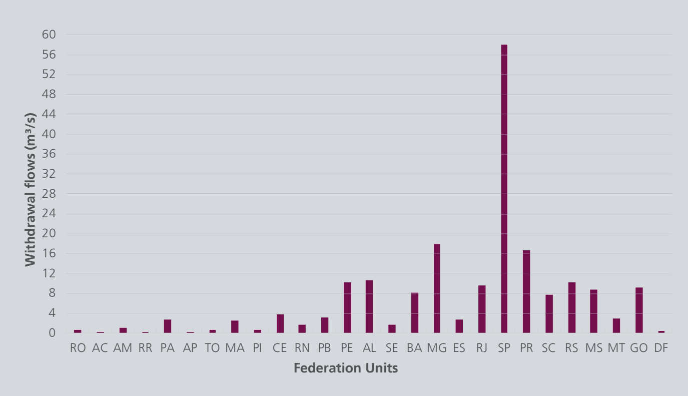


Figure 19 - Withdrawal Flows (m³/s) for the Industry Sectors in the FUs

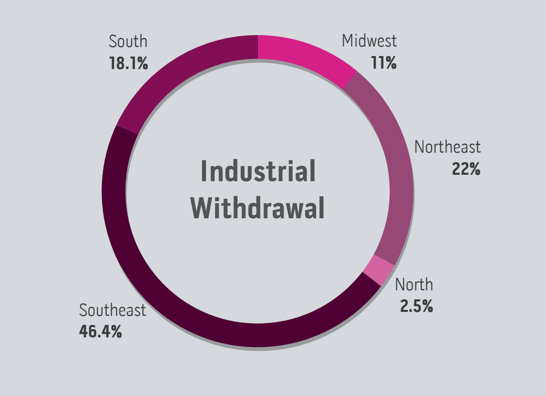


Figure 20 - Withdrawal Percentages for the Industry Sector in Relation to Total Withdrawal in Each Region

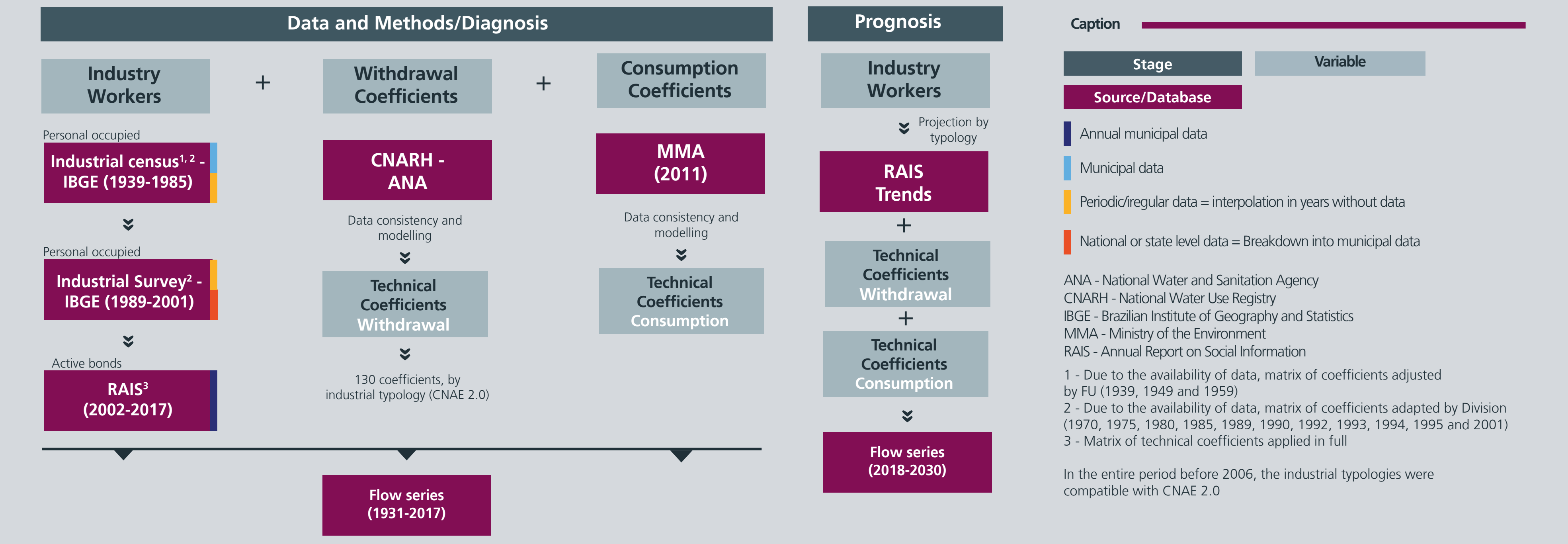


Figure 21 - Summary of the Method for Estimating Flows Associated with the Industry Sector

The method for estimating water use in the processing industry consists of the application of **technical coefficients** (average flows per employee per Industrial typology) to the **number of workers** in a specific typology and municipality. The main challenges of the method relate to the consistency and compatibility of databases with the number of workers and the obtaining and validation of technical withdrawal and consumption coefficients.

The proposed method was based on the availability of employee numbers by industrial typology over the decades. The number of employees is associated to a matrix of technical coefficients that indicates the average amount of water that processes linked to an industrial typology demand. The total demand in the municipality corresponds to the sum of the different typologies (equations 10, 11 and 12). This type of approach has been adopted in several applications in Brazil and in the world, as analyzed by ANA (2017).

For the construction of the matrix of **technical withdrawal coefficients**, data from the National Network of Water Users - CNARH/ANA, which includes users of federal and state water resources, were analyzed and made consistent. The analyses and modelling carried out are detailed in ANA (2017).

In the consideration of typologies, the National Classification of Economic Activities - CNAE 2.0 was adopted, which has 24 divisions for the processing industry (codes 10 to 33), 103 groups and 258 classes. Coefficients in the most detailed hierarchical level were sought, considering the number of records available, their variability, and representativeness. When this detailing was not possible, the coefficient of the respective group and, ultimately, of the division, was considered.

101 technical coefficients were obtained in this study according to the CNAE 2.0. class hierarchy. This means that coefficients were obtained for 40% of the classes, representing about 85% of the water supply. In the other classes (15% of the demand) single coefficients were obtained for the respective group or division.

Considering the average withdrawal value obtained, grouped by CNAE 2.0 Division, good coherence is observed in terms of magnitude, with national and international studies consulted (Figure 22). The complete matrix is available at www.snirh.gov.br/usos-da-agua.

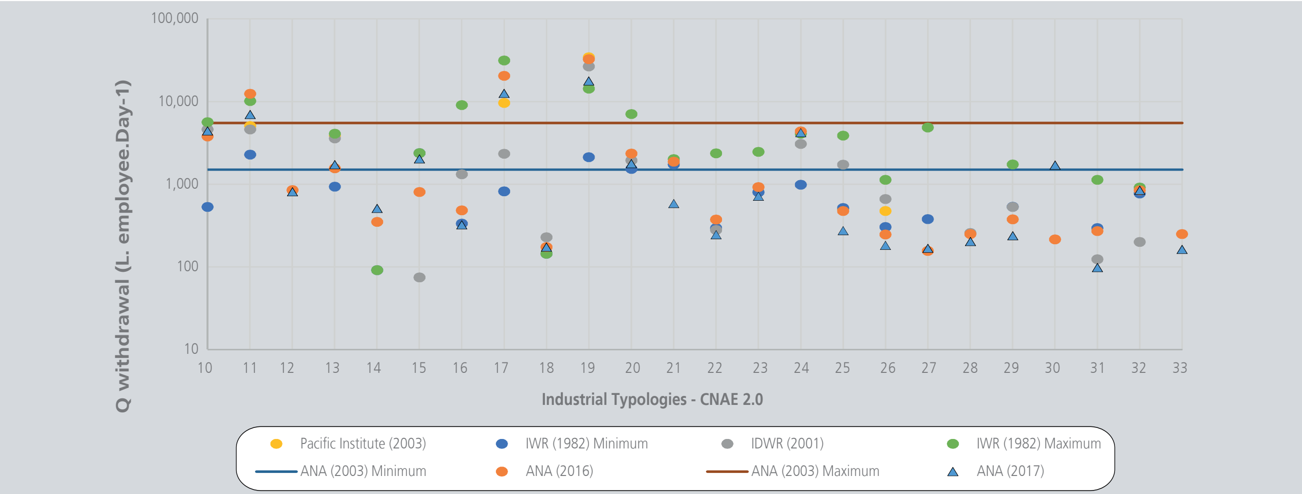


Figure 22 - Comparison of the technical withdrawal coefficients for the industrial sector by CNAE 2.0 division.

Equation 10

$$Q_{wit} = \sum \left(E_{(typology,\ workers)} \cdot k_{r\ (typology,\ workers)}\right)$$

Where:

Q_{wit} = withdrawal flow from the processing industry in the municipality

E = umber of employees by industrial typology for a given municipality;

k_r = Withdrawal coefficient by industrial typology (liters.n° of employees.day-¹).

The consumption flow was estimated by Equation 11:

Equation 11

$$Q_{Cons} = \sum \left(Q_{wit\ (tipology)} \cdot k_{c\ (tipology,\ workers)}\right)$$

Where:

Q_{Cons} = total consumption flow in urban area (m³/s);

Q_{wit} = withdrawal flow from the processing industry for a given typology in the municipality

k_c = consumption coefficient (%).

The municipal return flow was defined by the difference between withdrawal and consumption according to Equation 12:

Equation 12

$$Q_{return} = Q_{wit} - Q_{Cons}$$

Table 6 - Matrix of Technical Coefficients Agregated to Estimate the Water Demands of the Brazilian Industrial Sector			
CNAE 2.0	Industrial typology	Technical Coefficients*	
		Withdrawal (L/employee/Day)	Consumption (%)
10	Manufacturing of food products	4,600	75.9%
11	Manufacturing of beverages	8,713	24.4%
12	Manufacturing of tobacco products	811	20.0%
13	Manufacturing of textile products	1,873	22.5%
14	Manufacturing of apparel and acessories	510	18.5%
15	Preparation of leather and manufacturing of leather articles, travel articles, and footwear	2,027	15.9%
16	Manufacturing of wooden products	344	24.3%
17	Manufacturing of celulose, paper and paper products	8,865	16.6%
18	Printing and engraving	173	18.8%
19	Manufacturing of coke, petroleum products and biofuels	18,147	85.0%
20	Manufacturing of chemicals	1,715	34.4%
21	Manufacturing of pharma-chemical and pharmaceutical products	529	20.0%
22	Manufacturing of rubber and plastic products	248	20.8%
23	Manufacturing of non-metallic mineral products	676	46.5%
24	Metallurgy	3,781	24.3%
25	Manufacturing of metal products, except machinery and equipment	281	46.8%
26	Manufacturing of computer equipment, electronic and optical products	182	20.0%
27	Manufacturing of electrical machinery and equipment	167	20.0%
28	Manufacturing of machinery and equipment	203	18.9%
29	Manufacturing of automotive vehicles, lows and automotive body parts	235	29.4%
30	Manufacturing of other transportation equipment, except automotive vehicles	1,270	19.8%
31	Manufacturing furniture	98	20.0%
32	Manufacturing other products	842	20.0%
33	Maintenance, repair and installation of machinery and equipment	162	20.0%

*The average coefficients by CNAE 2.0 Division were estimated from the sum of the flow and the number of employees of the respective classes.

This value may show inter annual fluctuations depending on the different proportion of classes in the Division total. The complete matrix is available at www.snirh.gov.br/usos-da-agua.

Table 6 shows the average coefficients grouped by CNAE 2.0 Division. It should be noted that the methodology employed uses roughly 130 coefficients, the results of which are a grouping of the respective classes and groups in the 24 divisions of the processing industry.

The **technical consumption coefficients** for industrial typologies are based on a study carried out by the Ministry of Environment (Brasil, 2011). Although the matrix uses the production volume, and not the number of employees as an explanatory variable for water demand, the proportionality factors between the withdrawal and consumption coefficients (%) were adopted, since these values were proposed and validated with the participation of the industrial sector. For divisions 27, 31, 32 and 33 a 20% consumption was adopted, based on ANA (2013), due to the unavailability of data. The average consumption coefficients by division are also shown in Table 6.

It is observed that higher withdrawal and consumption coefficients indicate greater intensity of use in relation to the number of employees, but do not necessarily represent more hydro-intensive sectors. That is, there are activities where the coefficient is high simply because they are less labor-intensive, with low impact on total demand.

As for the databases on the **number of workers**, it should be noted that from 2002 onwards, the census information contained in the Annual Report on Social Information (RAIS) is available, which is compatible with the matrix of coefficients prepared. RAIS microdata is made available by the Ministry of Labor at http://pdet.mte.gov.br/microdados-rais-e-caged/.

For the industrial Censuses and Annual Industrial Surveys (before 2002), the databases had to be converted, filled in and disaggregated, depending on the case. In census years, the manual typing of about 80,000 records from booklets published by IBGE was carried out. In the case of PIAs (IBGE, 2016a), the data is made available at the IBGE Auto Recovery System - SIDRA (http://sidra.ibge.gov.br).

The technical coefficients in the period prior to RAIS were grouped into the hierarchy and scale for which the data was available.

In the 1939, 1949 and 1959 Industrial Censuses, only the total number of workers in the processing industry per municipality was used, without distinction of typology. One opted to produce a coefficient matrix by FU, considering the weight of the different industrial typologies present in the FU in 1970 (first year with data by typology), since the generic national coefficients would cause greater distortions in the estimates.

In the subsequent Censuses (1970-1985) and in the Annual Industrial Surveys - PIA (1989-2001) the data already presented industrial typologies, but in aggregate form (Division), without the current level of detail. In these cases, specific coefficients were adopted by the industry Division and adapted to the data hierarchy.

Additionally, due to the distinct conceptualization between Censuses and PIAs, which consider "occupied personnel" related to production and RAIS, which considers a more comprehensive concept (active bonds), it was necessary to make the matrix compatible by division for application in the pre-2002 period. For this purpose, a correction factor by industrial typology was applied between total occupied personnel and occupied personnel related to production observed in the PIAs carried out between 1966 and 1995.

Even in the years in which the PIA was adopted (1989-2001) it was necessary to breakdown data provided by FU or for the country as a whole into municipal data. This was achieved through the use of the proportions observed in the 2002 RAIS.

Moreover, in the pre-2002 period, surveys show irregular temporality, and the linear interpolation of the number of employees in years without information was necessary.

Lastly, the industry classification systems have evolved over the decades in which these different databases were generated, and all these systems had to be converted to the CNAE 2.0 classification. The conversion was necessary even for the most recent database (RAIS) between 2002 and 2005, when CNAE 1.0 was used.

The industrial water use projections were based on the same method for the current situation, the active bonds were projected and the same diagnosis coefficients were applied.

In the short-term, which corresponds to the first two years of the projection, the conjunctural indexes were nationally applied by Division for the Monthly Industrial Employment and Salary Survey (PIMES). These indexes reflect the recent downturn in industrial activity, not captured by other indicators.

In the other years, the average growth rate observed in the short (2008-2013) and medium-term (2002-2013) was used. The rates were calculated for the 137 Brazilian mesoregions, using a predominantly rural (Divisions 10, 16 and 17) and predominantly urban (other Divisions) grouping of industrial typologies. These rates were applied to the corresponding municipalities.

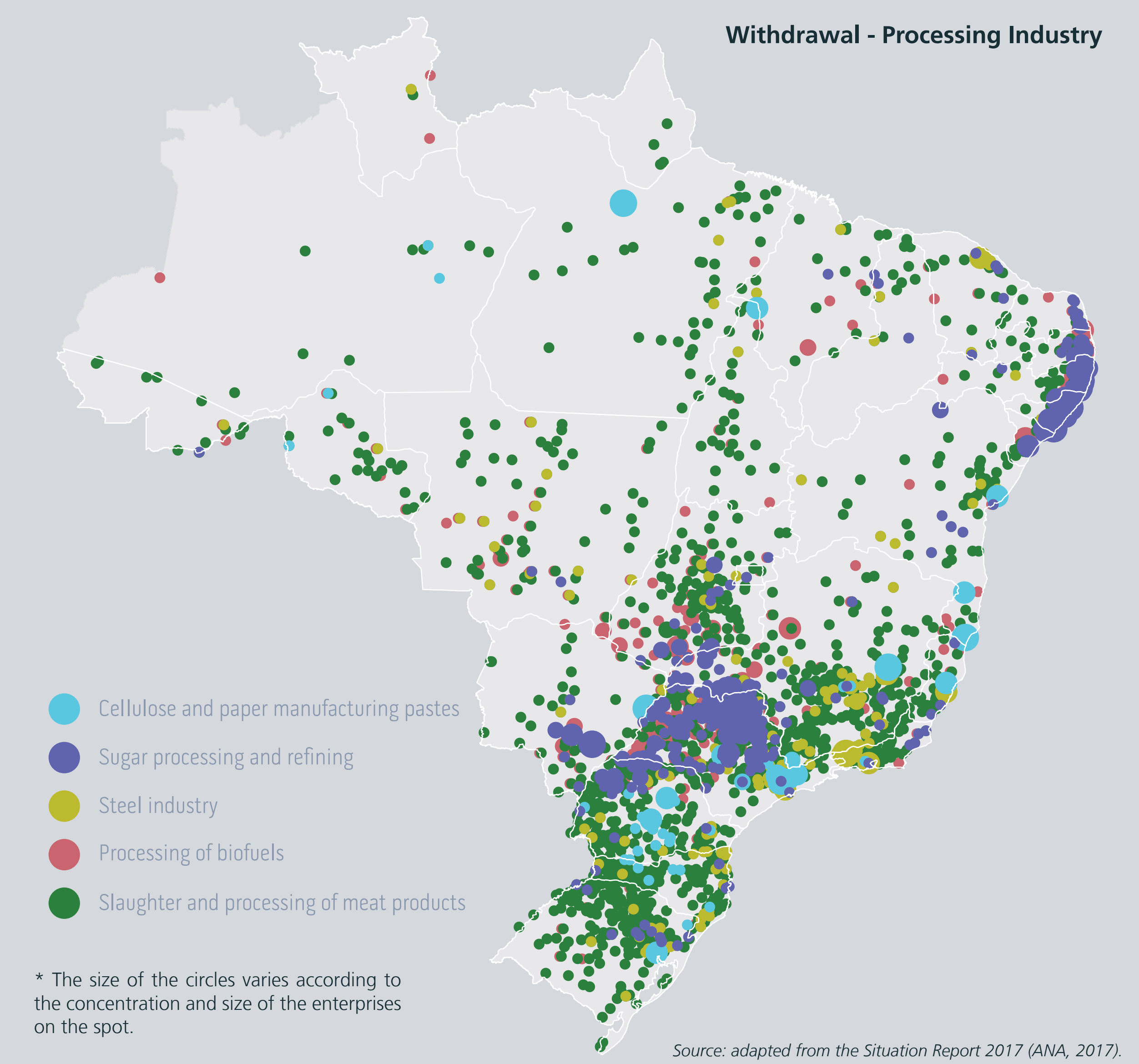
4.3 Results

Figure 23 presents the water use intensity for the main Groups in the processing industry. The food; beverages; cellulose, paper and paper products; oil and biofuels; chemicals; and metallurgical industries correspond to about 85% of the withdrawal demand and 90% of the consumption in Brazil (Figure 24).

The largest concentration of processing industries in Brazil is in the Southeast region, mainly in the states of São Paulo, Rio de Janeiro and Minas Gerais. There are diversified industrial parks in the Southeast region, with emphasis on the chemical, steel and automobile industries. In the Southern Region, the second most industrially developed region in Brazil, agroindustry that focuses on the processing and transformation of primary products stands out. The industrial activity profile of the Northeast region is mainly linked to textile production and the sugar/alcohol sector. The North and the Midwest regions have lower industrial concentration, but with the predominance of agroindustry, an important water consumer, which may affect the local water balance.

The infographic (Figure 25) provides a spatial and graphic representation of the results obtained for the industrial sector in the analysis period (1931-2030), totaling 189.2 m^3/s in 2017. The graph presents the historical series for withdrawal, consumption and return flows in m^3/s across the country. A table ranking the ten municipalities with the largest withdrawal flows is also presented.

Detailed results can be accessed at www.snirh.gov.br and metadados.ana.gov.br/.



Source: adapted from the Situation Report 2017 (ANA, 2017).

Figure 23- Water use intensity of the main industry groups (CNAE 2.0).

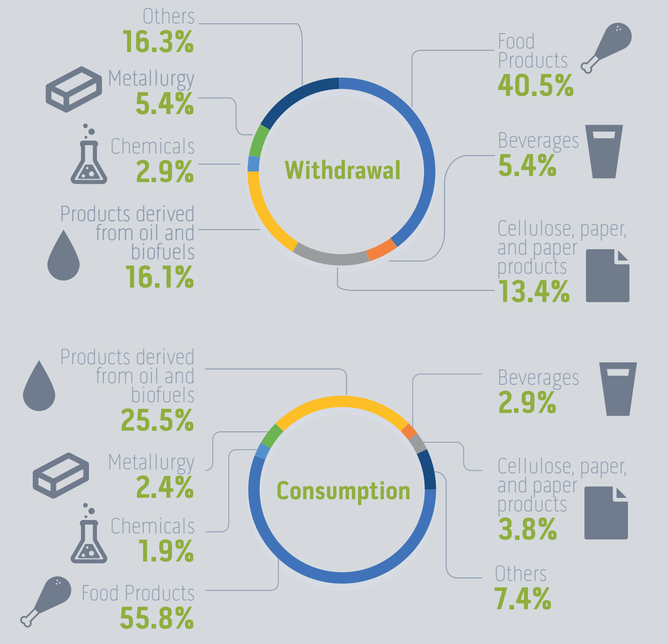
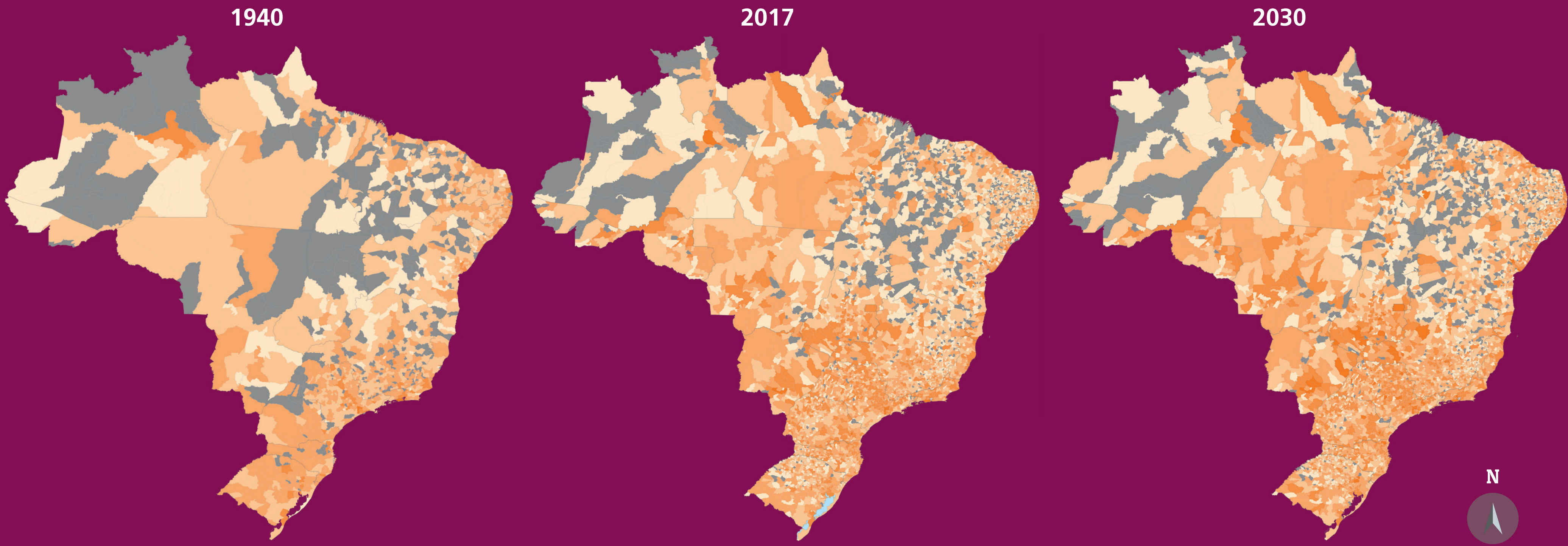


Figure 24 - Distribution of demands by industrial typology (withdrawal and consumption)

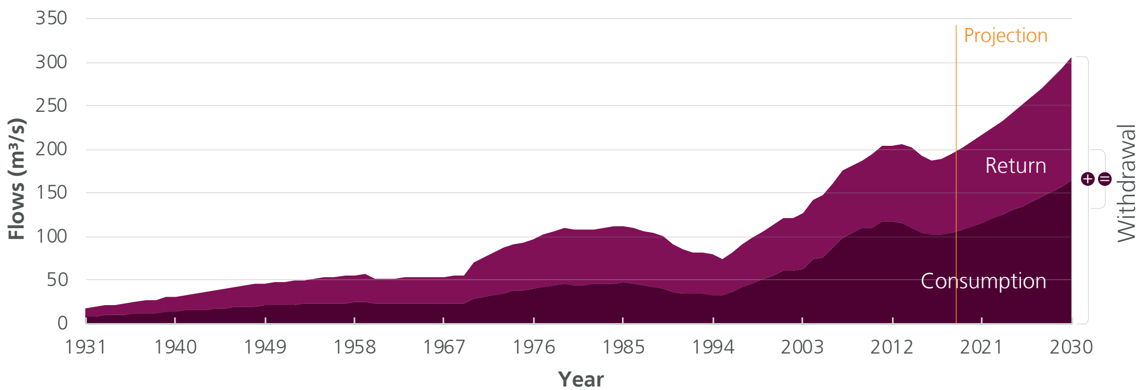
Source: adapted from the Situation Report 2017 (ANA, 2017).

Figure 25 - Withdrawal Flows 1931 to 2030 – Processing Industry



Withdrawal Flows by Municipality (m³/s)

- 0.000001 - 0.0003
- 0.0003 - 0.005
- 0.005 - 0.08
- 0.08 - 1.2
- 1.2 - 18.6



Larger withdrawal flows (m³/s) per municipality (2017) - Processing Industry			
Ranking	**FU**	**Municipality**	**Withdrawal Flow (m³/s)**
1st	SP	São Paulo	4.965
2nd	RJ	Rio de Janeiro	4.806
3rd	MS	Três Lagoas	3.244
4th	BA	Mucuri	1.921
5th	AL	Rio Largo	1.569
6th	PR	Telêmaco Borba	1.564
7th	AL	Coruripe	1.410
8th	RJ	Volta Redonda	1.351
9th	BA	Camaçari	1.345
10th	SP	Sertãozinho	1.328

The leadership of the municipalities of Rio de Janeiro (RJ) and São Paulo (SP) is highlighted in the withdrawal flow for industrial use. Other capital cities and neighboring municipalities with agro-industrial hydro-intensive poles (paper, celulose, steel, sugar and etanol, etc.).

Detailed results of historical series of consumptive uses for all municipalities can be accessed at www.snirh.gov.br/usos-da-agua.

Mining in Serrana (SP)
Raylton Alves – Image Bank/ANA

5.1 Introduction

The mining industry covers the extraction processes of mineral substances. Brazil is among the world's largest producers of various substances, such as iron ore (3rd in the *ranking*), bauxite and alumina (3rd), niobium (1st) and phosphate (5th).

Mining demands expressive volumes of water, nationally representing 1.6 of the withdrawal. The withdrawal volume is equivalent to the volume that supplies the entire rural population in Brazil, and the mining industry is characterized by its strong territorial concentration, notably in some municipalities in the states of Minas Gerais and Pará.

Previous studies (such as ONS, 2003; 2005) used coefficients related to the value of mineral extraction production, with parameters of 0.132 m³ (withdrawal) and 0.106 m³ (return) of water for each U.S. dollar produced.

The current method uses effective mineral production data, by type or group of substance, associated with specific technical coefficients (volume of water required to produce one ton, according to the typology). This approach provides a high level of accuracy for the estimates and allows for a more detailed analysis of the use of water by the extractive industry.

Considering the large amounts of water used in mining activity, Figure 26 illustrates the variation of withdrawal flows in the federal units. In addition to the outstanding leadership of the states of Minas Gerais (53%) and Pará (28% of the total), the demand is also greater in the South region and in the states of São Paulo, Mato Grosso do Sul, Goiás and Bahia.

Figure 27 shows the respective withdrawal percentage by region.

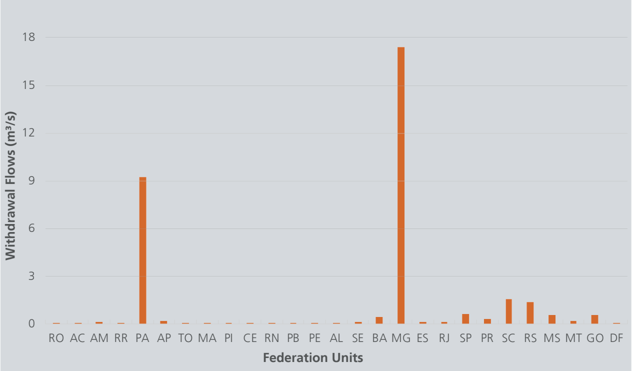
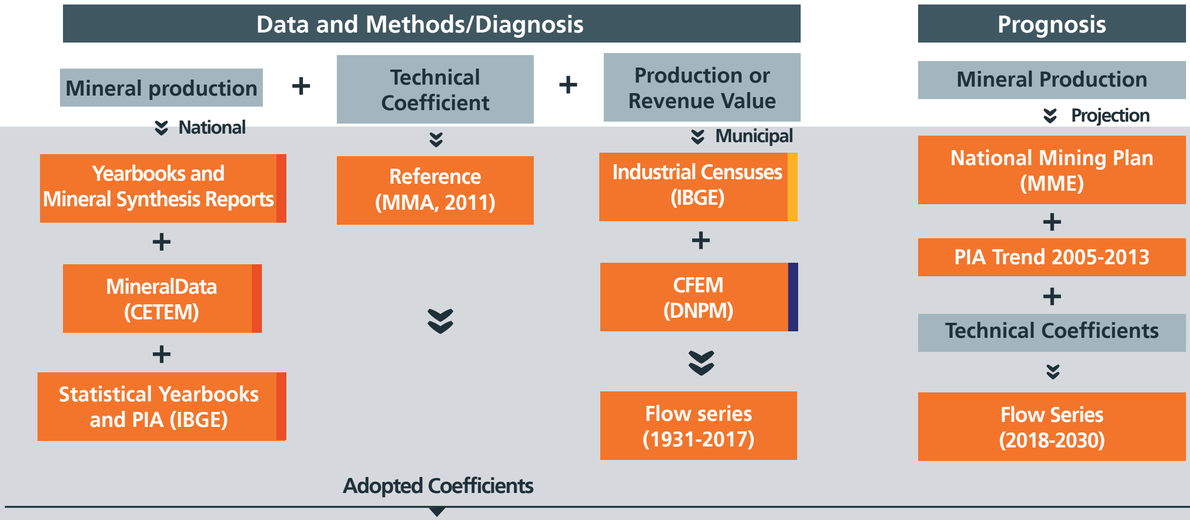


Figure 26 - Withdrawal Flows (m³/s) for the Mining Sector in the FUs.

Figure 27 – Water Withdrawal Percentages (Mining), by Region, in Relation to Total Withdrawal.

5.2 Method and Database

The flowchart (Figure 28) provides a synthesis of the method used for estimating flows associated with the mining industry.



Mineral Substance	Withdrawal (m³/t)	Consumption (%)
Coal mineral	6.5	20
Iron ore	1.05	17
Non-ferrous metallic minerals		
Aluminum ore	3.42	85
Tin ore	6.25	20
Manganese	6.25	20
Precious metal ores	1.64	8.6
Non-ferrous metal ore - others	1.86	85
Non-mettalic minerals		
Extraction of stone, sand and clay	0.04	25
Extraction of minerals for the manufacturing of fertilizers and other chemical products	15.55	23
Extraction and refining of marine salt and rock salt	6.25	20
Extraction of non-metallic	6.25	20

Caption

Stage

Variable

Source/Database

Annual municipal data = no further processing

Data on a national scale = Disaggregation by municipal base

Periodic/irregular data = linear interpolation in the years with no data

ANA - National Water and Sanitation Agency

CETEM - Mineral technology Center

CFEM - Financial Compensation for the Exploitation of Mineral Resources

DNPM - National Department of Mineral production

IBGE - Brazilian Institute of Geography and Statistics

MMA -Ministry of the Environment

MME - Ministry of Mines and Energy

PIA - Annual Industrial Production

Figure 28 - Summary of the Method for Estimating Flows Associated with the Mining Industry

The calculation method combines **mineral production** (tons/year), by type or group of substance, with **technical coefficients** (average water volume required to produce each ton). Considering the importance and representativeness of this information, four groups of ores were defined: mineral coal, iron ore, non-ferrous metal minerals and non-metallic minerals. Most of the current demand for non-ferrous metals corresponds to the production of aluminum and its concentrates (bauxite); and the demand for non-metallic minerals mostly corresponds to the manufacture of fertilizers, and other chemical products.

The historical series of **mineral production** volume are only available for the country as a whole. For the period before 2005, data from Mineral Data (http://mineraldata.cetem.gov.br/), maintained by the Mineral Technology Center (CETEM) was used. The main mineral data sources are the Brazilian Mineral Yearbook and the Brazilian Mineral Synthesis Reports, which have published data since 1972 and 1981 respectively. Data prior to the 1980s was obtained from IBGE[1] publications (since 1940) or, in the case of iron ore, the Brazilian Mineral Balance (DNPM since 1930). From 2005 on, production data from the Annual Industrial Survey - PIA is preferably used (IBGE, 2016b).

In order to breakdown the national production into municipal data, auxiliary series of mineral activity data were used such as the mineral production value series from Industrial Censuses (ten-year or five-year), from 1940 to 1985; and, from 2004 onwards, municipal revenue series from CFEM - Financial Compensation for the Exploration of Mineral Resources (DNPM).

[1] Data for the years 1940, 1950, 1970, 1975 and 1985 was obtained from the following publications:

Statistical Yearbook of Brazil 1960; Brazil: Retrospective Statistical Series 1977; and Statistical Yearbook of Brazil 1989.

The municipal breakdown of demands also considered the analysis of georeferenced data from mining pits, made available by the DNPM. The analysis also found that the production of iron ore is distributed throughout municipalities in the states of Amazonas, Amapá, Bahia, Ceará, Goiás, Minas Gerais, Mato Grosso, Mato Grosso do Sul, Pará, Pernambuco, Piauí, Rio Grande do Norte, Sergipe and São Paulo. The production of mineral coal is concentrated in the states of Paraná, Santa Catarina, and Rio Grande do Sul. In these two categories, which account for most of the demand, the municipal breakdown of the national production was only carried out in the respective producer states identified.

Given the concentration of large mineral activity in a few municipalities, the use of secondary data for the disaggregation of mineral production, employing the adopted criteria, results in an important detailing of the territorial allocation of demands. The global calculation using units effectively produced represents another important gain in detailing of sectoral estimates.

It should be noted that in years without data, with omitted data or with data gaps, the mineral production or production values were filled in based on another available source or were linearly interpolated between years with data.

The **technical coefficients** of withdrawal and consumption used to estimate the water demands of the mineral sector are based on a study carried out by the Ministry of the Environment (Brasil, 2011) (Figure 28). This study counted on the participation of the sector. An analysis of the most recent studies did not indicate the need for a revision of the coefficients.

In addition to the different withdrawal values (m³/t) the variation in average consumption is also highlighted: from 8.6% of withdrawal (precious metals) reaching up to 85% (aluminum) (Figure 28). Considering the participation of different typologies, the global average consumption for the activity is 30% of the withdrawal.

Once the information on mineral production (ton per mineral class) and the technical coefficients were adopted (m³ of water per ton), the withdrawal (Q_{Min}), consumption and return flows were calculated in accordance with the equations below:

Equation 13

$$Q_{Min} = \sum_{i-1}^{n} (P_{min} * k_r)$$

Where:

Q_{Min} = the total withdrawal flow for mining (m³/year); 1 year = 31,536,000 seconds;

P_{min} = is the amount produced of a specific mineral class per municipality in the year (t);

k_r = is the withdrawal coefficient per mineral class (m³.t).

The consumption flow was obtained by

Equation 14

$$Q_{Min.cons} = \sum_{i-1}^{n} (Q_{Min.class} * k_c)$$

Em que:

$Q_{Min.cons}$ = total consumption flow in the municipality (m³/s);

k_c = the consumption coefficient per mineral class (%).

The return flow was calculated by the difference between withdrawal and consumption:

Equation 15

$$Q_{Min.return} = Q_{Min} - Q_{Min.cons}$$

The main reference for the sectoral study that addresses the future perspectives for the mining sector is the National Mining Plan 2030 (Brasil, 2011), in which growth rates were defined for various mining classes for the near (2022) and distant future (2030).

The projection of GDP growth at 5.1% per year, in addition to the historical production of each mineral substance and contexts that could influence the projection, were considered as references for the definition of the National Mining Plan's growth rates of mineral production. However, the economic context used as a premise was quite optimistic and is incompatible with the series recorded after the National Mining Plan was published.

Therefore, in order to consider a more realistic projection, the simple averages between the growth context established in the Plan and the recent mineral production trend (2005-2013) observed in the PIA (IBGE, 2016b) were applied.

5.3 Results

The series of withdrawal, consumption and return flows (1931-2030) for the country are presented in the Infographic (Figure 29). The demands are currently concentrated in the states of Minas Gerais (53%) and Pará (28%), accounting for over 85% of the withdrawal, totaling 26.6 m³/s. The total extracted by the sector in 2017 was 32.9 m³/s.

The graph (Figure 29) shows that significant increases in withdrawal flows have occurred from the 1970s onwards. Demand doubled between 1970 and 1980 and quadrupled between 1980 and the present day. The recent downturn observed in 2009 was due to the global economic crisis experienced in the period, which had significant impacts in the international iron market. Future projections indicate a growth of up to 75% in mineral extraction flows, which should reach 55 m³/s by 2030.

Table 7 shows in a detailed way the proportion of withdrawal flows in 2016, according to the four mineral substance categories. The great importance of iron ore is observed in the composition of the withdrawal flow. Non-ferrous metal minerals account for most of the consumption demand due to the proportionally higher consumption in relation to the withdrawal, notably because of the expressive aluminum production, which accounts for 80% of the mining production of this class and whose average consumption coefficient is 85% of the withdrawal.

Retailed results can be accessed at www.snirh.gov.br and metadados.ana.gov.br/.

Table 7 - Relative withdrawal and consumption demand by mineral class

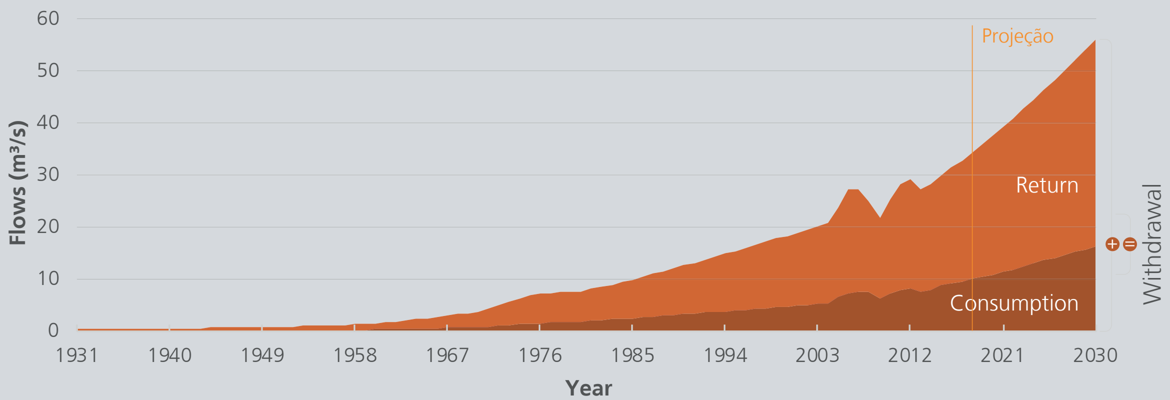
Class	Withdrawal (%)	Consumption (%)
Mineral coal	6.5%	4.8%
Iron ore	49.8%	31.5%
Non-ferrous metal minerals	14.6%	40.0%
Non-metallic minerals	29.1%	23.7%

**Deactivated mining area in Ritápolis (MG), Rio Grande Basin
Raylton Alves / ANA Image Bank**

Figure 29 - Flow Series 1931 to 2030 – Mining Industry

Withdrawal Flows by Municipality (m³/s)

	0.000001 - 0.2
	0.2 - 1.4
	1.4 - 3.4
	3.4 - 5.4
	5.4 - 15.7
	no demand



Larger withdrawal flows (m³/s) per municipality (2017) – Mining Industry			
Ranking	**FU**	**Municipality**	**Withdrawal Flow (m³/s)**
1st	PA	Parauapebas	7.244
2nd	MG	Mariana	2.967
3rd	MG	Nova Lima	2.448
4th	MG	Congonhas	1.959
5th	MG	Itabira	1.813
6th	MG	Itabirito	1.562
7th	MG	São Gonçalo do Rio Abaixo	1.438
8th	MG	Ouro Preto	1.266
9th	SC	Treviso	0.937
10th	MG	Brumadinho	0.775

The municipalities of Paraupebas (PA), Mariana (MG), and Nova Lima (MG) stand out among the withdrawal flow values for mining. Other municipalities in the state of Minas Gerais presente an average withdrawal superior to 1 m²/s. Treviso, in Santa Catarina, stands out for the production of withdrawal flows, in accordance with the perspectives expressed in the National Mining Plan.

Detailed results of historical series of consumptive uses for all municipalities can be accessed at www.snirh.gov.br/usos-da-agua.

6 IRRIGATED AGRICULTURE

Center pivot in operation in the Alto Rio Paranapanema (SP) region
Raylton Alves / ANA Image Banki

6.1 Introduction

Irrigation is the agricultural practice which uses a range of equipment and techniques to overcome water deficiency to plants totally or partially.

Irrigated agriculture is the largest use of water in Brazil and in the world. The intensification of this activity in Brazil occurred in the 1970s and 1980s and was due to some key factors, namely the expansion of agriculture to regions with unfavorable climatic conditions, government stimuli for regional development, and the benefits observed in the practice combined with the availability of funding. Most of the current irrigated area is private (97%) and the activity is spread out in all the Brazilian territory.

In view of irrigated agriculture's importance in the planning and management of Water Resources, ANA has recently invested in the consolidation of a new technical basis, which had its main results published in the Irrigation *Atlas: Irrigated Water Use* (ANA, 2017). This document is available at http:// atlasirrigacao.ana.gov.br, and further details the situation and prognosis of irrigated areas in Brazil.

This chapter sets forth details of the methodology and explanatory variables used for the generation of the monthly irrigation series in the analysis period (1931-2030) and summarizes its main results.

Considering the great volumes of water used in the irrigation activity, Figure 30 illustrates the variation of withdrawal flows in the federation units in 2017. The state of Rio Grande do Sul stands out with the largest withdrawal flow, with important participation from the traditional cultivation of flooded rice. Minas Gerais and Bahia, which have diversified irrigation, especially center pivots for grain production, also stand out. Figure 31 shows the regional distribution of the estimated demands.

6.2 Method and Database

There are several techniques for calculating water demand for irrigated agriculture; it is more common to use indirect methods based on the water demand for the crop at a given stage of development and at a given location. In this approach, the method is based on the water balance in the irrigated areas, attributing to irrigation the fraction of water required by the crops and not supplied by natural sources (rain and soil). Figure 32 shows a schematic representation of the main processes related to irrigation and the estimate of demands.

This type of estimate simplifies the processes that occur at the interface of agriculture - hydrological cycle, and is divided into three information groups: **climate**, **crops** and **irrigation systems**.

Climate data indicates the potential rainwater supply to plants and the potential evapotranspiration reference of a region. Evapotranspiration comprises both the evaporation of the soil surface and the vegetation as well as the transpiration of the plants.

Each **crop** needs a specific amount of water and this amount also varies at each development stage of the crop. This information is aggregated to calculate the real evapotranspiration of the crop, that is, the necessary supply for its physiological processes in that local climate.

Climate and crop, along with information on **soil type**, help in estimating the availability of water in the soil and the real rainfall (rainwater that the plant can effectively absorb). Irrigation aims to supplement the plant's needs, i.e. it complements what is provided by the other sources (soil and rain).

Finally, it is important to know the **efficiency of the irrigation** system adopted in order to estimate the losses that occur between the volume of water collected and the volume of water used by the plant.

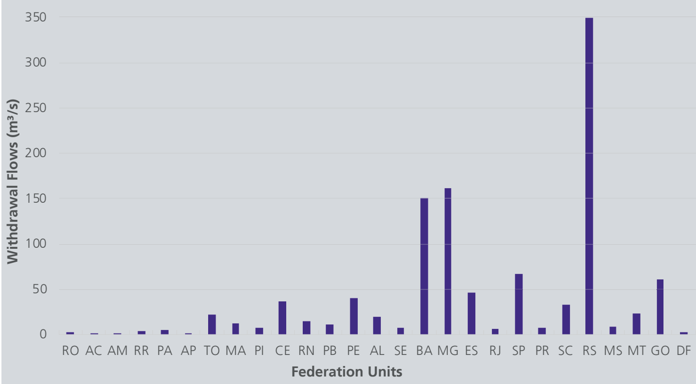


Figure 30 – Withdrawal Flows (m³/s) for Irrigation in the FUs.

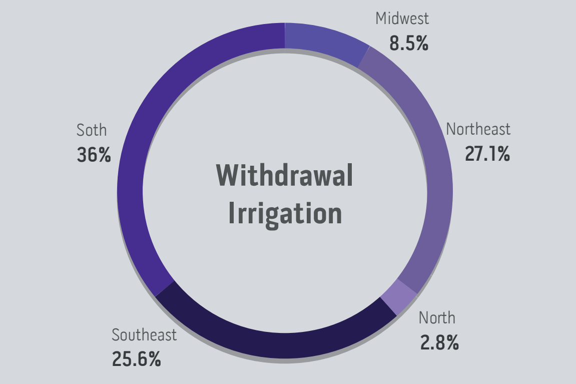


Figure 31 – Withdrawal Percentages for Irrigation in Relation to Total Withdrawal by region.

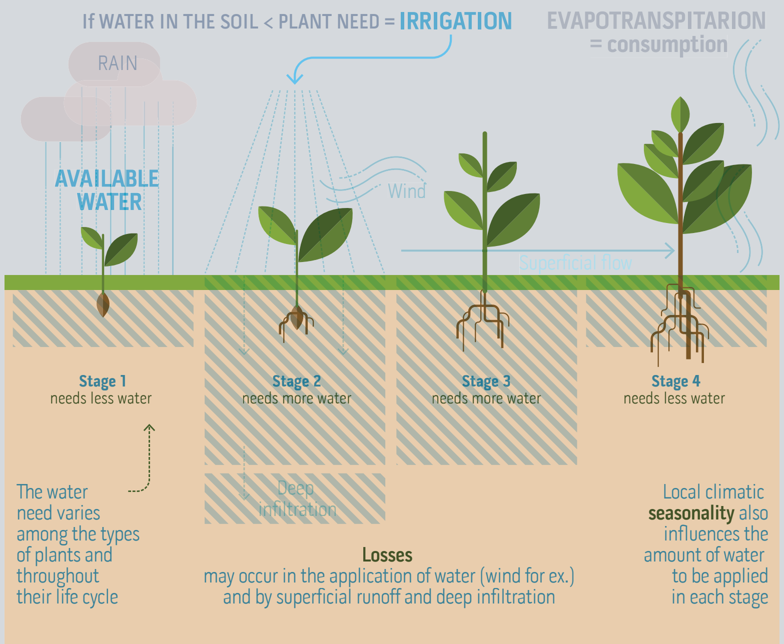


Figure 32 - Flow chart for the Estimate of Flows Demanded by Irrigation.

Source: ANA (2017).

In addition to the general method used for all crops, adaptations in the methodology were proposed for water use related to flooded rice and sugarcane plantations, as discussed in the Irrigation Atlas (ANA, 2017). This method allowed a better characterization of the demands in the two crops with the largest irrigated area in the country.

The flowchart (Figure 33) details the steps for estimating the flows associated with irrigation, which will be further detailed.

The general method requires climatic and crop information in order to ascertain real evapotranspiration and effective rainfall. The characteristics of the crops also include irrigated areas and the cultivation types and cultivation calendars in the municipalities. In turn, the irrigation systems allow us to estimate the efficiency of the water use and therefore the amounts of loss (water withdrawn not used by the plants), as well as the evaporation and dragging losses that are not directly returned to the water bodies.

The monthly withdrawal volume estimated used for irrigation in a certain municipality for a given crop and according to a specific cultivation date, is provided by Equation 16. After estimating the volume destined for a crop (c) in a given month (m) related to a specific harvest date (hd) in a certain municipality (mu), it is necessary to add the volumes destined for irrigation in the month for all cultivation dates of the crop, which is provided by Equation 17. The irrigation return volume in the municipality will be obtained by considering the water use efficiency and evaporation and dragging losses during sprinkler system application, according to Equation 18. The monthly consumption volume of a given crop is obtained by the difference between the withdrawal and return flows (Equation 19). The municipal demand is obtained by the sum of the volumes destined for each culture.

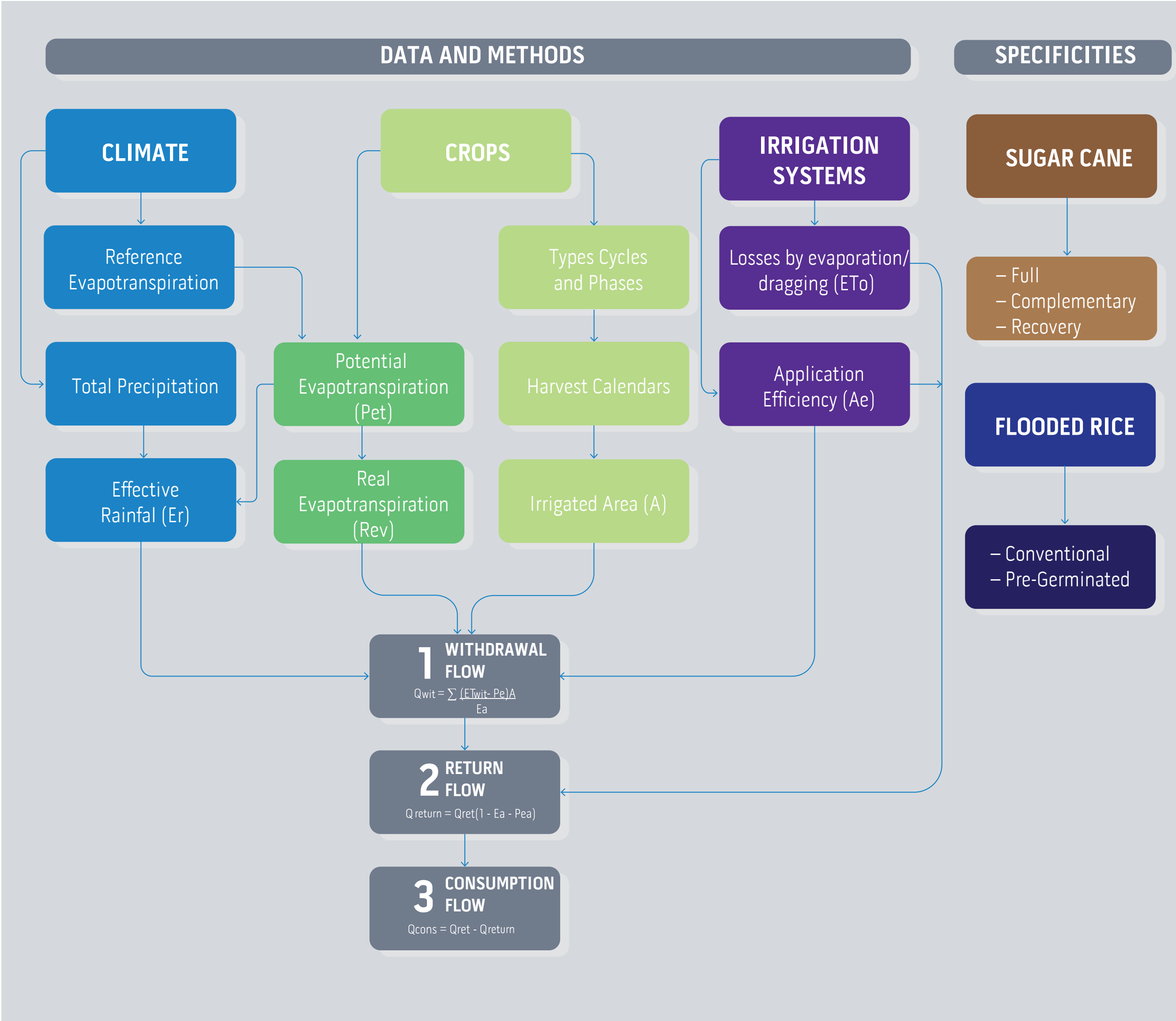


Figure 33 - Flowchart for the Estimation of Flows Demanded by Irrigation.

Equation 16

$$V_{c,m,mu,dc} = \frac{(ETrc_{c,m,mu,dc} - Pef_{c,m,mu,dc}).A_{c,m,mu,dc}.t_{c,m,dc}\ 86400}{Ea_{c,mu}}$$

Where:

$V_{c,m,mu,dc}$ = monthly (m) volume destined for irrigation of a crop (c) and relating to a cultivation date (cd) in a municipality (mu), m³;

$ETrc_{c,m,mu,dc}$ = real evapotranspiration for the crop (c), in the month (m), in the municipality (mu) and for a cultivation date (cd), mm d-1

$Pef_{c,m,mu,dc}$ = real rainfall for the crop (c), in the month (m), in the municipality (mu) and for a cultivation date (cd), mm d-1;

$Ea_{c,mu}$ = irrigation efficiency for the crop (c) in the region where the municipality (mu) is located, dimensionless

$A_{c,m,mu,dc}$ = monthly irrigated area of a given crop (c) in the municipality (mu) and related to a cultivation date, ha; and

$t_{c,mu,dc}$ = length of the crop cycle (c) in the given month (m) and corresponding to a specific cultivation date (cd), days.

Equation 17

$$V_{c,m,mu} = V_{c,m,mu,dc1} + V_{c,m,mu,dc2} + ... + V_{c,m,mu,dcn}$$

Where:

$V_{c,m,mu}$ = volume destined to irrigation of a crop (c) in a given month (m) for a given municipality (mu), m³

$V_{c,m,mu,dc1}$ = monthly volume destined to irrigation for a crop related to a cultivation date 1 for a given municipality, m³;;

$V_{c,m,mu,dc2}$ = monthly volume destined to irrigation for a crop related to a cultivation date 2 for a given municipality, m³; and

$V_{c,m,mu,dcn}$ = monthly volume destined to irrigation for a crop related to a cultivation date "n" for a given municipality, m³.

Equation 18

$$V_{r,m,mu} = V_{c,m,mu} - (V_{c,m,mu}.Pea_{s,c,mu}) - (V_{c,m,mu}.Ea_{c,mu})$$

Where:

$V_{r,m,mu}$ = irrigation return volume to a crop (c) in a given month (m) in a given municipality (mu) in analysis, m³;

$V_{c,m,mu}$ = volume destined to irrigation of a crop (c) in a given month (m) in a given municipality (mu), m³;

$Pea_{s,c,mu}$ = loss by evaporation/dragging of the predominant irrigation system for the crop in the municipality, dimensionless; and

$Ea_{c,mu}$ = irrigation efficiency for the crop (c) in the region where the municipality (mu) is located, dimensionless;

Equation 19

$$V_{cons,m,mu} = V_{c,m,mu} - V_{r,m,mu}$$

Em que:

$V_{cons,m,mu}$ = irrigation consumption volume for a crop (c) in a given month (m) for a given municipality (mu), in analysis, m³;

$V_{c,m,mu}$ = withdrawal volume for irrigation of a crop (c) in a given month (m) for a given municipality (mu), in analysis, m³;

$V_{r,m,mu}$ = irrigation return volume for a crop (c) in a given month (m) in a given municipality (mu), in analysis, m³.

6.2.1 Real Rainfall

In order to determine the monthly average rainfall series, data from the network of stations of the Hydrological Information Database (Hydro/ANA) was used.

10,083 stations with data availability above 60 months (five years) were used (Figure 34). The monthly series of the network of stations were interpolated to a square perimeter covering the entire Brazilian territory. Interpolation was performed considering the availability of data in the perimeter itself and nearby stations, resulting in a series of monthly interpolated data. This monthly series were subsequently extended and/or completed to complete periods without data or with data gaps, between 1931 and 2030, using the monthly average values of the interpolated series in order to preserve the local seasonality characteristics.

For the purpose of calculating irrigation, real rainfall corresponds to the portion of the total rainfall really used by the crop to meet its evapotranspirometric needs. Real rainfall is estimated as a function of water in the soil, of evapotranspiration of the crop and of precipitation, based on a study conducted by the USDA (1970) equation 20.

The average storage factor of water in the soil (SF) was set at 1.0, corresponding to an average storage value of 75 mm. As discussed in the MMA document (Brasil, 2011), variations in storage of the order of 30%, which covers most of the soils under irrigation, would imply corrections in rainfall less than 7%, which is potentially lower than the inaccuracy embedded in the aggregation of monthly values, their extrapolations and interpolations.

Equation 20

$$P_e = SF\ (0{,}70917\ P_t^{0{,}82416} - 0{,}11556)\ .\ (10^{0{,}02426\ ETc})$$

Where:

P_e = monthly average of actual rainfall, mm;

P_t = monthly average of total rainfall, mm;

ET_c = monthly average evapotranspiration of the crop, mm; and

SF = water storage factor in the soil (=1).

6.2.2 Evapotranspiration

In order to determine the real evapotranspiration of the crop, the method requires the calculations of the reference (or potential) evapotranspiration and the potential evapotranspiration of the crop.

Reference evapotranspiration (ETo) is the amount of water to be used on a surface of the soil completely covered with grass in active growth (height between 8 and 15 cm) and without water restriction. The ETo estimate was obtained by the Penman-Monteith-FAO method, according to Equation 21, as described in Allen et al. (1998).

The climatic variables were obtained from the network of conventional and automatic stations of the National Institute of Meteorology (INMET). For this purpose, 524 meteorological stations (261 automatic) were selected (Figure 35). The monthly series of the stations network were interpolated to a square perimeter of 50 x 50 km covering the entire Brazilian territory. Subsequently, this monthly series was extended and/or completed to

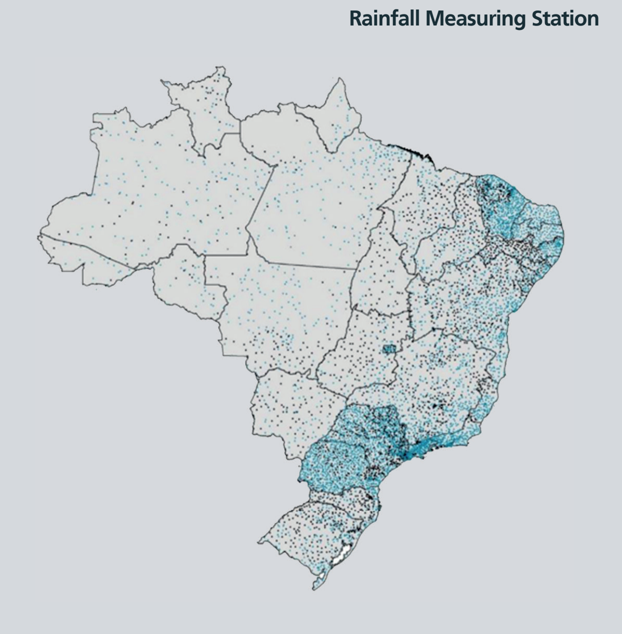


Figure 34 – Network of Rainfall Measuring Stations Used

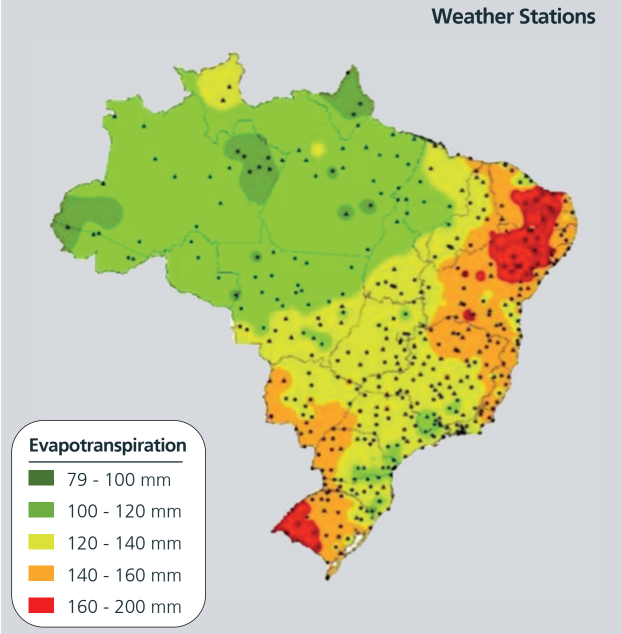


Figure 35 - Monthly Average Evapotranspiration in January

Equation 21

$$ET_0 = \frac{0{,}480\,\Delta\,(R_n - G) + \gamma\,\frac{900}{(T + 273)}\,U_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0{,}34\,U_2)}$$

Where:

ET_0 = reference evapotranspiration, mm d^{-1};

R_n = liquid radiation to the crop surface, MJ m^{-2}-d^{-1}

G = density of the soil's heat flux, MJ m-2 d-1;

T = average daily air temperature at 2 m height, °C;

U_2 = wind speed at 2 m height, m s^{-1};

e_s = saturation vapor pressure, kPa;

e_a = real vapor pressure, kPa;

$(e_s - e_a)$ = saturation pressure deficit of the saturation vapor,kPa;

Δ = slope of the vapor pressure curve, kPa $°C^{-1}$ and

γ = psychrometric constant, kPa ° C^{-1}.

Equation 22

$$ET_{pc} = ET_o\,K_c$$

Where:

ET_{pc} = evapotranspiration of the crop, mm d^{-1}; and

K_c = crop coefficients for a given development phase, dimensionless.

Equation 23

$$ET_{rc} = ET_{pc}\,K_S$$

ET_o = potential evapotranspiration reference of the crop, mm d^{-1};

ET_{rc} = real evapotranspiration of the crop, mm d^{-1}; and

K_s = the soil humidity coefficient, dimensionless.

Equation 24

$$K_s = \left(1 + \frac{\log(LAA+1)}{\log(CTA+1)}\right)/2$$

$$CTA = CAD\,.\,Z$$

$$LAA = CTA\,.\,f$$

Where:

LAA = current water blade, mm;

CTA = total storage capacity, mm;

CAD = water capacity available, %;

Z = effective depth of the crop's root system, m; and

f = water availability factor when there is no water stress, dimensionless.

complete the period between 1931 and 2030, using the monthly average values of the interpolated series in order to the average monthly values of the interpolated series to preserve the local seasonality characteristics.

Figure 35 also shows the monthly average evapotranspiration values for Brazil in January, illustrating the representativeness of the network of stations. The incorporation of automatic stations is an important quality gain compared to previous studies, since there was a lack of these measuring modalities in several irrigation poles, for which data from distant conventional stations was used.

The potential evapotranspiration of the crop (ETpc) consists in the evapotranspiration of a crop under optimal conditions of humidity and nutrients in the soil, so that the potential production of this crop is allowed under field conditions. The ETpc depends on the ETo and on the crop coefficient values of the different stages of development for each crop, which are available in *Allen et al.* (1998). The ETpc is provided by Equation 22.

Based on the crop development phases it is possible to determine the curve representing Kc changes throughout the crop cycle. FAO Bulletin 56 (Allen et al., 1998) details the division of crop development into cycles (initial phases, vegetative development, medium and final) and the reference values given for estimating demands.

The duration of the crop cycle (number of days in each phase) depends on several factors, such as planting season, crop variety and soil and climate conditions. Therefore, the reference values available in the FAO Bulletin 56 were adapted to the Brazilian conditions through the analysis of the main months of planting and harvesting of temporary crops - data available in the 2006 Agribusiness Census (IBGE, 2009). For permanent crops, it was not necessary to provide the estimated duration of the crop phases, since the average Kc was used for the entire crop cycle.

The real evapotranspiration of the crop (ETrc) is the amount of water evaporated by a given crop under normal cultivation conditions. In addition to the meteorological elements, ETrc is conditioned to the percentage of soil coverage, the type of crop and the availability of water in the soil and is calculated from the potential evapotranspiration (ETpc) and the soil humidity coefficient (Ks) (Equations 23 and 24).

The Ks considered corresponds to the average between the time at which the soil is close to field capacity and the water depletion limit (Equation 24); information on the current water blade (LAA) and total storage capacity (CTA) is required. The determination of these value depends on the water availability factor without water stress (f), the real depth of the root system of the crop(Z) and the water capacity available (CAD).

The availability factor or depletion coefficient (f)represents the limit percentage of water available in the soil for the crop not to suffer expressive reduction in its maximum evapotranspiration rate. The value depends on the crop and on the climatic conditions, adopting the reference values of FAO Bulletin 56.

The depth values for the root system (Z) were also obtained from FAO Bulletin 56.

The real water storage capacity in the soil (CAD) is obtained from the estimation of the field capacity and the permanent wilting point. To this end, pe-do-transfer equations are used, which allow the water retention capacity to be estimated based on soil characteristics such as texture, overall density and organic matter content, are used (Rossato, 2001; *Tomassela* et al., 2000). The pedo-transfer equations were obtained from contact with the team at the National Center for Natural Disasters Monitoring and Alerts (CEMADEN); the soil maps developed in the framework of the RADAMBRASIL project were also adopted.

6.2.3 Irrigated Areas and Crops

The irrigated area is a key piece of information in determining water use by irrigation. The annual municipal series of equipped areas were based on the agricultural censuses carried out by IBGE in 1960, 1970, 1975, 1980, 1985, 1996 and 2006 (IBGE, 2006; 2009).

More recent data was published by ANA (2017) in the Irrigation Atlas, referring to the year 2015 (Figure 36) and projections for the 2030 horizon. This publication details the history of the development of irrigated agriculture and the methods and databases associated with the recent survey of irrigated areas. Figure 36 presents a current overview of irrigated areas in Brazil, which total 6.95 million hectares.

The years without municipal information used a linear interpolation of the area between years that had available data. For the regression of areas from 1960 to 1931 the rates observed between 1960 and 1970 or between 1960 and 1975 were adopted, according to the availability of municipal data.

A coefficient representing the transformation of the equipped area into harvested area is applied on the equipped area; this coefficient depends on the municipal crop compositions and on characteristics related to the average number of crops. This coefficient was estimated using the (temporary and permanent) proportion of crops in the municipality.

In addition to the irrigated areas, the estimate method requires information on the crops present in the municipality and the time schedule for harvesting them – piec-

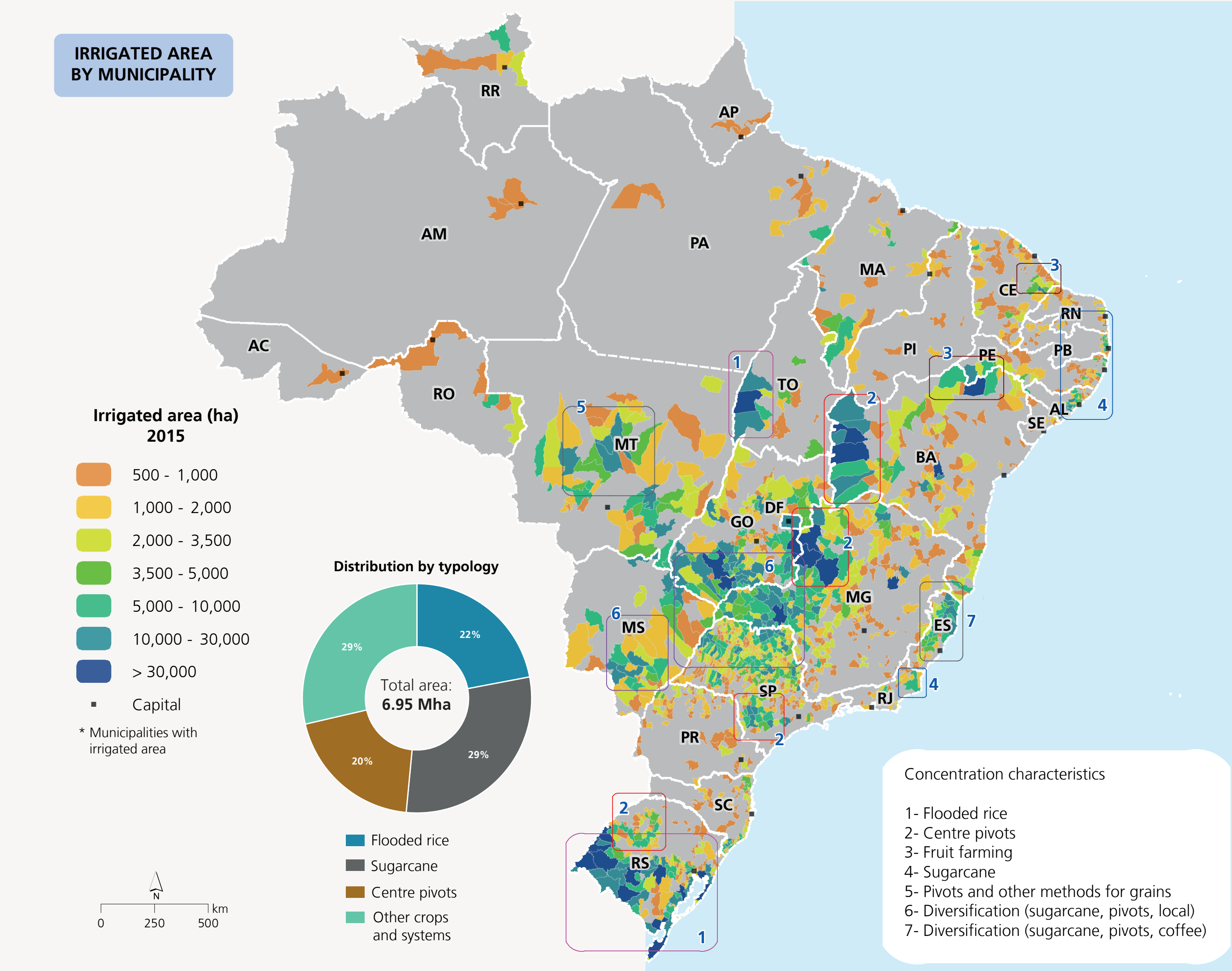


Figure 36 - Current area equipped for irrigation by municipality (2015)

Source: *Irrigation Atlas (ANA, 2017)* es of information, which are assumed to be constants on the calculation horizon.

The percentage of each crop in the municipality was obtained from the Agribusiness Census 2006 (IBGE, 2009) and from more recent surveys: for sugar cane and flooded rice (ANA, 2017); for about 900 municipalities in critical basins (ANA, 2016); and for the historical flooded rice survey (Embrapa, 2017).

The cultivation calendars determine which months and in what proportion the harvesting of a given crop takes place in the municipality. This data was initially obtained from the 2006 Agricultural Census, to which was added information provided by the National Supply Company - CONAB for the main irrigated crops (rice, beans, maize, cotton and soybean).

It should be noted that there are many disidentifications in the municipal census data (total equipped area and area harvested by crop), generally due to the low number of informants (less than three).Disidentified data was filled out calculating the number of disidentifications (x) and the difference between total identified area (without disidentifications) and total area obtained (Equation 25). Thus, for example, if the sum of the areas harvested from the crops identified in a municipality is 8,000 hectares, the total area (without distinction of crop) is 10,000 hectares; and there are two crops without data (disidentifications), the 2,000 hectares balance is also distributed (1,000 hectares for each).

Equation 25

$$A_x = \frac{A_{tot} - \Sigma A_{identif}}{n}$$

Where:

A_x = estimated area for each disidentification, ha;

A_{tot} = total area, ha;

$A_{identif}$ = total área identified, ha; and

n = amount of disidentifications.

6.2.4 Irrigation Systems

Irrigation systems determine the water use efficiency potential and, therefore, the losses incurred (water withdrawn not used by the plants). Losses can occur due to leaks in distribution and storage, evaporation, dragging or wind, surface runoff and deep percolation. Losses do not necessarily express waste of water, since no equipment guarantees 100% efficiency and it is not possible to accurately control all variables under field conditions (e.g., wind). Water use efficiency indicators are presented by type of system in the Irrigation Atlas (ANA, 2017).

Based on the 2006 Agribusiness Census carried out by IBGE, a preponderant irrigation system was associated for each crop in each municipality, adopting the reference values presented in Table 8. In the absence of data from the municipality, the predominant system is adopted in the respective geographical mesoregion.

It is also considered that part of the evaporation/dragging losses in sprinkler systems do not return to the water body. These consumption values are estimated at 8.0% of the withdrawal in center pivots and 12.6% in other spraying methods, based on ANA (2004). In other systems, losses due to evaporation/dragging are not considered except for flooded rice, the methodology for which will be subsequently addressed.

The irrigation return flow for a municipality is obtained considering the water use efficiency, the evaporation and the dragging losses during application by sprinkler systems. These losses are incorporated into consumption since they are not consumed by the crop's evapotranspiration but do not directly return to the water bodies.

Table 8 - Application Efficiency of Irrigation Systems

Irrigation system	Efficiency (%)	Loss evaporation/ dragging (%)
Flooding	60	-
Furrows	75	0
Sprinkler (center pivot)	85	8
Sprinkler (other methods)	80	12.6
Local (drip, micro-drip, etc.)	90	0
Other irrigation and/or watering methods	60	0

6.2.5 Sugarcane and Flooded Rice

The general method detailed above is used for all crops except for sugarcane and flooded rice, which have special water use handling characteristics not adequately represented by the general method. Significant progress was made in the characterization of demands in the two crops with the largest irrigated area in the country. Figure 37 shows the irrigated area distribution for these typologies in the Brazilian municipalities and federal units.

6.2.5.1 Sugarcane Irrigation

Sugarcane accounts for the largest irrigated area in Brazil when one considers the fertirrigation and recovery areas. At the same time, it presents peculiarities that make it difficult to identify irrigated areas and estimate water use, such as the widespread application of low irrigation blades; the high rates of reused water from the industrial processes of ethanol production; and the great mobility and variety of equipment used (ANA, 2017).

These characteristics differ from most other crops and characterize sugarcane as a low consumer of water per area unit. However, this crop is still of great relevance due to its large extension in Brazil, which may alter the country's water balance on a local and regional scale. Therefore, the general method previously described would overestimate the water applied in the sugarcane fields by considering that all its water demand would be supplied by irrigation, which is not the case for most of the irrigated areas.

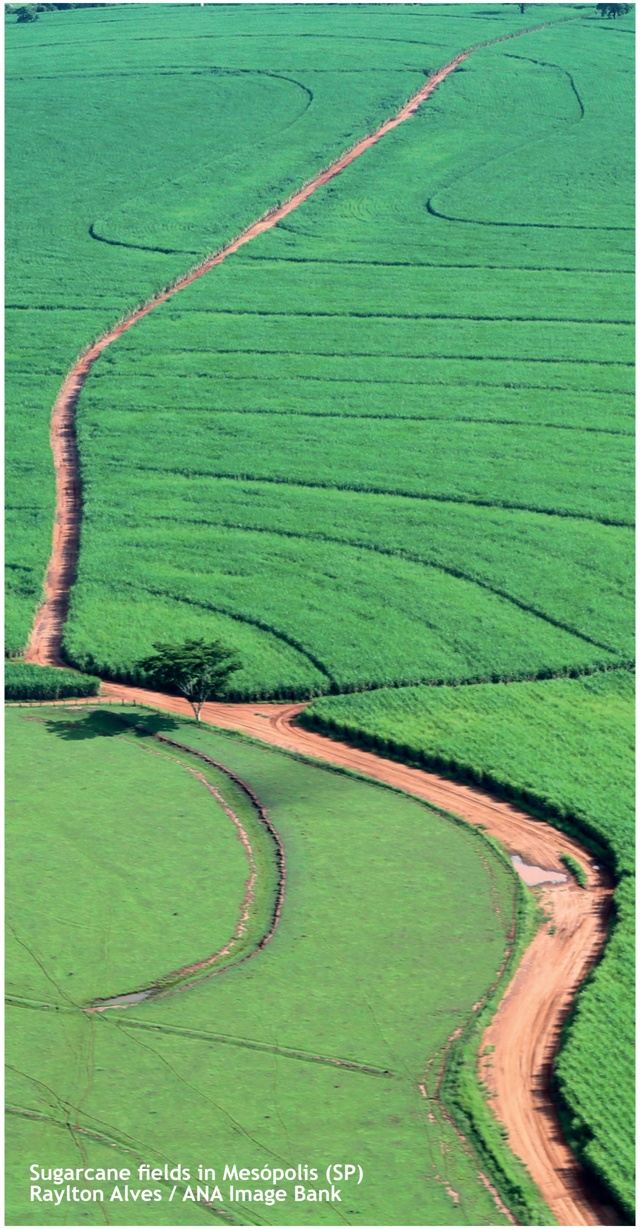
Thus, three crop handling modalities were adopted, each of them having a distinct estimate: full irrigation, complementary irrigation, and recovery irrigation, the latter being the most predominant modality. This detailing was possible based on the *Irrigated Sugarcane Survey in the Center-South Region of Brazil* (ANA, 2017), which brought a new overview on irrigated areas divided into these distinct typologies, based on geotechnologies and field work.

Full irrigation consists in the application of the water blade to supply the full water deficit of the crop, as was calculated for the other crops (general method). However, in the tenth month of the sugarcane crop cycle, irrigation must be suspended to encourage maturation, which means cuts in water use (Scarpare et al., 2015). Maximum blades were also defined by municipality, based on average climate conditions, aiming to limit water application to the dimensioning conditions of the equipment for full irrigation.

Complementary irrigation consists in partially supplying the water deficit. Productivity rates tend to be lower, but there is an increase in efficiency of application and a reduction in operational costs. In addition to foreseeing the interruption of irrigation in the tenth month of the cycle, the method also considers that up to 50% of the water deficit may be supplied by irrigation under average climatic conditions, limiting the water application to the dimensioning of the complementary irrigation equipment.

Recovery irrigation, which corresponds to over 90% of the irrigated area for sugarcane, consists in the application of water in a relatively short period or at a specific stage of the crop. Recovery is carried out with a reel (*Hydro roll*) or a towable pivot, normally with blades of 60 to 80 mm after each yearly cutting of the sugarcane (Pereira et al., 2015), allowing for its recovery, productivity and longevity. In this way, the method considers the application of 80 mm of water distributed into the three months immediately after the cutting of the sugarcane (harvest), guaranteeing germination in the dry periods.

Recovery largely re-uses vinasse and other by-products from the industrial process of producing ethanol. These effluents may be applied pure or further diluted in water collected directly from the water bodies. Consequently, part of the estimated consumption related to sugarcane refers to the reuse of water from industrial processes. More comprehensive assessments are being carried out by ANA to estimate the proportions of real water withdrawn if compared to water reused.


Sugarcane fields in Mesópolis (SP)
Raylton Alves / ANA Image Bank

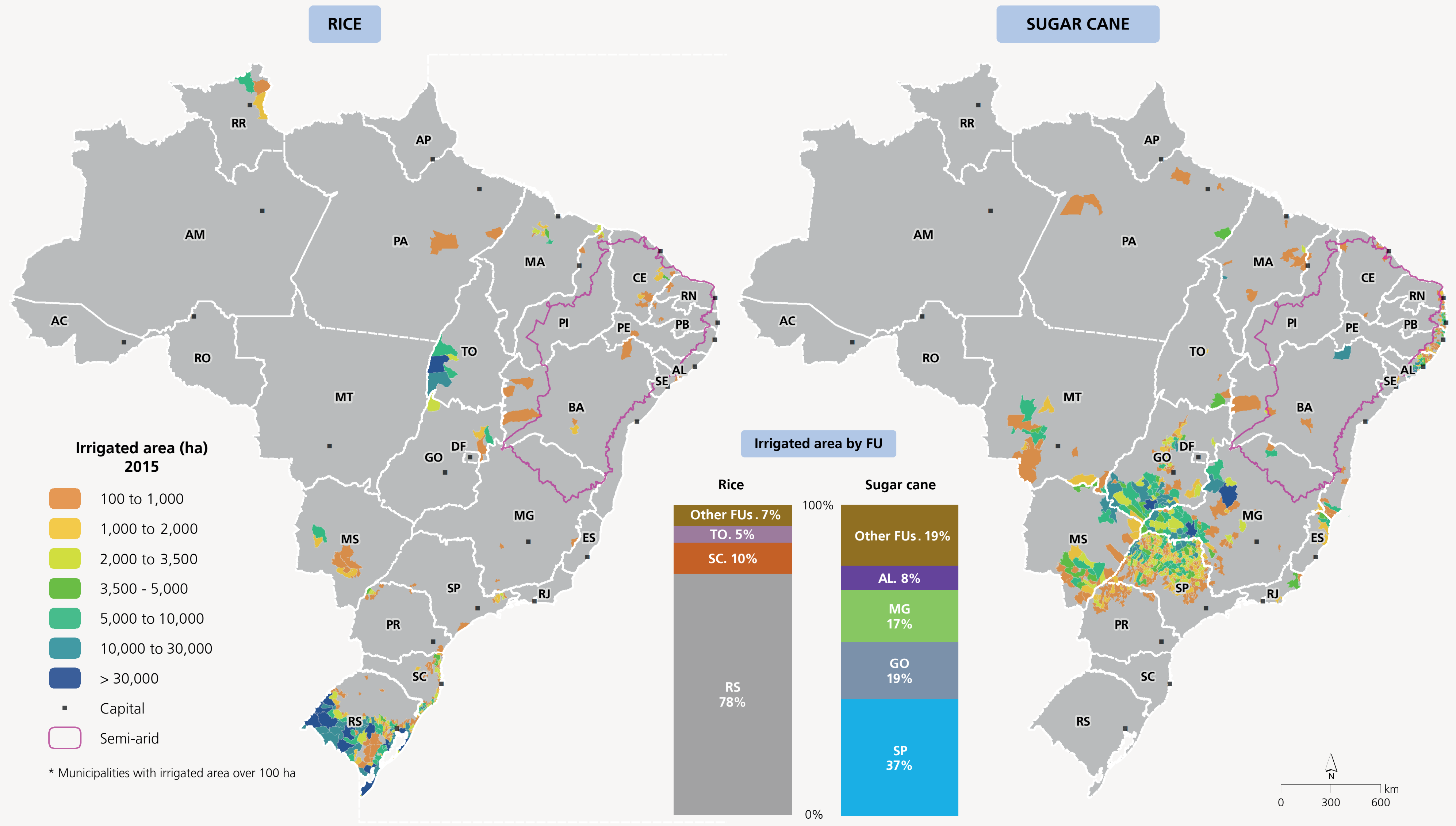


Figure 37- Current area equipped for irrigation by municipality - rice and sugarcane.

Source: *Irrigation Atlas (ANA, 2017)*

6.2.5.2 Flooded Rice Irrigation

Rice cultivated under flood represents the second largest irrigated area in the country and accounts for the largest amount of water consumption.

Evaporation of the water blade is a critical factor to be considered in the calculation, in addition to the different types of handling – grouped into conventional and pre-germinated systems. In the first case, the sowing is carried out on dry soil, and the flooding process is initiated a few days later, when the plants begin to appear. In the pre-germinated system, irrigation is started before sowing, during the final soil preparation procedures. After this step, the height of the water blade is raised to a certain level and maintained until the sowing, which occurs in flooded soil.

The special conditions of the water use dynamics relative to other crops required a specific estimation methodology based on the method developed by Amaral et al. (2005). The calculation was carried out in all municipalities where this type of irrigation was identified, focusing on the states of Rio Grande do Sul, Santa Catarina and Tocantins (Figure 37).

The methodology developed covers two cultivation systems: the conventional and pre-germinated system, whose periods and calculation formulae are summarized in Tables 9 and 10.

Two consumption classes are considered for this cultivation type, in addition to the withdrawal (water withdrawn from the water bodies) and return (water returned to the water bodies) flows: the real consumption, which refers to what is consumed by the crop during the irrigation period; and the consumption flow, provided by the monthly difference between withdrawal and return.

Figure 38 shows the crop coefficients in the different development phases, as well as the duration of each phase. The average length of the crop cycle between appearance and maturation (harvest) is 122 days. This period has been defined based on the characteristics of the main crops cultivated in the states of Rio Grande do Sul and Santa Catarina (Tronchoni, 1995; SOSBAI, 2003; IRGA, 2005). Since the seed germination process is accelerated in the pre-germinated system, it was considered that the appearance date coincided with the sowing date.

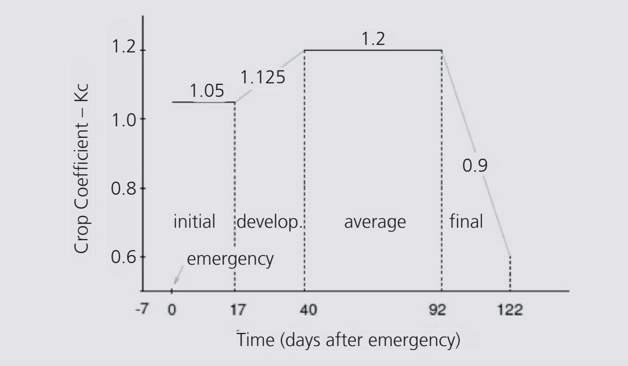


Figure 38 – Crop Coefficient for the Different Rice Development Stages, Adopted for the Average Rice Crop Cycles Used in the Southern Region of Brazil
Source: adapted form Allen et al. (1998)

Conventional System

The irrigation periods and their duration were defined by Amaral et al. (2005) using information contained in Embrapa (2003), Sosbai (2003), Weber *et al.* (2003) and Gomes et al. (2004). Table 9 presents the periods and respective calculations or values adopted (unit and withdrawal, consumption and return flows).

The unit/withdrawal flow is considered null in the first and last periods (post-appearance, emptying of the trays, and harvest), where no irrigation withdrawal occurs.

During the period when the trays are filled, the unit flow is calculated based on the fact that, at the time flooding begins, the water volume necessary for the saturation of the profile corresponds to the volume of the macropores in the soil from its surface to the depth of the impermeable layer, in accordance with Equation 26. In the normal demand period, the unit flow of 1.75 liters per second per hectare is adopted (Sosbai, 2003).

The average value for soil macro-porosity used was 0.051 m3/m3. (based on König (1983), Costa (1993), Vasconcellos (1995) and Machado et al. (1996). The flooding blade was 0.10 m, defined based on technical recommendations and on blades commonly used in commercial crops. The depth of the impermeable layer was set at 1 meter.

The flow withdrawn in these periods (filling of trays and normal demand) was similarly calculated, using Equations 27 or 28 (Table 9).

The real consumption in the conventional system, regardless of the period considered, is calculated by Equation 29. In the post-appearance period Ks equal to 0.9 was considered, while in the other periods Ks equal to 1.0 was considered.

The return flow was considered null in the periods of post-appearance and of filling of trays. In the period corresponding to normal demand, the return flow was the difference between the withdrawal and consumption flows, and if the consumption flow was greater than the withdrawal flow, the return flow would be zero (Equation 30). In the emptying of the trays, the height of the surface water blade, the period of emptying, the rainfall, and the consumption flow were considered, as shown in Equation 31.

Equation 26

$$Q_{unit} = \frac{100[(uP_{imp}) + H_{bla}]}{T_{fil}864} + \frac{(ET_0\, K_c K_s)}{8.640}$$

Equation 27

$$Q_{wit} = \left[Q_{unit} - \left(\frac{P}{8.640}\right)\right] A$$

Equation 28

$$Q_{wit} = 0$$

Equation 27 is used when $\left(\frac{P}{8.640}\right) < Q_{unit}$ and Equation 28 is used in all other situations.

Equation 29

$$Q_{cons} = \left[\frac{(ET_0\, K_c K_s)10}{86.400}\right] A$$

In the post emergency period K s was considered to be equal to 0.9, while in the other periods Kswas considered equal to 1.0.

Equation 30

$$Q_{ret} = Q_{wit} - Q_{cons}$$

if $Q_{ret} < 0$, então $Q_{ret} = 0$

Equation 31

$$Q_{ret} = \left(\frac{H_{bla}\, 1.000\, A}{T_{empt} 86.400} + \frac{P\, 10}{86.400} A\right) - Q_{cons}$$

Table 9 - Periods for calculating flooded rice irrigation needs – conventional system

Period	Duration (days)	Unit Flow (l/s/ha)	Withdrawal Flow	Actual Consumption	Return Flow
Post-emergency	from 1 to 24	0	0	0	0
Filling of the Trays	from 25 to 29	Equation 26	Equations 27 or 28	Equation 29	
Normal demand	from 30 to 97	1.75			Equation 30
Emptying of the trays	from 98 to 109	0	0		Equation 31
Preparation of the harvest	from 110 to 122	0	0	0	0

Table 10 - Periods for calculating flooded rice irrigation needs -pre-germinated system

Period	Duration (days)	Unit Flow	Withdrawal Flow	Actual Consumption	Return Flow
Filling of trays	from -25 to -21	Equation 32	Equation 27 or 28	Equation 34	0
Pre-sowing	from -20 to -1	1			Equation 30
Post-sowing	from 1 to 3				
Withdrawal from water blade	from 4 to 10	0	0		0
Water blade re-filling	from 11 to 17	Equation 33	Equation 27 or 28		
Normal demand	from 30 to 97	1		Equation 29	Equation 30
Emptying of trays	from 98 to 109	0	0		Equation 31
Preparation for harvesting	from 110 to 122	0	0	0	0

Equation 32

$$Q_{unit} = \frac{10.000[(uP_{imp}) + H_{bla}]}{T_{fil}86.400} + \left(\frac{ET_0}{K_T}\frac{10}{86.400}\right)$$

Equation 33

$$Q_{unit} = \left(\frac{H_{bla}}{T_{fil}}\frac{10.000}{86.400}\right) + \left(\frac{ET_0}{K_T}\frac{10}{86.400}\right)$$

Equation 34

$$Q_{cons} = \left(\frac{ET_0}{K_T}\frac{10}{86.400}\right) A$$

Equation - Captions:

- Q_{wit} = withdrawal flow, $ms^3 s^{-1}$;
- Q_{unit} = unit flow, $m^3 s^{-1} ha^{-1}$;
- Q_{return} = return flow, $m^3 s^{-1} ha^{-1}$;
- Q_{cons} = fective consumption flow, $m^3 s^{-1} ha^{-1}$;
- A = *irrigadated area, ha;*
- u = *average macroporosity of the soil* $m^3 m^{-3}$;
- P_{imp} = *average depth of the impermeable layer, m;*
- P = total rainfall, mm;
- H_{bla} = *height of the surface water blade, m;*
- T_{fil} = *duration of the period of filling of the trays, days;*
- T_{empt} = *duration of the period of emptying of the trays, days;*
- *ETo* = *potential evapotranspiration of the crop, mm* d^{-1};
- *Kc* = *crop coefficients for a given stage of development, dimensionless;*
- *Ks* = *soil humidity coefficient, dimensionless; and*
- *Kt* = *class A tank coefficient, dimensionless*

Pre-germinated system

The irrigation periods and their duration were defined by Amaral et al. (2005) using information contained in Gomes & Pauletto (1999), Embrapa (2003), Sosbai (2003), Weber et al. (2003) m Marchezan et al. (2004) and Petrini et al. (2004). Table 10 shows the periods and the respective calculations or values adopted for the flows.

The filling of trays in the pre-germinated system will begin before sowing, during the final soil preparation procedures. Thus, even before the crop is established, there is already considerable loss of water to the atmosphere due to evaporation. In addition, evaporation is the predominant process at the beginning of rice cultivation, decreasing as the crop develops and the canopy cover increases.

The withdrawal flows in the filling of the trays, pre-sowing, post-sowing, in the water blade replacement, and corresponding to normal demand are calculated using Equation 27 or 28. In the periods of withdrawal of the water blade and emptying of the trays, the flow withdrawn was considered null.

The calculation of the unit flow varies in these phases and is determined by Equation 32 in the filling of the trays period and by Equation 33 in the blade replacement period. For the pre-sowing, post-sowing and normal demand periods the unitary flow was considered equal to 1.0 L s-1 ha-1, in accordance with Sosbai's recommendations (2003).

Since the evaporation process of the water in the trays does not significantly change during the first days after sowing, considering that the transpiration of the plants and the canopy coverage are still small. The real consumption of water by the crop, in the period between the beginning of the filling of the trays and the end of the water blade replacement was estimated considering only the occurrence of evaporation according to Equation 34 and adopting Kt = 0.8.

The evaporation estimate was considered equal to evaporation in the Class A tank since, as provided by Gomes et al. (2004), the evaporation that occurs during the first days of rice cultivation is similar to that obtained in evaporimeters.

In the periods of regular demand and emptying of the trays the real consumption estimate was carried out considering the real evapotranspiration of the crop, according to Equation 29.

The return flow was considered null in the filling of the trays and water blade withdrawal periods. In the periods corresponding to pre-sowing, post-sowing, water blade replacement and regular demand, the return flow was the difference between the withdrawal and the consumption flows, and if the consumed flow was greater than the withdrawal flow, the return flow would be zero (Equation 30). In the emptying of the trays, the height of the surface water blade, the period of emptying, the rainfall, and the consumption flow were considered, as shown in Equation 31.

The calculation to ascertain the monthly volume withdrawn by the rice crop is carried out by adding all the volumes withdrawn in the respective municipality in that particular month. Similar reasoning is used to estimate the monthly return volume in a given municipality. The consumption volume is given by the difference between the monthly volumes of withdrawal and return for a given municipality.

6.2.6 Total Irrigation Flow

Lastly, considering the aforementioned calculation procedures for all crops, the estimated flows for each municipality (withdrawal, consumption and return) correspond to a sum of the flows estimated for each crop in addition to the specificities for sugarcane and flooded rice (Equation 37).

Equation 37

$$Q_{ret,mu} = \frac{(V_{w1,m,mu}+V_{w2,m,mu}+...+V_{wn,m,mu}) + V_{w,sc,m,mu} + V_{w,r,m,mu}}{t_{mon}.86400}$$

Where:

$Q_{ret,mu}$ = monthly **withdrawal** flow (wit) for irrigation in a given municipality (mu), m³ s-1;

$V_{w1,m,mu}$ = monthly volume (m) of withdrawal for crop 1 (w1) in the municipality (mu), m³;

$V_{w2,m,mu}$ = monthly volume (m) of withdrawal for crop 2 (w2) in the municipality (mu), m³;

$V_{wn,m,mu}$ = monthly volume (m) of withdrawal for crop n (wn) in the municipality (mu), m³;

$V_{w,sc,m,mu}$ = monthly withdrawal volume (m) (w) for sugarcane (sc) in the municipality (mu), m³;

$V_{w,r,m,mu}$ = monthly withdrawal (w) volume (m) for flooded rice(r) in the municipality (mu), m³;

t_{mon} = duration of the month analyzed, days.

Similar reasoning is used for the determination of monthly **consumption** and **return** flows in a given municipality

6.3 Results

Irrigated agriculture demanded 1,083.6 m³/s in Brazil in 2017, answering for 52% of all of the flow withdrawn and 68.4% of the flow consumed - disregarding the liquid evaporation of artificial reservoirs.

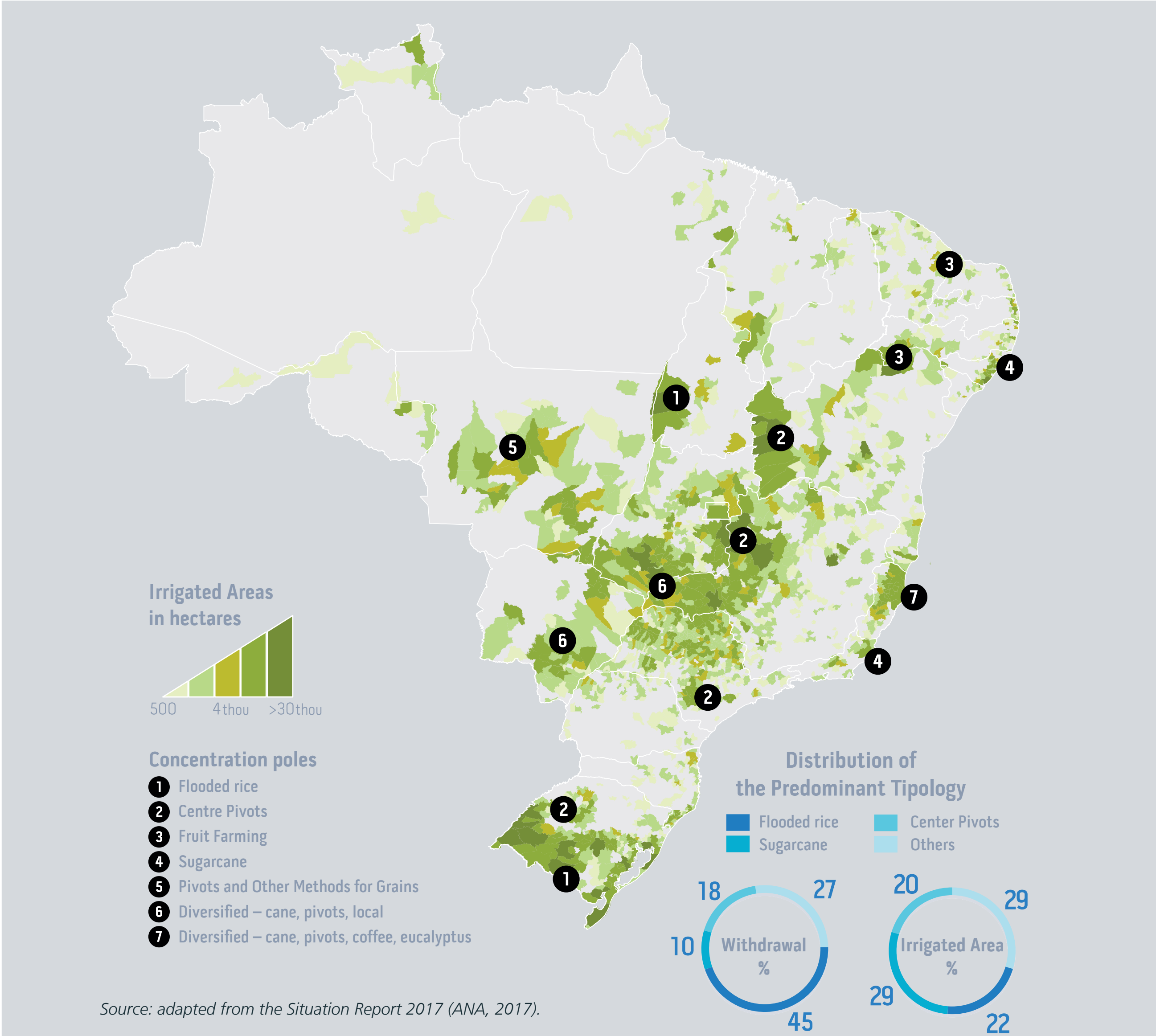
Figure 39 presents an overview of the concentration of irrigated areas with the location and characteristics of the main irrigation poles in the national context. It also graphically represents the spatial distribution of the withdrawal demand, divided into four groups: flooded rice, sugarcane, other crops in center pivots, and other crops and systems. The different proportions between area and demand are noted, which are a reflection of the different water use intensities.

Figure 40 presents a summary of the evolution of withdrawals for irrigated agriculture in Brazil.

From a territorial perspective, the predominance of the activity in the South region, and in the states of São Paulo, Minas Gerais, Bahia and Santa Catarina is noted in the 1940s. The activity is currently more widespread throughout the country, still focused in the traditional Southern poles and with more recent poles in the West of Bahia, in the *Triângulo Mineiro* in Northwest of the state of Minas Gerais, in the Semi-arid region, in the state of Tocantins, and in São Paulo.

The graph in Figure 40 presents the withdrawal flow series for irrigation between 1931 and 2030. The activity has experienced rapid growth, especially after 1970. There is a great potential for expansion, and the incorporation of 3 million hectares is foreseen for the 2030 horizon.

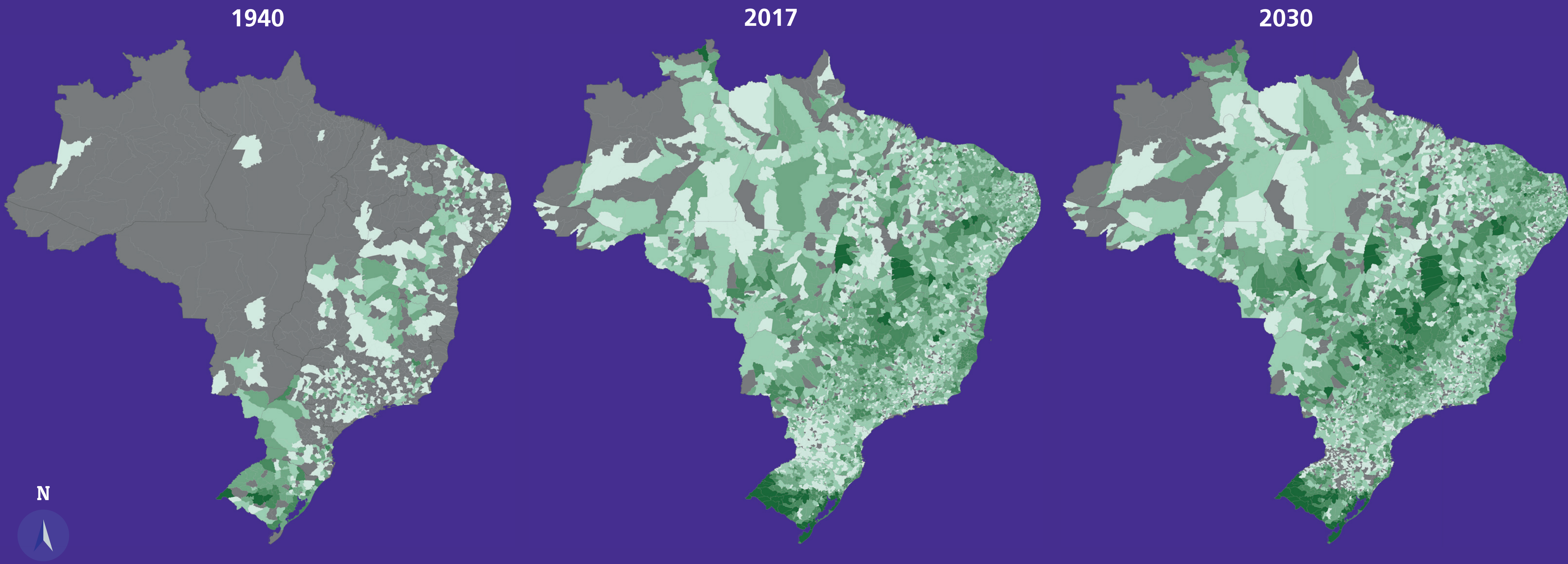
The largest annual average oscillations in dams (graph in Figure 40) are justified due to climatic anomalies, where the peaks represent dryer years in important irrigated agriculture poles (greater supplementation needs) and decreases represent humid years (less need for irrigation).



Source: adapted from the Situation Report 2017 (ANA, 2017).

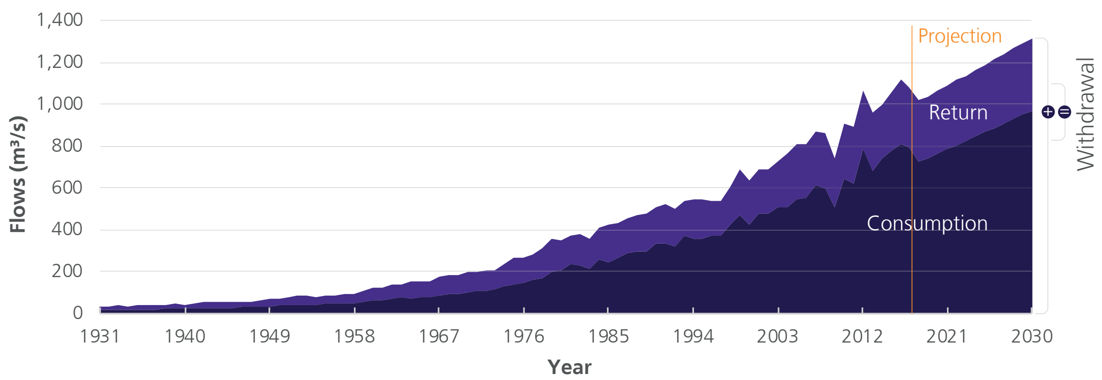
Figure 39 - Irrigated area in Brazil, concentration poles and area and water withdrawal ratio by groups.

Figure 40 – Flow series 1931 to 2030 – Irrigated Agriculture



Withdrawal Flows by Municipality (m³)

- 0.000001 - 0.003
- 0.003 - 0,03
- 0.03 - 0.3
- 0.3 - 2.9
- 2.9 - 27.9
- no demand



Larger withdrawals (m³/s) per municipality (2017) - Irrigated Agriculture			
Ranking	FU	Municipality	Withdrawal Flow (m³/s)
1st	RS	Santa Vitória do Palmar	24.204
2nd	RS	Uruguaiana	23.764
3rd	RS	Alegrete	21.332
4th	RS	Itaqui	20.614
5th	BA	Juazeiro	17.040
6th	RS	São Borja	16.526
7th	RS	Mostardas	15.726
8th	PE	Petrolina	15.114
9th	BA	Barreiras	14.616
10th	RS	Arroio Grande	12.982

Producing municipalities in the state of Rio Grande do Sul stand out with high demands – the rice crops in these municipalities are associated to the flooding system and presents high unitary water demands. Petrolina/PE and Juazeiro/BA - neighboring municipalities - also present large irrigated areas, mainly in public perimeters, and high unitary water demands, due to their location in the Semi-Arid part of the country. Barreiras/BA is located in the West of Bahia - part of the Cerrado biome, marked by a strong dry period, when the agricultural practice is only possible with irrigation.

Detailed results of historical series of consumptive uses for all municipalities be accessed at www.snirh.gov.br/usos-da-agua.

7 THERMOELECTRICITY

Camaçari - BA Thermoelectric Plant
Manu Dias - Image Bank/ANA

7.1 Introduction

Thermoelectric energy is produced by a power station with heat generated by the burning of solid, liquid or gaseous fuels. A significant part of the heat is not converted into electricity and is released mainly through the steam cooling systems of the turbines. These cooling systems demand significant water volumes.

Thermoelectric plants have gained relevance in the Brazilian power generation context, especially since the 2000s, reaching 27% participation in the electric matrix in 2016 - only behind hydroelectricity, with 64.5%. In addition to providing the national energy system with flexibility and security, thermoelectric plants have been expanding due to the impacts and difficulties present in hydroelectric power generation, such as the inter-annual changes in the hydrological regime, the high costs and the long time it takes for carrying out studies, designing, licensing, and constructing a hydroelectric plant.

The growing trend of this technological alternative in power generation, its high demand for water and the manner through which residual water is returned to the environment have led ANA to develop estimates for the sector. The inclusion of this use category represents a challenge and, at the same time, a possibility to better characterize the use of water resources in the national territory.

The water demand in Thermoelectric Power Plants - TPPs depends on the generation technologies, type of fuel and cooling system, as well as the environmental conditions involved. The irregular operation - used many times as a complementary source to supply demands unmet by hydropower generation - also expressively influences the intra and inter-annual variation of the estimates.

Considering the large volumes of water used to the supply thermoelectric plants, Figure 41 illustrates the variation of withdrawal flows in the federation units. Rio de Janeiro (with 21% of the total demand), Santa Catarina (13%), São Paulo (11%), Pará (9%), Maranhão (9%), and Pernambuco (8%) concentrate 72% of the total demand, which was 79.5m³/s in 2017 (3.8% of the total withdrawal in the country).

Figure 42 presents the respective withdrawal percentages in the Brazilian regions, where the leadership of the Southeast region is noted, followed by the Northeast, South and North regions. The Midwest less relevant in terms of thermoelectric activity.

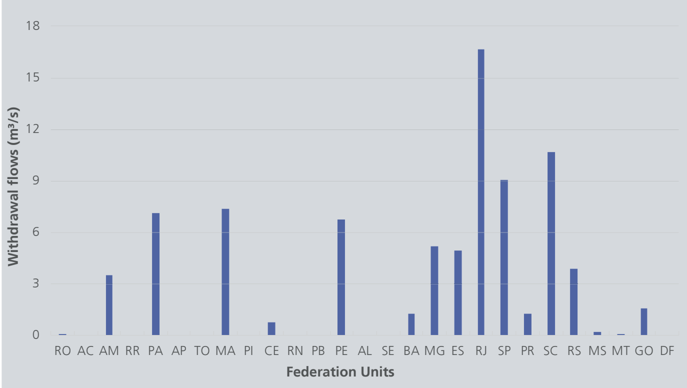


Figure 41 - Withdrawal Flows (m³/s) for Thermoelectric Power Plants in the FUs

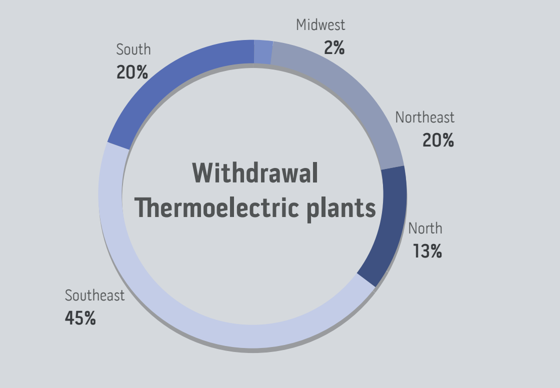
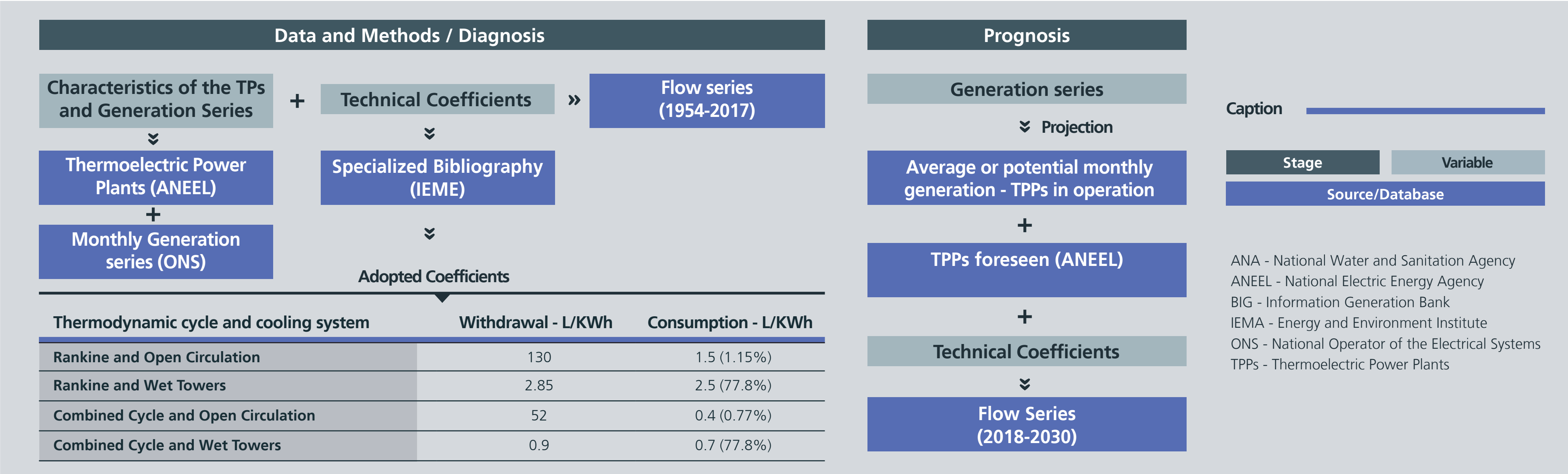


Figure 42 - Withdrawal Percentages for TPPs, by Region, in Relation to Total Withdrawal

7.2 Method and Database

The flowchart (Figure 43) provides a synthesis of the method used for estimating flows associated with thermoelectric power generation.



Thermodynamic cycle and cooling system	Withdrawal - L/KWh	Consumption - L/KWh
Rankine and Open Circulation	130	1.5 (1.15%)
Rankine and Wet Towers	2.85	2.5 (77.8%)
Combined Cycle and Open Circulation	52	0.4 (0.77%)
Combined Cycle and Wet Towers	0.9	0.7 (77.8%)

Figure 43 - Summary of the Method for Estimating Flows Associated with TPPs

The method for estimating water consumption in the thermoelectric sector consists of applying technical co-efficients (liters per energy generated) to the generation series (energy really generated) or, in the absence of this information, the generation potential.

The coefficients are grouped into four categories, with association between the heat conversion into electric power technology (thermodynamic cycle) and the cooling system of each TEP.

Out of the most widely used conversion technologies - Rankine, Brayton (open cycle), combined (combination of the previous two), and combustion engine - only the Rankine and combined modalities usually depend on cooling systems, which may operate with air or water. Water cooling may occur in an open or in a semi-closed system with humid evaporation towers, as shown in Figure 44.

Therefore, the relevant water demand occurs in plants that use the combined or Rankine thermodynamic cycles and that have a water-based cooling system (open circulation or wet towers).

Out of the 3 thousand thermoelectric power generation plants operated with fossil fuels, biomass and nuclear power in Brazil, making up 45 GW of the country's power capacity, the majority of them operates with small diesel generators. Angra I and Angra II (nuclear plants) have a capacity of 2 GW and use sea water in their cooling systems. According to the survey carried out, about 100 TPs really demand significant water volumes in their processes - about 45% of the total installed capacity (Figure 45).

ANEEL provides some information on the country's thermoelectric plants through its Electric Sector Georeferenced Information System (SIGEL) and its Power Generation Information Bank (BIG). This information includes: location, beginning of operations, power granted, power supervised, destination of power, owner, municipality and source/fuel.

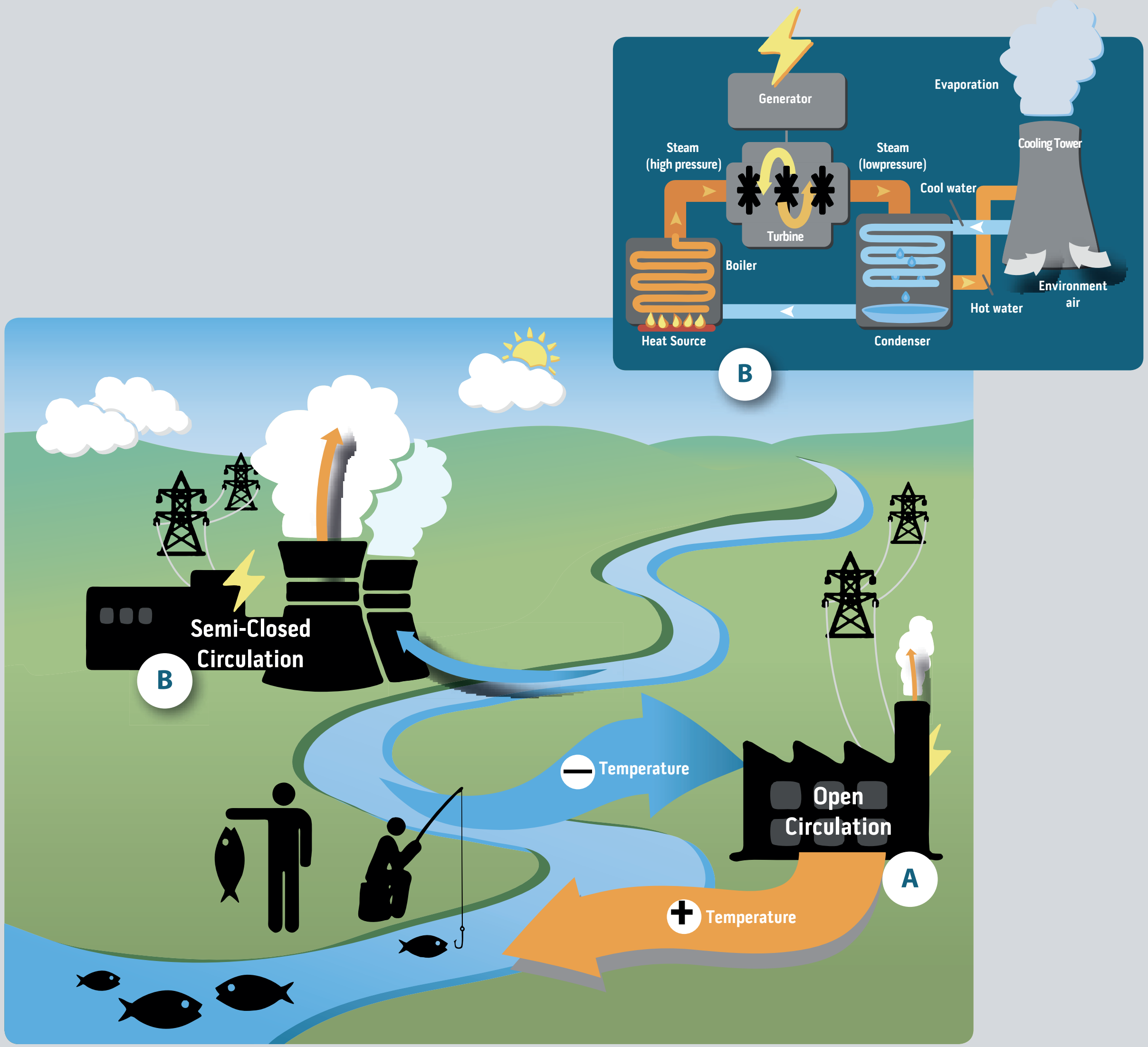


Figure 44 - Schematic representation of thermoelectric plants with semi-closed circulation, evaporative towers and open circulation. Source: adapted rom Averyt et al. (2011)

The characteristic information for each TPP for the application of the technical coefficients (thermodynamic cycle and cooling system) were directly obtained from ONS and from specific publications, mainly IEMA (2016). Information about the cooling systems of TPPs operating with mineral coal was also obtained from Arroyo (2012). For natural gas TPPs the thermodynamic cycle is included in the 2030 National Electric Power Plan (Brasil, 2007).falhas foram utilizados para projetar até 2030 a demanda das UTEs que já se encontram em operação. Ou seja, foi utilizada a média mensal do histórico disponível ou, quando ausente, a potência outorgada.

In the case of unavailability of data referring to the thermodynamic cycle and the cooling system, which define the value of the coefficients used, the characteristics presented to Table 11 were assumed.

The technical coefficients adopted (Figure 43) were obtained by the institute of energy and the environment (IEMA)2016), based on work by Stillwell (2011) and Delgado and Herzog (2012). 50% efficiencies were considered for the combined cycle and 34% efficiencies were considered for the Rankine cycle.

It is noted that in open circulation cooling the withdrawal coefficients are significantly higher, but consumption is of the order of 1% (almost all the water is returned). In the wet cooling towers, the water intake is much lower, but consumption is higher. Thus, the consumption values for generated energy are comparable between the different cooling systems, being superior in the use of wet towers (Figure 43).

The monthly average generation series (2000-2017) of centrally operated TPPs were obtained in direct consultation with the ONS. These TPPs concentrate 70% of the power granted and have wide annual and inter-annual generation fluctuations, due to its variable activation, as a source that is complementary to hydroelectricity. In years with no information or with data gaps, the

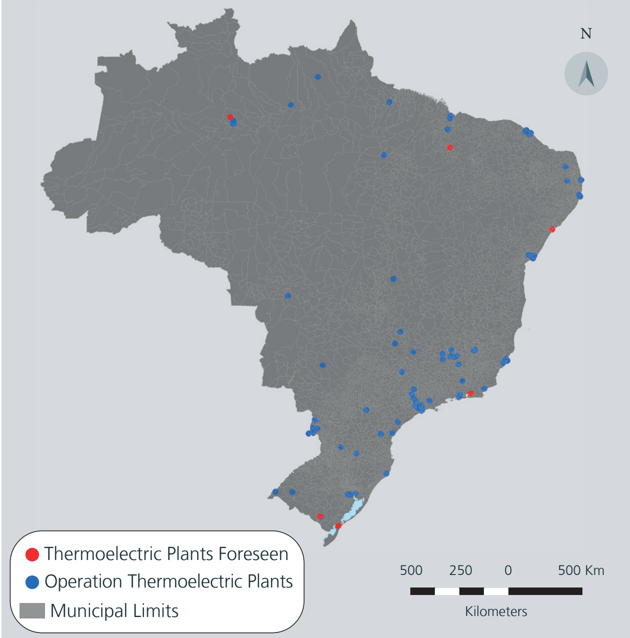


Figure 45 – Spatial Distribution of the STPs

monthly average generation of each TPPs was based on the available series.

For plants without generation series available, a constant generation corresponding to the power granted was considered.

the withdrawal, consumption and return flows were applied with the preparation of the database associated with the knowledge on the thermodynamic cooling cycle of each TPPs (Equations 38 and 40).

The same criterion adopted to fill in the gaps were used to prospect the demand for TPPs that are currently operational, considering the 2030 horizon. That is, the monthly average of the available history was used or, in its absence, the capacity granted.

Withdrawal flow:

Equation 38

$$Q_{TPP} = \frac{E_{el} \cdot C_r}{3600000}$$

Where:

Q_{TPP} = the withdrawal flow of the TPP ($m^3.s^{-1}$);

E_{el} = the electric power generated or capacity granted (Kw)

C_r = the coefficient of withdrawal ($l.kWh^{-1}$)

Consumption and return flow:

Equation 39

$$Q_{TPP,c} = Q_{TPP} \cdot Cc$$

Equation 40

$$Q_{TPP,r} = Q_{TPP} - Q_{TPP,c}$$

Where:

$Q_{TPP,c}$ = the consumption flow of the TPP (m^3s^{-1});

Q_{TPP} = the withdrawal flow of the TPP(m^3s^{-1});

Cc = the consumption coefficient (%);

$Q_{TPP,r}$ = the withdrawal flow of the TPP (m^3s^{-1}).

Table 11 - Correlation between fuel, cooling system and thermodynamic cycle

Fuel	Cooling system	Thermodynamic cycle
Biogas	Open Circulation	Combined
Mineral coal	Open Circulation	Rankine
Refinery gas	Open Circulation	Combined
Natural Gas	Wet Tower	Combined
Fuel Oil	Open Circulation	Rankine
Gaseous Effluent	Open Circulation	Combined
Sulphur	Open Circulation	Combined
Blast Furnace Gas	Open Circulation	Combined
Process gas	Open Circulation	Combined
Steel Gas	Open Circulation	Combined

In addition, some new TPPs were considered to be in operation, using the Thermoelectric Power Plants Monitoring Report (ANEEL, 2016) as reference. The plants that are listed as "not foreseen" have not been included in the estimate of future demands. The thermoelectric power plants with a date foreseen for the beginning of their operation were considered in the future scenario and are presented in Table 12. In these cases, the potential demand was considered the same as the granted power, until operational information is available. The revision of beginning of operation dates and the inclusion or exclusion of undertakings will be updated as information is available.

The recent entry into operation of two important TPPs is also noted: Maranhão III, in Santo Antônio dos Lopes (MA), with a power of 519 MW; and Mauá 3, in Manaus (AM), with a power of 591 MW.

7.3 Results

Even though it is an activity that has been more recently intensified, the withdrawing of water by TPPs in Brazil is higher than the sum of all withdrawals for mining and human supply in the rural area of the country.

Average consumption, however, is low, being equivalent to 3% of the withdrawal, since most of the demand is related to TPPs with open circulation cooling systems, where almost all the water returns to the water body. However, there are TPPs whose consumption is over 70% of the withdrawal, this being related to the wet tower cooling system.

The series of withdrawal, consumption and return flows (1931-2030) for the country are presented in the Infographic (Figure 47). The water demands for thermoelectric plants began in 1954, in the city of São Paulo, with de inauguration of the Piratininga TPP. Up until 1960, this demand was concentrated in São Paulo and in Rio Grande do Sul, totaling 2 m³/s. Between 1980 and 2000 a greater spatial distribution of the thermoelectric plants is observed, resulting in an increase in withdrawal flows, with records varying between 33.6 m³/s in 1980, to 62.6 m³/s in 2000.

From 2000 onwards significant advances were made in the participation of thermoelectric energy in the Brazil's installed electric power capacity (Figure 46), reflecting increases in water demand, which went from 62.6 m³/s in 2000 to 70.5 m³/s in 2017. The states with the highest demands are highlighted in Figure 41.

In the future scenario, with the entry into operation of new plants and the continuous operation of the current active plants, the average demand should reach 93.7 m³/s by 2021.

For economic reasons, thermoelectric plants are operated as a complementary source, and are often activated to supply the unmet demands by hydroelectric power generation that have a certain degree of risk. This characteristic makes thermoelectric power plants significantly variable when it comes to operation, as observed in the graph (Figure 47), especially since the year 2000, when the monthly real generation series became available.

The operational variability and, consequently, the water use variability is significant, expressive increase in demand are observed, exceeding 100 m³/s in 2014 and 2015, due to the high level of activation of TPPs when compared to previous history. This was due to the water crises that significantly affected hydropower generation in these years. Therefore, the future scenario related to water use by thermoelectric plants may be highly affected by the country's hydrological conditions.

Detailed results can be accessed at www.snirh.gov.br and metadados.ana.gov.br/.

Table 12 - Planned Thermoelectric Plants

Name	Municipality	Fuel	Power (MW)	Operation
Pampa Sul	Candiota/RS	Mineral coal	340	2019
Sergipe I Port	Santo Amaro das Brotas/SE	Natural Gas	1,515	2020
Rio Grande	Rio Grande/RS	Natural Gas	1,238	2020

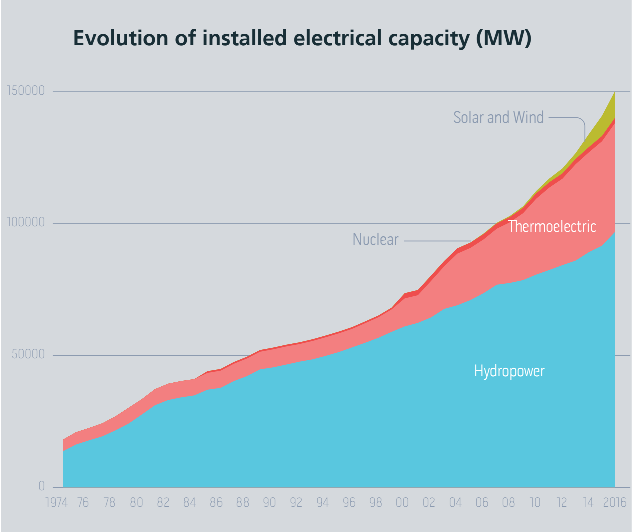
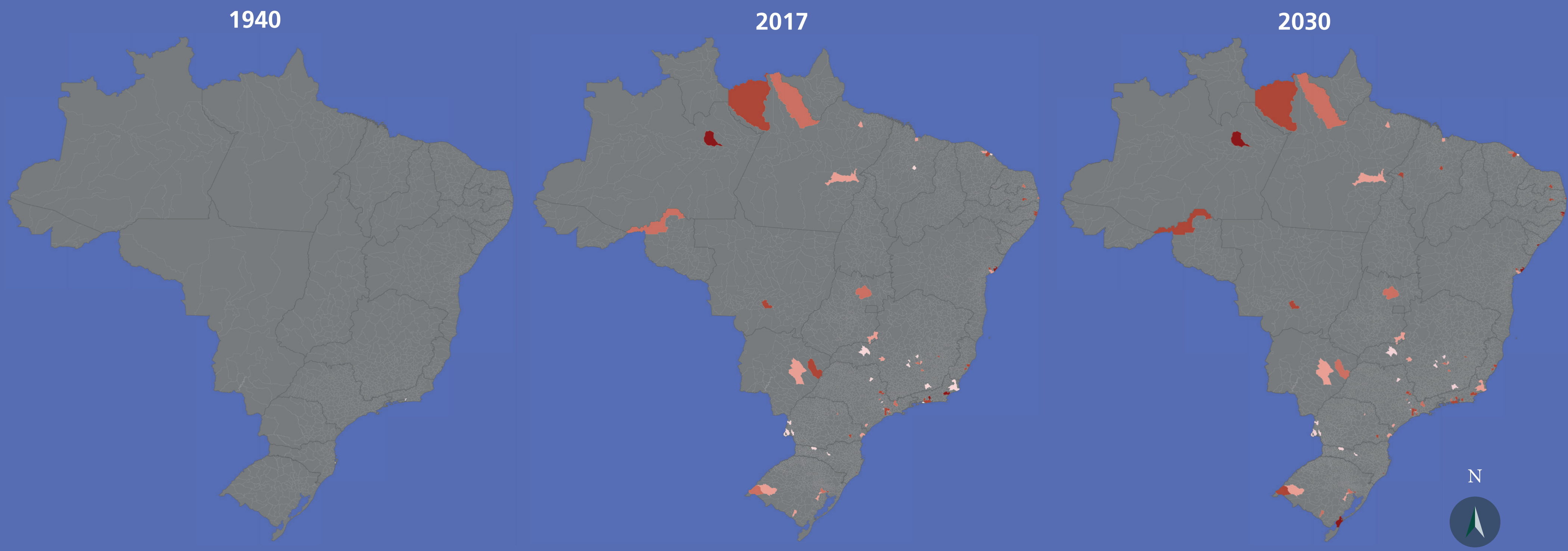


Figure 46 -Evolution of the Installed Electrical Capacity in Brazil.

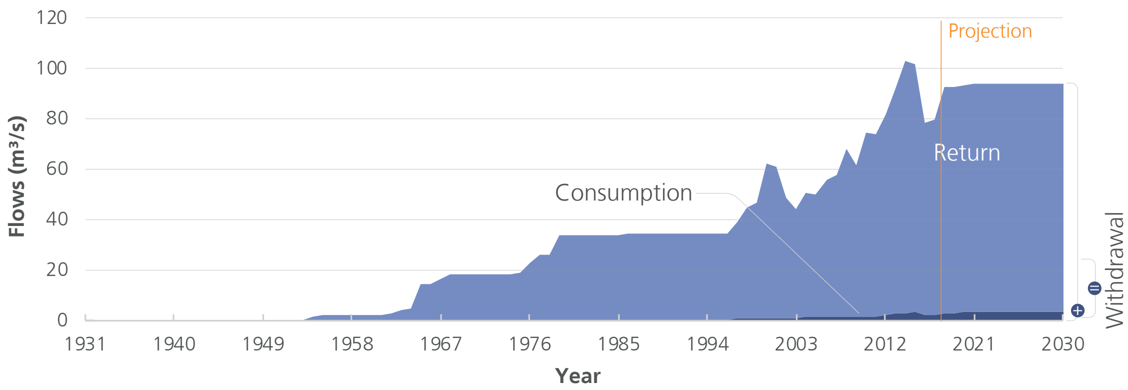
Source: adapted from the Situation Report 2017 (ANA, 2017).

Figure 47 – Withdrawal Series 1931 to 2030 - Thermoelectric Power Plants



Withdrawal Flows by Municipality (m³/s)

- 0.0002 - 0.06
- 0.06 - 0.3
- 0.3 - 1.7
- 1.7 - 8.2
- 8.2 - 38.0
- no demand



Largest Withdrawal Flows (m³/s) per municipality (2017) - Thermoelectric Plants

Ranking	FU	Municipality	Withdrawal Flow (m³/s)
1st	RJ	Rio de Janeiro	16.246
2nd	SC	Capivari de Baixo	10.620
3rd	MA	Imperatriz	7.036
4th	PE	Ipojuca	6.682
5th	SP	Mogi Guaçu	4.989
6th	ES	Serra	4.872
7th	PA	Barcarena	3.750
8th	AM	Manaus	3.468
9th	RS	Canoas	2.596
10th	PA	Oriximiná	2.206

The demands of municipalities where there is a concentration of large thermoelectric plants with high annual and intra-annual operational variability are highlighted in different federation units. The chart shows several peak years for demand, most recently in 2014 and 2015, due to unfavorable hydrological conditions for hydroelectric generation. In the 1930s and 1940s there was no water withdrawal for this use in Brazil, and the series began in 1954 in the city of São Paulo.

Detailed results of historical series of consumptive uses for all municipalities may be accessed at www.snirh.gov.br/usos-da-agua

8 LIQUID EVAPORATION OF ARTIFICIAL RESERVOIRS

Dam at the Ilha Solteira Hydroelectric Plant on the Paraná River
Raylton Alves Batista - Image Bank /ANA

8.1 Introduction

The liquid evaporation of artificial reservoirs is defined as the difference between the real evaporation of a water surface (gross evaporation) and the real evapotranspiration expected for the area if the reservoir had not been built.

Real evapotranspiration corresponds to water transported from land surface to the atmosphere by evaporation from the soil and transpiration from plants in real environmental conditions. The evaporation of a surface is affected by several factors, but fundamentally depends on the available energy from solar radiation. On water-free surfaces, air temperature, wind and vapor pressure more intensely interfere with the evaporation phenomenon.

Liquid evaporation is a major multiple consumptive water use and constitutes necessary information in reconstituting the natural flow series in the basins where these reservoirs are located, for example. The evaluation of this use becomes even more relevant in water scarcity and energy crisis scenarios. Given the continental dimensions of Brazil and, consequently, its hydroclimatic heterogeneity, it is a great challenge to build spatially representative databases and models.

In addition to the climate and characteristics of reservoirs, the mapping of scale and the quality of water mass mapping are other important aspects for estimating liquid evaporation. The database used comprises the 148 reservoirs of the National Interconnected System (SIN) – which occupy 31 thousand km² (Figure 50) – and about 7,200 other reservoirs spread throughout the territory - most of them small in size, occupying a total area of 9,5 thousand km². SIN reservoirs are well known and monitored, while for the other reservoirs it is difficult to establish a historical series for liquid evaporation, since there is usually no information available about the date of implementation of the reservoir or the variation history for the water surface area.

Considering the large numbers of water use for the liquid evaporation of artificial reservoirs, Figure 48 illustrates the variation of withdrawal flows in the federal units. The withdrawal flow is considered equal to the consumption (zero return). São Paulo, Minas Gerais, Bahia and Ceará are the states with the highest water consumption related to liquid evaporation, reflecting the history of large reservoirs being implemented for hydroelectric generation or for multiple uses, especially for public supply.

Figure 49 shows the distribution of the flows in the Brazilian regions and highlights the significant participation of the Northeast (33%), the Southeast (27%) and the Midwest (17%).

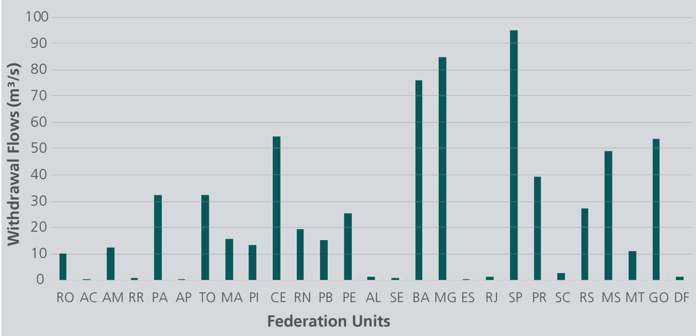


Figure 48 - Withdrawal Flows (m³/s) for Liquid Evaporation in the FUs

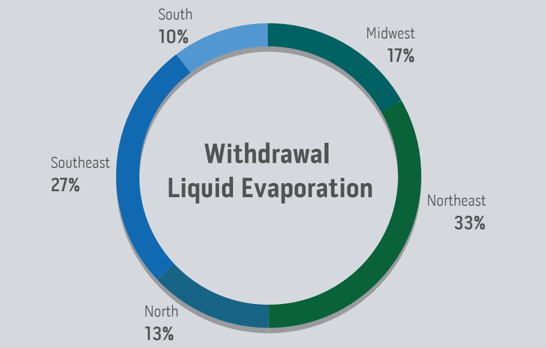


Figure 49 - Withdrawal Percentage for Liquid Evaporation in Relation to Total Withdrawal in Each Region

8.2 Method and Database

In this study, the estimate of the liquid evaporation height was defined based on the complementary relationship (Morton, 1983a; 1983b), using the CRAE models (Complementary Relationship Areal Evapotranspiration) for estimating the real evapotranspiration and the CRLE (Complementary Relationship Lake Evaporation) for obtaining the real evaporation of the lake. Liquid evaporation is obtained by subtracting the real evapotranspiration from the area of the real lake evaporation.

The CRAE and CRLE models were automated by the WREVAP software (Morton et al., 1985; McMahon *et al.*, 2013), which considers altitude (m) and latitude of the meteorological station, average temperature values (°C), relative humidity (%), annual average rainfall (mm) and insolation(h) (or global radiation), the temperature and insolation/radiation being the most sensitive parameters for the models. In the CRLE model, the salinity of the lake was considered null and all reservoirs were

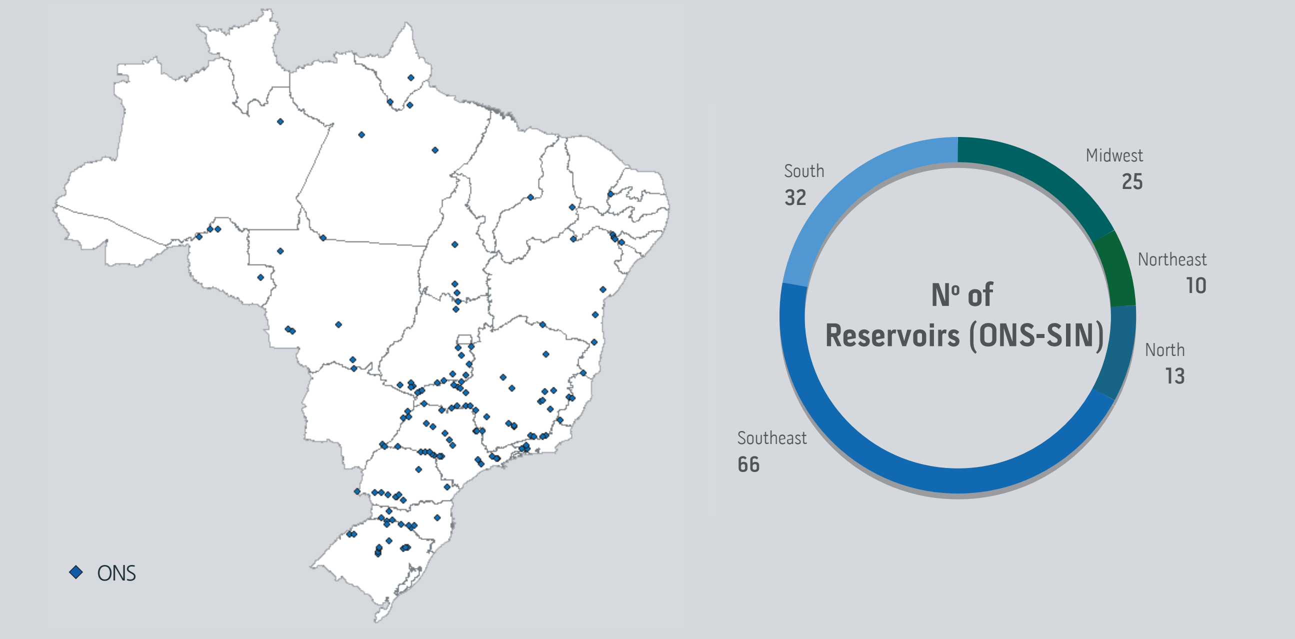


Figure 50 - National Interconnected System (SIN) Reservoirs Operated by ONS.

classified with constant depth (50 m). Thus, liquid evaporation series were calculated for 524 locations of conventional and automatic INMET meteorological stations, whose monthly data series were made consistent and available.

It should be noted that the conventional stations have long monitoring series made available by INMET, beginning in 1961. Automatic stations have more recent series, beginning in the 2000s. Automatic stations with at least 60 months of data were selected and those coinciding with the conventional stations were excluded. In this way, 524 meteorology stations were used by Brazil - 263 conventional (long series) and 261 automatic (shorter series with intensification in the 2000s).

The liquid evaporation monthly series obtained for the locations of the meteorological stations were interpolated for the other locations of artificial reservoirs. That is, a surface was calculated for each month/year pair. The pixel values that intersect the mapped surface were considered for each reservoir, together with the informed or mapped area corresponding to the lake surface. These calculations can be carried out for any

water body mapping base. In this study, the ANA database, which counts on 7,360 artificial water reservoirs with area above 20 hectares (ha) was used, in addition to 148 reservoirs operated by the ONS occupying 31 thousand km^2 (76.5%) and for which there is a monthly area variation history (Figure 50). The other reservoirs mapped total 9.5 thousand km^2 (23.5%) and a fixed area corresponding to the mapped area was used.

For most of the water reservoir areas there is an implementation date and the average monthly area variation history available. For the other water surfaces, a fixed area corresponding to the mapped area is adopted, noting that this variation tends to not be as dynamic as the reservoirs operated by the electric power sector. As this information becomes available, it will be possible to enter it into the calculation routine.

8.3. Results

Figure 51 shows the map with the average annual liquid evaporation height interpolated for the whole country, in addition to the distribution of the meteorological stations used in the study. The lower liquid evaporation values are concentrated in the North and South regions, which is explained by the higher volumes and regularity of rainfall. The highest expected values are observed in the Semi-Arid region, and even the possibility of negative liquid evaporation is observed in humid regions of the Amazon, due to the fact that the real evapotranspiration can surpass the evaporation of a lake in local environmental conditions.

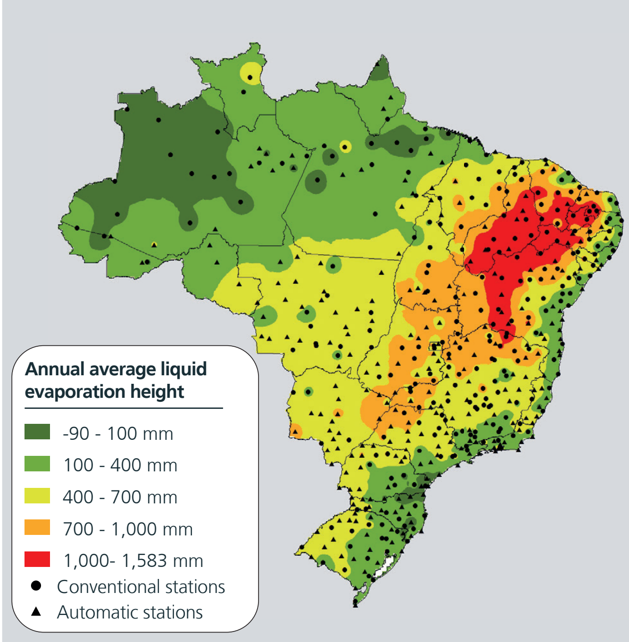


Figure 51 – Distribution of Annual Average Liquid Evaporation

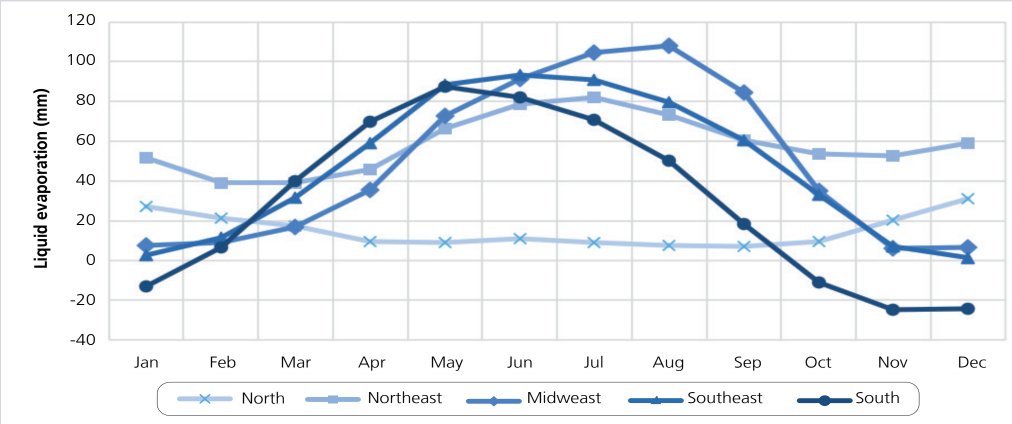


Figure 52 Monthly Liquid Evaporation Average by Brazilian Region

Figure 52 presents the monthly averages of liquid evaporation height by region of the country, highlighting magnitude and seasonality.

Figure 53 shows the behavior of the annual average liquid evaporation flows, reflecting inter-annual seasonality. In the reservoirs operated by ONS the complete series ever since the implementation of each reservoir are presented (1960 to 2017), representing the entry into operation dynamic of new reservoirs and climatic and average area variations in the water surfaces. The biggest jump identified in this national aggregate is verified between the year 1977 and 1979 with the filling of the Sobradinho lake - one of the largest artificial lakes in the world, with 4.2 km², located in an area with high evaporation rates.

Figure 53 presents the annual average liquid evaporation series between 2008 and 2017 for the other water surfaces.

Figure 54 shows the correlation between the values obtained by WREVAP/ANA and those previously obtained by ONS through the SisEvapo project (ONS, 2003; 2004). The average values of the two estimates are similar for the country, although the seasonal amplitude is greater for the series calculated by ANA, especially in the dry period of use located in the Centre-South (Cerrado biome areas), which leads to an increase in the estimated use values for this region.

Even though both estimates adopt Morton's complementary relationship (1983) operated by CRAE and CRLE models, as well as the monthly average surface areas, the climatological data series are quite different: ANA considers the monthly values observed in 524 meteorological stations across the country - 263 conventional (long series) and 261 automatic (shorter series wit intensification in the 2000s). In the case of the ONS study, 12 monthly fixed values were calculat-

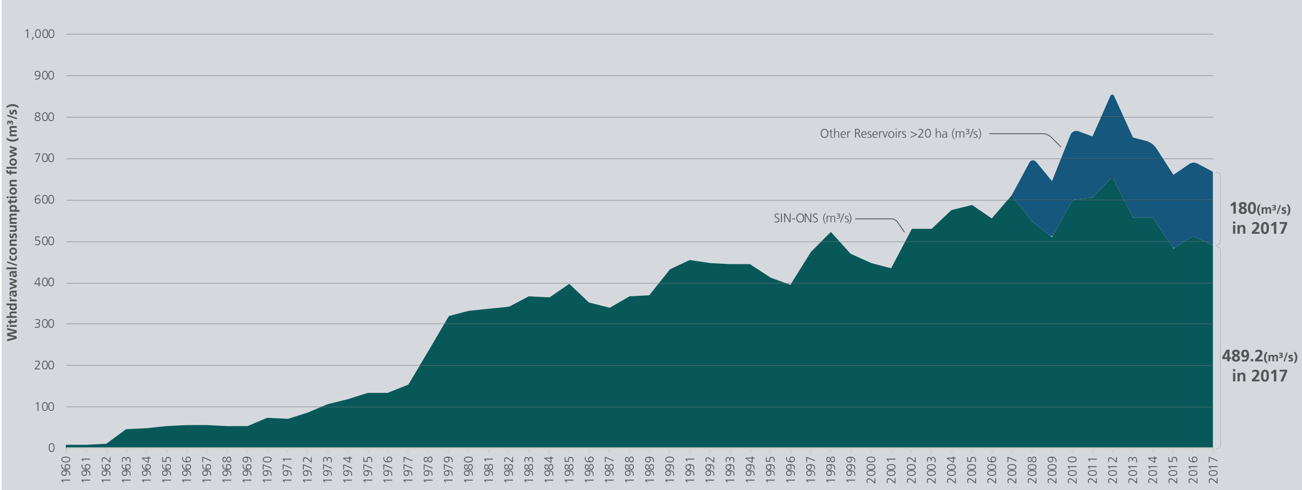


Figure 53 - Estimated Average Flow Rates for Electric Sector Reservoirs (SIN) and other Artificial Water Surfaces

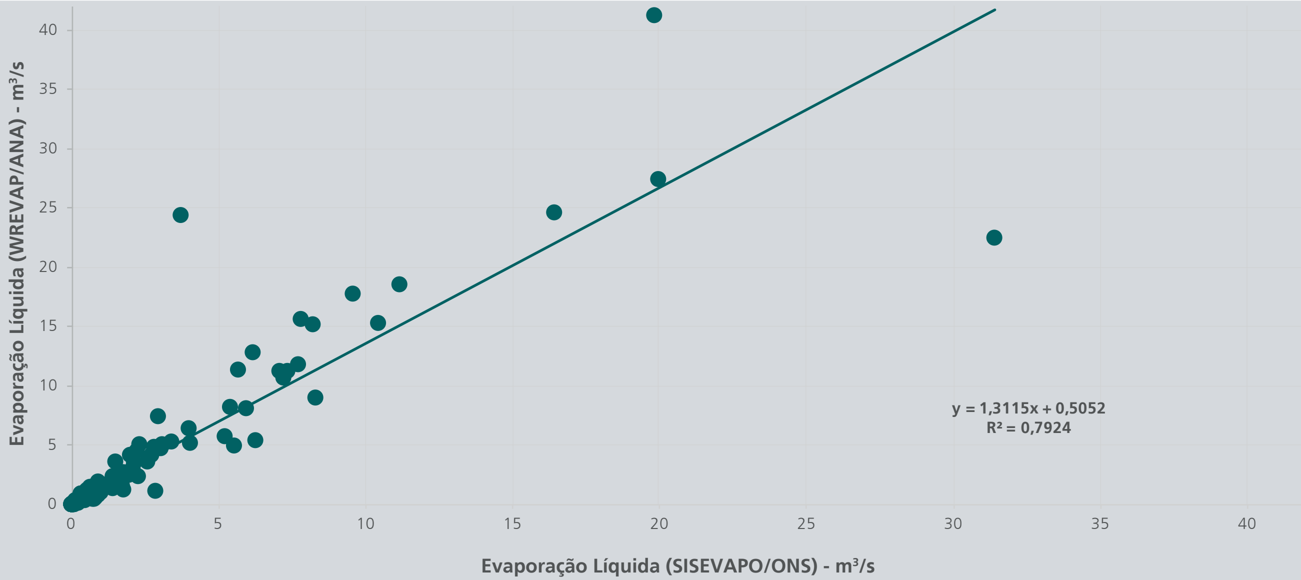


Figure 54 - Comparison between total annual flows of the Hydroelectric Plants calculated by SisEvapo/ONS and WREVAP/ANA.

ed using 205 stations with climatology averages between 1961-1990. Differences in data regionalization methods in SisEvapo and WREVAP/ANA, as well as the different adjustments and programming versions of the CRAE and CRLE models, can also explain differences in results.

Considering the consolidation of the results for the water mass basis used, the National Interconnected System (SIN/ONS) reservoirs totaled an annual average flow of 489.2 m3/s, and the other 179.9 m³/s in 2017. The proportion of demand (73.1% and 26.9% respectively) is similar to the proportion of area (74.5% x 25.5%). Figure 55 shows the spatialization of these results with emphasis on the reservoirs with demand higher than 1 m³/s in 2017.

The total withdrawal/evaporation consumption flow was 669.1 m³/s in 2017, placing this use as the second largest use in the country. Along the same lines as irrigation (withdrawal of 1.083 m³/s and consumption 792 m³/s), liquid evaporation presents significant seasonal amplitudes and its behavior is completely influenced by inter and intra-annual hydrometeorological conditions.

Considering the same universe of reservoirs, the liquid evaporation demand can total 759 m³/s in years with average climate and operation characteristics. In 2012, with climatic conditions drier than the average observed, liquid evaporation was at 850 m³/s (Figure 53).

Finally, it should be stressed that the currently produced results represent an important quality leap in the consolidation of databases and in the automation of liquid evaporation calculations. At the same time, further improvements will continue to be the subject of study by ANA.

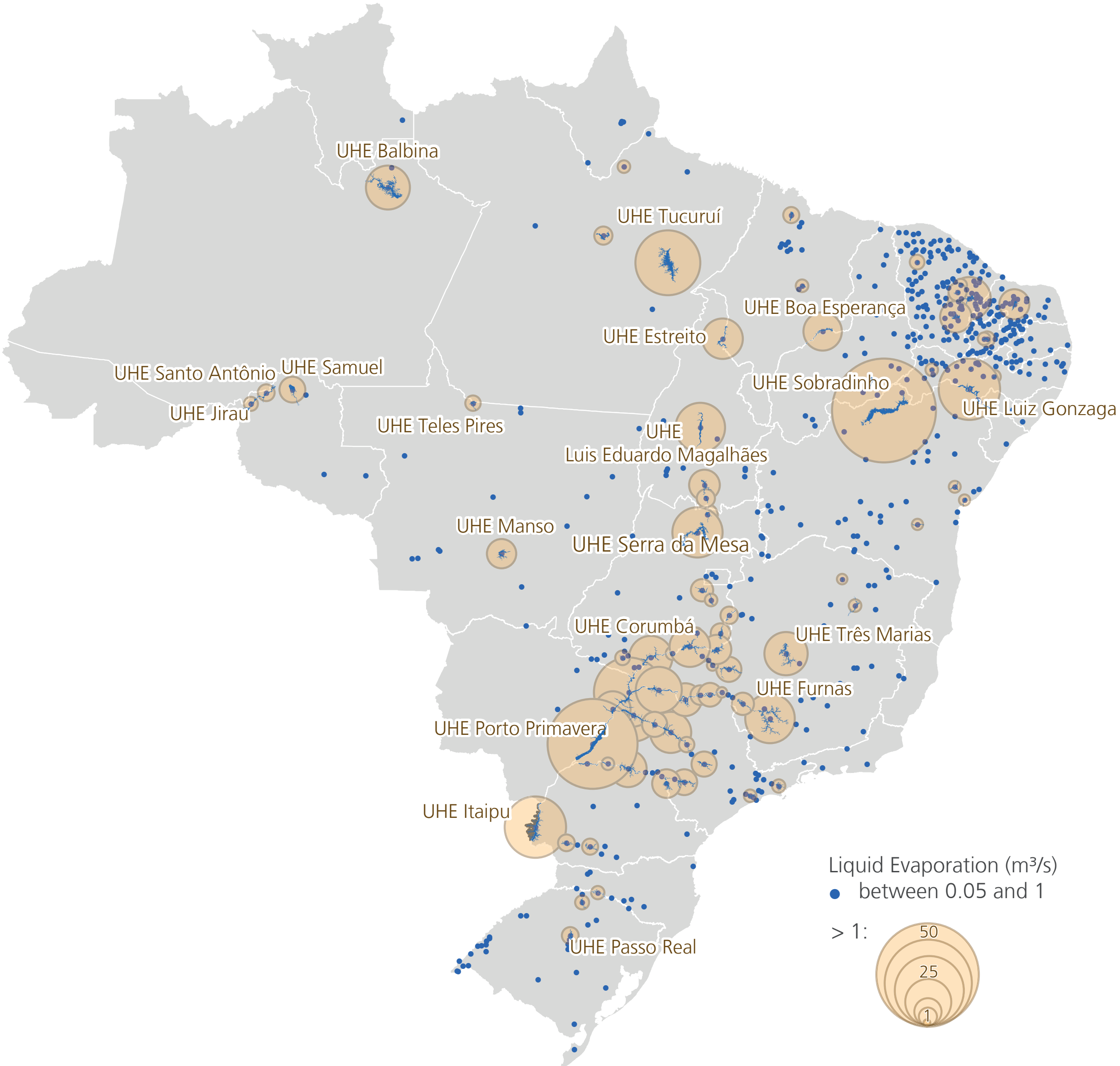


Figure 55 - Liquid Evaporation Flows from Artificial Reservoirs (above 0.05 m³/s).

FINAL CONSIDERATIONS

Amazonas Hydrographic Region - Amazonas, Acre, Rondônia, Roraima, Pará and Mato Grosso do Sul
Rui Faquini - Image Bank/ANA

The planning and management of water resources in Brazil requires accurate and up-to-date information about the country's water balance, that is, the relationship between water supply and water uses.

Studies on water supply have significantly advanced over the last few decades, with the extension of the hydrometeorological network and the provision of historical data series. The improvement of hydrological models and the ottocoded hydrographic database, in addition to other technological developments, have contributed to the more precise characterization of national water availability. Incorporation of climate change and its impact on supply has also been a new research frontier in planning studies.

Several improvement efforts have been undertaken by the National Water and Sanitation Agency - ANA in relation to water demand, these efforts follow two main approaches: the first relates to constant methodological and technological improvement, the second, consists of the production, refinement or recovery of consisted databases, that is, primary and secondary input data for estimate models.

The Handbook of Consumptive Water Use in Brazil is an important systematized result of the efforts towards the improvement and standardization of the estimates. It consolidates and extends the recent efforts to estimate water use in all municipalities of the Brazilian territory throughout a 100-year horizon, including future projections (1931-2030), which were unprecedented. In addition to the revision of traditionally surveyed uses - human supply (urban and rural), animal supply, processing industry, mining and irrigation – uses such as in thermoelectric power plants and the liquid evaporation of artificial reservoirs (multiple use) have been incorporated.

Great efforts related to the assembly of a consistent and updatable geospatial database support the presented results. This will allow the constant incorporation of methodological, technological and database advances.

The importance of strengthening partnerships with data producing and research institutes such as CONAB, EMBRAPA, IBGE and Brazilian Universities should be highlighted here; in addition to partnerships with international organizations such as FAO and the United States Geological Survey (USGS). The partnership with the Universities of the Federation Units should also be further explored and strengthened.

Through the wide dissemination and transparency of the results it is also expected that the users of this information will contribute to the improvement of methodologies and databases, especially regarding sectoral analyses at a municipal or micro-regional level.

The identification and quantification of current and potential uses in the Brazilian sub-hydrographic basins by economic sector also represents an opportunity to improve the participatory process in water management and the definition of operational agendas focused on sectoral action and the prioritizing of basins that present balance issues between offer and demand for water resources.

This new technical basis is now the national reference on water uses for the drafting of public policies related to water resources, water safety, sanitation, and regional development, all of which are the responsibility of the newly created Ministry of Regional Development (MDR), in addition to the interfaces with the electric power policy, considering that the national matrix mainly consists of hydroelectric power generation. Within the framework of the water resources management system, this information notably in the Water Resources Plans and in the approval of water grants. Thus, the new water use estimates will be at the core of the 2021-2035 National Water Resources Plan, guiding both the formulation and implementation, and the monitoring of this important instrument of the National Water Resources Policy.

In the sectorial sphere, this database provides the productive sectors with a new overview and a vision of the future of water uses, in addition to providing the water balances in the hydrographic basins of the national territory, combining risk analysis and water sustainability for the enterprises. The planning carried out by the states with the respective sectors will also rely on this reference information, which will guide important instruments such as the National and State Irrigation Plans and the revisions of the National Energy Plan.

The expansion of knowledge about water uses has important implications for water security analyses – a concept that includes guaranteeing water supply for human use and for productive activities. This knowledge supports both water supply management (water infrastructure, reservoir operation, negotiated water supply) and the management of the demand itself (rational use, control of demand, and reduction of losses in supply systems). It is also important to highlight the incorporation of the results of this study into the National Water Security Plan.

Finally, we reiterate that disaggregated results of the consumptive uses series generated in the study (1931-2030) by user sector and by municipality, as well as the interactive maps, indicator panels and other content, can be accessed at the National Water Resources Information System – SNIRH website, at www.snirh.gov.br > Usos da Água.

Rio Grande downstream of the Mascarenhas de Moraes (MG) Hydroelectric Power Plant
Raylton Alves/ANA Image Bank

BIBLIOGRAPHICAL REFERENCES

Dam System Canal - Pedra do Cavalo - BA
Eraldo Peres - Image Bank/ANA

AGÊNCIA NACIONAL DE ÁGUAS (Brasil). **Programa de ações estratégicas para o gerenciamento integrado da bacia do rio São Francisco e da sua zona costeira**: relatório final. Brasília: ANA, 2004.

________. **Disponibilidade e Demandas de Recursos Hídricos no Brasil**. Cadernos de Recursos Hídricos. Brasília: ANA, 2005, 134p.

________. **Relatório de Conjuntura dos Recursos Hídricos 2009**. Brasília: ANA, 2009, 204 p.

________. **Atlas Brasil:** abastecimento urbano de água: panorama nacional. Brasília: ANA, 2010.

________. **Manual de procedimentos técnicos e administrativos de outorga de direito de uso de recursos hídricos**. Brasília: ANA, 2013a, 252 p.

________. **Conjuntura dos Recursos Hídricos no Brasil:** 2013. Brasília: ANA, 2013b, 432p.

________. **Conjuntura dos recursos hídricos no Brasil:** informe 2015. Brasília: ANA, 2015, 88 p.

________. **Estudo de Modelagem Quantitativa e Qualitativa de Trechos de Rio em Bacias Hidrográficas Consideradas Críticas:** resumo executivo. Brasília: ANA, 2016.

________. **Água na Indústria:** uso e coeficientes técnicos. Brasília: ANA, 2017a, 76 p.

________. **Atlas Irrigação:** uso da água na agricultura irrigada. Brasília: ANA, 2017b, 86 p.

________. **Conjuntura dos Recursos Hídricos no Brasil 2017:** relatório pleno. Brasília: ANA, 2017c, 177 p.

________. **Levantamento da cana-de-açúcar irrigada na Região Centro-Sul do Brasil**. Brasília: ANA, 2017d.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (Brasil). **Boletim de Acompanhamento das Centrais Geradoras Termelétricas**. Brasília: ANEEL, 2016.

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop Evapotranspiration:** guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, n. 56. Rome: FAO, 1998.

AMARAL, L. G. H. do; RODRIGUEZ, R. del G.; PRUSKI, F. F.; RAMOS, M. M. Vazão retirada e consumo efetivo de água em diferentes sistemas de irrigação do arroz. **Engenharia na Agricultura**, Viçosa, v. 13, n. 3, p. 178-192, jul./set. 2005. Available at: <http://www.ufv.br/dea/reveng/arquivos/Vol13/v13n3p178-192.pdf>.

ARROYO, E. M. V. **Proposta metodológica para avaliação da vulnerabilidade da geração termelétrica a carvão mineral no brasil às mudanças climáticas**. Dissertação (Mestrado em Planejamento Energético). Rio de Janeiro: UFRJ/COPPE, 2012, 176 p.

AVERYT, K. et al. **Freshwater use by U.S. power plants:** electricity's thirst for a precious resource. Cambridge/MA: Union of Concerned Scientists, 2011.

BRASIL. Ministério do Meio Ambiente. Secretaria de Recursos Hídricos. **Plano Nacional de Recursos Hídricos:** Síntese executiva. Brasília, DF, 2006. 135 p.

BRASIL. Ministério de Minas e Energia. **Plano Nacional de Energia 2030**. Brasília: MME: EPE, 2007.

________. **Plano Nacional de Mineração 2030**. Brasília: MME, 2011b.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Brasil Projeções do Agronegócio 2010/2011 a 2020/2021**. Brasília: MAPA, 2011a.

BRASIL. Ministério do Meio Ambiente. Secretaria de Recursos Hídricos. **Desenvolvimento de matriz de coeficientes técnicos para recursos hídricos no Brasil:** relatório final dos coeficientes técnicos de recursos hídricos das atividades industrial e agricultura. [S.l. : s.n.], 2011.

BRASIL. Ministério das Cidades. **Sistema Nacional de Informações sobre Saneamento:** Diagnóstico dos Serviços de Água e Esgotos - 2016. Brasília: SNSA/MCidades, 2018, 220 p. Available at: <http://www.snis.gov.br>. Acessed on: 10 out. 2018.

CONFEDERAÇÃO NACIONAL DA INDÚSTRIA (Brasil). **Indústria em números (março/2017)**. Brasília: CNI, 2017, 8 p.

COSTA, A.D.M. **Quantificação de atributos físicos de solos de várzea, relacionados com a disponibilidade de água, o espaço aéreo e a consistência do solo**. Dissertação (Mestrado em Agronomia). Pelotas: UFPEL-FAEM, 1993, 134p.

DELGADO, A.; HERZOG, H. J. **A simple model to help understand water use at power plants.** Massachusetts Institute of Technology: Energy Institute, 2012.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). South African Water Quality Guidelines. **Livestock Watering**. ed. 2, 1996, 163 p.

EMBRAPA. **Cultivo do arroz irrigado no Brasil**. Embrapa Clima Temperado, 2003. Available at: <http://www.cpact.embrapa.br/sistemas/arroz/>. Acessed on: 09 maio 2005.

________. **Estimando o Consumo de Água de Suínos, Aves e Bovinos em uma Propriedade**. Cartilha. Concórdia/SC: Embrapa Suínos e Aves, 2005.

________. **Consumo de água na produção animal:** comunicado técnico 102. São Carlos/SP: Embrapa Pecuária Sudeste, 2013, 6p.

________. **Dados conjunturais da produção de arroz (Oryza sativa L.) no Brasil (1986 a 2017):** área, produção e rendimento. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2017. Available at: <http://www.cnpaf.embrapa.br/socioeconomia/index.htm>. Acessed on: 20 out. 2018.

FEDERAÇÃO DAS INDÚSTRIAS DO ESTADO DE SÃO PAULO. **Outlook Fiesp 2025:** projeções para o agronegócio brasileiro. São Paulo: FIESP, 2015.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). **Livestocks's Long Shadow:** Environmental issues and options, FAO, 2006.

GLEICK, P. et al. **Waste not, want not:** the potential for urban water conservation in California. [S.I.]: Pacific Institute, 2003

GOMES, A. do S.; PAULETTO, E.A. (Ed.) **Manejo do solo e da água em áreas de várzea**. Pelotas: EMBRAPA Clima Temperado, 1999. 201p.

GOMES, A. da S.; MAGALHÃES JUNIOR, A. M. **Arroz irrigado no Sul do Brasil**. Brasília: EMBRAPA Informação Tecnológica, 2004.

IBGE. **Estatísticas do Século XX**. Rio de Janeiro: IBGE, 2006, 577 p

________. **Censo Agropecuário 2006**. Rio de Janeiro: IBGE, 2009.

________. **Evolução da divisão territorial do Brasil 1872 - 2010:** conteúdo digital, 2011. Available at: <http://www.ibge.gov.br/home/geociencias/geografia/default_evolucao.shtm>. Acessed on: 11 set. 2014.

________. **Projeções da População:** Brasil e Unidades da Federação. Série Relatórios Metodológicos, v. 40. Rio de Janeiro: IBGE, 2013a, 40 p.

________. **Produção da Pecuária Municipal**. Rio de Janeiro: IBGE, v. 41, p.1-108, 2013b.

________. **Pesquisa Industrial:** empresa. Rio de Janeiro: IBGE, v. 35, n. 1, p. 1-44, 2016a.

________. **Pesquisa Industrial:** produto. Rio de Janeiro: IBGE, v. 35, n.2, p.1-20, 2016b.

________. **Produção da Pecuária Municipal**. Rio de Janeiro: IBGE, v. 45, p.1- 17, 2017.

IDAHO DEPARTMENT OF WATER RESOURCES (IDWR). **Domestic, Commercial, Municipal and Industrial Water Demand Assessment and Forecast in Ada and Canyon Counties**. Idaho: [s.n.], 2001.

INSTITUTO DAS ÁGUAS DO PARANÁ. **Plano Estadual de Recursos Hídricos do estado do Paraná:** Relatório 1.1.: Diagnóstico das Demandas e Disponibilidades Hídricas Superficiais. Curitiba, 2010.

INSTITUTO DE ENERGIA E MEIO AMBIENTE. **Uso de água em termoelétricas**. Série Termoeletricidade em foco. São Paulo: IEMA, 2016, 34 p.

INSTITUTO DE MEIO AMBIENTE DE MATO GROSSO DO SUL (IMASUL). SECRETARIA DE ESTADO DE MEIO AMBIENTE, DO PLANEJAMENTO DA CIÊNCIA E TECNOLOGIA. **Plano Estadual de Recursos Hídricos do estado de Mato Grosso do Sul**. Campo Grande: IMASUL: SEMAC, 2010.

INSTITUTO RIOGRANDENSE DO ARROZ (IRGA). **Cultivares**. [S.l. : s.n.], 2005. Available at: <http://www.irga.rs.gov.br/arquivos/cultivares.pdf>. Acessed on: 09 maio 2005.

KONIG, O. **Rendimento do milho sob três níveis estáticos de drenagem e irrigação sub-superficial em plano-sol (RS)**. Dissertação (Mestrado em Engenharia Agrícola). Santa Maria: Departamento de Engenharia Rural, Universidade Federal de Santa Maria, 1983, 85p.

MACHADO, R.L.; TURATTI, A.L.; MACHADO, A.L.; ALONÇO, A.S.; REIS, A. Estudo de parâmetros físicos em solo de várzea, antes e após escarificação. **Revista Brasileira de Agrociência**, v.2, n.3, p.175-178, 1996.

MARCHEZAN, E. et al. Desempenho de genótipos de arroz irrigado cultivados no sistema pré-germinado com inundação contínua. **Ciência Rural**, Santa Maria, v.34, n.5, p.1349-1354, 2004.

MAUPIN, M.A. et al. **Estimated use of water in the United States in 2010:** U.S.Geological Survey Circular 1405, 2014.

McMAHON, T.A.; PEEL, M.C.; LOWE, L.; SRIKANTHAN , R.; McVICAR, T.R. **Estimating actual, potential, reference crop and pan evaporation using standard meteorological data:** a pragmatic synthesis. Hydrology and Earth System Sciences, 17, 1331–1363, 2013. Available at: <http://www.hydrol-earth-syst-sci.net/17/1331/2013/>. Acessed on: 08 mar. 2017.

MEDEIROS, A. M. **Bases metodológicas para a incorporação da variável ambiental no planejamento da expansão termelétrica no Brasil**. Dissertação de mestrado. Rio de Janeiro: COPPE/UFRJ, 2003, 126 p.

MORTON, F.I.; RICARD, F.; FOGARASI, S. **Operational estimates of areal evapotranspiration and lake evaporation:** Program WREVAP. NHRI Paper 24. Ottawa: National Hydrology Research Institute, 1985.

MORTON, F.I. Operational estimates of areal evaporation and their significance to the science and practice of hydrology. **Journal of hydrology**, v. 66, p. 1-76, 1983a.

________. Operational estimates of lake evaporation. **Journal of hydrology**, v. 66, p. 77-100, 1983b.

NORTHERN IRELAND ENVIRONMEN AGENCY (NIEA). **How to Calculate Water Usage on Farms**. [S.l. : s.n.], 2009, 10p.

ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS - OMAFRA (Canada). **Water Requirements of Livestock**. Ontario, Canada, 2009.

OPERADOR NACIONAL DO SISTEMA ELÉTRICO (ONS). **Estimativa das vazões para atividades de uso consuntivo da água em bacias do Sistema Interligado Nacional – SIN**. [S.l. : s.n.], 2003a.

________. **Vetores de Evaporação Líquida para o Subsistema Nordeste** (ONS-NT-074/2003). Rio de Janeiro: ONS, 2003b, 41 p.

__________. **Evaporações líquidas nas usinas hidrelétricas**. Rio de Janeiro: ONS, 2004, 61 p.

__________. **Estimativas das Vazões para as Atividades de Uso Consuntivo da Água em Bacias do Sistema Interligado Nacional – SIN**. Brasília: ONS: FAHMA-DZETA: ANA: ANEEL: MME, 2005.

ORANGE, M.N. et al. California Simulation of Evapotranspiration of Applied Water and Agricultural Energy Use in California. **Journal of Integrative Agriculture**, 12(8), p. 1371-1388, 2013.

PEREIRA, R.M. et al. Viabilidade econômica da irrigação de cana-de-açúcar no cerrado brasileiro. **Irriga & Inovagri**, Botucatu, SP, p. 149-157, 2015.

PETRINI, J.A. et al. **Sistema de cultivo de arroz pré-germinado e transplante de mudas**. In: GOMES, A. da S.; MAGALHÃES JUNIOR, A. M. Arroz irrigado no Sul do Brasil. Brasília: EMBRAPA Informação Tecnológica, 2004.

ROSSATO, L. **Estimativa da capacidade de armazenamento de água no solo do Brasil**. Dissertação (Mestrado em Meteorologia). São José dos Campos: Instituto Nacional de Pesquisas Espaciais, 2001, 139 p.

ROSSATO, L.; ALVALÁ, R. C. S.; TOMASSELA, J. Variação espaço-temporal da umidade do solo no Brasil: análise das condições médias para o período de 1971-1990. **Revista Brasileira de Meteorologia**, v.19, p.113 - 122, 2004.

SCARPARE, F. V. et al. Sugarcane water footprint under different manegement practices in Brazil: Tietê/Jacaré watershed assessment. **Journal of Cleaner Production**, ELSEVIER, 1-9, 2015.

SHAFFER, K; RUNKLE, D. **Consumptive Water–Use Coefficients for the Great Lakes Basin and Climatically Similar Areas**. U.S. Geological Survey Scientific Investigations Report 5197. Virginia: USGS, 2007.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO (SOSBAI). **Arroz irrigado:** recomendações técnicas da pesquisa para o Sul do Brasil. Itajaí/SC: SOSBAI, 2003.

STILLWELL, A.S.; KING, C.W.; WEBBER, M,E; DUNCAN, I.J.; HARDBERGER, A. The Energy-Water Nexus in Texas. **Ecology and Society**, v. 16(1), n 2, 2011. Available at: <http://www.ecologyandsociety.org/vol16/iss1/art2/>. Acessed on: 12 fev. 2016.

SUPERINTENDÊNCIA DE DESENVOLVIMENTO DE RECURSOS HÍDRICOS E SANEAMENTO AMBIENTAL - SUDERHSA (Estado do Paraná). **Manual Técnico de Outorgas**. Curitiba: SUDERHSA, 2006, 107 p.

SUPERINTENDÊNCIA DO DESENVOLVIMENTO DO NORDESTE (SUDENE). **Plano de Aproveitamento Integrado dos Recursos Hídricos do Nordeste – PLIRHINE**. Recife/PE: SUDENE, 1980.

TOMASELLA, J., HODNETT, M.G., ROSSATO, L. Pedotransfer functions for the estimation of soil water retention in Brazilian soils. **Soil Science Society of America Journal**, 64, 327-338, 2000.

TRONCHONI, J.G. Pré-germinação e semeadura. In: ENCONTRO ESTADUAL DO SISTEMA PRÉ-GERMINADO EM ARROZ IRRIGADO, 1., Pelotas, 1995. **Resumos**... Pelotas: EMBRAPA-CPACT, 1995, p.41-45.

U.K. Environment Agency (EA-UK). **Waterwise on the Farm:** a simple guide to implementing a water management plan. UKEA: 2007.

UNIVERSIDADE FEDERAL DE MINAS GERAIS. **Cenários para a Pecuária de Corte Amazônica**. Belo Horizonte: Ed. IGC/UFMG, 2015, 146 p. Available at: http:<//csr.ufmg.br/pecuaria/>. Acessed on: 11 fev. 2017.

U.S. DEPARTMENT OF AGRICULTURE (USDA). **Irrigation water requirements**. Tech. Rel. n. 21, 1970.

U.S. GEOLOGICAL SURVEY (USGS). **Method for Estimating Water Withdrawals for Livestock in the United States:** 2005. [S.I.]: USGS, 2009.

VASCONCELLOS, E.B. **Levantamento dos atributos físicos e hídricos de três solos de várzea do Rio Grande do Sul**. Dissertação (mestrado em Agronomia). Pelotas: UFPEL-FAEM, 1995, 120 p..

WARD D.; McKAGUE K. Water requirements of livestock. **FactsSheet**. v. 5, p. 07-23, 2007.

WEBER, L.; MARCHEZAN, E.; CARLESSO, R.; MARZARI, V. Cultivares de arroz irrigado e nutrientes na água de drenagem em diferentes sistemas de cultivos. **Ciência Rural**, Santa Maria, v.33, n.1, p.27-33, 2003.

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