Facing the Challenge of Extreme Climate: the Case of Metropolitan São Paulo

by

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ABSTRACT

Climate variability has always posed important challenges to water resources planners and engineers. Recent hydrologic data from different parts of the world show that the use of traditional stationary series statistical methods to assess risk and uncertainty may not produce reliable estimates. In particular, the 2014 – 2015 drought in Metropolitan Sao Paulo that was followed by a major flooding in 2016 shows the intensification of climatic extremes in this part of Brazil. The probability of this drought event is only 0.004 when estimated with data available from 83 years of record, until 2013. The critical drought of 2014-2015 is as an outlier or it is necessary to consider it in the planning as an event that can occur again along the planning horizon? The paper describes the hydrologic conditions that resulted in the most severe drought experienced by the State and the structural and non-structural initiatives taken by water authorities to avoid social chaos in the Metropolitan Region of São Paulo (21 million inhabitants). Furthermore, it discusses how the drought affected the existing water resources development plan, especially the anticipation of investments on water security. Because financial resources are limited, other investments, equally important but less urgent, are being delayed.

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Introduction

Water availability, both in quantitative and qualitative terms, is today one of the major concerns of both the business community and government authorities worldwide. Water is a fundamental element in achieving food, energy and health security. Water is the engine for socio-economic development. In September 2015 the United Nations General Assembly passed the resolution 70/1 - Transforming our world: the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) - in which a standalone target on water was approved. A recent report issued by the U.S. National Security Council (2012) claims that “water may become a more significant source of contention than energy or minerals out to 2030 at both the intrastate and interstate levels”.

Given the importance of water in the global scene and understanding that peoples’ concerns about climate are not climate per se, but the consequences of excess or lack of water resources due to climate change, we must prepare ourselves to increase our resilience to climate variability. By and large, all the impacts of climate variability are manifested through, by and with water whether you talk about impacts on ecosystems or hydrological extremes.

Hydrologic extremes have recently manifested themselves in different parts of the planet. It is salient the case of the States of California, Texas and Arizona in the United States since 2013; Australia has gone through the Millennium drought from 2000 – 2010; Singapore has faced unexpected climate during 2013 to list some of many situations around the world. In all these cases, we have noticed the importance of water infrastructure and demand management to face the challenge.

The State of São Paulo in SE Brazil has experienced its most severe water crisis in the historic hydrologic record during 2014 – 2015. This extreme drought is as an outlier or it is necessary to consider it in the planning as an event that can occur again along the planning horizon? The paper describes the hydrologic conditions that resulted in the most severe drought experienced by the State and the structural and non-structural initiatives taken by water authorities to avoid social chaos in the Metropolitan Region of São Paulo.

Furthermore, it discusses how the drought affected the existing water resources development plan, especially the anticipation of investments on water security. Because financial resources are limited, other investments, equally important but less urgent, are being delayed.

The physical and hydrologic context

Figure 1 shows the 12 hydrographic regions of Brazil and their correspondent freshwater availability, in terms of average annual yield. Brazil has 12 % of the world's freshwater resources, but as can be appreciated in the figure, most of this water is concentrated (70%) in the Amazon basin that hosts 7% of the Brazilian population. SE Brazil, which is the focus of this paper, is located in the Paraná Basin that shows the third larger average availability (361 km³/year).

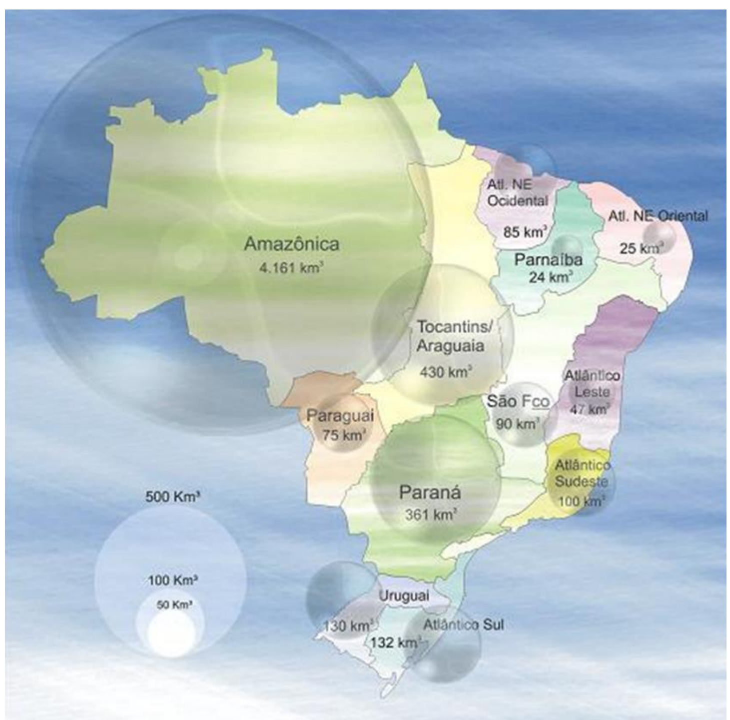

Figure 1. Brazil and its 12 major hydrographic regions

There are three States in SE Brazil: Sao Paulo, Minas Gerais and Rio de Janeiro. The population of Sao Paulo is 43 million, which corresponds to 21% of Brazilian population[3], and the GDP is equivalent to 32 % of Brazil[4].

A recent report from the National Water Agency of Brazil – ANA (2015) indicates that SE Brazil has experienced in 2014 anomalous precipitation patterns. Figure 2 shows the rainfall amounts and the correspondent return periods during the rainy season (January, February and March) for years 2012 – 2014. Warmer colors represent drier climate (red means return interval of the seasonal precipitation larger than 100 years). It can be appreciated the exceptionality of year 2014 for a large extension of central and eastern State of São Paulo.

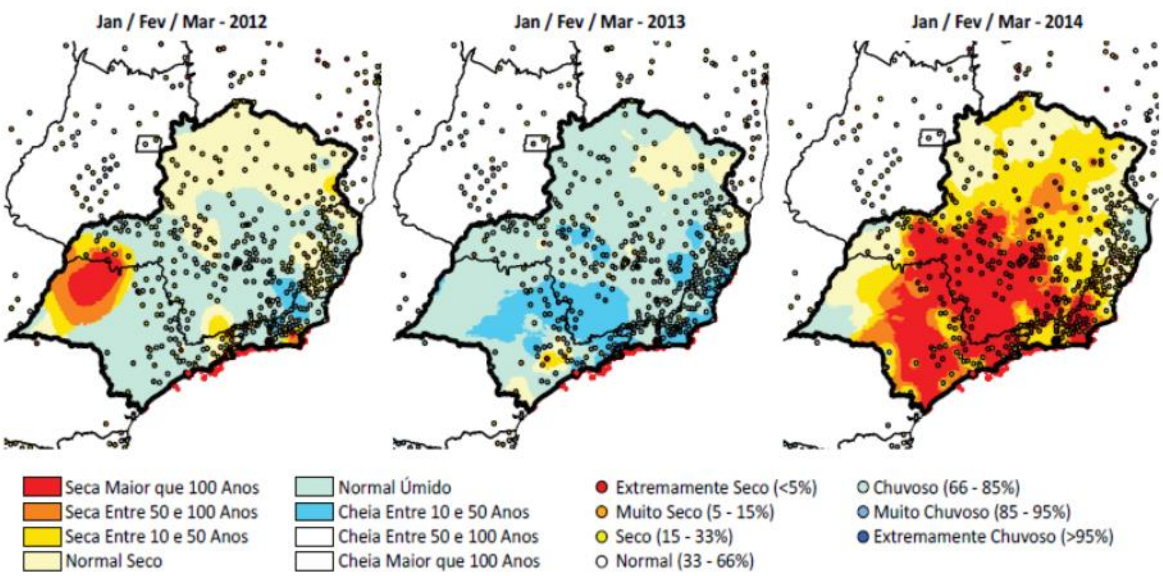

Figure 2. Criticality of rainfall during rainy period (JFM) for 2012 – 2014 in SE Brazil (ANA, 2015)

Figure 3 shows the average annual rainfall distribution in the State for the period 1979 – 2013.

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[3] http://www.bibliotecavirtual.sp.gov.br/temas/sao-paulo/sao-paulo-populacao-do-estado.php

[4] https://pt.wikipedia.org/wiki/Lista_de_unidades_federativas_do_Brasil_por_participa%C3%A7%C3%A3o_no_PIB

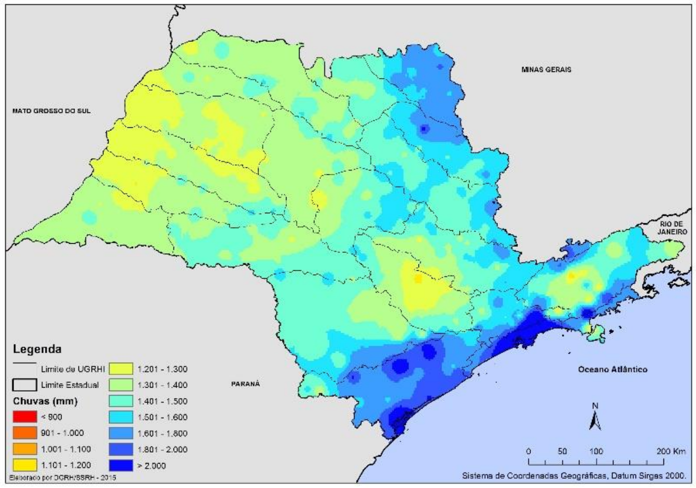


Figure 3. Annual Precipitation in the State of São Paulo (1979 – 2013)

Figure 4 shows the contrast with what happened during 2014.

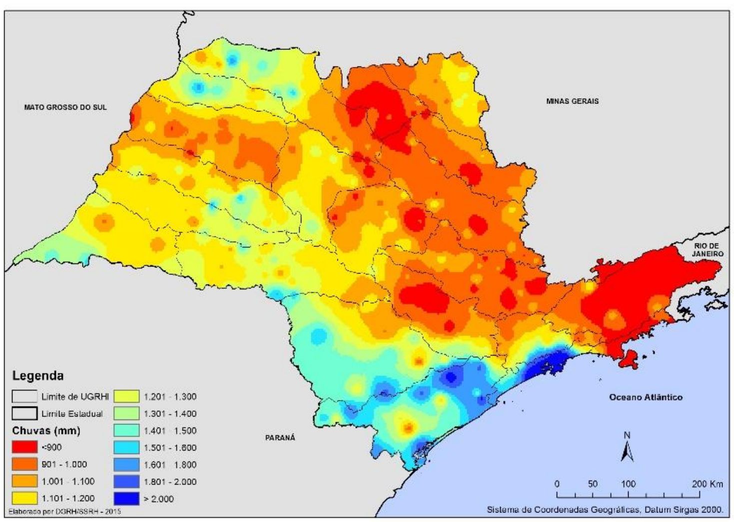


Figure 4. Annual Precipitation in the State of São Paulo in 2014

During the drought, most of the northern and eastern parts of the State experienced annual rainfall below 900 mm, while the average annual rainfall is above 1,200 mm. This situation led the Water Resources Department of the State of Sao Paulo (DAEE) to issue water permits exclusively for the water supply of the population. Many municipalities in these areas passed municipal decrees of “state of public calamity” by which they became entitled to receive state and federal funds and to use expedite bidding processes for emergency civil works. Figure 5 shows the water resources management regions affected and the respective municipalities involved.

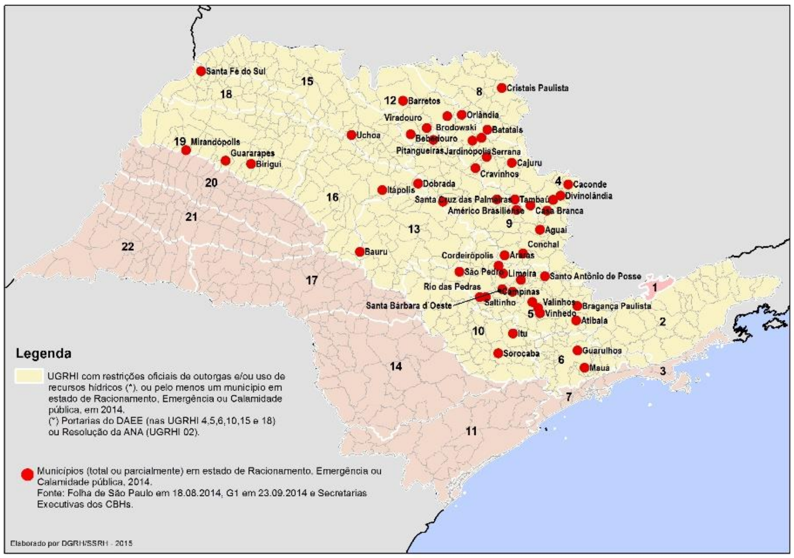


Figure 5. Water resources management units and municipalities affect by the 2014 drought

The Case of the Sao Paulo Metropolitan Region – SPMR

SPMR is located in the upstream reach of the Tiete River, a tributary of the Parana River (Figure 6). It is the most active economic region of Brazil (18% percent of Brazilian GDP), with a population of 21 million[5]. Eight water treatment plants (Figure 6) operated by SABESP (Water and Sanitation Company of the State of Sao Paulo) provide all the potable water for SPMR. Their joint Maximum Production Capability – MPC is almost 73 m^3/s. Based solely on the hydrologic record available before the 2014-2015 drought, the

[5] https://www.pdui.sp.gov.br/rmsp/https://www.pdui.sp.gov.br/rmsp/

firm yield from the rivers and reservoirs feeding these water treatment plants would roughly match the MPC. However, if the full hydrologic record is used, including the years 2014-2015, the firm water yield shrinks to less than 52 m³/s. This 31% drop is the most vivid expression of the severity of the drought.

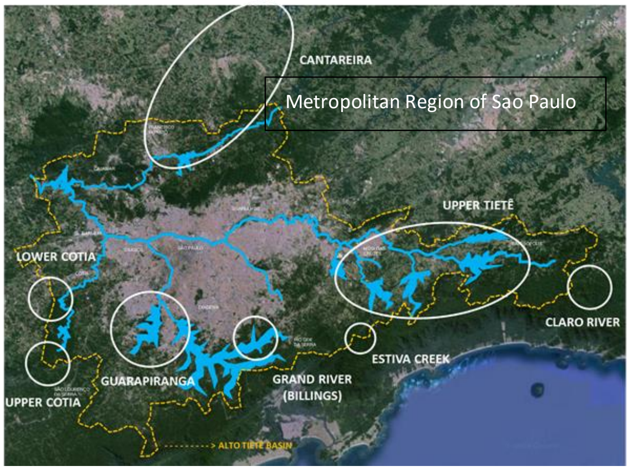
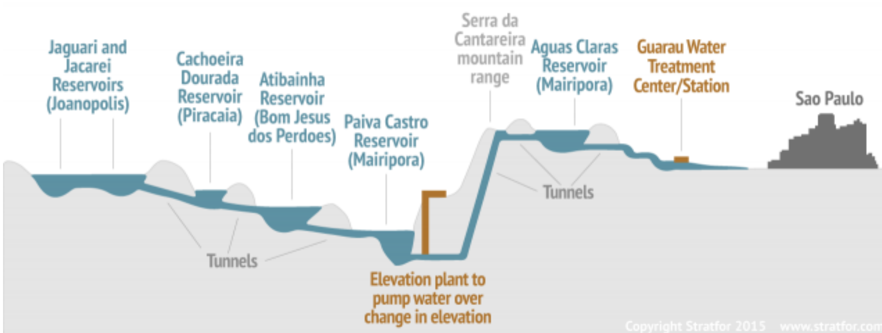


Figure 6. Water sources in the Metropolitan Region of São Paulo - MRSP

MRSP draws most of its water from the neighboring Piracicaba river basin through the Cantareira System (Figure 6). Water travels some 80 km through a set of interconnected reservoirs, tunnels, channels and pumping stations (Figure 7) comprising one of the largest water supply schemes in the world, with a nominal capacity of 33 m³/s (Barros and Netto, 2010). Figure 8 shows the monthly inflows to the Cantareira system. The magnitude of the drought experienced by this system, that provides almost 50% of the supply, is such that the 2014 inflow to Cantareira was roughly 50% of the all-time low discharge along 83 years of record, which had occurred in 1953.



.........**Figure 7. The Cantareira System is a set of reservoirs linked by tunnels, a pumping**

plant and a treatment plant with installed capacity of 33 m³/s

As a result, in January of 2015, the Cantareira System storage was just at 5% of maximum storage, including dead storage, and the water level was several meters below the intake elevation. Since May 2014, water had being pumped out from the dead storage.

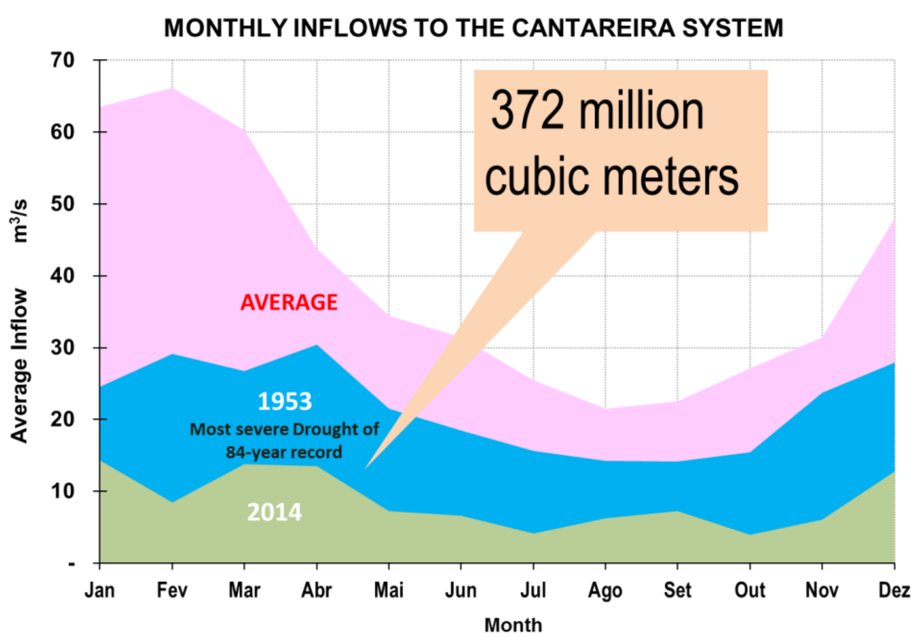


Figure 8. Monthly Hydrographs of the Inflows to the Cantareira System

Table 1 compares the potable water production in February 2014, just before the adoption of anti-crisis measures (described later) with the production in April 2015, when these measures were in course.

Table 1 Potable water production before and during the water crisis (m3/s)

SYSTEM	FEB/14	APR/15	DIFF
Cantareira	31,77	13,48	-18,29
Guarapiranga	13,77	15,05	+1,28
Alto Tietê UPPER TIETÊ	14,97	12,25	-2,72
Rio Grande GRANDE RIVER	4,94	5,09	+0,15
Rio Claro CLARO RIVER	3,83	3,87	+0,04
Alto Cotia UPPER COTIA	1,16	0,76	-0,40
Baixo Cotia LOWER COTIA	0,88	1,01	+0,13
Ribeirão Estiva ESTIVA CREEK	0,096	0,086	-0,010
TOTAL SPMR	**71,42**	**51,60**	**-19,82**

The water supply system operated by SABESP serves practically the entire population that lives in the formally urbanized area of SPMR, where one can find meters in virtually all households. However, this is not the case in many of the informal settlements, where roughly 10% of the population lives (IBGE, 2011). Most people living in the informal settlements have illegal and unpaid access to potable water through precarious and wasteful distribution systems formed by a bundle of small diameter plastic tubes connected to the mains (Figure 8).

Several barriers impede the water utility from entering these irregular settlements to provide regular services. Some relate to judicial disputes about the land ownership (people have invaded private property), other to environmental restrictions (people have invaded protected areas), and still other – the majority – to the impossibility of installing water supply and sewage collection systems in neighborhoods where there are no streets to bury the pipes. This unorganized urbanization process began in the fifties, when only 30 per cent of the Brazilian population lived in the cities, and has grown worse, especially in the early 1970s with the intensification of the industrialization process.

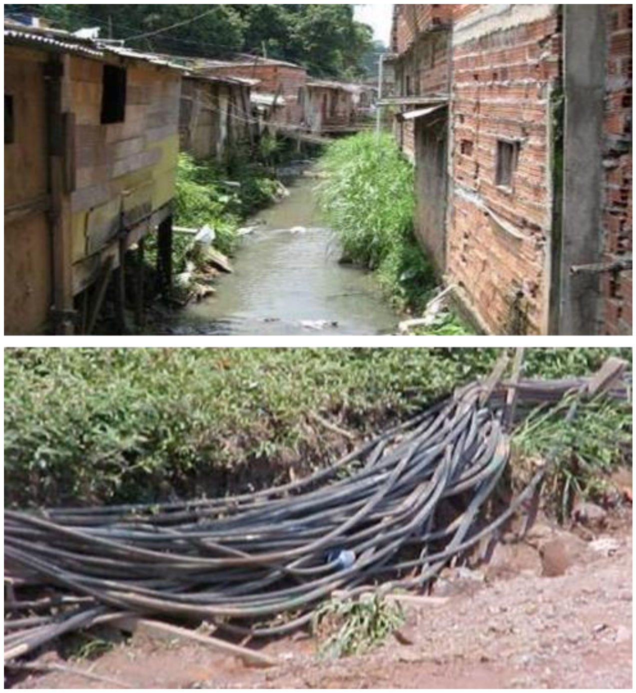


Figure 8. Illegal Connections in Informal Settlements

In a few years, the urban population swelled to 70 per cent of the national population, but the infrastructure growth was much slower, resulting in several problems. Among them, a large quantity of untreated sewage dumped into the local water bodies, impelling the search for new water supply sources far away from the demand center (Braga et al., 2006). In spite of difficulties, practically all people living in metropolitan São Paulo have access to potable water in their households, either through formal or informal connections.

Facing the Challenge of the 2014-2015 drought

The strategy adopted by the State Government and SABESP to face this potential social disaster included the implementation of structural (building of emergency infrastructure) and non-structural measures (demand management via economic instruments and raising public awareness) (Figure 9).

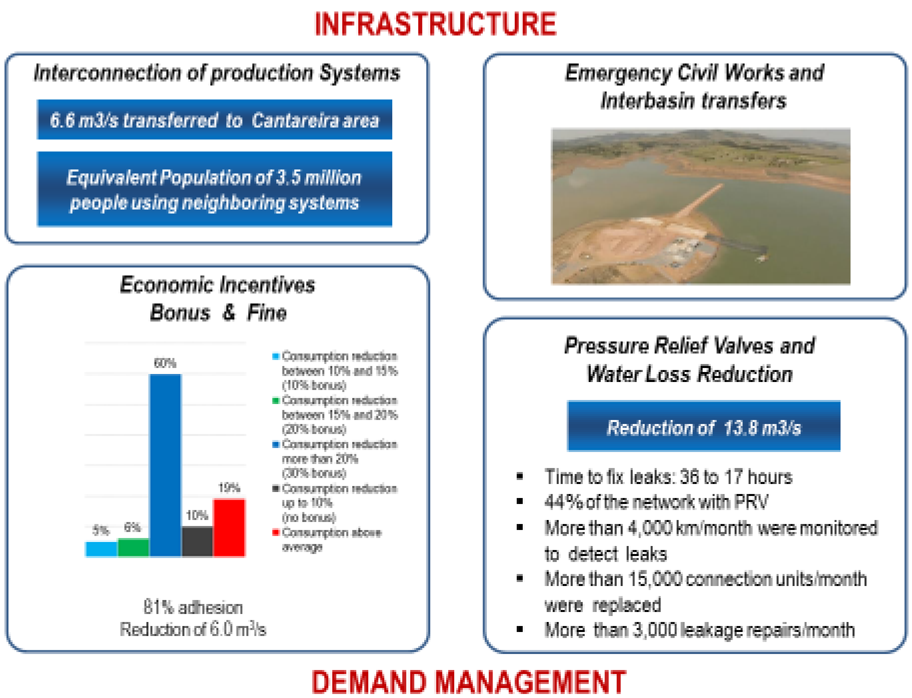


Figure 9. Strategy to fight the drought of 2014 in Metropolitan Sao Paulo

INFRASTRUCTURE DEVELOPMENT

Emergency Civil Works

When water level was approaching the minimum elevation necessary for the free flow through the intake of the upstream Jaguari reservoir (Figure 10), SABESP installed a set of floating pumps and built channels and cofferdams in order to pump up water from the dead storage to a provisional upper pond built adjacent to the intake (Figure 11).

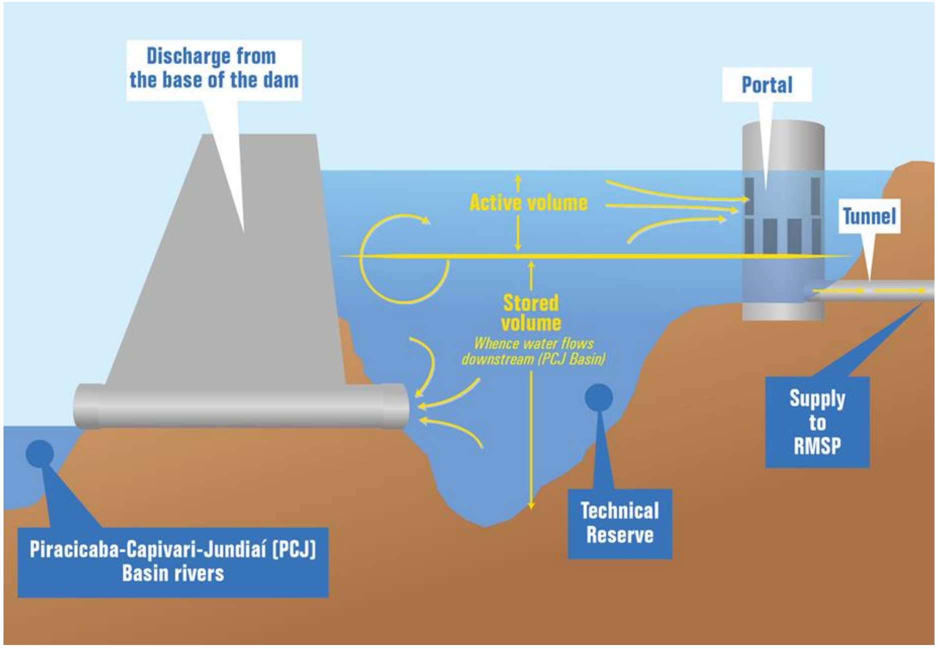


Figure 10. Tapping the Dead Storage of Jaguari Reservoir

Figure 11. Floating pumps and cofferdam to tap Dead Storage

This simple engineering solution stirred a public debate fueled by the media about alleged health hazards for the people that would drink water from the "dead" storage. In fact, this was a false problem because a bottom gate had been, for many years, continuously releasing water from the reservoir to downstream in order to ensure the minimum environmental flow along the natural waterway. Nevertheless, it was necessary a strong media action to explain that there was no risk to the health, including the change of the name “dead storage” to “technical reserve”.

Interbasin transfers and Interconnection of Production Systems

Many construction works were performed in the distribution network during 2014 – 2015 in order to increase the operational flexibility of the eight producing systems of the SPMR. In this way, sectors that before the crisis were only be supplied with water from the Cantareira System began to receive water from other better-stocked producing systems. Some 3.5 million people stopped consuming water from Cantareira, and instead received water from the Guarapiranga, Upper Tiete and Grande river systems.

Since April 2015, the Grande river system has also became a new source of supply for some 250,000 people who were previously served by Guarapiranga system. This was achieved by installing 2.1 km of water mains to carry the water to the southern part of the city. The surplus water from Guarapiranga was redirected to areas previously served by the Cantareira system. At the end of May 2015, it was the Claro river system’s turn to boost its contribution to the area previously attended by the Cantareira, with a new link being installed between two water mains in the eastern part of São Paulo.

Pumping stations and mains that had been decommissioned due to excessive leakage were refurbished. In the case of the Franca Pinto pumping station and main, this required the injection of HDPE piping into 550 m of the 6,600 m water main. This allowed an additional supply from Guarapiranga to help the sector served by the Cantareira system.

The steps taken during the two-year period 2014-2015 to increase the operational flexibility of water production and distribution relieved the water sources most affected by the drought. Overall result was the increase of the capacity to transfer flows between the production systems by 6.6 m^3/s. This meant that 3.5 million people that previously received water exclusively from the Cantareira started to also receive water from other systems (Figure 11).

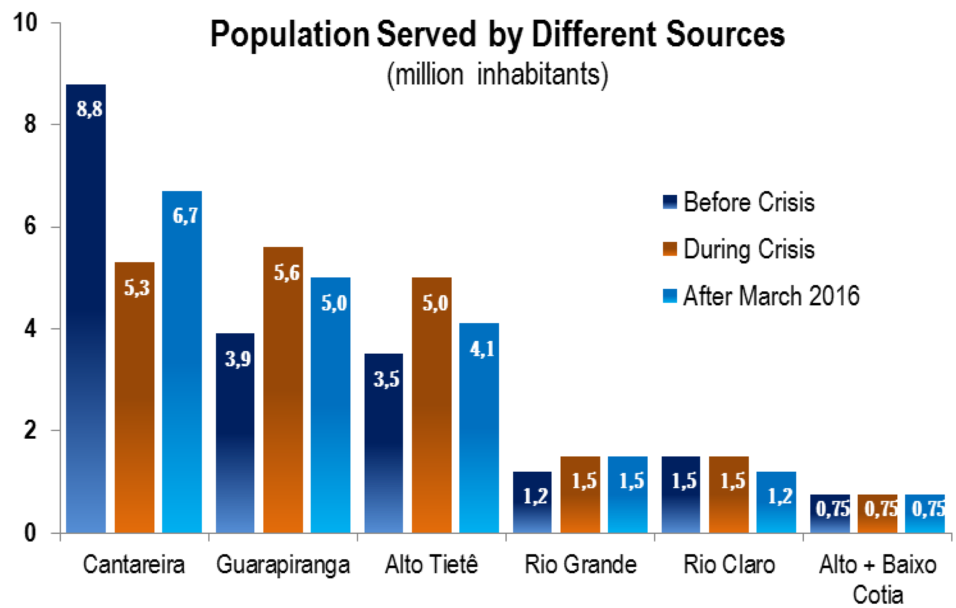


Figure 11. Interconnection of sources and population served

An important initiative undertaken in 2015 was the constructions of the pipelines to interlink different water sources. The Grande river and the Upper Tiete river systems were interconnected by two parallel water mains made of high density polyethylene (HDPE) with a flow capacity of 4 m^3/s over a distance of 10.5 km (Figure 12). This construction work also stirred much public debate, mostly fueled by the press, and a litigation presently is in course in the Judiciary. Some feared that this arrangement would jeopardize the quality of the drinking water. Others were concerned with the impacts on the environment. Still others used the debate as a political weapon to blame the Government for alleged poor planning. It was necessary to launch a difficult battle at the public opinion front.

Figure 12. Interconnection of water sources Grande River and Upper Tiete river systems

Once the links were in place for redistributing areas of the city from one production system to another, the next step was to increase the water treatment capacity and to build new water storage within the distribution system. A module of ultrafiltration membranes was installed at the Guarapiranga, increasing its capacity production from 14 m^3/s to 16 m^3/s. Steel storage reservoirs were installed in different sectors of the city, to supplement supply safety. These reservoirs provide a reserve of treated water and uninterrupted supplies to districts, which are located far from the principal water mains. During the crisis, 22 reservoirs with a storage capacity of 147,000 m^3 were installed and are now operating.

DEMAND MANAGEMENT

Pressure Relief Valves and Water Loss Reduction

The MRSP´s distribution system is divided into sectors for better management. Boosters pump the water to serve regions at a higher altitude and pressure relief valves

(PRVs) installed at lower levels alleviate leaks and eventual damages to the pipes and other structures. PRV technology is used in the best systems worldwide and has been used in MRSP since the 1990s. PRVs are also used for remote control of pressure at times of low demand, such as the early hours of the morning, when there is more pressure in the networks. Starting in October 2014, with the worsening of the drought, the water loss due to leakages decreased 7.6 m^3/s, which corresponds to around 42% of the total water savings during the crisis, thanks to the pressure reduction in the distribution system that was extended to time intervals beyond the early hours of the morning. This policy resulted more effective than the traditional method of rotating shut downs among sectors.

At the start of 2016, the periods of pressure reduction returned to normality, that is, were restricted to nighttime. Currently there are 1,303 PRVs operating in the SPMR. During the crisis, a large number of these PRVs were installed, representing today a coverage of 55% of the distribution network, which consists of 33,000 km of secondary pipes and 1,200 km of water mains.

Reducing water losses has been a priority of the water supply sector in the State of São Paulo for more than two decades. In 2009, SABESP introduced the Corporate Loss Reduction Program, in technical partnership with JICA (Japan International Cooperation Agency) with forecasted investment cash flow until 2020 of R$ 5.5 billion. The objective is to decrease the unaccounted for water down to 18%. In 2015 the unaccounted for water corresponds to 27.1%, which includes 17.8% due to leakages (Figure 13).

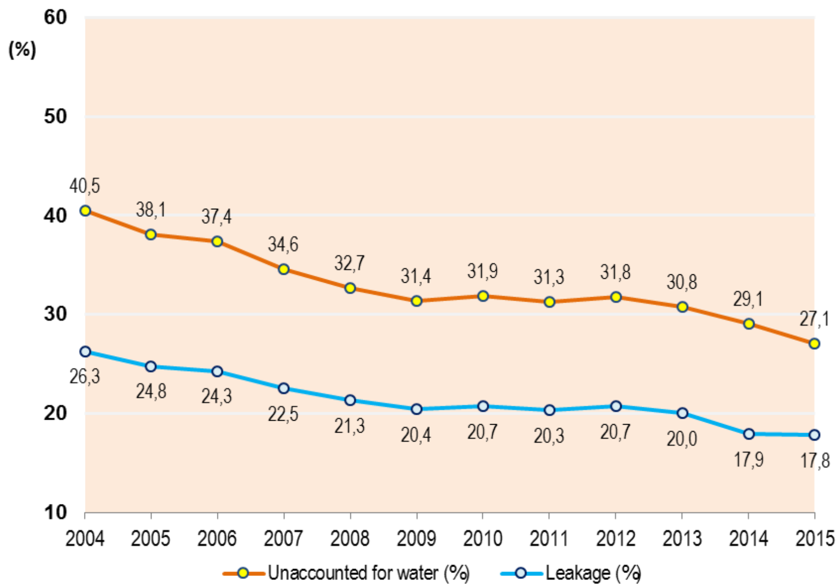


Figure 13. Water losses in Metropolitan Region of São Paulo

The reduction of leakages demands the installation of PRVs, substitution of mains, acoustic sweeps to locate leaks (so far, more than 87,000 repairs) and substitution of connection pipes to households (so far, more than 280,000 branches). The reduction of non-physical losses due to illegal connections or frauds, as well as inaccurate metering, demand respectively the action of anti-fraud patrols and the substitution of meters. In 2015 alone, it was possible to identify a volume of 3.7 billion liters illegally consumed and to replace more than 255,000 water meters.

Economic Instruments – Bonus and Fines

The granting of bonuses to those who reduce water consumption and charging of a contingency tariff to those who waste water were strategic measures to restrain demand. Starting in February 2014, at the beginning of the crisis, a discount on the water bill (bonus) was granted to the water savers. That is, to those that would decrease water consumption, compared to their own average, of at least 20%. This program got support from the majority of the families. More than 80% of the consumers indeed reduced consumption, from which 49% received discounts in 2014 and 70% in 2015. The net effect was a lumped reduction of 3.5 m^3/s in the potable water production, which corresponds to around 19% of the total water savings during the crisis (Figure 14). Starting in January 2015, a penalty was imposed to those who did not understand the severity of the crisis and increased the consumption. Some 19% of consumers were in this situation, but 8% were exempt from the charge because they did not exceed the minimum consumption level of 10 m^3 per month.

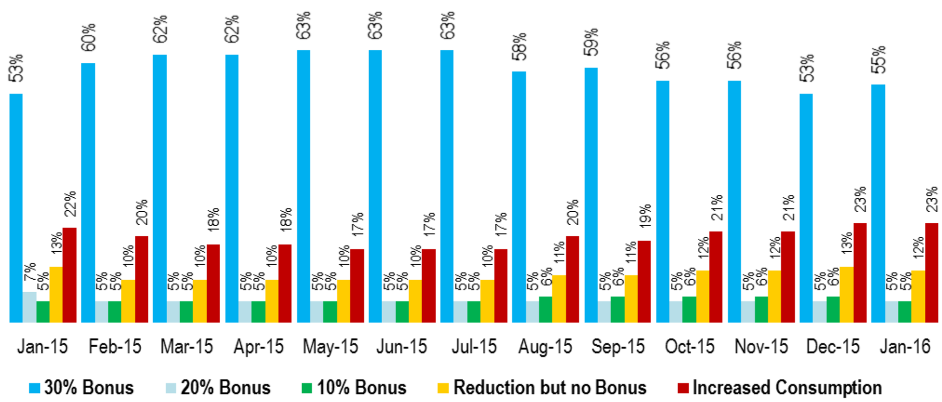


Figure 14. Impact of economic instruments in water consumption in MRSP

Communication campaigns

The Government of the State of São Paulo and SABESP encouraged conscientious use of water through visits, lectures and the distribution of posters and leaflets at condominiums, schools, commercial establishments and homes, making people aware of the importance of economizing water. Concurrently with the growing press coverage, eight advertising campaigns were also carried out in 2014, with over 3,000 TV insertions and other 13,000 radio insertions, besides publications in newspapers and magazines, allowing estimating that each São Paulo State citizen has been reached, at least, 40 times by water-saving messages.

In February 2015, the State government began a campaign called Each Drop Counts, reinforcing the relevance of the water rational use. More than 20 million printed materials were distributed by the “Guardiões das Águas” (Water Guardians) team. Campaign teams made almost 74 thousand visits in 2015. Two million people were approached directly and almost 20 million indirectly. Additionally, it was necessary to launch a media campaign consisting of ads, spots and publicity by radio.

Figure 15 shows the compound effect of economic incentives and communication campaigns in the consumption pattern of the population of MRSP. These incentives have produced a reduction of 25% in prevailing per capita water consumption. It is expected that this lower per capita consumption will persist for many years to come.

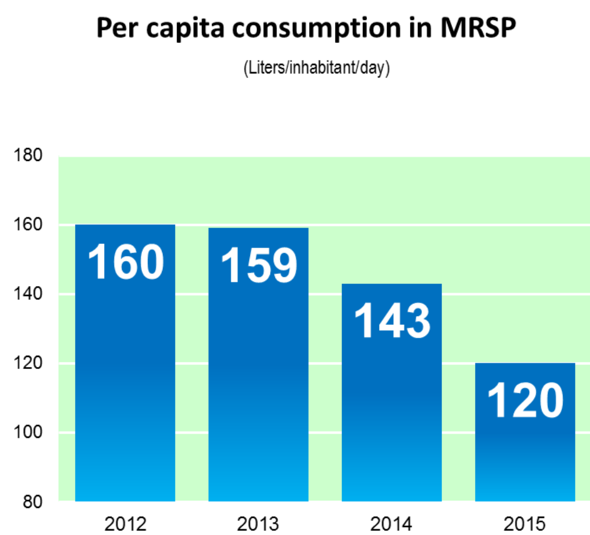


Figure 15. Impact of non-structural measures in per capita consumption in MRSP

Reduction in Water Supply Production of the Cantareira System

Figure 16 synthetizes the overall result of all these actions: it was possible to reduce potable water production from approximately 32 m^3/s to 13 m^3/s. The breakdown from different actions show that this enormous saving were due to: PRV/leakage reductions (7.7 m^3/s); interconnection of systems (6.6 m^3/s); economic incentives (3.4

m³/s) and reduction in supply to partner utilities in MRSP (0.8 m³/s). This reduction of almost 60% was essential to avoid Cantareira storage from hitting the bottom, which would mean a major collapse in the water supply system of MRSP (Figure 17).

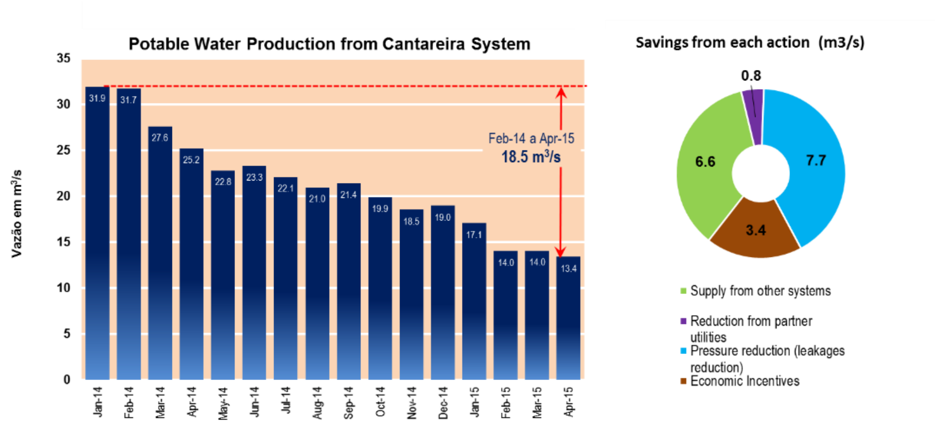


Figure 16. Water Supply Production in MRSP during water crisis

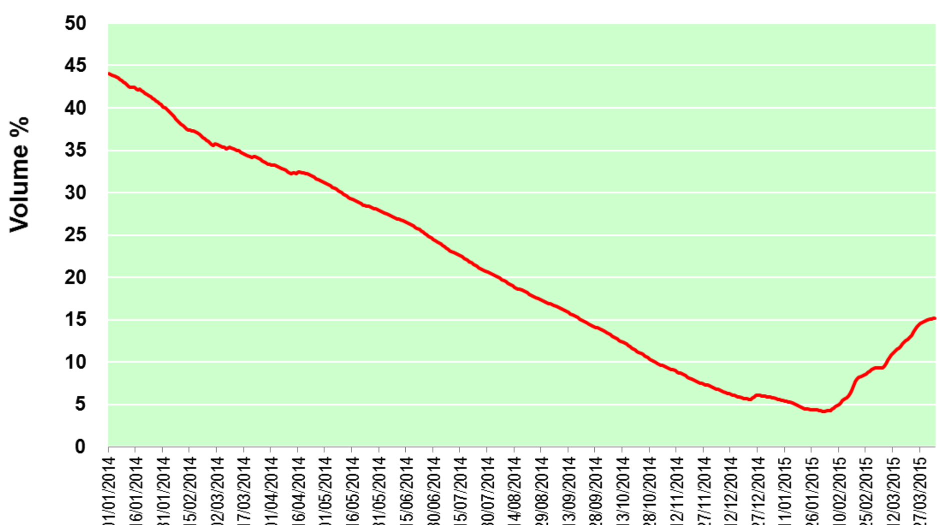


Figure 17. Depletion of storage in the Cantareira System during the crisis

LESSONS LEARNED

The worst drought in the history of RMSP could have led to social unrest. The storage level in the most important water source system reached the impressive mark of 5%. A combination of structural and non-structural measures including an important collaboration from the population in using water more efficiently were essential in facing this challenge. A large number of emergency water infrastructure have been implemented in record time allowing a more flexible use of the 8 reservoir systems in the region. Today, the RMSP is far better prepared to face much worse droughts than those foreseen in the various water resources plans produced since the 1960s.

Based on a long time series and assuming stationary conditions, the 2014-2015 is such a rare event that one could be tempted to consider it as an outlier, with no relevant consequences for planning. However, the prudent decision maker has to consider that the stationary hypothesis may be wrong, due to climate and land use changes, and that the prudent attitude is to be prepared for the repetition of similar events (the “firm yield” criteria). For this reason, the Government of the State of Sao Paulo and SABESP have decided to invest heavily on new strategic infrastructure to secure normal water supply, even if the adverse water situation observed in 2014-2015 occurs again. Part of this new infrastructure is currently under construction, namely the interbasin transfers from nearby basins (Ribeira River Basin - 6.4 m^3/s and Paraiba do Sul River Basin - 8.5 m^3/s). A third interbasin transfer, the Itapanhau River Basin (up to 2.5 m^3/s) is currently under environmental impact assessment.

Reducing wastage is another fundamental task to guarantee supplies. In the last ten years, the State Government has made major efforts in this direction. However, much more needs to be done. A key initiative is being launched by the State Government for demand management including: subsidies for the poor to install domestic water efficient equipment; low interest rate loans for apartment owners to install individual metering and regulation for non-potable water reuse. SABESP is working towards eliminating the maze of pipes scattered along the alleyways of the irregular but irreversibly established settlements. This of course will require articulation with city councils and the Public Attorney`s Office. The Catholic Church, which included sanitation as a theme of its 2016 Fraternity Campaign, is another important partner.

Giving priority to works to underpin water security means, inescapably, that other equally important, but less urgent, investments have to be postponed. This situation, however, does not exclude the permanent goal of providing sewage collection and treatment services for everyone.

Another important lesson learned from the water crisis is that there is an urgent need to review how water supply and sanitation tariffs are established. When population rightly become more parsimonious on the water use, the income of water utilities decreases. SABESP relies solely on revenues from consumers for operation and expansion of the system supply. No subsidies from taxpayers are provided.

It is also necessary for society and the courts to understand that the purpose of sanitation is to maximize social wellbeing with the resources available, making water treatment and distribution the priority, followed by sewage collection and, lastly, by sewage treatment. In other words, Brazil has to follow the example of developed countries: put people's health above any other consideration. It makes little sense, therefore, to use the scarce financial resources of the water companies to pay the so-called "environmental compensation" fees, which are penalties intended to punish companies for polluting the rivers or the ocean during the period that sewage is collected but not treated. Such impositions have the effect of eliminating resources that are extremely necessary for the expansion and improvement of the quality of these services.

CONCLUSIONS

The water crisis that RMSP suffered in the two-year period 2014-2015 is an example that the impacts of climate variability and change are felt in water sector. This impact was magnified by the fact that the drought hit a densely populated area. The consequences could have been catastrophic if structural and nonstructural measures were not timely implemented.

Tapping water from the dead volume of the largest reservoir in the Cantareira system through the construction of cofferdams and the use of floating pumps was an essential measure in such crisis. The interlinking of storage reservoirs was fundamental to provide flexibility in the joint operation of the three major water sources in the region. Structural integration, in the form of extending the system to sectors belonging to other water sources, was made possible by a series of operations, such as refurbishing the water mains and the pumping stations, and replacing or adapting boosters. To increase water treatment capacity, the option selected took into account the advantages offered by membrane filtration technology. The stocks of treated water at strategic points was increased with the construction of sector reservoirs, minimizing interruptions in supply. Large investments were necessary to reduce physical and commercial water loss by replacing networks, branch lines and water meters, and by strict measures to control fraud.

Demand management is fundamental to face the challenge of a water crisis. The economic incentives provided by the water utility allowed a significant reduction in the consumption rate. The contingency tariffs, with reduction for those saving and increase for those using water in excess, worked admirably. However, the extension of these incentives for a long period of more than a year affected severely the income of water utility. SABESP had to adjust its budget to anticipate investments on water infrastructure needed to increase water security at a time when there was a severe drop in revenues due to the combination of lower water sales and lower tariffs. The unavoidable result was a temporary slowdown in initiatives already under way to expand the sewage collection and treatment.

As the Chinese wisdom teaches, every crisis represents an opportunity - for innovating, for changing paradigms and, above all, for implementing sustainable long-term solutions. After two years of intense challenges and much hard work, the population and the political class are much more aware of the importance of water security. The lesson learned is that in the future we need to be more resilient to the vagaries of climate. This implies more infrastructure and good governance through strong public institutions, efficient regulatory agencies, adequate legal frameworks and the consciousness of the population to use water parsimoniously and efficiently.