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Management Potential of Aquifers in the Greater São Paulo Region, Brazil

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Abstract

Ground water is an increasingly important component of the water resources of the Greater São Paulo region- GSP- (8,051 km²). This study provides an understanding of the functioning of regional ground water systems, their potential, and management options,. Two main aquifer types have been distinguished in this area: Tertiary sedimentary deposits (1,452 km²) and Precamrian bedrock (6,599 km²) with deeply weathered mantle. Although not being highly productive (10-50 m³/h), they are of considerable importance, particularly for domestic water supply, industrial use. The amount of free water stored in pores and fissures of basement water-bearing formations (10.000 million m³) was evaluated using an average thickness for the saturated aquifer zone of 50 m and a specific yield of 3%. The Tertiary formations of the S5o Paulo Basin consist mainly to sand, silt and clay of fluvial origin. The amount of water stored in the sedimentary deposits (9,000 million m³) was evaluated using an average thickness for the saturated aquifer layers of 100 m and a specific yield of 6%. While rainfall is infiltrating into the ground-water reservoir, other ground water is discharging into streams. It should be emphasized that values of the ground water discharge, characterizing the natural productivity of the aquifer systems, are the main indicator of ground water resources availability in an area. The average baseflow recession for the upper Tietê River basins represents available resources in the crystalline rock context of 2,343 million m³/year, and in the sedimentary deposits of 900 million m³/year. The amount of water that leaks from the public distribution system, which gets most of its Water from a complex reservoir networks located in the upper basins of the Tietê and Piracicaba (55 m³/sec) rivers, represent an induced recharge of about 500 million m³/year (1 5 m³/sec). The long-term experience in ground water development has shown that is advisable to develop the natural resources of the aquifers (3,243 million m³/year). Nevertheless, taking into account the urban development and the high heterogeneity of the water-bearing formations, the available resources have been estimated at being 25% of the annual discharge values.

As a result, it is advisable to recover about 600 million m³/year (18 m³/sec) from the Precambrian aquifer zones, and about 200 million m³/year (7 m³/sec) from the sedimentary deposits. The total amount of 25 m³/sec represents around 50% of the current total municipal water consumption of the GSP area. The current total withdrawal by the around 10,000 existing drilled wells in the GSP is difficult to estimate because most comes from uncontrolled private wells. The State Water Plan (1990) reports that the withdrawal of ground water in GSP was estimated to be about 200 million m³/year, or only 25% of the available resources. Thus, the amount of ground water which can be obtained with rational water intakes in technical-economic terms, and with the water quality satisfying the standard requirements, may supply one-third of the suburban and urban population and industrial establishments. The suburban areas of the GSP are expected to become increasingly dependent on the ground water supply. The water production costs are very low, between US$ 10 to 40 cents/m³, for wells of 100 to 150 m deep, and yields between 10 and 30 m³/h, with pumping rates of 16 h/day. The wise use of ground water in the GSP involves two general principles: protection of ground water quality, and utilization of available resources for their higher or most valuable use to society.

General Features

The Greater São Paulo-GSP- covers 8.051 km², and is located at the Southeast part of the State of São Paulo-Brazil. Currently, the 39 Municipalities forming the GSP are home to about 16 million inhabitants.

International congress of IAH, 26, 1995. Proceedings. CD-Rom.

The area is crossed by the Tropic of Capricorn and has a subtropical climate-, its average annual temperature is 20°C, varying from a low average of 14°C in winter (July) to a high of 26°C in summer (January). Average annual rainfall ranges from 1,500 to 2,000 mm, and can reach 4,000 mm/year in neighboring hill areas. The relief is undulated, with elevations ranging from 700 to 900 m above sea level.

During the last decades GSP has become a strong industrial centre, producing goods for both national consumption and for export. Some of the most important industrial activities include metallurgy, automobile manufacture, chemical, mechanical, textile, and food industries, resulting a Gross Industrial Product-GIP- of about 100 billion US$. The regional environmental dilemma is that the scale on which water resources are being consumed and wastes are being produced.

Brazil is a federation of states, and under the Federal Constitution the responsibility for ground water use and protection rests with the state governments. In São Paulo state the Departamento de Aguas e Energia Elétrica- DAEE- is the administrative body responsible for ground water use and protection. Other concerned organizations are environmental state agencies, water supply companies and universities.

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The needs to have an integrated management of surface and ground water is a consensus of all technicians dealing with the water resources. Unfortunately our governors and administrators have not been sensitive to the needs to have a detailed knowledge about ground water and/or the development and maintenance of a technical staff, materials and services.

The last decade has seen a significant increase of interest and profitability in the business of ground water use in the GSP. This study results from a convention celebrated between SABESP-São Paulo Water Supply and the Centre for Ground Water Research-CEPAS, University of São Paulo. This contract follows CEPAS urban hydrogeology research that have been carried out with the financial supports from FAPESP, FINEP/ PADCT-Brasil, and IDRC-Canada.

The Hydrogeologic Maps

Although the patterns of surface water resources are relatively well known and the potentials of surface reservoirs on principal rivers of the upper Tietê basin have been extensively appraised, knowledge on the GSP's ground water resources are still limited.

Consequently, the primary step of this research was to provide a synoptic representation of water-rocks related information, based on the available geologic maps (1:50,000) and technical reports. The methodic approach puts major emphasis on permeability and porosity of the geologic context, to identify the vocational hydrogeologic characteristics of the different geologic and/or lithologic units, as well as the structural features such as fault lines, contacts between rock types, and other breaks indicated by lines on geologic maps.

The second phase consisted of the inventory of the available data of selected drilled deep wells, considering: lithologic logs, well yields, water quality, hydraulic conductivity, specific yield, storage coefficient, geophysic logs. The data base of the DAEE and of the major private drilling companies have been the main source of the data.

The integration of all these data has resulted in hydrogeologic maps which provide information about the presence of ground water. A set of 22 sheets at the scale of 1:50,000 covers the GSP.

The hydrogeological maps portray the following information by colours, symbols, lines or patterns:

- Lithologic composition and structure of hydrogeologic units, derived mainly from geologic information,

Availability of ground water within hydrogeologic units, derived from considerations on permeability, porosity, ground water reserves and resources, and well yields.

- Point information on ground water related features such as water table depth, ground water quality, and specific capacities of the drilled wells.
- Additional information on the climatic, geographical and geological setting of the area is presented in an accompanying explanatory text to the map.

They show on a suitable topographic base, various kinds of ground water-related information (point, line or aerial information). They bridge the gap between the technical level and the public or political level, and are usable by both specialists and non-specialists in hydrogeology.

In this way it has been possible to distinguished in the GSP three major ground water zones, as indicated in the hydrogeologic maps:

- Zone A: The higher natural ground water resources, free-recharging, hilly and undulated areas in the Precambrian and Tertiary contexts, where permeable water-bearing-formations crop out or have a thin Quaternary cover.
- Zone B: The medium ground water resources, free-recharging, hilly and undulated areas in the Precambrian and Tertiary contexts, where medium permeable water-bearing formations crop out or have a thin clayey/silty covers.
- Zone C: A transitional zone along valleys of the upper Tietê/Pinheiros rivers system with shallow water table aquifers conditions.

Ground water flow systems connect recharge areas with discharge areas and may cut across aquifers, aquitards and aquicludes, as well as high vulnerable sectors with still low contamination risk and vice-versa. Consequently, each of the major ground water zones can be subdivided further by hydrological, geological, geomorphological, pedological and land use factors in subzones, coinciding roughly with landscape types.
This hydrogeological portray can be used e.g. in following applications:

- As part of the development towards a more complex and integrated approach of the surface and ground water flow systems.
- As a basis for evaluation of pollution vulnerability and restoration potential of ground water using the system concepts.
- As a conceptual framework for the better understanding of the theoretical background, hydrogeology and practice of ground water protection zones.
- As a systematic way to identify the uncertainties inherent in urban/industrial ground water contamination risk assessment.

Ground Water Conceptual Model

Traditionally, ground water resources are divided into renewable resources and non-renewable or very few renewable reserves. This division is somewhat artificial because all water is conserved and is thus renewable, although not all on a human time scale. A ground water system can be considered as an organism-, it was born, grows and will die eventually. It has an input, throughput and output of energy in various forms. In the ground water conceptual model analysis the aquifer is no longer the central focus of interest. In fact it is not the aquifer which acts as the main functional unit but the ground water flow system.

As ground water is in constant movement, infiltrated water that reaches the water table and/or a confined aquifer layer does not become stored in the underground reservoirs- In fact while freshly infiltrated precipitation is entering the aquifer, the ground water flow, known as baseflow, is discharging into the streams. It should be emphasized that the ground water discharge values, characterizing the natural productivity of aquifer systems, are the main indicator of ground water resources availability in an area.

Recharge to confined aquifer layers of the GSP can occur in places where the confining bed is absent or there is an important hydraulic descontinuity, commonly related to tectonic features or the deposits or weathering patterns. Moreover, if there is a hydraulic gradient across the leaky confining bed in a direction that promotes flow into the aquifer, then recharge can occur from the higher to the lower aquifers. In this case, the vertical hydraulic conductivity and the thickness of the confining layer, and the head difference across it control the amount of recharge.

Recharge to the confined aquifer layers may come from both downflow from higher aquifers or upflow from a lower aquifer. In this case, it should be emphasized that aquifers formed by the crystalline weathered overburden (or regolith) may provide recharge to the sedimentary aquifer layers, because it might exist head difference across them that promotes recharges. Besides this, one shall consider that about 61% of the total 8.501 km^2 are under legal environmental protection, consequently of effective ground water recharge.

When the pumping cone reaches the Tietê and Pinheiros rivers, the potenciometric gradient toward these discharge areas is lowered and the amount of natural discharge proportionally reduced. Thus, it may induced additional recharge of ground water that was previously rejected. Ross (1992) reports that a such situation was identified by the mathematical modeling of pumping wells placed nearby the Tiet6 and Pinheiros rivers.

In any event, the pumping cone will continue to grow until it has sufficiently reduced natural discharges or increased the recharges to balance the volume of water removed by pumping- With this occurrence, a new condition of dynamic equilibrium is reached. Under such conditions, an important source of available resources are the induced recharge generated by the conjunctive use of surface and ground water.

Thus, when estimating the real available ground water resources of the GSP region, one should consider the possibility of using natural storage, including elastic reserves of the confined aquifer layers, natural recharges and induced recharges in the course of the development (intake of surface water and of ground water unproductive water bodies, reuse of wastewater or use of storm runoff). These procedures are currently being used successfully in areas where water resources are limited- Often these procedures, even those requiring water treatment, do not add prohibitively to the cost of water.

It should be emphasized that the amount of water leakage from the public distribution systems, which gets most of its water (55m^3/sec) from a complex network reservoirs located in the upper basin of the Tietê and Piracicaba rivers, represent induced recharges of about 500 million m^3/year.

Ground Water Reserves and Resources

In the Greater São Paulo-GSP- two main aquifers are of particular importance, those in Tertiary deposits of the São Paulo sedimentary basin and those associated with the thick mantle of weathered material of the Precambrian basement context.

Ground water is often referred to as the "hidden" component of the hydrological cycle, In fact, it is not directly observable, and its existence and characteristics can only be inferred with some degree of uncertainty, But, in this area ground water resources are relatively important, and its occurrences and socioeconomic significance cannot be neglected in water management planning, mostly in the perspective of sustainable development.

The Tertiary formations of the São Paulo sedimentary basin consist mainly of sand, silt and clay of fluvial origin, with an area of 1,452 km^2. The deposits fill a downfaulted graben in the basement rocks, with thicknesses of 50 to 300 m (see *Table 1*). A better knowledge of the stratigraphy of this basin is, of course, fundamental to the study of the distribution of the aquifers and the accumulation of water in them. These are occasionally separated by prominent clay/silty beds, which also have many sandy beds that yield water. As a result, locally and incidentally one may have water table aquifer conditions and/or confined/leaky aquifers.

The natural reserves or the amount of gravitational water stored in the sedimentary deposits are of 9,000 million m^3 (see *Table 2*), which was evaluated using an average thickness for the saturated aquifer layers of 100 m and specific yield of 6%.

The Precambrian bedrock context covers around 6,599 km^2 . The deeply weathered mantle has thickness ranging between 20 and 130 m (see *Table 1*).

The typical weathered profile (Rebouças, 1993) may be summarized as follows:

-Surficial zone formed by clayey massive material, with thickness varying from few meters to 1 0 m. Both the hydraulic conductivity (10 -04 to 10E-05 cm/sec) and the specific yield (0. 1 to 2%) are low.

- Friable material formed by disintegrated crystal aggregates, and rock fragments, with thickness between 5 to 30m. Hydraulic conductivity is moderate to high (10E-03 to 10E-02 cm/sec.), with a moderate specific yield (25%).

- Fractured and fissured rock zone up to 50 m in depth. Hydraulic conductivity is usually high (locally 10E-01 to 10E-03 cm/sec).

The natural reserves of water stored in the weathered mantle are of 10,000 million m^3 (see *Table 2*), which was evaluated using an average thickness for the saturated aquifer zone of 50 m and a specific yield of 3%.

The average baseflow recession for the upper Tietê River basins represents natural resources of the crystalline rock context of 2,343 million m^3/year, and in the sedimentary deposits of 900 million m^3/year.

The total natural resources have been estimated to about 3,243 million m^3/year (see *Table 2*).

The long-term experience in ground water development has shown that it is advisable to develop the natural resources of the aquifers. Nevertheless, taking into account the urban development and the high heterogeneity of the water-bearing formations, the available resources have been estimated to be about 25% of the annual discharge values (Rebouças, 1990). As a result, it is advisable to recover from the Precambrian aquiifer zones, about 600 million m^3/year 18 m^3/sec), and from the sedimentary deposits about 200 million m^3/year (7 m^3/sec). The total value of 25 m^3/sec represents around 50% of the current total municipal water consumption of the GSP (see *Table 2*).

The Current total withdrawal by around 10,000 existing drilled wells in the GSP is difficult to estimate because most comes from uncontrolled private wells. The State Water Plan (1990) reports that the withdrawal of ground water in GSP was estimated to be about 200 million m^3/year, or only 25% of the available resources. Thus, the amount of ground water (800 million m^3/year), which can be obtained with rational water intakes in technical-economic terms, and with the water quality satisfying the standard requirements may supply one-third of the suburban and urban population and industrial establishments. The suburban areas of the GSP are expected to become increasingly dependent on the ground water supply. The GSP metropolitan region is facing a difficult environmental future unless careful management of its water resources and appropriate environmental policies are implemented. Unfortunately, ground water resources are not abundant. In addition, the authorities have failed to control river pollution and ground water resources are not protected either.

In more densely urbanized areas, ground water may have a complementary or strategic role, that means, to control emergency situations due to severe drought or flood events and environmental accidents, to supply vital needs. In this case, an integrated management of surface and ground water shall be established. To accomplish this situation it is necessary to select a basic network of drilled wells, and determine the management rules for the use and the compensation to the owners of the required wells.

To make suitable these invisible water resources, it is necessary to decentralized the actions taking into account the regional and even local characteristic of the water resources, including a control on the private well used for self supply. In other words, the giant tree that constitutes the huge water supply company, will need to be replaced by small tree plantations.

Ground Water Monitoring Purposes

Water quality is a result of the natural physical and chemical state of the water. as well as any alterations that may have occurred as a consequence of human activity.

The natural quality of ground water in GSP varies from place to place and in function of the well depths. The total dissolved solids (TDS) contents are usually between 20 and 300 mg/L. Iron is the secondary constituent more frequently present in all aquifer systems, with contents ranging between 0.1 and 3 mg/L. Trace elements, such as lead, cadmium, and chromium may be present in water from wells located in industrial areas. The main factors responsible for the ground water contaminations are the badly constructed and the abandoned wells in the industrial sectors (Parissot, 1983, Pacheco and Rebouças, 1985). The main sources of ground water contamination are the septic tanks and cesspools in the suburban areas, the badly constructed and/or abandoned drilled well in urban and industrial sectors, domestic and industrial waste disposal, chemical spills and underground leaking from tanks.
The GSP produces over 25 million t of waste per year. These untreated wastes are among the main causes of environmental degradation, especially water contamination as they are carried into aquifers or join surface runoff into streams.

The first step in designing a ground water monitoring program is to determine the purpose- There are at least four major reasons to monitor ground water in the GSP:

- To determine the water quality and chemistry of the GSP. This activity should be assigned to the DAEE and/or Iinstitute of Geology, selecting existing wells as part of its basic hydrometric networks.
- To determine the water quality and chemistry of a specific water-supply well or well-field. In this case, nearby wells may be sampled to establish regional water quality. This activity should be assigned to SABESP and/or others water-supply companies existing in the GSP area. It is important to integrate private well owners in order to maintain high quality in ground water.
- To determine the extent of ground water contamination from a known source, and to monitor a potential source of contamination to determine if the ground water becomes contaminated. This

activity should be assigned to CETESB or other environmental agency.

Universities and other research groups should be integrated to promote methodological development and training facilities to meet current needs.

Finally, there is the problem of informing and educating the public: it is necessary to find appropriate ways and means of disseminating information and of popularizing understanding of the nature of this hidden resource.

The ground water classification scheme presented in the hydrogeologic maps is of fundamental importance in promulgating rules and regulations at the state and regional levels. Special attention should be given where ground water resources are highly vulnerable to contamination due to the hydrogeological characteristics of the areas under which they occur and that are also either an important source of drinking water.

Recent regulations have greatly increased the amount of ground water monitoring required. As a result, numerous instances of ground water contamination have been revealed. Consequently, increased research related to the exploration, assessment and management of ground water resources in GSP is a necessity if further usage and development is to be carried out wisely; further research is also required to estimate the effects of human activity, including land use changes on ground water quality and quantity.

Conclusions

Greater São Paulo region possesses important ground water resources which are locally a viable and economic source of good quality water supply for individual and community water supply systems as well as for industrial uses. The contribution of ground water for these uses will continue to grow, especially because available surface water supplies are already allocated, or are too costly to treat or to develop.

Current and future conflicts between ground water users and surface water planners as well as the potential for ground water contamination are two concerns that will become increasingly important as further ground water development takes place in the GSP in the years ahead time.

Increases in exploration, assessment and management of ground water resources in GSP are a necessity if further usage and development is to be carried out wisely. Further research is also required to estimate the effects of human activity, mostly land use changes on ground water quality and quantity.

Further possibilities for ground water use in Greater São Paulo metropolitan region will include a more effective application of the existing legal and institutional instruments for ground water use and protection and sounder management.

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