

GROUNDWATER USE AND PROTECTION IN PETROCHEMICAL COMPLEX REGION, CAMAÇARI, BAHIA, BRAZIL.

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ABSTRACT.

The Petrochemical Complex Region (COPEC) is located on the top of a huge aquifer (10,000 km², with average thickness of 600m), chiefly composed of undifferentiated deposits of coarse to fine sands and gravels with lenses of interbedded silts and clays. This paper provides an overview of the problems, and proposes the data and organization requirements for developing a local groundwater protection programs. The freshwater reserves (120 billion km³ and global groundwater flow to rivers of 3 billion m³/yr) may be considered a resource of unusually high value. The issue of contamination with Synthetic Organic Chemicals (SOCs) and toxic metals was first raised during the mid 1980s. This poses significant water quality problems and imposes special restrictions on the industrial development in this area, mostly because few high-quality alternative sources of drinking water remain in proximity to human population of 3.5 million peoples. The policy of neglect cannot be continued without grave threats to human health.

KEYWORDS

Wastes management and groundwater protection. Contaminant hydrogeology. Planning for groundwater use and protection. Environmental hydrogeology. Quality of groundwater.

INTRODUCTION

Groundwater protection against contamination by man's activities is one of the most important tasks of modern hydrogeology on a world wide scale.

In the past decade, many instances of groundwater contamination with Synthetic Organic Chemicals (SOCs) and toxic metals have been reported in Brazil. This proliferation of known problems is due in part to the fact that more samples are being collected and analyzed for toxic contaminants. Groundwater contamination affects both public and private wells, and, given current wastes disposal practices, the prodigious quantities of toxic chemical in use, and possibilities for accidental spills, all municipalities should take action now to be prepared to minimize the potential for crisis if groundwater contamination occurs, and most importantly to plan a program tailored to local conditions that will help protect groundwater from toxic contaminants.

Every groundwater system is unique , as are the patterns of human activities that may cause contamination. Thus , lists of approaches to protect groundwater are not too useful unless they are linked to the unique social , cultural , economic and physical conditions in a community. In the present case , many of the regional and local environmental problems are result of ill-planned development or other forms of private and public mismanagement. Normally to increase exports and expand the economy , large amounts of capital are invested to attract international outmoded industries or processes . Likewise austerity measures are reported to have left environment control agencies without enough financial conditions to carry out their basic tasks. Furthermore groundwater protection is a complicated problem , the solution of which needs an interdisciplinary approach , and must be integrated into the processes of planning , investigation , development , use and management of global water and other natural resources. So far , there seems to be a general impression that little is known about the occurrence of groundwater and that the science of groundwater contamination process is in its infancy.

PHYSICAL SETTING

The COPEC is the most important petrochemical complex in South America. It is located some 30km north of Salvador conurbation area (3 million inhabitants) , in the Reconcavo Geological Basin , which is viewed by residents and visitors alike , to be a water wonderland. This region occupies the southern portion of the Bahia Graben (56,000 km²) ; which is filled by sedimentary deposits with thicknesses of 3,000 to 8,000m (Fig. 1). The area receives an annual average rainfall between 1,200 and 2,200mm , and the climate is tropical humid with temperatures between 20° and 35°C . The high stable pattern of river runoff , thanks to a higher proportion of groundwater discharges to streams , is the main source of potable water for Salvador conurbation. Yet, Reconcavo communities and COPEC are becoming

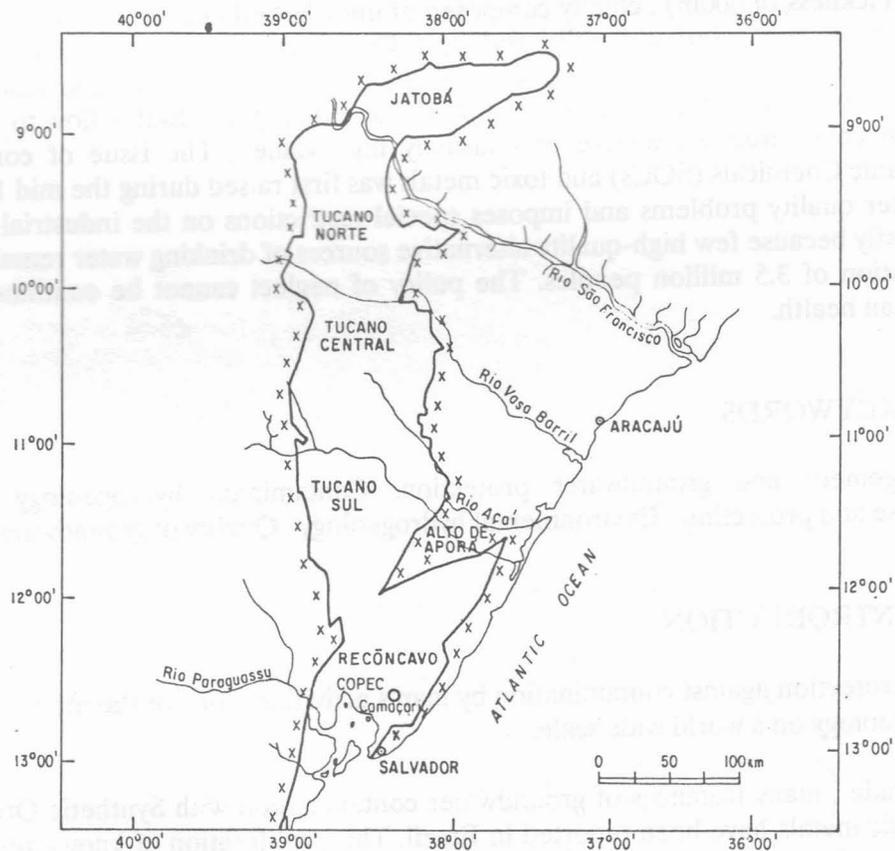


Fig. 1. Location of the COPEC Region.

hard-pressed to meet their ever-increasing demands for potable water. The global demands are estimated to some $10\text{m}^3/\text{s}$ by the year 2000. One of the reasons is that these communities and the COPEC are building directly on the top of their main freshwater reservoir, the São Sebastião Aquifer. This poses significant water quality problems, and given the emerging knowledge regarding the contamination of groundwater with toxic chemicals and the potential health effects of this contamination, the challenge to local governments is becoming obvious whereas the solutions are not.

THE GROUNDWATER SYSTEM

Reconcavo sedimentary deposits fill a downfaulted graben in the basement rocks, and cover about $10,000\text{km}^2$. The most developed and widespread freshwater-bearing deposits are the Lower Cretaceous São Sebastião and the Upper Cretaceous Marizal Formations, with total thickness of more than 1,000m. Locally and occasionally occur Tertiary sediments of Barreiras Group. The São Sebastião, which is the prime source of potable water, underlies the Marizal Formation, with extensive outcropping at the surface (Fig.2).

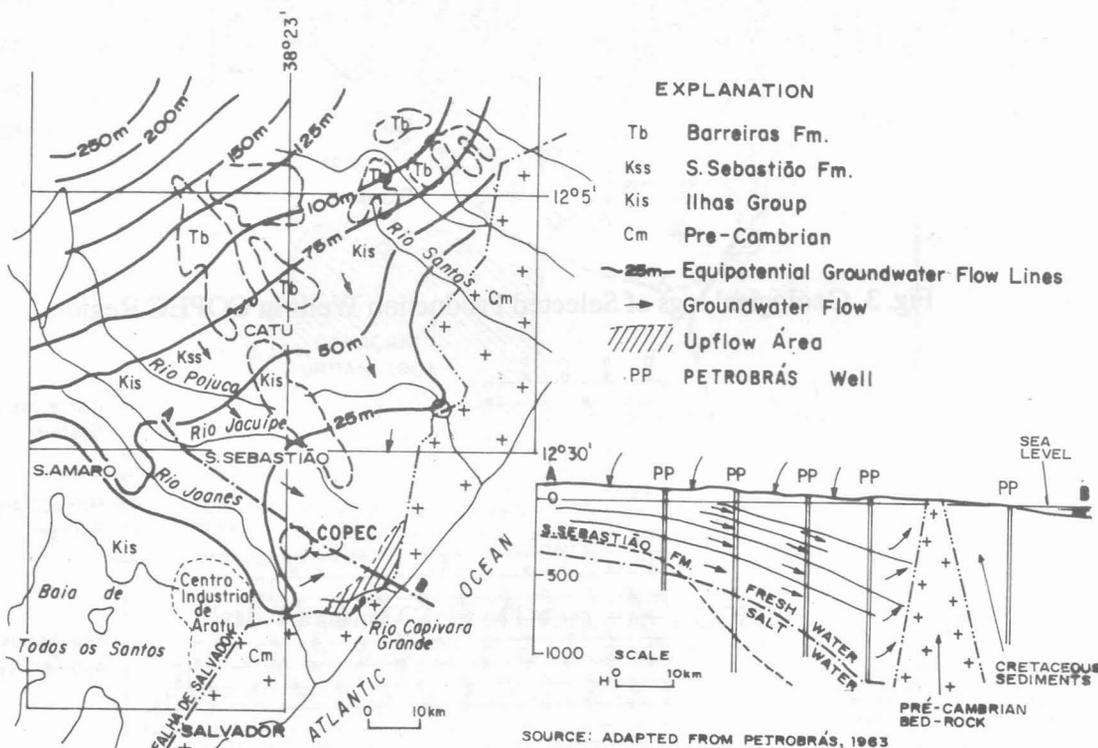


Fig. 2. Hydrogeological Context and Generalized Cross Section of the São Sebastião Aquifer.

The aquifer layers are chiefly composed of undifferentiated deposits of coarse to fine sands and gravels with lenses of interbedded silts and clays of fluvial or deltaic origin (Fig.3). Its surface is fairly irregular due to erosion by streams. The COPEC occupies the water-divided between the Joanes and Jacuipe rivers, the main sources of potable water to supply the cornubation of Salvador.

Because of its shape, structure and geology setting, Reconcavo has a rather unique groundwater flow system that can be broadly described on a regional basis (Fig. 4). Groundwater in the water table aquifer, near the hills carved mostly in the Marizal /Barreiras sandstones, is subject to hydraulic gradients that tend to carry some of the water, locally infiltrated, downward to the deepest parts of the São Sebastião aquifer. Towards the south and southeastern of this water in the São Sebastião aquifer

has a vertical upward component while water in shallower deposits flows essentially horizontally until it discharges to streams.

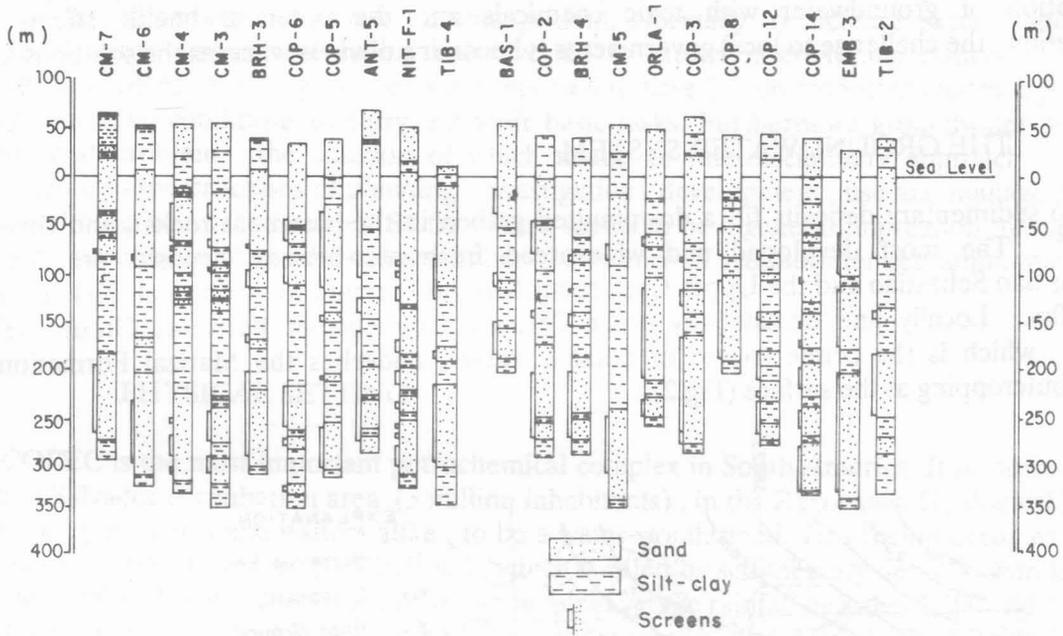


Fig. 3. Geological logs of Selected Production Wells in COPEC Region.

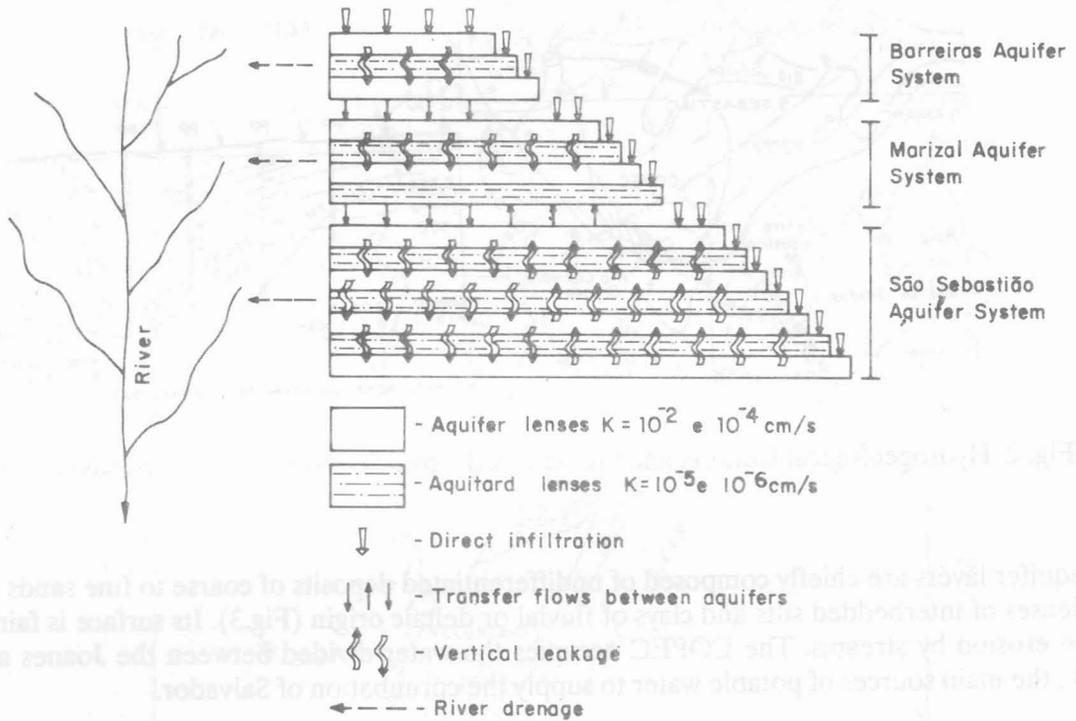


Fig. 4. Simplified Pictorial of the Groundwater Flow Systems in Reconcavo Region.

Local groundwater flow in the São Sebastião aquifer may be poorly or well confined depending on location. In areas where the overlying clays are laterally continuous and of substantial thickness, vertical movement between the water table and the deeper aquifer layers is reduced. Further, towards

the southeastern , geological boundaries induce generalized upward flows toward the water table , resulting in the wetland features of the Camaçari region . However overpumping rates and/or mismanagement of wellfields in the COPEC zone disturb these regional groundwater flow systems and induce recharges from the water table , as the cone of depression progresses radially outward from the wellfields (Fig.5).

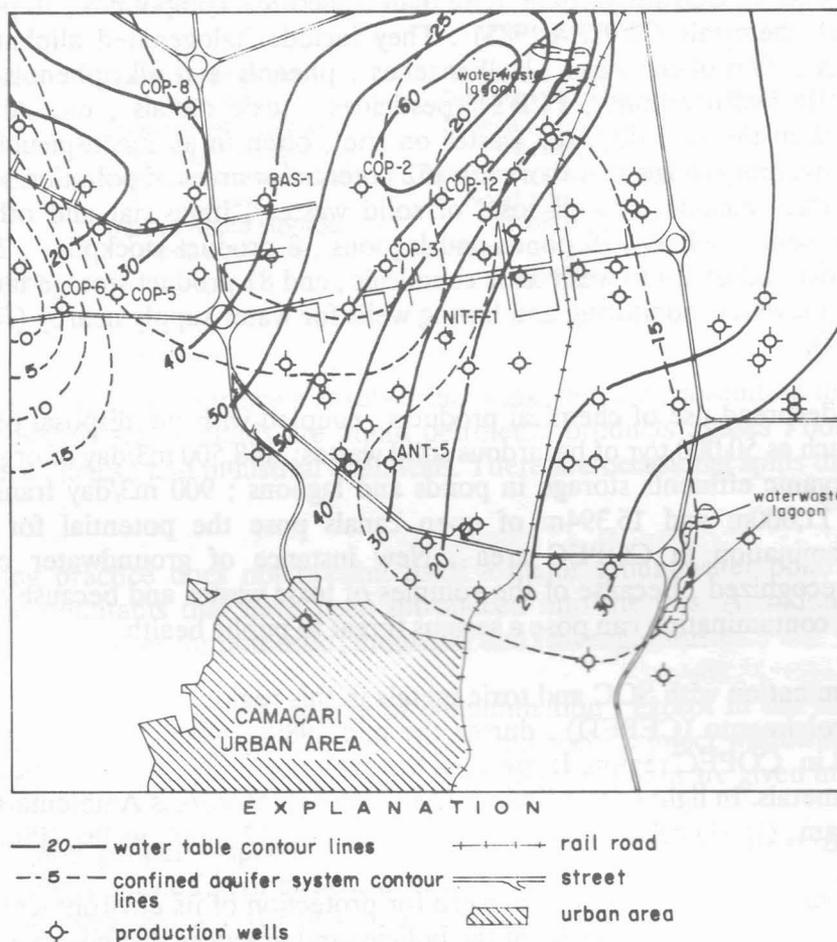


Fig. 5. Regional Cones of Depression in COPEC

About 200 wells have been drilled in the past decade in COPEC area and as 50 percent are currently in use. Most of them are generally 20cm in diameter and depths between 57 and 450m ; 58 percent have between 200 and 400m and 86 percent between 100 and 400m in depth. The volume of groundwater stored in Reconcavo region has been evaluated to some 120 billion m^3 adopting an average aquifer thickness of 600m and an effective porosity of 2 percent . Global groundwater discharges to river have been estimated to some 3 billion m^3/yr or 100 m^3/s . In the catchment basins of the Joanes and Jacuibe rivers (2,413 km^2) the groundwater discharges have been estimated as 40 m^3/s (Rebouças , in Hidroconsult,1989). The hydraulic conductivity is moderate to high (10^{-2} to 10^{-4} cm/s) , with moderate storage coefficient 10^{-4} . Vertical hydraulic conductivity of aquitards has been evaluated based on geothermal data to some 10^{-5} to 10^{-6} cm/s (Lima and Miranda , 1988). Specific capacities of wells vary widely , from 1 to about 30 m^3 per hour per meter of drawdown. Wells in the São Sebastião commonly yield in excess of 300 m^3 per hour , depending on the well design , construction and operation technical levels used.

On the basis of past experience and engineering projection , the groundwater resources seem to be adequate , in quantity and quality , to serve an estimated demand of approximately 30 m^3/s or equivalent population of some 10 million of persons (Rebouças , op. cit).

GROUNDWATER PROBLEMS

Groundwater in Reconcavo region may be considered a resource of unusually high value. Furthermore, they are highly vulnerable to contamination and are irreplaceable source of drinking water.

The industrial activities in COPEC include more than 200 critical compounds, 70 percent of them are listed as hazardous chemicals (USEPA,1985). They include halogenated aliphatic hydrocarbons, brominatedmethanes, chlorobenzenes, alkylbenzenes, phenols and alkylphenols, chlorophenols, polynuclear aromatic hydrocarbons, PCB's, pesticides, toxic metals, etc. Almost every major industrial plants has in the past disposed wastes on site, often in an inconspicuous location on the property. Current inventory shows that there are 152 potential sources of pollution within the COPEC. Contamination sources include land disposal of solid wastes, industrial and other wastewater or leachable impoundments such as, 29 ponds and lagoons, 8 product stockpiles, 24 industrial waste discharges, 10 service industries to wash toxic chemicals, and 81 product storage tanks, most of them without soil or groundwater monitoring and having wells for water supply nearby (Rebouças et al., in Hydroconsult, 1990).

Therefore, the widespread use of chemical products, coupled with the disposal of large volumes of waste materials, such as 50,000 t/yr of hazardous solid wastes; 148,500 m³/day of organic effluents; 3.5 million m³ of inorganic effluents storage in ponds and lagoons; 900 m³/day transported through a piping system of 11,000m and 15,394m of open canals pose the potential for widely distribute groundwater contamination in COPEC area. New instance of groundwater contamination are continually being recognized. Because of the volumes of toxic wastes and because of their stability in groundwater, such contamination can pose a serious threat to public health.

The issue of contamination with SOC and toxic metals in this region was first raised by the Centro de Pesquisa e Desenvolvimento (CEPED), during the mid 1980s, when they analyzed drinking water from wells located in COPEC region. It revealed the presence of low concentration of a wide variety of SOCs and toxic metals. In light of this finding The Centro de Recursos Ambientais (CRA) has setup a monitoring program, (1984) currently interrupted, including 42 supply wells, (Pinheiro, 1985,1986).

In response to the community's increased concern for protection of its environment and water supply sources, COPEC conducted an evaluation of the policies and practices that govern water management and land use, around its site and new expansion area. The "Estudo de Impacto Ambiental (EIA)", Study of Environmental Impact, as it is called, was developed at the instructions of the CONAMA - Federal Board of Environment Policies (1986), and culminated with the acceptance by the Bahia State Boards (CEPRAM-CRA) of the "Relatório de Impacto Ambiental" (RIMA) - Report on Environmental Impact, (Hydroconsult-COPEC,1989).

These researches have determined that there are many sources and causes of groundwater contamination in COPEC sector. They can be divided into four categories. The first two categories represent discharges of contaminants that are derived from solid and liquid wastes. The third category concerns discharges of contaminants that are not wastes, and the fourth category lists those causes of groundwater contamination that are not discharges at all. Table 1 summarizes the list.

There are additional commercial and industrial discharges not covered by the inventory. These include trucks washes and industries discharging wastewater not connected in the CETREL sewage treatment plant effluents.

One of the most important problem associated with domestic landfills in this area is the generation of leachate and because these landfills receive a wide range of materials, including septic tank sludge, auto tires, plastics, chemicals, textiles, cans, oils hydrocarbons, etc.

TABLE 1 Classification of Sources and Causes of Groundwater Contamination in COPEC Region.

CATEGORY I: Systems, facilities, or sources designed to discharge waste or wastewater to the land, groundwater	CATEGORY II: Systems, facilities or sources not specifically designed to discharge wastes or wastewater to the land and groundwater	CATEGORY III: Systems, facilities or sources that may discharge or cause a discharge of contaminants that are not wastes to the land and groundwater	CATEGORY IV: Causes of groundwater contamination that are not discharges
Domestic on-site waste disposal systems, Sewage treatment plant effluent, Industrial waste discharges, Storm water basin wastewater, Treatment sludges, Scavenger waste disposals, Past-waste disposal practices	Sanitary Sewers, Landfills, Wastewater pipelines, Flushing toxic spills, Evaporation Ponds and lagoons, Implant waste storage, Road accidents	Products storage, Tanks and pipelines, Spills and incidental discharge, Sand and gravel mining, Road accidents, Stockpiles, Sewage from ponds and lagoons.	Airborne pollution, Water well construction and abandonment.

A number of products are stored in surface and subsurface tanks and are transmitted through pipelines. Among the most frequently stored fluids are liquid petroleum products, gases, both liquefied and gaseous under pressure, acids, and industrial chemicals. There are occasional spills that contaminated groundwater.

Sand and gravel mining practice does not present itself a major groundwater pollution threat. The greater threat is from pollutants that have been introduced into the pits. Abandoned pits serve as attractive but illegal disposal sites for domestic, industrial and scavenger wastes.

Water wells themselves are not normally source of contamination, except in the cases of improper construction, well failure, and, in some instances, use of the well to inject wastewater. Some of the most common conditions that have resulted in groundwater contamination are given in Table 2.

Modern construction and proper inspection during installation generally minimize the chance of contamination due to improper design or structural failure. However, usually casing and wells are not inspected for structural integrity, and the volume of gravel or grout used is not carefully checked to avoid creation of voids or opening that might allow vertical migration of shallow contaminated water.

TABLE 2 Examples of Conditions Under Which Water Well Can Cause Groundwater Contamination

IMPERFECT CONSTRUCTION	WELL FAILURE	WELL USE
Inadequate surface protection. Poor or no grouting. Well finished at or below land surface. Poor location. Split screen in shallow positions.	Casing corrosion. Casing electrolysis (chemicals). Stray currents in ground. Accidental holing of casing during construction and or maintenance.	Movement of contaminants caused by pumping. Direct recharge of contaminants. Improper abandonment of well. Improper backfill of test holes.

In many cases, the annular space between the inside wall of the drilled hole and the outside casing are backfilled with the natural uncontrolled sediments and grouted only near the surface. Migration of contaminants along this annular space may be an important source of contamination for deep COPEC site.

Another way in which a well can become a vehicle for contamination is through improper abandonment . Usually the unused wells are not filled with impermeable materials , and the open casing provides easy access for contamination , which can enter at the surface or through a break in the casing. Flooding from surface water and cleanup methods , specially when accidents occur involving hazardous products and even deliberate dumping of various , sometimes toxic substances into the unused well can occur.

PLANNING FOR GROUNDWATER PROTECTION

During the past two decades a complex set of laws and instructions attempt to protect environment from degradations . Policymakers and legislators have turned for guidance to the well entrenched air and surface water pollution control programs , that depend on the natural process of dispersal , dilution, and absorption to mitigate the impacts of pollutant discharges. The goal has been to find the carrying capacity of the environment beyond which unacceptable negative impacts on human health and the environment occur. Typically , pollution control agencies regulate industrial discharges and waste disposal , often implementing the federal programs through delegation. This has resulted in increased disposal of waste in the subsurface.

In contrast to the programs established to respond to air and surface water pollution , no one federal , state or local law sets the standard for preventing and responding to groundwater contaminant discharges. So far , groundwater as a hidden resource , is still frequently approached as something mystic or metaphysic by the population in general , and even by professionals. Furthermore , to respond to economic interests especially those arising from external market , the federal , state or local governments are more likely to ignore industrial pollution than decrease production and associated taxation. It is , however , becoming evident that groundwater once contaminated can rarely be cleaned up completely and only at great expense. Therefore , today , soil and groundwater pollution are widely recognized as a major environmental problem.

In response to earlier perceived growth problems the Brazilian Environmental Council (CONAMA,1986) issued its guidance regulations EIA (Estudo de Impacto Ambiental - Study of Environmental Impact) and RIMA (Relatório de Impacto Ambiental - Report on Environmental Impact) , searching for better methods for managing the future and today's environmental degradations, and for rectifying yesterday's mistakes.

As a result of the EIA/RIMA a guideline program was established and should be implemented by COPEC , under the directions of the Environmental Bahia State Agencies - CEPRAM , CRA . The main objective of this program are to restrain the deterioration of groundwater. The program is primarily concerned with contamination problems resulting from past activities on the COPEC as opposed to ongoing operations. It has been organized to allow a phase approach in developing and implementing contaminant control systems thereby accelerating the reduction of effective environmental hazards.

The groundwater management plan for COPEC has three major phases. The first is a Physical Resource Definition. This phase includes an analysis of the existing wells in terms of yield and protection vis a vis the contamination sources and definition of new wellfields.

The CRA staff in cooperation with COPEC support must develop the first model zoning ordinance for protecting groundwater in COPEC area. The ordinance should protect groundwater resources by imposing appropriate restrictions on land use and activities located within the wellhead or wellfield protection zones.

In addition a control zone should be defined around the facilities or activities having high potential of contamination and imposing appropriated restrictions on the groundwater use within that zone.

Groundwater protection can be a surprisingly complex undertaking , requiring extensive data collection and evaluation . The only efficient way to approach this topic is to build on existing information up to the greatest extent possible , and to carefully target additional data collection and evaluation activities.

The second phase is Monitoring . This element will monitor all current and planned groundwater contamination sources and set priorities for future groundwater monitoring in the COPEC region. The analysis of physical resource data , the inventory of potential contamination sources , and the estimated severity of potential , on human and the natural ecosystem , will determine monitoring priorities.

The third element of the plan is Management Recommendations . The team will analyze each problem area identified and develop a set of recommendations specific to that problem area. The recommendation will include regulatory options applicable at the state , municipal and COPEC levels and site specific best management practices.

The importance of groundwater protection in Reconcavo region makes public support for the plan essential for effective implementation. The municipalities will encourage public involvement through frequent media coverage and through a series of public information meetings.

CONCLUDING OBSERVATIONS

As can be seen in the preceding descriptions of events and actions , the process of planning for groundwater protection and assurance of drinking water quality has not followed a comprehensive planning approach even though such an approach is obviously demanded by an issue of this magnitude.

There is no one agency centrally responsible for the protection of groundwater, nor is that likely to be the case in the future. While that fact may be unappealing to those who are most concerned with the issue and are prepared to allocate the necessary resources, it nonetheless remains true. As a result, the continued planning for groundwater protection in the COPEC region must of necessity be an iterative one and one of shared responsibility. Further, the issues go well beyond the basics of prevention, inspection, and abatement.

Given overwhelming precedents of established development, it would have been impractical to attempt to drastically reverse or eliminate the established trend of development. To be effective groundwater protection programs must be planned for and implemented by the entire region in which the aquifer exists. By this action the RIMA established a long-range policy to allow industrial development to occur immediately. The geographic area governed by the EIA/RIMA protection regulation will change with each future time phase.

The five elements of the current protection program are: 1) Water management and monitoring. 2) Waste treatment facilities. 3) Land use policies and controls. 4) Environmental regulations and enforcement. 5) Public awareness and involvement.

At this time , it is not clear whether the ordinances goals of aquifer water quality and area wide environmental protection will be realized. However , whether local government is purely interested in the economic vitality of this area , protection of groundwater is of no less importance than the basics of providing transportation system or electricity supply . Clean groundwater and linked surface water are the lifeblood of urban communities , settlements in general , and even industries.

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