AQUIFERS RESTORATION

A SOLUTION TO PUERTO RICO DRINKING WATER SHORTAGE PROBLEM

By

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Introduction

The contamination of our natural resources has been one of the major problems that have affected our way of life. Although several laws have been passed in the last few decades in an effort to control this situation, the truth is that this problem is affecting adversely the environmental quality that characterizes Puerto Rico worldwide. One of the resources that have been affected by this problem is the groundwater. As it is well known, one of the major problems in Puerto Rico is the lack of potable water available to the public. Although the government of Puerto Rico is trying to solve this problem investing millions of dollars, nothing is being done in the environmental restoration of the contaminated aquifers representing more than 80 drinking water wells (60 MGD) closed to public use due to contamination.

Aquifers in Puerto Rico

Groundwater is water underground in saturated zones beneath the land surface. It fills the pores and fractures in underground materials such as sand, gravel, and other rocks. Aquifers are formed when an underground body of porous sand, gravel or fractured rock filled with water is capable of supplying useful quantities of water to a well or spring. In Puerto Rico about 660 MGD (million gallons per day) of freshwater were withdrawn from all water sources in 1997. Of this total about 37.8% or 250 MGD were groundwater withdrawals.

Principal aquifers in Puerto Rico consist mostly of limestone, alluvium, or volcanic rocks. The most important are the alluvial valley aquifers, the South Coast aquifer, and the North Coast Limestone aquifer system. In 1985 the alluvial valley aquifers supplied about 14% of the total of fresh groundwater withdrawals and it was used, mostly, for industrial and public supply. The South Coast aquifer underlies the coastal plain that extends about 40 miles from Patillas to Ponce. In 1985 it supplied about 42% of the total groudwater withdrawals, mostly for agricultural or industrial use, and public supply. The North Coast Limestone aquifer system is one of the largest and most productive sources of groundwater in Puerto Rico. The aquifer system underlies a large area that extends about 90 miles along the north coast of the island and encompasses an area of nearly 700 square miles. Total fresh groundwater withdrawals in 1985 were about 38.8% on the North Coast Limestone aquifer system. Most of it was used for public supply, agricultural and industrial use.

Water Quality

In the last couple of decades this resource has been threatened by the contamination generated mostly from landfills Leachates, Leaking Underground Storage Tanks (LUST), Superfund Sites, CERCLIS Hazardous Waste Sites, and other sites in the National Priority List. In Puerto Rico there are about 50 landfills located over aquifers that provide freshwater to different communities.

Water pollution originates from two different sources: point sources and non-point sources. Point source pollution is contributed to water from a discrete source, such as a pipe, ditch, tunnel, or well. Non-point source means that the pollution comes from a broad area, such as a large field that has been covered with fertilizer or pesticides.

In Puerto Rico the Environmental Quality Board (PREQB) is the state agency responsible for ensuring the quality of all waters, including groundwater as stated in the Safe Drinking Water Act. In October 1988 the Environmental Protection Agency (EPA) approved the "*Groundwater Management and Protection Strategy for Puerto Rico*" submitted by the PREQB. As part of this strategy was developed the Wellhead Protection Program (WHPP), which was approved in April 5, 1991. The purpose of the WHPP is to protect the immediate wellhead area of all drinking water wells in Puerto Rico. It consists basically of the following elements:

- Development of the methodology and procedures for the delineation of the Wellhead Protection Areas
- Identification and management of all potential pollution sources for groundwater protection
- Development of a contingency plan
- Planning process for establishing new wells

This program is being established in coordination with different federal and state agencies, where the PREQB is the interagency coordinator.

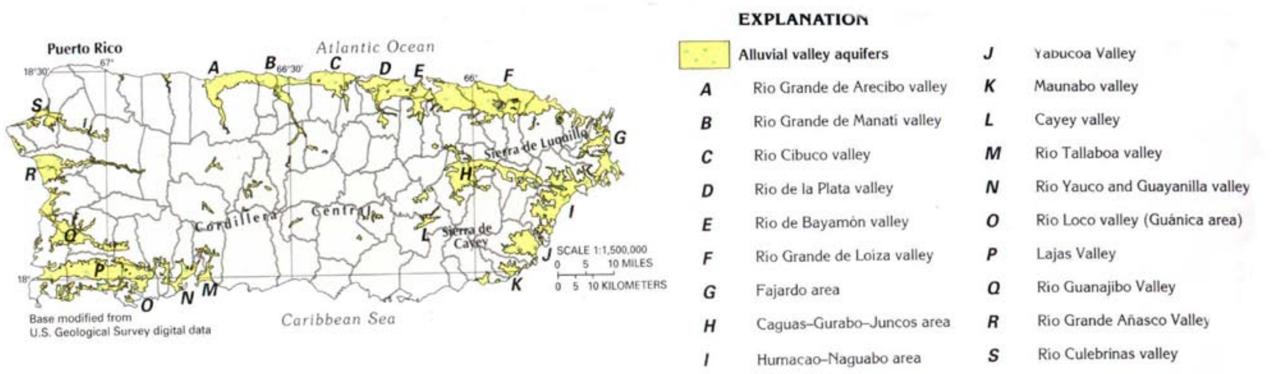

Figure 1. River alluvium that fills bedrock valleys located in the interior and coastal areas of Puerto Rico forms small aquifers that are locally important sources of water for industrial, municipal, and domestic supplies.

Figure 2. The South Coast aquifer extends from Patillas to Ponce in southeastern Puerto Rico.

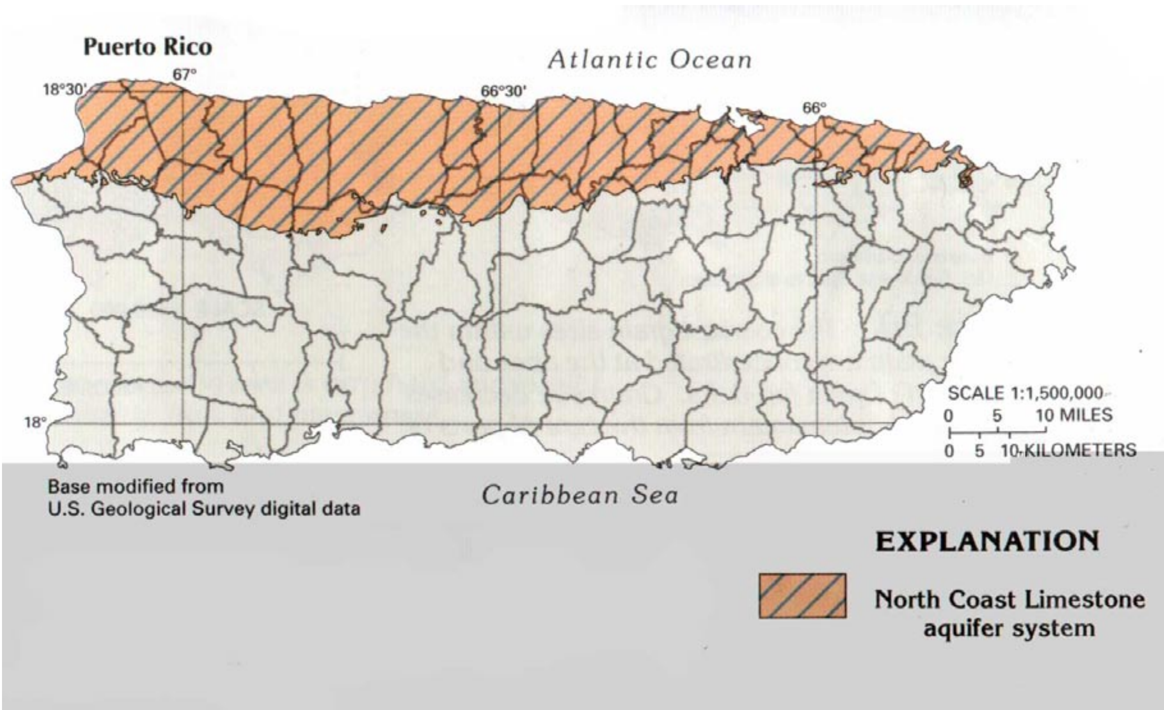

Figure 3. The North Coast Limestone aquifer system underlies a populous and industrialized area that extends approximately 90 miles along the north coast of Puerto Rico.

<u>List of Water Supply Wells that have been closed because of contamination</u>

This list is available in Table 1. All of the towns and surrounding areas where the wells are located have been seriously affected by the loss of these wells. To solve these problems the Government has been digging new wells and leaving the contaminated wells without any type of remediation. With time the problem gets worse and there is less water for the continuously rising population.

<u>Parameters of contamination in water</u>

These parameters can be found in the document of the Department of Health (DH) "*Reglamentación Nacional Primaria de Agua Potable".*

Table 1. Wells closed because of contamination and what type of contamination.

List supplied by the Puerto Rico Aqueduct and Sewer Authority (PRASA).

Wells closed because of contamination

Town	*Name of the well*	*Type of contamination*	*MGD (Aprox)*
Vega Baja	Pugnado 3	Contaminated with nitrate	0.95
Vega Alta	Bajura 1	Contaminated with VOC	1.20
Vega Alta	Bajura 2	Contaminated with VOC	0.85
Vega Alta	Bajura 3	Contaminated with VOC	0.70
Vega Alta	Bajura 4	Contaminated with VOC	1.30
Vega Alta	Bajura 5	Contaminated with VOC	0.85
Vega Alta	Vega Alta 1	Close to contamination	0.95
Vega Alta	Vega Alta 2	Close to contamination	1.30
Vega Alta	Regadera	Contaminated with VOC	1.20
Vega Alta	Ponderosa	Contaminated	0.70
Manatí	Cotto Sur 2	Contaminated with nitrate	0.85
Manatí	Cotto Sur 3	Contaminated with nitrate	0.95
Dorado	Los Puertos	Contaminated with VOC	1.35
Ciales	Rossy 1	Contaminated with TCE	0.75
Barceloneta	Tiburones 1	Contaminated by UpJohn	0.95
Barceloneta	Vila	Contaminated with mercury	0.80
Arecibo	Garrochales 1	Contaminated	0.90
Arecibo	Garrochales 2	Contaminated	0.85
Hato Rey	Pozo Truman	Contaminated with VOC	0.70
San Juan	Miguel Such	Contaminated with VOC	0.75
Cabo Rojo	5A	Contaminated	0.65
Juana Díaz	Autopista	Contaminated with VOC	0.75
Ponce	Colegio Tecnológico	Contaminated with VOC	0.65
Ponce	Oliver Viejo	Contaminated with VOC	0.70
Ponce	Sauri	Contaminated with VOC	0.60
Ponce	Vocacional	Contaminated with nitrate	0.50
Cayey	La Ley	Contaminated with VOC	0.65
Cayey	Mínimas 1	Contaminated	0.60
Cidra	Pozo #3	Contaminated	0.45
Cidra	Pozo #4	Contaminated	0.50
Cidra	Pozo #8	Contaminated	0.40
Guayama	Fibers 2	Contaminated	0.45
Guayama	Fibers 3	Contaminated	0.55
Guayama	Fibers 4	Contaminated	0.55

Guayama	Fibers 5	Contaminated	0.50
Maunabo	Maunabo 1	Contaminated	0.45
Patillas	Pta. Alc. (pozo #2)	Contaminated	0.40
San Juan	Detrás del cuartel	Contaminated	0.50
San Juan	Mínimas 2	Contaminated with VOC	0.55

There are other reports made by the United States Geological Survey (USGS) about groundwater quality that will be handed with this work.

This report is to provide a summary of information about the 28 groundwater

remediation case studies, including comparing results among sites, to further assist those involved in evaluating and selecting remedies for groundwater contamination at hazardous waste sites. The case studies present a range of the type of cleanups typically performed at groundwater-contaminated sites.

Nine are state led. The sites have been grouped by the type of contamination that was targeted for cleanup at each (volatile organic compounds [VOC], VOCs combined with other contaminants, or metals).

Cleanup has been completed at two of the sites and the remediation systems at three other sites. At one site the goal has been changed from restoration to containment.

Chlorinated VOCs were the type of contaminant most frequently present, found at 21 of the 28 sites. With trichloroethene (TCE), treated at 18 sites, the most common. Benzene was the most commonly treated nonchlorinated VOC (at five sites). Chromium was the most common metal, treated at seven of the sites.

For most of the sites, the extent of contamination was quantified by the volume of contaminated groundwater.

The volume of contaminated groundwater at the sites ranged from 930,000 gallons to 5.6 billion gallons. The average volume of the contaminated plume was 440 million gallons, and the median volume was 29 million gallons.

Air Sparging

Air sparging (AS) involves injecting a gas (usually air or oxygen) under pressure into the saturated zone to volatilize contaminants in groundwater. Volatilized vapors migrate into the vadose zone where they are extracted by vacuum, generally by a soil vapor extraction system.

AS also is used to supplement P&T systems. For example, AS may be added to remediate specific portions of a contaminated plume that are not treated effectively by P&T alone or to accelerate cleanups. For the purpose of this report, the use of air to promote biodegradation (sometimes referred to as “biosparging”) in saturated and unsaturated soils by increasing subsurface concentrations of oxygen is referred to as *in situ* bioremediation.

Permeable Reactive Barriers

A PRB, or treatment wall, consists of an in-ground trench that is backfilled with a reactive medium. The selection of the reactive medium is based on the targeted contaminants and the hydrogeologic setting of the site. Zero-valent iron is the most common medium used in PRBs to date. Examples of other reactive media include, microorganisms, zeolite, activated carbon, peat, phosphate, bentonite, limestone, and amorphous ferric oxide. The treatment processes that occur within the trench are degradation, sorption, or precipitation of the contaminant. PRB systems may be configured as “funnel and gate” designs; in such configurations groundwater flow is routed by two or more impermeable walls through a permeable reactive zone.

PRBs may or may not be similar to P&T systems in both purpose and function. Like a P&T system, PRBs may be used to treat contaminated groundwater at the boundary of a site, or to restore the groundwater throughout a site. However, the volume of groundwater treated by a PRB at a site is typically much lower than it would be for a P&T system at the same site because PRBs treat only the groundwater that passes through the barrier, while P&T systems actively extract groundwater from an aquifer, usually at multiple locations throughout the plume.

In Situ Bioremediation

In situ bioremediation (ISB) involves microbial degradation of organic constituents through aerobic or anaerobic processes. *In situ* bioremediation includes processes by which nutrients (such as nitrogen and phosphorus), electron donors (such as methane for aerobic processes or methanol for anaerobic processes), or electron acceptors (such as oxygen for aerobic processes or ferric iron for anaerobic processes) are added to the groundwater to enhance the natural biodegradation processes. The addition of oxygen by biosparging is an example of such a process.

Treated groundwater was reinjected into the aquifer (11 sites), discharged to an adjacent surface water by a permitted outfall (10 sites), discharged to a publicly owned treatment works (POTW) (2 sites), or discharged using a combination of these methods (2 sites).

On the operation of the remedial systems, including the volume of groundwater treated and the percent of time the systems were operational. The volume of groundwater treated per year of operation for the P&T systems ranged from 1.7 million gallons to 554 million gallons. Estimated through put per year for the PRB sites ranged from 200,000 gallons to 2.6 million gallons.

The remedial goals for the sites included the restoration of all groundwater beneath the site and any off-site groundwater that may have been affected by the site, as well as the containment of on-site contamination.

Cleanup goals for the sites were established based on one or more of the following factors:

1) Maximum contaminant levels (MCL)
2) Primary drinking water standards

In addition to the two sites listed above at which the specified aquifer cleanup goals have been met, progress has been made toward meeting the specified remedial goals for most of the sites.

- Meeting aquifer cleanup goals in one or more zones at the site

the cleanup goals for the within two years of startup of the remediation system.

It is important to note that groundwater cleanup is ongoing at most of the case study sites;

- Average operating cost per year of operation
- Capital cost per 1,000 gallons treated per year
- Average annual operating cost per 1,000 gallons treated per year

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Average annual operating costs ranged from 2.9 to 56 percent of the capital costs. The median capital cost was $1.9 million and the median average annual operating cost was $190,000; with median unit costs of $96 of capital cost per average 1,000 gallons of groundwater treated per year and $18 of average annual operating cost per average 1,000 gallons of groundwater treated per year.

Conclusion

As it can be appreciated, there are various reasons why our contaminated groundwater and aquifers should be restorated.

Groundwater remediation systems at the 28 sites, including: design, operation, and performance of the systems; capital, operating, and unit costs of the systems; The average annual volume of groundwater treated ranged from 1.7 million to 550 million gallons (at P&T sites).

For the 26 P&T systems, the approximate median capital cost was $1.9 million and the median average annual operating cost was $190,000; with median unit costs of $96 of capital cost per average 1,000 gallons of groundwater treated per year and $18 of average annual operating cost per average 1,000 gallons of groundwater treated per year. For the three PRB systems, the approximate median capital cost was $500,000 and the median average annual operating cost was $85,000; with median unit costs of $520 of capital cost per average 1,000 gallons of groundwater treated per year and $84 of average annual operating cost per average 1,000 gallons of groundwater treated per year.

Groundwater remediation technologies currently in use to clean up these sites 112 other case studies.

Bibliography

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