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Land Use and Water Pollution in Puerto Rico

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LAND USE AND WATER POLLUTION IN PUERTO RICO

By

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ABSTRACT

LAND USE AND WATER POLLUTION IN PUERTO RICO

By

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In Puerto Rico, previous water quality analyses have indicated that most surface waterbodies, as well as groundwater, are polluted with both organic and inorganic substances. Contributions to water quality deterioration come from point and nonpoint sources. These pose a threat on a densely populated island.

In Puerto Rico urban and industrial development occurred rapidly with a lag in the required infrastructure for expansion. Water pollution has been a by-product of this process and is regarded as the most serious environmental problem on the island.

This study examines water quality parameters in three hydrological basins. It attempts to determine how extensive a problem it is and how the concentration of pollutants compare in different land use situations.

A total of 33 sampling sites distributed among the three watersheds was chosen. The sampling sites include surface waterbodies and wells used for potable water supply. Each site was sampled three times during a six month period. The spatial design of the sampling sites was as specific as possible so as to differentiate among suspected pollutant sources.

Fifteen water quality parameters were examined. All of the waterbodies in spatial association with the land uses considered in this study presented detectable concentrations of the selected water quality parameters.

Although most of the parameters were detected at concentrations below standard limits, some of them either classified as toxic substances and/or priority pollutants, were above standard limits. If these waters were to be treated for potable supply, it is not certain that the contaminant substances would be removed. Furthermore, the potential health hazards are unknown, particularly when pollutant substances occur in combination.

The quality of the waters in Puerto Rico is under the surveillance of official monitoring networks. However pollutant monitoring has been limited mainly to the analyses of heavy metals. Unfortunately we live in an environment with multiple exposures to contaminant sources and many different disease potentials are related to water resources. The degree to which these potentials actually materialize depends on the treatment of water supplies and sewage, and the distribution of industrial, agricultural, and urban activities.

Dedicated to my parents
Charles and Carmen Arbona,
for their love and support.

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INTRODUCTION

The purpose of this study is to develop a reconnaissance survey of water pollutants and their association with land use in three hydrological basins in Puerto Rico: Cibuco River watershed, Guayanés River watershed, and Yagüez River watershed.

Since water pollution is usually measured against the intended use of the water, it can have several definitions. In this study we understand water pollution as excessive concentrations over periods of time of particular substances sufficient to cause detrimental effects against biological and human health.

In Puerto Rico, water quality analysis has indicated that most surface and groundwater, are polluted with organic and inorganic material or substances. Contributions to water quality deterioration come from many point and non-point sources. Practices at the individual, community and industrial level can create high risk situations with long term health implications. These pose a threat to public health on an island that covers only 3,500 square miles, with an estimated population of 3.2 million, a very densely populated country.

In the 1950's Puerto Rico was involved in a program of industrialization which attempted to convert the island's economy from an agricultural to an industrial base. Urban and industrial development occurred rapidly, but a lag arose in the provision of the infrastructure necessary for a balanced expansion. The distribution of industries reflects

the industrialization policies of the government. It covers the whole spectrum from heavy to light industries. On an island-wide map of point sources, a band along the coast can be traced where most of the industries are located. These coastal plains are where most population growth has occurred, and also where most of the island's underground water reservoirs are found.

According to the Puerto Rico Environmental Quality Board, pollution by pathogens, nutrients and suspended solids were the principal water quality problems of the island during 1986-87. Non-point sources of pollution originated mainly from agricultural activities, waste disposal and wastewaters from communities, and urban surface runoff. Discharges from municipal sewage treatment plants, as well from industrial discharges, were responsible for most of the impact from point sources. Large manufacturing firms have also been known to dispose of their wastes individually and improperly into surface streams, sinkholes and sanitary landfills. Toxic wastes in Puerto Rico are mainly generated by electronic, electrical and chemical companies, and also by the agriculture sector through the use of pesticides.

Moreover, the Puerto Rico Department of Health has reported gastroenteritis as the most frequent transmissible disease during recent years. The quality of the potable water served by the official Puerto Rico Aqueduct and Sewer Authority has been implicated as a possible culprit in some of the outbreaks.

With regard to groundwater, which provides nearly 30 per cent of the total water used island-wide, high concentrations of various volatile

organic compounds have been detected, especially in the northern part of the island. Contamination of groundwater may come from spills, direct land disposal or by septic tank leakage. The Puerto Rico Environmental Quality Board has just recently reviewed its water quality standards and for the first time there are some specific regulations to govern groundwater quality.

The quality of most of the streams in Puerto Rico is under the surveillance of an official monitoring network which consists of 57 stations. However, toxic pollutants monitoring has been limited mainly to the analyses of heavy metals. Special monitoring for other toxic substances such as pesticides, volatile organics, and acid/base neutral fractions of priority pollutants was initiated at some stream stations in 1985.

The sources of dangerous contamination are ubiquitous. Although the assessment of human health impacts caused by pollution is difficult, and a cause-effect relationship is not by any means established, the need for a better assessment of water quality and health implications is imperative.

In this exploratory reconnaissance survey, water from 33 selected sites in the three hydrological basins was sampled three times during a six-month period. The sampling sites included waterbodies surrounded by different land use situations such as industrial activities, sewage treatment plants, livestock activities, commercial and residential areas, and the main agricultural areas of sugar cane, pineapple, coffee and plantains.

The sampling sites include surface running waters such as rivers and creeks, and wells that are currently in use for potable supply. We did not measure depth, size and volume of water bodies.

Laboratory analyses included BOD-5, total and fecal coliforms, semivolatile organic compounds, ammonia, nitrite, nitrate, total kjeldahl nitrogen, cyanide, arsenic and the heavy metals mercury, lead, cadmium, chromium, and nickel.

In general, studies to assess water quality in Puerto Rico have been conducted on a site-by-site basis with the objective of fulfilling the specific needs of a particular agency or industry at a given site or area, especially regarding groundwater quality.

A more complete and comprehensive environmental monitoring assessment is needed to obtain data showing the pollution and land use relationship. This study, as a preliminary survey, can provide additional information for the evaluation and modification of monitoring activities, including site selection and parameters investigated. Assessment and reappraisal of monitoring activities is much needed since many waterbodies can be polluted by toxics, but a lack of monitoring data will make it impossible to estimate how widespread the problems are, or to determine whether conditions are getting better or worse.

CHAPTER I

WATER POLLUTION

Environmental pollutants can be divided into three broad categories: those occuring naturally, those either transformed or concentrated by living or nonliving systems, and those produced by man's activities. When a balance is upset by either natural or man-made events, the background levels of many compounds in the biosphere increase to such an extent that they pose a threat to many living forms (Greenberg, 1987). Any substance that is added to the environment at a rate greater than it can be removed will build up. Water pollution can be defined in a number of ways, but most definitions refer to excessive concentrations of particular substances for sufficient periods of time to cause particular effects.

Water quality is a term associated with the analysis of physical, chemical and bacteriological parameters. Physical parameters include color, odor, temperature, solids, turbidity, oil and grease. Chemical parameters are associated with the organic content of water and include analysis for organic chemicals, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) and total oxygen demand (TOD). The inorganic chemical parameters include pH, hardness, chlorines, sulfates, sulfides, heavy metals, nitrogen (organic, ammonia, nitrite, and nitrate) and phosphorus. Bacteriological parameters include total coliforms, fecal coliforms, specific pathogens and viruses.

Pollutants are transported in water as dissolved ions and molecules or on suspended particulate matter. Water soluble pollutants that move freely are diluted as uncontaminated water mixes with contaminated water. Concentrations of soluble pollutants, therefore, decrease as distance from the source of pollution increases. Chemical and biological degradation reduces the concentration of contaminants, and most water soluble organic compounds are biologically degraded within a few days or weeks.

The insoluble pollutants and those that are adsorbed to particulate matter are moved as suspended particles. Over a long time, total movement can be extensive and long-distance, if the contaminant is persistent. Chemicals that persist in the environment for long periods can be deposited in sediment along streams and in other bodies of water and accumulate there. The ultimate sink is the ocean floor (Chiras, 1985).

Point Sources and Non-Point Sources

Water quality degradation comes from many sources. Water is an important pathway for pollutants: most will find their way into surface and underground water after their release into the environment, and others are directly discharged into waterbodies since water is usually the most convenient disposal route for many wastes.

Point sources of water pollution are those that discharge pollutants at discrete locations. Industrial wastes that are discharged directly into surface waterbodies, or that seep into groundwater from land disposal

sites, fall into this category. Point sources occur at specific locations and are, at least theoretically, easier to detect and control than non-point sources.

Non-point or areal sources of pollution refer to those substances which can be introduced into receiving waters from broad areas such as urban or rural runoff. Whereas municipal and industrial point sources of pollution are discharged directly to receiving waters, nonpoint sources must rely on the transport mechanisms of the hydrologic cycle to provide the means of movement from the land. The pollution of lakes and streams is the direct result of the interaction between land use activities and the hydrologic cycle. Runoff from urban areas may contain numerous types of chemical and microbiological pollutants and the runoff from agricultural areas contain not only barnyard wastes but also fertilizers and pesticides. Many of the industrial and agricultural wastes coming into waterbodies from these sources have proven to be highly toxic. Since these sources of pollutants are areal and dispersed they are difficult to detect and to subject to regulation.

Groundwater and Surface Water Pollution

Groundwater has been generally regarded as safe from contamination and as requiring minimum treatment before use. In most cases the pollution must pass through a layer of soil where attenuation of contaminants occurs. However, if the soil is polluted to such a degree that its adsorptive retention power is exceeded, then pollutants can be released to groundwater. Moreover, water movement through limestone may be

extremely fast, so that groundwater can be similar to surface water in relation to contaminants.

In landfills, for example, the largest component of waste is paper, but substantial food wastes, glass, metals, plastics and liquid wastes are included. Municipal sites also receive industrial process residues, where manufacturing wastes are included. Hazardous constituents are often present in the leachate from these wastes. The leachate can reach surface waters or percolate to an aquifer (Cyr et al, 1987). Because groundwater generally moves slowly through an aquifer, it may take years for water polluted in one location to appear in another. Additionally, once an aquifer is contaminated the pollutants may remain for centuries. Contaminants in groundwater may partition between the water and organic matter in soil particles. Chemicals adhere to the soil particles making removal through groundwater pumping difficult (Travis and Doty, 1990).

Innumerable waste materials and natural and man-made products, with the potential to contaminate water sources are stored or disposed of on, or beneath the land surface. For control of groundwater contamination, effluent limits apply to a broad range of activities, such as limits on types of materials disposed of in sanitary landfills, limits on specific contaminants injected into an aquifer by mean of a disposal well and pollutant discharge limitations for surface impoundments.

Industrial waste water impoundments are a more serious source of groundwater contamination for their potential of leaking hazardous substances. Liners are no guarantee against eventual leakage of contaminants. They can fail mechanically or can be physically altered by

the contained wastes. Most of the substances found in industrial wastes are complex and are not normally included in routine analysis of water supplies. Alternatives to industrial impoundments are available, such as above ground tanks, and digestion for sludges or wastes with high organic content, but these can have a major economic impact on industries.

Surface waters such as rivers, lakes and ponds can be easier to pollute than groundwater. Pollutants can be disharged directly into the surface waterbody or may be washed into streams and lakes by the action of rain.

Rural non-point sources that contribute to the pollution of surface water include runoff from land where animal manure or sewage waste has occurred, or runoff from lands utilized by grazing animals or where intensive use of pesticides and fertilizers have been used without regard to their pollution potential. Particularly, feedlots may be located where natural drainage aids in the transport of wastes to the nearest streams. Thus, transport of pollutants to nearby surface waterbodies can be effective via surface runoff.

Chemical and Microbiological Pollution

The effect of pollution on the receiving waterbodies depends on the type and concentration of pollutants. The contamination of water by physical pollution, and by organic and inorganic chemicals has been identified as the most important aspect of water pollution but, in some

areas, microbiological contamination of water can still present a serious health hazard.

Microbiological Pollution

One of the greatest potential health hazards associated with water supply is the possibility that it could become a vehicle for the spread of a waterborne infectious disease. This is particularly true in less developed countries without an adequate water supply. Although widespread disinfection of water supplies has considerably reduced this problem in developed countries, waterborne diseases such as cholera and hepatitis are a present health problem to many in developing countries. The basic problem is a lack of, or inadequate water treament and supply facilities. However, countries with an adequate water infrastructure may still experience waterborne disease outbreaks as a result of inadequacies in the system at the treatment stage or during delivery (Page, 1987).

Pathogenic organisms are found in the stools of populations of who are suffering from acute disease. The release of fecal pollution into water can produce outbreaks of gastro-intestinal illnesses which are characterized by diarrhoea, abdominal cramps, vomiting, acute distress and fever. Sewage treatment plants are usually very effective in reducing the introduction of human and animal wastes into water resources. However, as the water supply sources become more polluted they require more extended and consistent treatment, thus the risk of an error becomes greater both with the increased complexity of the treatment and the pollution load being treated, all of which may adversely affect the required

continuity of high level of performance. In addition, untreated sewage can reach underground and surface water through leaking sewers, cesspits and septic tanks. Surface waters, as well as underground waters, may be polluted by pathogenic bacteria, viruses and protozoan parasites.

When community outbreaks occur, in all countries, large number of cases receive only home treatment. Even countries with relatively elaborate reporting systems admit that their data are incomplete and biased. It is commonly estimated that the reported outbreaks of waterborne diseases represent about 10 per cent of the true number; the remainder are unreported (Page, 1987).

Bacterial diseases can be effectively controlled by water treatment. But measuring the actual level of each pathogenic organism is costly and time consuming, therefore water quality control programs routinely monitor coliform bacteria levels in water samples to obtain an indication of how much fecal contamination has occurred. The assumption is that the higher the coliform count, the more likely it is that the water contains some pathogenic agent from fecal contamination. However, there are some pathogenic strains of the indicator bacteria, *Escherichia coli*, which apparently grow in water in tropical environments and may become part of the natural flora thus rendering the coliform parameter inappropriate as an indicator of recent fecal contamination.(Hazen et al, 1987).

Bifidobacterium adolescetis has been suggested as an alternative indicator in tropical environments. It is also one of the dominant anaerobes in the gut of humans and is incapable of surviving in an oxygenated environment (Mara and Oragui, 1985). These characteristics

make it a good indicator. It should be noted that while the World Health Organization (WHO) has established international guidelines for coliform counts, these were stated only as general rules.

The use of indicator bacteria does not guarantee a perfect treatment, since the possibility remains for waterborne bacterial illness caused by low levels of virulent pathogens. Viruses can retain the ability to cause human infections. They have been found to survive longer in natural waters and during water treament than bacterial pathogens and indicator bacteria. The extent of illness caused by waterborne viral infection is unknown. Gastroenteritis, a common waterborne disease may be caused by a viral infection. Poliovirus and infectious hepatitis A are among the viruses most often identified in water and that can cause episodes of illnesses in a population whose water sources are sufficiently contaminated (Page, 1987).

A number of protozoa can be transmitted to humans through water (Raidt and Acierno, 1985). Current chlorination procedures do not destroy *Giardia lamblia,* a pathogenic protozoa that causes giardiasis and that may be present in drinking water supplies which meet the coliform standard. The symptoms of giardiasis may involve diarrhea, loss of apetite, dehydration, cramps and in some cases vomiting. The cysts of *Giardia lamblia* and other protozoa can be removed by sedimentation and filtration through sand, but in order to be effective in removing protozoa from water the filters must receive proper maintenance. The respective use of coagulation, sedimentation and filtration in water treatment plants will vary with the number of customers of the water supply system in order to be effective. *Giardia lamblia* may be responsible for cases of gastroenteritis for which no known etiological agent can be identified.

Chemical Pollution

Since the Second World War a vast number of organic chemicals have been produced and introduced into the environment. Synthetic organic compounds constitute a major type of pollutant and can be found in urban or rural land uses from point or non-point sources. Usually organic chemicals are found at very low concentrations in water. Many are non-biodegradable or are so slowly degraded that they persist in the ecosystem (Greenberg, 1987).

Industries continue to produce large amounts of synthetic organic materials. Many of these substances do not occur naturally and the end uses of many products tend to disperse them widely in the environment. Production and waste disposal sites also can release synthetic organic chemicals and their decomposition products into the atmosphere and hydrosphere.

The potential for water pollution by chemicals depends upon factors such as direct or indirect release into water, solubility, vapor pressure, and use. Following emission, chemicals may be chemically degraded in the environment or they may have volatility characteristics that cause their release from water. The rates of degradation may differ. The accumulation of materials in systems and organisms is primarily a function of water and lipid solubility, sedimentation, and binding to inorganic or organic substances. The toxicity of many industrial chemicals is partly known in humans largely because of potential exposure of the

labor force, but the effects, especially chronic ones, are poorly known for the vast majority of organisms (Anderson and Abdelghani, 1985).

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) required the U.S. Environmental Protection Agency to develop a comprehensive program to improve the quality of the waterbodies in the United States. Section 307(a) mandated publication of a list of toxic pollutants for which effluent standards were being established. These substances were selected on the basis of their known occurrence in effluents, their presence in drinking water or fish, their known or suspected cacinogenic, mutagenic, or teratogenic properties, their likelihood of human exposure, their persistence in the aquatic food web, their propensity for bioaccumulation, and their toxicity to aquatic organisms and those (including humans) which might feed on such organisms (Middlediteh et al, 1981). The list includes 114 organic priority pollutants. In addition, 13 metals (antimony, arsenic, berylium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc) along with three miscellaneous categories; cyanides, asbestos and phenols, complete the list of 129 priority pollutant species (Code of Federal Regulations, 1979). Many which have been created since then have not yet been added to the official EPA list.

Most of the organic chemicals that cause health concerns are man-made. While acute effects of exposure to organics are known, it is generally assumed that the long term effects of the ingestion of small quantities for very long periods of time would not necessarily resemble the acute toxic effects of a substance (Page, 1987).

The causes of outbreaks of infectious disease are better understood than the possible chronic effects of chemical contamination. The acute effects of organics are known from industrial exposures, but most synthetic organics in water are found at low concentrations and may be ingested over many years. Little is known about the long term effects of trace levels. There is virtually no information on factors such as nutrition and the influence it may have on the response to a chemical insult. The effect might be just as great as that caused from a change in the dose of the chemical exposure (Lioy, 1990).

It is known that some chemicals can be stored in fat cells where they can accumulate faster than they are degraded or eliminated, hence their potential for disease causation. These substances constitute 90 per cent of those listed in United States as potencial carcinogens. But cancer is not the only threat; nervous system disorders and genetic damage are among other possible health impacts. There is also the potential for synergisms among the mixtures of many different organic chemicals that may simultaneously be present and for which there is only rudimentary knowledge.

The problem is complicated because new organic chemical compounds are being created and introduced into the environment. The processes by which they reach water sources vary. Some, like the pesticides, are intentionally released into the environment. Unintentional releases occur during accidents. But they are also released from industrial as well as domestic landfills and their storage and distribution facilities.

Domestic sewage and treated effluents are, in principle, of a nature that the contaminants they contain can be absorbed by the stream without

causing serious long term damage. However, few municipal sewages are strictly domestic. Most contain some industrial waste and virtually all contain evidence of the wide array of chemical products used in the modern home.

Toxic chemicals entering sewage disposal plants, which use biological degradation systems, often poison the bacteria, the essential biological catalyst of the system, and lead to failure. This results in partially treated or untreated municipal sewage being discharged into streams causing great environmental damage from the high biological oxygen demand of sewage and the consequent low dissolved oxygen content in water (Marrack, 1981).

Among different technologies of water treatment, activated carbon has been found effective in removing many organic chemicals. However the cost of operation makes it too expensive to be widely used. Moreover, commonly used purification systems actually could increase the levels of toxic chemicals found in water supplied to consumers by the addition of chlorine for disinfection purposes. The organic content in the water reacts with chlorine creating a multitude of toxic and carcinogenic organic chlorination by-products, such as trihalomethanes, the most widely identified toxic organic chemicals in water supplies (Canter, 1985).

Metals are inorganic chemical compounds, and some of them have essential physiological roles. But there are others having similar chemical characteristics that may also interact with biological tissues, possibly resulting in toxic effects when present at sufficient concentrations. These elements are called heavy metals because they are metals or metalloids that

have higher atomic weights than do the essential elemental metals (Mailman, 1980).

While there is some unavoidable mobilization of heavy metals which results from leaching of ores by rain or running water, more important sources of heavy metals pollution are industrial discharges, urban runoff, mining, soil erosion, sewage effluents, and even air pollution fallout. Solid wastes in municipal dumps also contain metals, and if the dump sites are placed in the wrong hydrogeologic environment, rain water can leach out the metals, along with a variety of other pollutants that can reach surface and underground waterbodies.

Because of their wide distribution in nature and their extensive industrial uses toxic levels of heavy metals are now found increasingly in human food, in their water supplies and as suspended particulate matter in the atmosphere. Metals discharged in industrial wastes have been reduced, but the legacy of past excessive discharges may remain in many river bottoms and could reappear when stream erosion patterns change or in any situation that disturbs the sediments at the bottom.

Since heavy metals are elements, they cannot be degraded once they are released into the environment. This same characteristic prevents them from being eliminated from tissues by metabolic degradation and provides for the potential accumulation in the body, leading to chronic effects. Once in the body the rate and pathway of metal excretion vary from one metal to the other. The biological half life in human beings and other organisms not only varies with the metal but also with the type of body tissue involved (Clarkson, 1979).

The consumption of aquatic organisms from contaminated waters can also have an effect on human health. The term bioaccumulation refers to the accumulation of a chemical within an organism due to the ingestion of contaminated food as well as water. Feeding is an important source for bioaccumulation of many toxic heavy metals. The process of bioaccumulation may result in biomagnification, that is, an increase in concentration of chemicals within organisms.

Accumulation in tissues does not necessarily imply the occurrence of a toxic effect. Storage depots may form in body tissues. The long term effects of this retention over a human life span is not yet fully understood. Organ storage can prevent the acute toxic effects of the metal, but it is not clear to what extent it is without hazards over long periods of time.

Heavy metals and organic forms of nitrogen are among the major groundwater contaminants. Nitrogen is present in the atmosphere, hydrosphere and biosphere. All forms of nitrogen - nitrate, nitrite, ammonia and organic - are components of the nitrogen cycle.

Organic nitrogen includes such natural materials as proteins and peptides, nucleic acids and urea, and numerous synthetic organic materials (Standard Methods, 1985). Nitrogen in reduced or organic forms is converted by soil bacteria into nitrite and nitrate. Nitrogen occurs in water as nitrite (NO2), nitrate (NO3) and ammonia (NH4). Some other forms such as cyanide (CN) may occur in water affected by waste disposal. The nitrites and organic species are generally considered to be indicators of pollution through disposal of sewage or organic waste. The presence of nitrate or ammonia might be indicative of such pollution also, but generally

the pollution would have occurred at a site or time substantially removed from the sampling point (Hem, 1985). Nitrates may be reduced to nitrites in the gastrointestinal tract. Nitrites in turn, combine with the hemoglobin in red blood corpuscles and form metahemoglobin, which has a reduced oxygen-carrying capacity. Nitrites can be dangerous and even fatal in infants younger than three months (Chiras, 1985). The production and use of synthetic fertilizers such as ammonia and other nitrogen compounds may have increased the presence of nitrate in rivers and groundwater. Farm animals in confinememnt can produce considerable concentrations of nitrogenous organic waste. Drainage from nearby barnyards or septic tanks and cesspools can also be implicated.

With regard to chemical pollutants more research is needed to decide what can be accepted as a safe concentration. Many chemicals have been pronounced safe on the basis of short-term tests whereas subsequent ecological experience has shown that they can have long-term adverse effects. Another problem is to discover how many other chemicals, about which relatively litte is known, are present in the environment and to determine the means to control them.

The majority of the studies which provide information on which decisions are made are those using animals. Extrapolations from experimental animals to people have many limitations (Calabrese, 1987). Sometimes data on the direct effects of a compound on humans are available as a result of pharmaceutical and medical research or from industrial toxicology, epidemiology or poisonings, but this type of information is usually limited. A means for measuring the synergistic and antagonistic effects of chemicals is necessary, as well as better case control

data to assess the exposure of the populations to other, that is, non-water related toxic treats.

Accurate assessment of human health impacts caused by pollution is extremely difficult. Overall, however, available scientific evidence continues to substantiate the link between toxics in water and serious public health concerns.

Regarding pollutants and land use, previous studies have found the following associations: a) gross organic pesticide contamination with agricultural, forest and horticultural land uses; b) gross light chlorinated hydrocarbon pollution and industrial and commercial areas; and c) gross heavy metal contamination with industrial, commercial and agricultural areas (Greenberg et al, 1982).

Heavy chlorinated hydrocarbons, which include pesticides, are noted for their low volatility and high persistence in the environment. The light chlorinated hydrocarbons are more volatile and less persistent in the environment than the pesticides. These substances are commonly used in industrial products including industrial solvents, gasoline additives, disinfectants and cleansing agents. Heavy metals may find their way into waterbodies from the natural weathering of rock formations and soil, but they may find their way into waterbodies from industrial activities, urban runoff, municipal wastewater treatment, or abandoned mines.

The Nationwide Urban Runoff Program, developed by the U.S. Environmental Protection Agency as a program to obtain data on control of urban water quality and its impact on receiving waters, has confirmed that pollution problems such as coliform bacteria, nutrients or heavy metals

result from urban runoff. But agricultural activities, especially tillage practices and animal waste management, are the main contributors of non-point sources pollution in both lakes and rivers (Humerik et al, 1987).

Many different diseases are potentially related to water resources, as it has been discussed, and the degree to which these potentials actually materialize depends largely on matters such as the treatment of water supplies, methods of agricultural and industrial production, and monitoring and implementation of control strategies.

CHAPTER II

WATER POLLUTION IN PUERTO RICO

The island of Puerto Rico is located about 18 degrees north latitude and 66 degrees west longitude. Roughly rectangular in shape, it is 100 miles east-west and about 35 miles north-south (Fig.1). Puerto Rico is one of the most densely populated countries in the world with about 800 persons per square mile. Approximately 43 percent of the population is concentrated within 15 miles of San Juan and 12 percent within 5 miles of Ponce, the second major urban center outside the San Juan metropolitan area.

Although small in size the island of Puerto Rico has a diverse physical environment. The diversity is caused mostly by the topographic relief and its effect on rainfall distribution more than by any other factor. A complex central ridge system averages 2,800 feet, with a maximum altitude of 4,400 feet, and forms a barrier to the northeast trade winds. As a result, most of the south coast averages less than 45 inches of rainfall per year, while the northern part of the island averages about 80 inches per year.

Even though the mean annual rainfall seems high compared to that of temperate climates, much of the rain occurs in short intense showers and is lost to evotranspiration. Of the 75 inches that the island receives in an average year, 45 inches are lost to

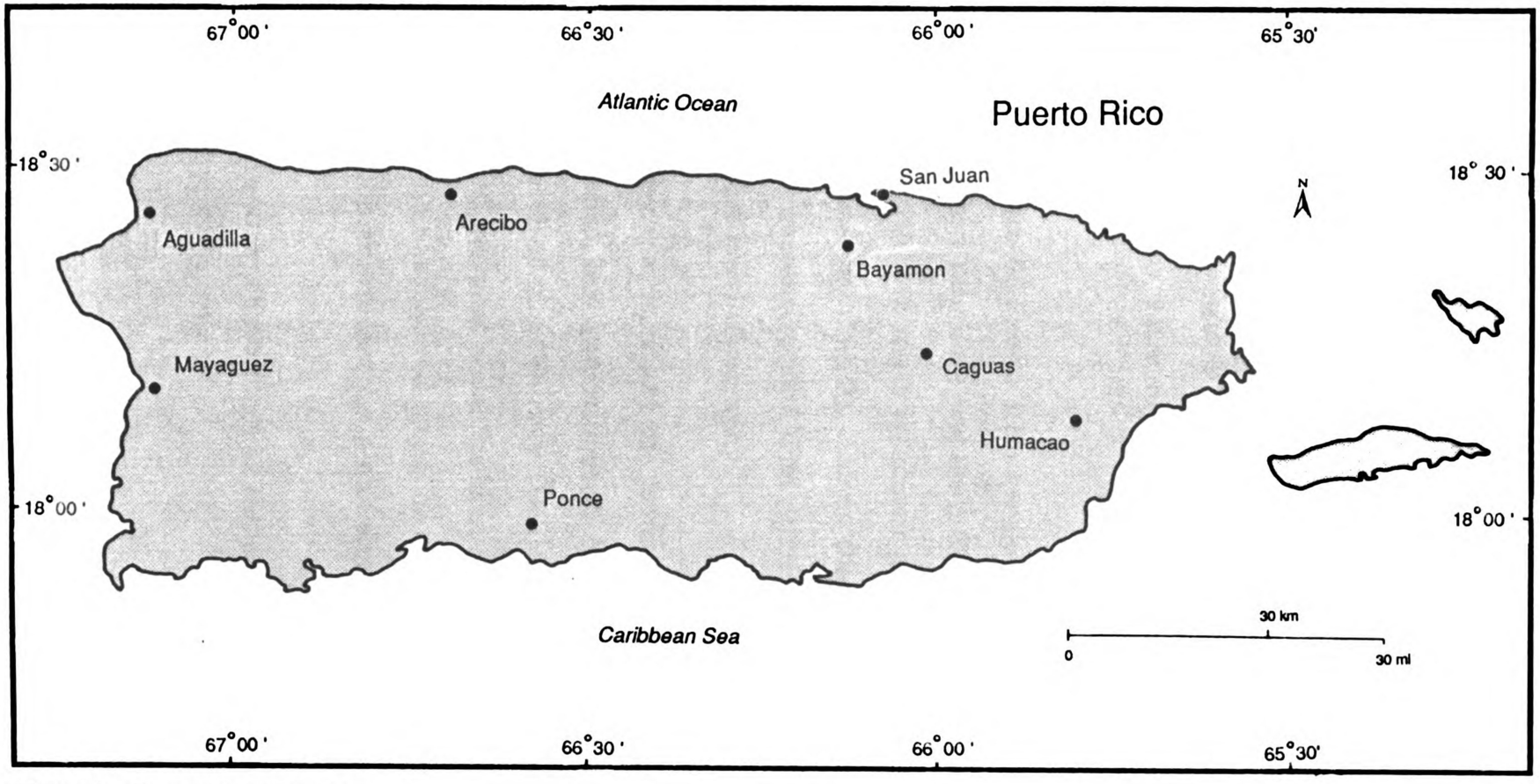

Figure 1. Geographical Location

evapotranspiration, 27 inches are accounted as streamflow and about 3 inches is ground-water discharge (U.S.G.S., 1987).

The principal rivers flow from the central ridge to the sea (Fig.2). There are approximately 100 streams and rivers contained in 33 principal basins. No natural lakes exist in Puerto Rico, but 28 reservoirs and ponds have been constructed for water supply, irrigation and hydroelectric power (U.S.G.S., 1987).

The central core of Puerto Rico consists primarily of volcanic and intrusive rocks of Late Cretaceous and early Tertiary age. The central core is flanked in the north and south by clastic sediments and limestones of Oligocene and Miocene age (Fig. 3). Along the north coast, the limestone has been subjected to extensive solutional activity which has resulted in the formation of a mature karst topography.

The aquifer system is one of the prime sources of water supply for industrial, agricultural, and domestic use. According to information from the United States Geological Survey (USGS), groundwater constitutes nearly 30 percent of the total water used in Puerto Rico (U.S.G.S., 1985). Irrigation is the main use followed by public water supply and industry, the main users being the pharmaceuticals and electronics plants. The coastal plains, especially the northern one, have the great majority of the population and are also where most of the urban and industrial growth have occured (U.S.G.S., 1987).

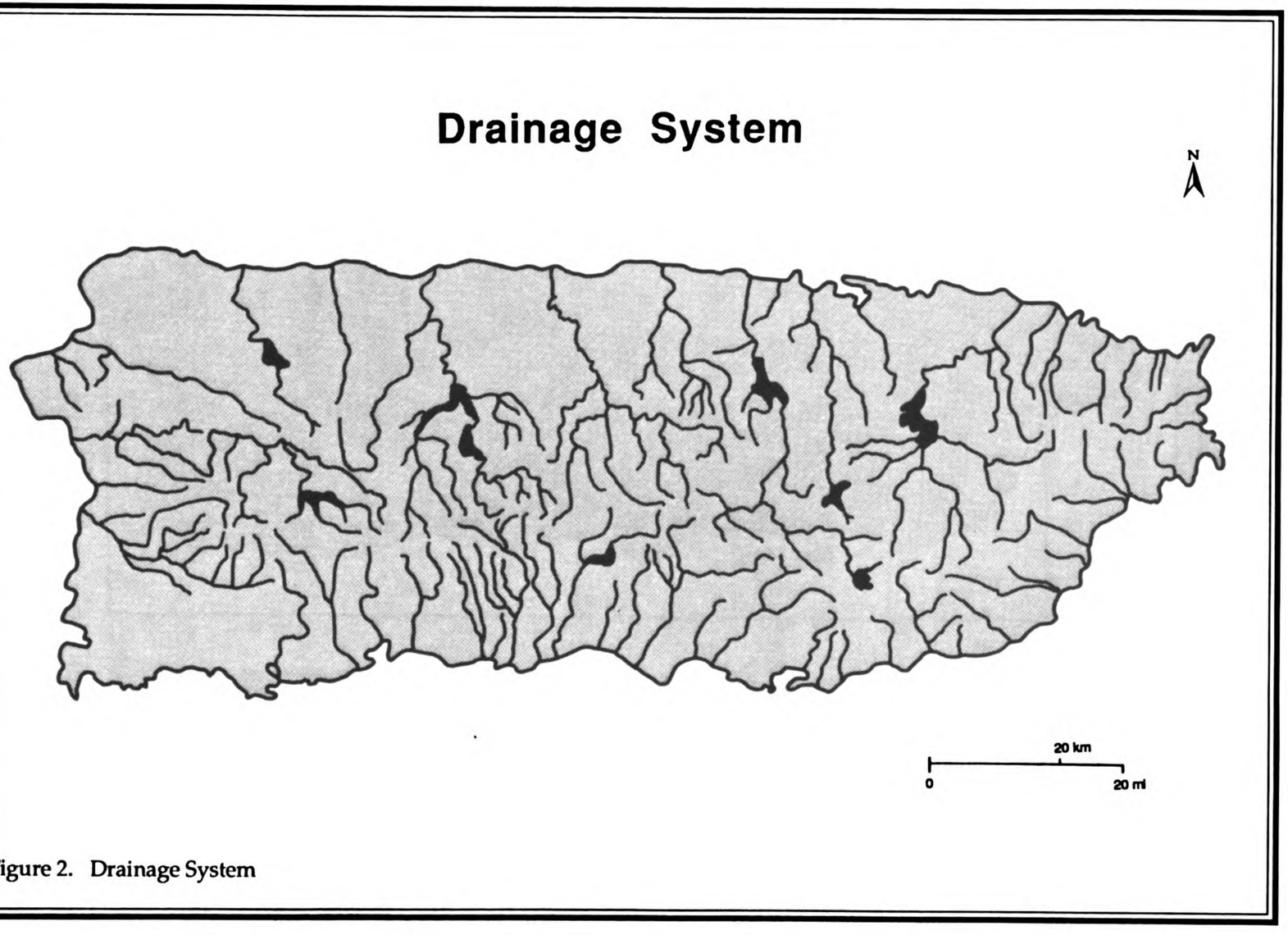

Figure 2. Drainage System

Geology

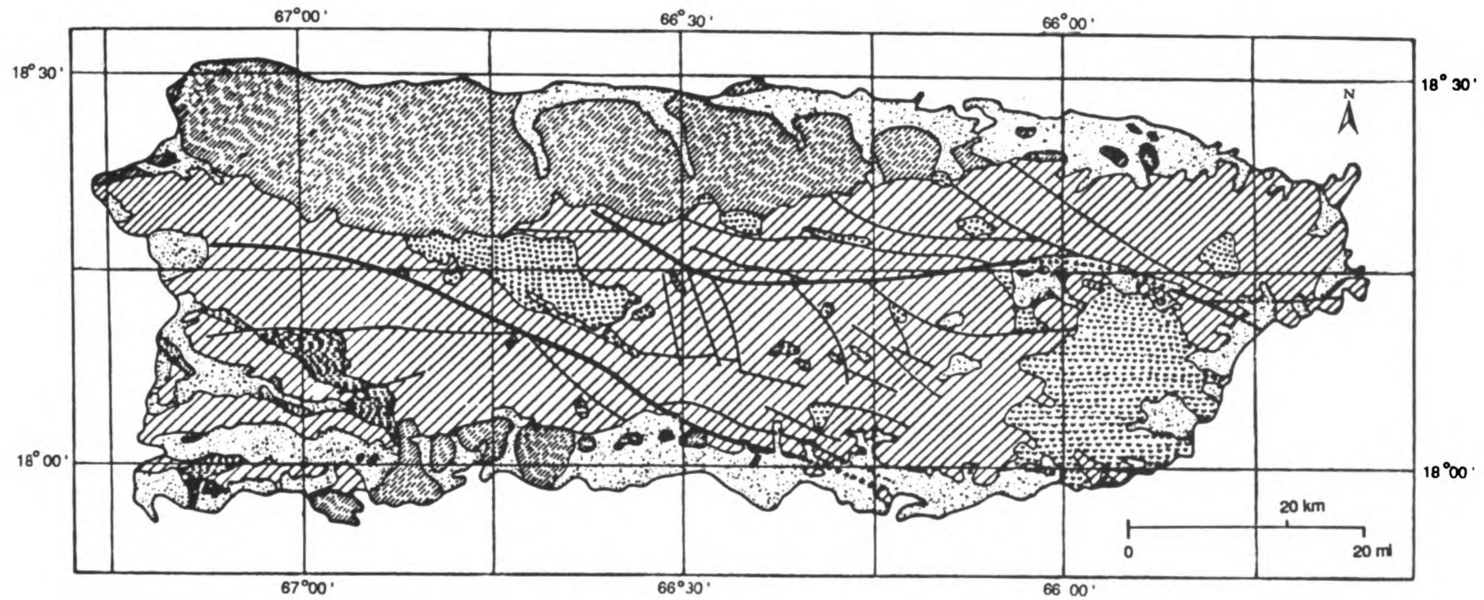

Figure 3. Geology

After U.S.G.S. 1987

Starting in the 1950's Puerto Rico was involved in a program of industrialization which attempted to convert the island's economy from an agricultural to an industrial base (Parrilla, 1977). During the first years of the industrialization effort, firms from the United States were attracted to Puerto Rico by lower labor and production costs, and later by tax exemption. In those early years, emphasis was placed upon labor-intensive industries such as food processing and related activities including rum distilling, textiles, apparel and tobacco products. The manufacture of cement, bricks, tiles, ceramics and glass was also important. These industries were established in the principal cities, especially in San Juan, which not only created an industrial concentration in and around San Juan, but also promoted a migration from the countryside to the capital city.

With rapid growth, the provision of facilities and necessary services for the new city inhabitants became difficult. In an attempt to divert the flow of population toward the capital, a program of industrial decentralization was adopted. The program was based on providing better incentives for those industries that were to be located in less developed municipalities.

Later on, in the mid 1960's the establishment of chemical and petrochemical activities exhibited rapid expansion. These industries are more capital-intensive and require less labor, but more specialized and capable of operating complex machinery of high productivity. The production of alcoholic beverages, electronic and scientific devices, metal products and glass also increased considerably (Cruz, 1988).

With a time-lag necessary for infrastructure support, urban development also rapidly expanded. In a period of about thirty years Puerto Rico has changed from being a predominantly agrarian society to one of services and manufacturing. The most evident results of this impact have been a deteriorated rural landscape, some industrial nuclei, and a highly comercialized urban landscape. Water pollution has become a by-product of this process and constitutes the most serious environmental problem of the island.

According to the Puerto Rico Environmental Quality Board the presence of high concentrations of fecal coliforms and streptococci bacteria is the principal water quality problem of surface water bodies in Puerto Rico. Available data on river water quality show the following violations: (1) dissolved oxygen, 75 percent of rivers violate current standards; (2) biochemical oxygen demand, 64 percent of rivers violate current standards; and (3) for total coliforms, 95 percent of rivers violate current standards (Puerto Rico Environmental Quality Board, 1984-85).

There are 526 administratively listed polluting entities that generate toxic substances on the island, of which 76 are sewage treatment plants. Coliform violations are attributed to a large rural population lacking adequate waste disposal, inadequate treatment plants and inadequate disinfection together with commercial runoff from dairy farms and pasture lands. About 90 percent of the biochemical oxygen demand to water quality standards are the result of discharges from industries and municipal sewage treatment plants.

The Puerto Rico Aqueduct and Sewer Authority (PRASA) created in 1945 is the agency responsible for treatment and distribution of potable water. In addition this agency is responsible for the operation and maintenance of sanitary wastewater (sewage) treatment plants. Currently PRASA has serious problems with the sewage treatment plants. From a total of 114 treatment plants 85 were included in a Federal Court Order issued in 1978 in which the United States Supreme Court assumed jurisdiction over those treatment facilities that were not properly operated by PRASA. These plants were included in the Order because they did not comply with the National Pollutants Discharge Elimination System (NPDES) permits. As a result of substandard sewage treatment plants, the waterbodies received discharges that seriously reduced the water quality, thus causing a threat to health in the potable water served by PRASA. Today, 13 years later, 54 of the 114 treatment plants remain under the Federal Court Order. Eight of these regularly receive discharges that exceed their processing capacity thus resulting in overflow releases of raw sewage into the environment.

Filtrations from these plants are also a threat to groundwater and bacterial contamination has been detected in groundwater. In a report by the U.S. Geological Survey in 1982 it is indicated that four wells in the northern aquifer were contaminated with fecal bacteria from 40 up to 100 percent of the time. According to EPA officials on the island, contamination of rivers with schistosomes, the disease agent of schistosomiasis or bilharzia, may also be related with fecal wastes that reach the bodies of water either by direct contamination or through inadequate filtrations and treatment.

The Puerto Rico Department of Health has reported gastroenteritis as the most frequent transmissible disease during recent years. The number of reported cases in 1988 was 61,321 and in 1989 69,775 were reported. Bacterial contamination of water was suspected as the source of disease transmission.

Giardiasis has been mentioned as another posible culprit in the gastroenteritis cases. However, the position of PRASA officials is that *Giardia lamblia* is resistant to chlorination and therefore its presence in potable water supplies does not imply an inefficient filtration system. However, the cysts of this protozoan can be removed through the process of coagulation and sedimentation at the treatment plant, provided the system is working properly at the volume or capacity for which it was designed.

But bacterial contamination is not the only problem with the water in Puerto Rico. Most large manufacturing firms had been known to dispose their wastes individually and inadequately in surface streams, sinkholes and sanitary landfills. In general, little control exists over the treatment and discharge of industrial wastes.

The Puerto Rico Environmental Quality Board (PREQB) reports that more than 110 chemical sustances are handled in several industries operating on the island. The most commonly used chemicals are presented in Table 1. In 1988, a total of 510 major industrial concentrations were distributed as follows: 76 in Humacao, 71 in San Juan, 69 in Arecibo, 68 in Ponce, 58 in Carolina, 55 in Guayama, 40 in Aguadilla, 39 in Orocovis and 34 in Mayagüez. All of these industries, with the exception of the ones in Orocovis, were located in coastal areas (PREQB, personal communication).

Table 1. The Most Common Chemicals Used By Local Industries in Puerto Rico

Chemicals	Uses	Hazards
Methanol	Highly flammable liquid used in solvents, cleaners and fuels.	Severe exposure can cause dizziness, loss of sight, unconsciousness, death. Absorbed through skin.
Toluene	Solvent for perfumes, medicines, explosives, dyes, detergents and aviation fuels.	Explosive and flammable. Toxic if ingested, inhaled or touched.
Dichloromethane	Industrial solvent and paint stripper; used in aerosols and pesticides, also in films.	Carcinogen
Acetone	In paint, varnish and lacquer; solvent for cement in the leather and rubber industries.	Dangerous fire hazard that is moderately toxic; irritates eyes and nervous system.
Freon 113	Common solvent used for electronic components; refrigerant.	Depletes ozone layer.
Carbon Disulfide	In rayon, cellophane, carbon tetrachloride.	Highly flammable; toxic even by touch; attacks nervous system.
Acetonitrile	Solvent; also used in organic synthesis.	Cyanide poison that attacks the nervous system, irritates skin and eyes.
Benzene	Petroleum by-product; solvent; in detergents and nylon.	Flammable, toxic carcinogen; poisonous if inhaled or absorbed through skin.
Cyclohexane	Used in making nylon, glass substitutes and solid fuels.	Fire hazard; moderately toxic with pungent odor.
1,1,1-trichloroethane	Solvent for cleaning precision instruments; also in pesticides and textiles.	Severe eye irritant, but moderate irritant if absorbed through skin or inhaled, large dose can cause cardiac arrest.

Source: U.S. Environmental Protection Agency

Toxic wastes in Puerto Rico are mainly generated by oil refineries, petrochemicals, electronic, electrical, and chemical companies, medical product industries and thermoelectric manufacturers (PREQB, 1978). Moreover, although small scale agriculture has been almost eliminated from the island, the remaining commercial agriculture uses a wide array of pesticides. Puerto Rico's industries produce and use chemical solvents, many of the polychlorinated type. In the electric and electronic industries these solvents are used, like mercury, as well as other heavy metals in electro-plating.

In the early years of industrialization, it was a general practice to dump industrial wastes in sanitary landfills. These were not designed to meet the conditions necessary to receive that type of waste. The disposal of industrial wastes in this manner is now prohibited, but toxic substances remain buried under tons of sanitary landfill, and illegal dumping of industrial waste is still in practice.

In fact any sanitary landfill on the island may be suspected of containing toxic wastes. Currently the Environmental Quality Board has a list of 169 sites where it is suspected or known that toxics have been dumped, and 74 of these are sanitary landfills. It is also a matter of concern that out of 68 municipal landfills only two are working adequately according to PREQB regulations. The dumps are mostly located on highly permeable soils that allow contamination to spread by seepage and drainage far beyond the landfills.

While in 1987 45,000 metric tons of toxic wastes were generated on the island, the EPA projects that for 1993 this number will increase to 112,000

metric tons. Of the total toxic wastes generated in Puerto Rico, 50 percent are exported to the United States for disposal. The remaining 50 percent are eliminated by local industries (mainly through incineration), or they are inadequately disposed of in sanitary landfills, waterbodies, open terrain, or through the sewage system. PROTECO (Protección Técnica Ecológica), a private company that used to receive, treat, store and dispose of hazardous materials, failed to meet EPA requirements to operate a facility for such purposes and had its operations banned by the EPA in the mid-1980's. Another private firm, the Safety Kleen Envirosystems Co. in Manatí, has permission to operate but this firm disposes of solvents only.

The federal government has designated nine sites in Puerto Rico on the Superfund National Priority List. This is an inventory of contaminated sites that represent an imminent threat to human health and the environment. The cost of cleaning up a contaminated site can vary depending on the contamination and other environmental factors. The Superfund created in the 1980's is a federal fund that taxes the main generators of toxic waste with the objective of creating a fund for cleaning up the sites where no culprit has been identified, or specific liability established (Kimbrough, 1990).

The Superfund sites in Puerto Rico include:

1) The Barceloneta landfill which accepts municipal and industrial waste. The site is underlain by permeable limestone formations and waste has been placed in sink holes. There is no natural or artificial barrier to prevent the migration of contamination.

2) The Juncos landfill where thermometers containing mercury from the pharmaceutical company Becton Dickinson were dumped. Leachate from the fill zone enters a highly wet area and drains toward an artificial channel that is utilized for agricultural watering. Preliminary studies have indicated that soil and air may contain higher than background concentrations of mercury. Several streams flow through the landfill into the Gurabo River, which drains into Lake Loíza, a reservoir that supplies drinking water for the San Juan metropolitan area.

3) Public supply wells at Guayama contaminated with tetrachloroethylene, trichloroethylene and other waste chemicals detected by the U.S. geological Survey during a survey of public water wells. Solvents were discharged through the drainage system into lagoons and seeped into the soil. Four out of five wells show contamination and are closed, the fith one, which is yet to show contamination, is still open. The firms Phillips Petroleum, Chevron and American Home Products have been identified as responsible for the contamination.

4) Vega Alta public supply wells are contaminated with volatile organic compounds. The sources of contamination have been identified as General Electric del Caribe, The West Company, Motorola, Harman Automotive, Teledyne Packaging, and the Puerto Rico Industrial Development Company.

5) Wells in Arecibo are contaminated with vinyl chloride, TCE and other solvents. The source of contamination may be a closed phtalic anhydride manufacturing facility, a subsidiary of Hooker Chemical and Plastic Corp.

6) The General Electric Company Wiring Devices site in Juana Díaz is contaminated. On the property is an inactive open dump for off-specification products. Contaminants can further erode in this dump, which is uncovered, into adjacent agricultural land. The site is also located in a residential area. Testing by the company for the PREQB has found mercury in the open dump.

7) Frontera Creek in Humacao is a small creek that receives industrial waste discharges including mercury pesticides. Adjacent to the creek are two large fresh-water lagoons which are directly connected to the creek. There is concern that contaminants will enter the aquatic food chain. Local residents use the lagoons for fishing and recreation. Finfish and shellfish trapped in the lagoons are significant in the local diet. Revlon has been identified as the responsible party.

8) RCA del Caribe in Barceloneta manufactures aperture masks for television picture tubes. The process generates wastes containing chromium, selenium, and iron which were discharged into four holding lagoons. Soluble limestone formations below the site subsequently developed sink holes

which then resulted in the subterranean discharge of the waste contents of the holding lagoons. Public supply wells serving a population of 12,000 people are located within 1.5 miles of the site.

9) At the Upjohn site in Barceloneta approximately 15,000 gallons of a mixture containing 65 percent carbon tetrachloride and 35 percent acetonitrile leaked from a buried tank into the soil and limestone groundwater. UpJohn conducted remedial measures at the site which removed large areas of contamination. However, concern exists as to whether the total extent of the pollution plume has been delineated. EPA requires UpJohn to sample downgradient private water supply wells to be sure that no one is drinking contaminated water.

It is expected that another eight sites will be added to the list, and, in addition, another 140 sites are designated with the potential to be included (Puerto Rico Environmental Quality Board, personal communication). This represents a ratio of one hazardous site for every 22 square miles. No cleanup has begun yet on any of the Superfund sites with the exception of the UpJohn site. Environmental officials say that cleaning up all the contaminated sites in Puerto Rico will cost at least 5 billion dollars. Under the Superfund law, federal authorities will pay 90 percent and the state 10 percent of the cost of cleaning up sites on the national priority list. However, since the EPA has identified the parties reponsible for eight of the island's nine hazardous waste sites they will be the ones required to cover the cost of the clean ups.

The quality of the streams in Puerto Rico is under the surveillance of a water quality monitoring network which consists of 57 stations. Samples are collected and analyzed by the United States Geological Survey under a cooperative agreement with the government of Puerto Rico. Through this network one fifth of the streams are monitored, and 14 percent of these have been detected with toxic levels that excede federal and state regulations.

The monitoring network includes analysis for some pesticides at a selected number of stations. During a period from 1982 to 1985, diazinon, lindane, malathion and parathion were found exceeding their standards. Diazinon was the pesticide most commonly found. It was detected at 23 out of 28 stations tested for pesticides.

The stream quality monitoring also includes analyses for some heavy metals. The evaluation of the data revealed that several stations exceeded the maximum concentration allowed in Puerto Rico's Water Quality Standards Regulations for cadmium, copper, mercury and silver (U.S. Geological Survey, 1985).

Some of the primary pollutants mentioned were detected in effluents from industrial and municipal discharges to different streams. In each case, either the NPDES permit effluent limitations or water quality standards were exceeded at the point of discharge.

Of the 28 reservoirs only 6 are monitored and sampled on a regular basis by the U.S. Geological Survey. Most of the lakes present eutrophication problems caused by nutrient loads proceeding from point sources, like sewage treatment plants, and non-point sources such as livestock enterprises and other agricultural related activities.

Because of its use as a public water supply, groundwater has acquired great importance. It is suspected that the main pollution source of the aquifers in these areas has been the practice of industrial waste disposal directly into sinkholes. In the last eight years 33 contaminated wells, about 11 percent of Puerto Rico's public wells, have been closed by the Health Department. The most recent episode occured when the contamination of at least five wells was noticed in June of 1989, when the Health Department found concentrations of nitrates fluctuating between 0.30 mg/l and 16.9 mg/l in the wells. The wells supplied 1.3 million gallons of water daily for the Manatí area.

Specific regulations governing groundwater pollution and discharges to groundwater will be enforced by the PREQB in 1990, after the new regulations receive the final aproval. Until now the Puerto Rico Environmental Quality Board attempted to prevent groundwater pollution through its general regulatory powers.

Before 1970 there were no regulations strong enough to protect the environment in Puerto Rico or in the United States. However toxic substances were handled long before 1970. In Puerto Rico no government agency is solely responsible for the administration and management of the waters. Six different agencies are involved: the Puerto Rico Planning Board, the Puerto Rico Environmental Quality Board, Puerto Rico Aqueduct and Sewer Authority, the Puerto Rico Department of Health, the United States Geological Survey, and the United States Environmental Protection Agency. The analysis of the roles of these agencies indicates that there are areas of overlapping reponsibilities and that greater efforts of coordination are needed. So far, no local or federal agency has undertaken a

comprehensive study of the island's water supplies particularly regarding their quality. Furthermore, no comprehensive epidemiological study of health risks has been made. The field study that follows is the first attempt to examine the relationship between water quality and geographic patterns of land use. The scale of investigation is modest but can point the way to a better understanding of environmental relationships under pressure of modern industrialization and urbanization.

CHAPTER III

METHODOLOGY AND DESCRIPTION OF THE STUDY AREA

This study examines water quality parameters in three hydrological basins. It attempts to determine how extensive a problem water pollution is and how the concentrations of pollutants compare under different conditions of land uses The selection of the basins is based on the presence of land uses considered as predominant on the island, such as commercial, industrial (manufacturing, chemicals, electronics), residential, agricultural crops (sugarcane, coffee, pineapple, plantains), livestock, and specific point sources of pollution like sewage treatment plants.

In Puerto Rico, water quality analyses have indicated that most surface waterbodies, as well as groundwater, are polluted with both organic and inorganic substances (Puerto Rico Environmental Quality Board, 1988). Contributions to water quality deterioration come from point and nonpoint sources. These pose a threat on a densely populated island that covers only 3,421 square miles with an estimated population of 3.2 million.

This study addresses the following postulated relationship: primarily that the presence of pollutants in waterbodies is recognizably associated with geographical patterns of land use.

Related considerations derived from the over-arching postulate are:

(1) The presence of pesticides in waterbodies is associated with runoff from agricultural crop production activities, i.e. sugarcane, coffee, plantains.

(2) The presence of nitrogenous waste in waterbodies is associated with runoff from livestock activities.

(3) The presence of nitrogenous waste in waterbodies is associated with discharges from sewage treatment plants.

(4) The presence of synthetic semi-volatile organic compounds in waterbodies is associated with discharges from industrial and commercial land uses.

(5) The presence of synthetic semi-volatile organic compounds in waterbodies is associated with runoff (non-point source) from urban land use.

(6) The presence of heavy metals in waterbodies is associated with discharges from industrial and commercial land uses.

(7) The presence of heavy metals in waterbodies is associated with runoff from agricultural crop production activities.

(8) The presence of total and fecal coliforms in waterbodies is associated with runoff from agricultural crop production activities.

(9) The presence of total and fecal coliforms in waterbodies is associated with discharges from sewage treatment plants.

Description of Study Area

A. Selection of Sampling Sites

Land use maps were studied to obtain a general pattern of the distribution and types of land use on the island. This was followed by the examination of air photographs from 1985 at a scale of 1:20,000 in order to update the data portrayed in the maps and to make a preliminary selection of sampling sites. Field visits were necessary to corroborate the adequacy of the sites in terms of their accesibility, and any changes in land use not previously identified. Three watersheds were chosen (Fig.4) and among these, 33 sampling sites were selected: 12 in the Cibuco River basin (Fig.5), 12 in the Güayanés River basin (Fig.6), and 9 in the Yagüez River basin (Fig.7). All samples were analyzed for a set of fifteen water quality parameters. Laboratory analytical methods are described in Appendix A.

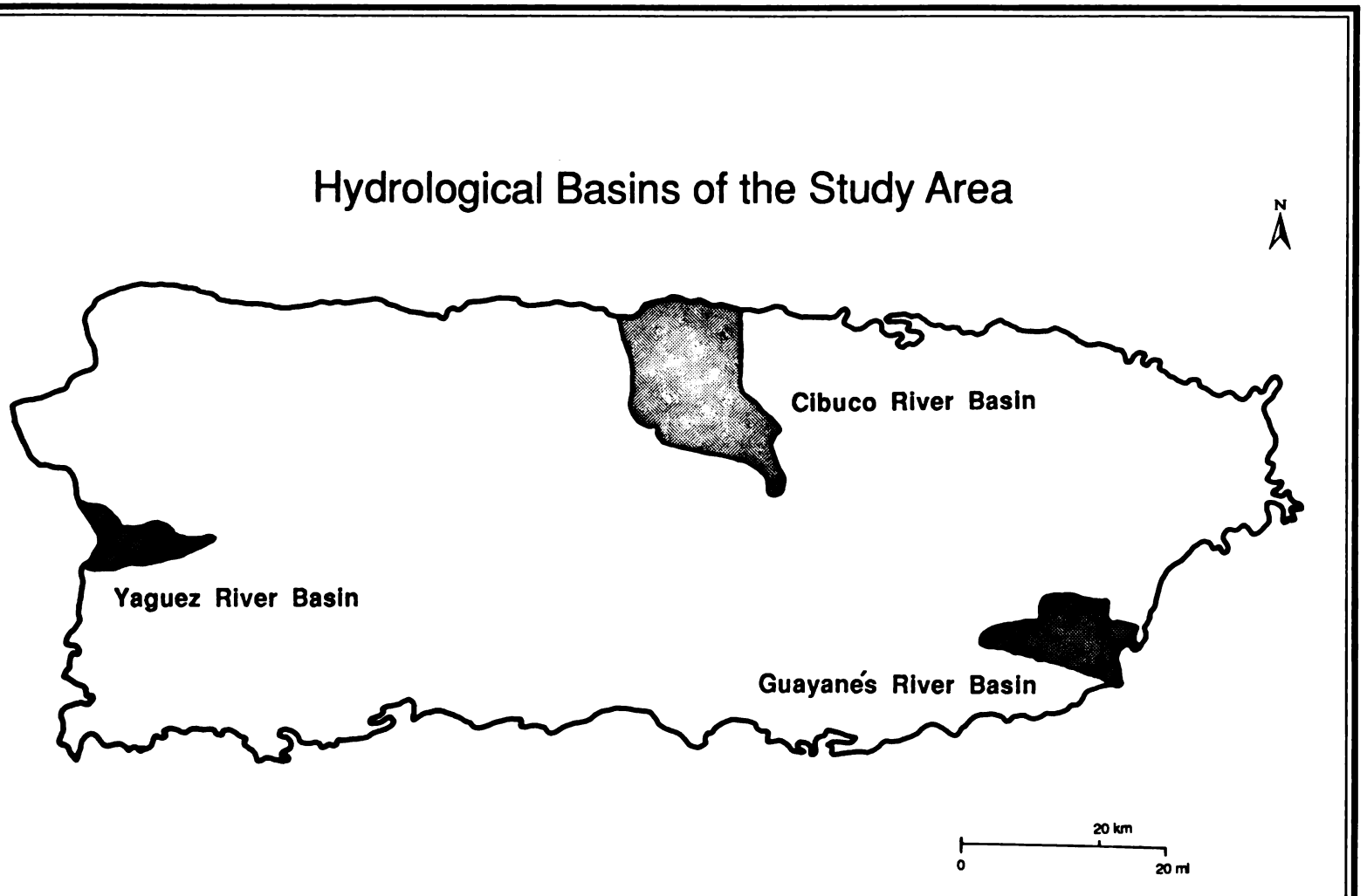

Figure 4. Hydrological Basins of the Study Area

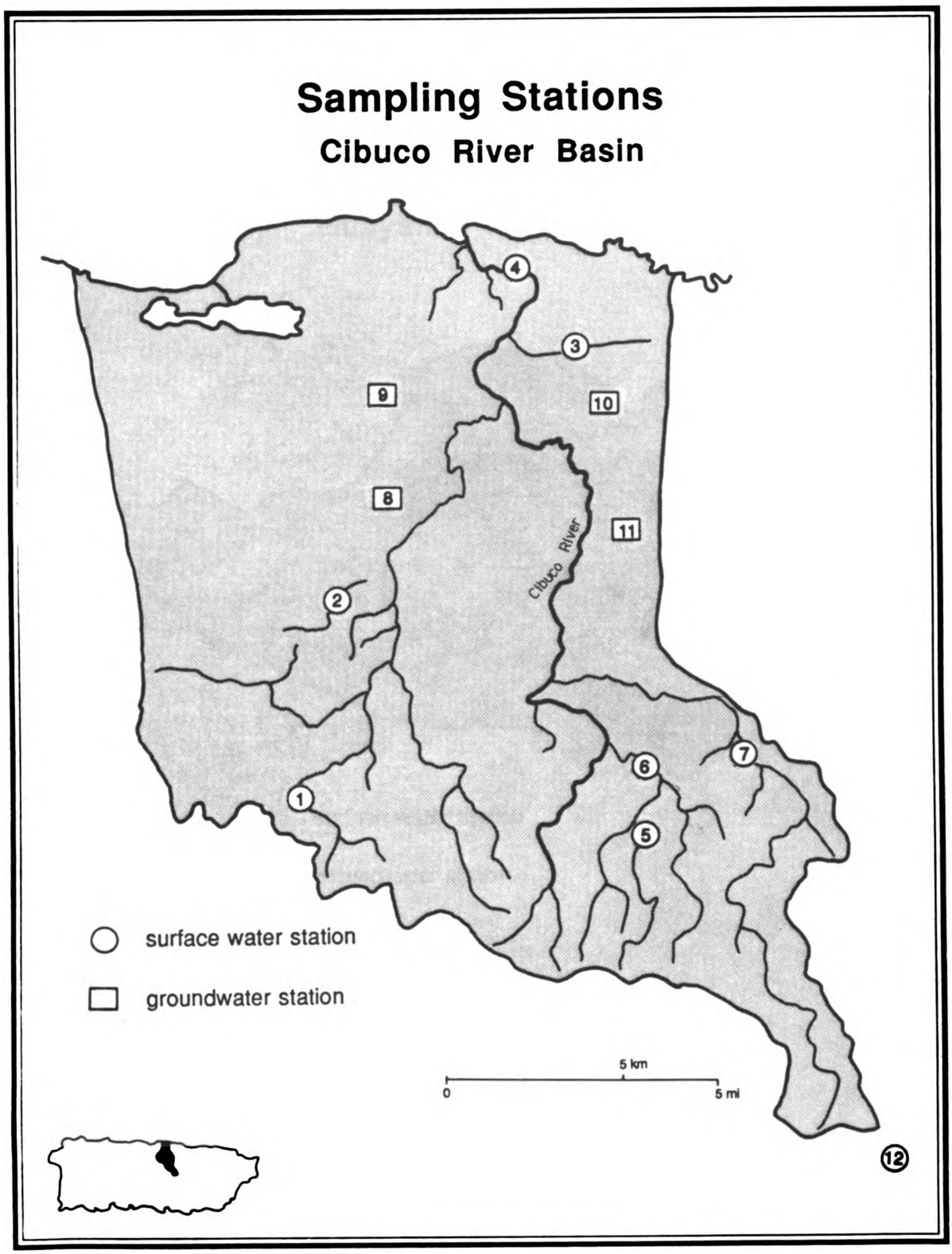

Figure 5. Sampling Stations, Cibuco River Basin

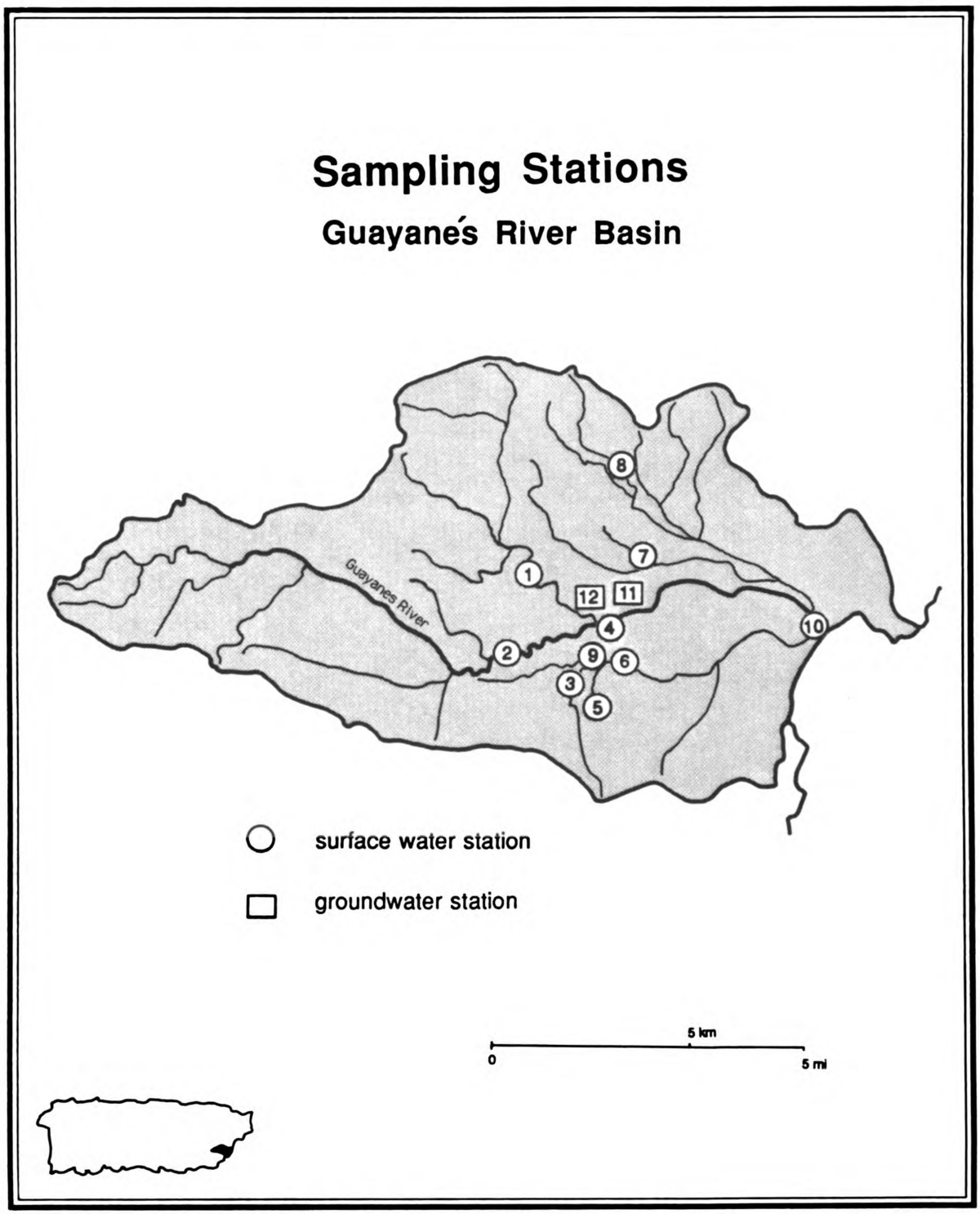

Figure 6. Sampling Stations, Guayanes River Basin

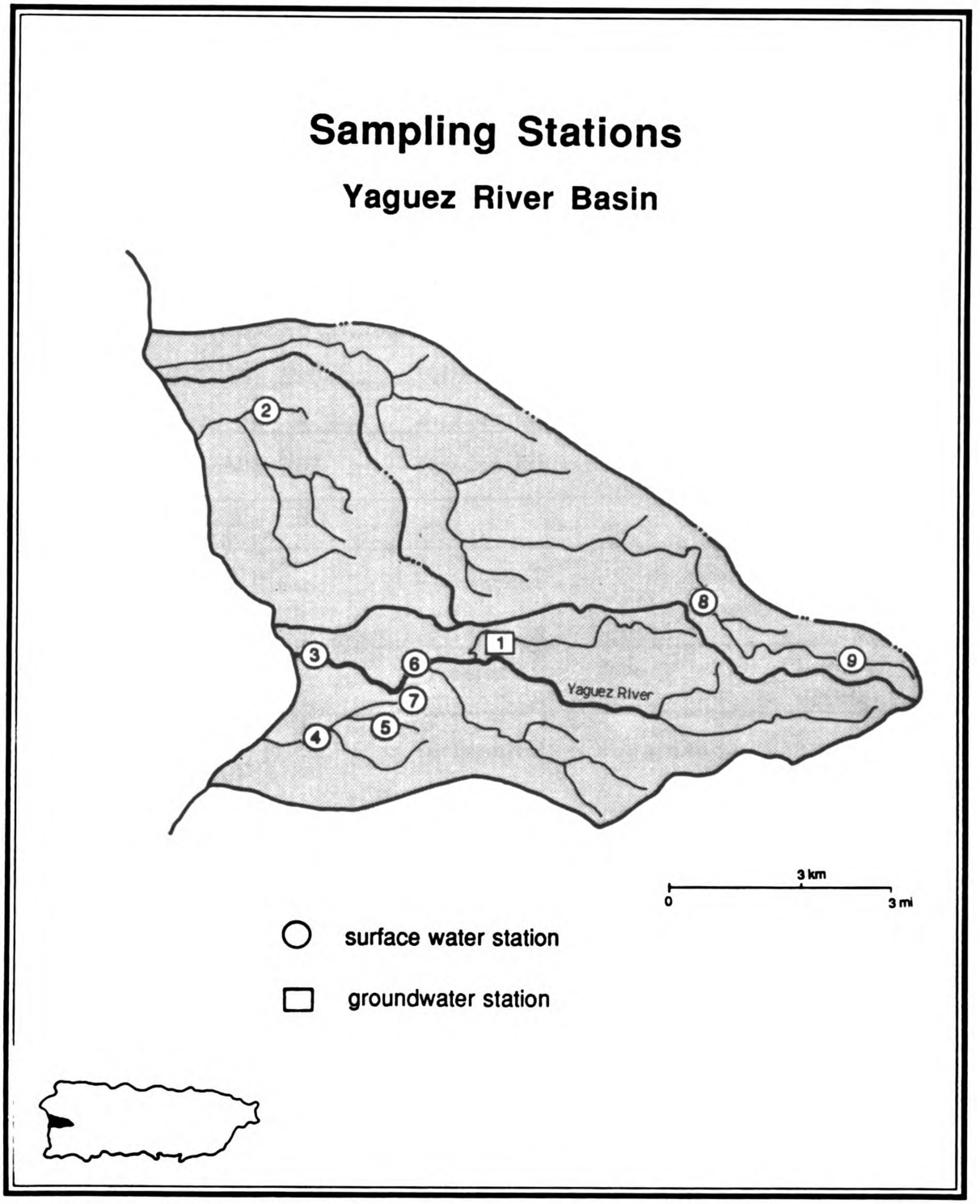

Figure 7. Sampling Stations, Yaguez River Basin

Table 2. Sampling Stations and Surrounding Land Uses Cibuco River Basin

Stations	/Waterbody	Landuse (1)	Landuse (2)	Landuse (3)
8	Pugnado well	residential		
9	Vega Baja well	residential		
10	Sabana Hoyos well	residential	sugarcane	horticulture
11	Vega Alta well	residential	industrial (electronic)	
12	spring	forest		
5	Corozal River	plantains		
6	De Los Negros River	residential	textiles	
7	Mavilla River	livestock	forest	textiles residential
3	Cienaga Prieta channel	residential	sugarcane	industrial (chemical)
4	Cibuco River	sugarcane	grassland	
2	Hicatea creek	forest	livestock	cattle
1	Morovis River	forest	sewage plant	

Table 3. Sampling Stations and Surrounding Land Uses Guayanes River Basin

Stations	/Waterbody	Landuse (1)	Landuse (2)	Landuse (3)
1	Limones River	livestock		
2	Guayanes River	sugarcane plantains	livestock	residential
4	Guayanes River	sugarcane	commercial	residential
11	La Grua well	sugarcane	industry (sugar refining)	
12	Roig well	sugarcane		industry (sugar Ind.)
3	Aguas Largas creek	residential	forest	
9	Santiago creek	residential	sugarcane	
6	Santiago creek	sewage plant	sugarcane	
5	Santiago creek Trib.	textiles	residential	
7	Del Ingenio River	industry (Union Carbide)	sugarcane	
8	Aguacate creek	industry (Reynold's Tobacco)	livestock	forest
10	Guayanes River	sugarcane		

Table 4. Sampling Stations and Surrounding Land Uses Yaguez River Basin

Stations	/Waterbody	Landuse (1)	Landuse (2)	Landuse (3)
2	Boquilla creek	sugarcane	commercial	
1	Marini well	plantains	forest	
6	Yaguez River	residential	industry	
3	Yaguez River	commercial	residential	industry
5	Grande creek	residential	forest	
4	Sabalos creek	industry	residential	forest
7	Majagual creek	commercial	textiles	residential
9	Canas River	coffee		
8	Canas River	coffee/ plantains		

Twenty-six of the sites are surface water bodies (streams, creeks), and the remaining seven are wells used as potable water supply which belong to the Puerto Rico Aqueduct and Sewage Authority. The spatial design of the sampling sites is as specific as posible so as to differentiate among suspected pollutant sources.

The sampling sites include water bodies associated with: point sources of pollution in urban settings such as industrial plants and sewage treatment plants effluents and in the rural areas, with livestock in confinement. Non-point sources are represented by rural areas dedicated to agriculture (sugarcane, coffee, pineapple, plantains), dispersed livestock, and in the urban areas, by residential and commercial uses.

The name of each sampling site together with associated patterns of land use (in diminishing order of predominance) is given in Tables 2, 3 and 4 respectively for the Cibuco, Guayanés and Yagüez basins.

Parameters Employed in the Study

The readings obtained for the water quality parameters considered here indicate that the number of samples with detectable concentrations exhibit variation among the parameters and among the three hydrological basins. These concentrations were compared against the standards for water quality in Puerto Rico (Table 5) which are prescribed by the Puerto Rico Environmental Quality Board based on recommendation by the United States Environmental Protection Agency (U.S.E.P.A.).

Table 5. Water Quality Standards
(All standard concentrations in parts per billion (PPB)

Parameters	Surface Water	Groundwater	Potable Water
Total Coliforms	10,000 colonies /100 ml		1-4 colonies /100 ml
Fecal Coliforms	2,000 colonies /100 ml		
BOD-5	5,0000		
Nitrate	10,000		10,000
Nitrite			1,000
Cyanide	20		
Arsenic	50	0.022	50
Cadmium (previous Std. 50.0)	0.68 (1) 1.22 (2) 1.48 - 1.72 (3)		10
Nickel	90.7 (1) 170.9 (2) 209.6 -246.9 (3)		
Chromium	50		50
Lead (previous Std.50.0)	1.4 (1) 3.6 (2) 4.9 - 6.3 (3)	50	50
Mercury	1.0		2.0

(1) Standard limits Guayanés River Basin
(2) Standard limits Yagüez River Basin
(3) Standard limits Cibuco River Basin

No published standards for ammonia and total Kjeldahl nitrogen

Sources:
Water Quality Standards Regulation, Ammended Version 1990, Environmental Quality Board, Commonwealth of Puerto Rico.
Drinking Water Regulations, Regulation Number 50, Puerto Rico Department of Health.

The Water Quality Standards Regulation for Puerto Rico was amended in 1990, during the period of this field study. In the amended version standard limits have been set for the first time for concentrations of cadmium, lead, arsenic and selected plaguicides in groundwater. The numerical limit set for arsenic is of 0.022 ug/l. This number is based on recommendations contained in the document Water Quality Criteria of 1986 by the U.S.E.P.A. (D. Laaves, Puerto Rico Environmental Quality Board, oral communication, 1991). The new standard limit is a very low concentration, particularly when compared against the standard of 50.0 ug/l for arsenic in surface waters and drinking water as well. The discrepancy reflects the need for changing standards, and delays in the process.

Groundwater samples in this study were withdrawn from wells being used for potable supply by the Puerto Rico Aqueduct and Sewer Authority (P.R.A.S.A). The samples were collected from pipe connections prior to receiving the chlorination treatment provided by the authority before its distribution for public consumption. However, chlorination by itself does not eliminates substances such as heavy metals or chemical forms of nitrogen if they are present in groundwater. Thus, with the exception of the parameters for total and fecal coliform colony counts, the concentration of substances from groudwater will be compared against the regulated standards for drinking water.

The new regulation also sets a standard limit for nickel in surface waters. The setting of this and other heavy metals standards now takes into consideration water hardness since calcium carbonate is known to influence the toxicity of metals. Formulations have been developed that

estimate the decrease in toxicity of certain heavy metals with increasing hardness. These formulations permit higher ambient levels of metals in hard waters than they do in soft waters. Concentrations of calcium carbonate were not obtained during sampling, since water hardness was not a variable required in the setting of standard limits for heavy metals at the time the samples were being collected. However, in order to have an estimation of the quality of the waters sampled under the new amended regulation for heavy metals, values for the concentration of calcium carbonate were obtained from the United States Geological Survey in their Water Resources Data, Water Year 1989. The concentration readings were selected from streams, although not the same sampling stations, in the three hydrological basins under study. Samples were collected by the U.S.G.S. in August 1989, two months before the collection of the first samples for this survey.

Regarding semi-volatile compounds, there are no specific water quality standards, however the regulations state that the waters of Puerto Rico shall not contain any substance in a concentration which is toxic or which produces undesirable physiological responses in human, fish or other animal life, or plants. Moreover, the waters of Puerto Rico shall not contain two or more substances whose combination is toxic. However no information is available as to assess the toxic concentration limit for the semi-volatile compounds detected, either by themselves or in a combination that may promote additive or synergistic effects. Although some potential toxicants are mentioned specifically in stream or drinking water standards, many others are not because they may have been developed only

recently or their potential for causing harmful effects is not yet fully understood.

All samples were collected from untreated waterbodies. The doubtful fecal origin and the inappropriate use of total coliforms as an indicator of fecal water pollution is well documented. Growth of coliforms can occur in tropical waters and they can survive several months in natural tropical river water. Fecal coliform enumeration is less ambiguous than total coliform enumeration, however, recent studies have demonstrated that *Escherichia coli*, the target organism of the fecal coliform group is capable of long term survival in tropical environmental conditions (Hazen et al, 1985). Nevertheless, bacteriological water quality standards in Puerto Rico are based on parameters of colony counts for the coliform group. Hence, the inclusion of this parameter in the study.

CHAPTER IV

ANALYSIS OF RESULTS BY HYDROLOGICAL BASIN

In this chapter a description of each hydrological basin and the readings obtained for the set of parameters under study will be discussed.

A. Yagüez River Basin

The Yagüez river has its origin in the municipio of Mayagüez, into which bay it discharges. The basin extends 8.2 miles east from the Mayagüez Bay and into the Cordillera Central mountain range. The 12.9 square mile drainage area includes the most densely populated portion of the City of Mayagüez. Two main tributaries, Caricosa and Gandel Creeks, which flow roughly parallel to the Yagüez river comprise the drainage pattern of the basin.

The mountainous portion of the watershed is largely covered by trees and brush with practically no grass. This, combined with the steep slopes result in high rates of runoff and erosion. The City of Mayagüez occupies the northern portion of the coastal plain, and it extends into the surrounding foothills. Since the terrain within the watershed is extremely rugged with elevations as high as 1,575 feet, the most accessible land areas have been substantially populated. To the south the cover consists of pasture in the foothills, with sugar cane fields extending westward into the coastal plain.

In the Yagüez river valley, alluvium is the principal aquifer and has a maximum known thickness of 200 feet. The alluvial deposits are underlain by alternating layers of clastic sediments and limestone. Goundwater recharge occurs principally from rainfall infiltration, and discharge occurs mostly as seepage to the streambed (U.S.G.S., 1987). Urbanization has approximately covered the entire valley area and the use of the alluvial aquifer has been abandoned.

The temperatures are relatively moderate and uniform throughout the year, following the general temperature pattern of all coastal areas of Puerto Rico. The average annual temperature for the coastal plain is 77.5 Farenheit degrees, and for the highlands at the east limit of the watershed is about 75 Farenheit degrees.

Average annual rainfall is about 76 inches in the coastal plain and increases to approximately 100 inches in the eastern mountainous region. The average monthly precipitation was as follows during the sampling period: November 2.27 inches or 0.61 inches below normal; January 0.36 inches or 0.59 inches below normal; March 4.67 inches or 1.14 above normal (National Oceanic and Atmospheric Administration, 1989 and 1990).

The municipio of Mayagüez, which is the only one contained in this small basin, is located in the central portion of the west coast. It covers 77 square miles (199 sq. kilometers) sub-divided in 21 barrios. The City of Mayagüez is the third largest Metropolitan Area and ranks third among developed cities in Puerto Rico. Consequently, the Yagüez River basin is the most densely populated of the three watersheds under study. The population of Mayagüez was estimated at 109,213 inhabitants in 1990 or

1,418.4 persons per square mile. In 1930 the population figure was 58,270 inhabitants or 757 persons per square mile, and there was an increase in 1960 to 83,850 or 1,089 persons per square mile.

When the total 60 year period is considered, the population increase has been 661 persons per square mile since 1930, with about half of this increment occurring during the period between 1930 to 1960, and the other half occurring during the last 30 years. Mayagüez has 89.1 percent of its inhabitants classified as urban dwellers, the highest percent of urban population for the three basins.

The economy of Mayagüez is based on manufacturing and commerce. In 1985 it had about sixty industries, among them, tuna canning, chemical and pharmaceutical products, electric and electronic equipment, food and beverages, and rum distilling. Sugarcane and cattle are the principal agricultural products of the region. Coffee cultivation also remains important in this western part of the island.

In this basin the standards for total and fecal coliforms were exceeded at all surface water stations during the third sampling (Table 6). The readings reached 2,400,000 colony counts/ml. Since precipitation was above average during this sampling activity, the high readings obtained for all surface water stations can be attributed to runoff from urban and rural areas as well.

Precipitation was below normal during the first two samplings, under those circumstances the standards for total and fecal coliforms were also violated in most of the stations, but the colony counts were not as

Table 6. Yaguez Basin - Detected Concentrations of Water Quality Parameters

Parameters	*1YAG1*	*2YAG1*	*3YAG1*	1YAG2	2YAG2	3YAG2	1YAG7	2YAG7	3YAG7
Total Coliforms	<2.2	<2	-	94	**35000**	**2400000**	**240000**	**240000**	**2400000**
Fecal Coliforms	<2.2	<2		94	**35000**	**2400000**	**240000**	**240000**	**2400000**
Organic Comp.	0.4	0	0	0	0	0	**39.8**	1	0
BOD-5	<5000	<5000		<5000	<5000		**15700**	**10500**	
Nitrate	1030	1240		<200	<200		2160	4100	
Nitrite	<20	<20		<20	<20		90	50	
TKN	2396	<2000		6934	2040		8962	2070	
Ammonia	<100	<100		<100	<100		<100	280	
Arsenic	<0.1	**4.2**		<0.1	4.5		<0.1	4.2	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	1.1	8.1		<0.05	**6.1**		<0.05	**22.6**	
Mercury	0.5	1.7		<0.5	0.8		**2.3**	1	
Cadmium	<0.003	0.7		<0.003	1.1		<0.003	1.5	
Chromium	<0.5	<0.5		0.6	<0.5		5	32	
Nickel	<0.1	<0.1		<0.1	<0.1		12.1	44.6	

Parameters	1YAG5	2YAG5	3YAG5	1YAG4	2YAG4	3YAG4	1YAG8	2YAG8	3YAG8
Total Coliforms	**54000**	**240000**	**2400000**	**54000**	**24000**	**2400000**	4900	**160000**	**2400000**
Fecal Coliforms	**54000**	**240000**	**2400000**	**54000**	**24000**	**2400000**	4900	**160000**	**2400000**
Organic Comp.	0	0	0	0.1	0	0	0	0	0
BOD-5	**6000**	<5000		<5000	<5000		<5000	<5000	
Nitrate	590	500		390	310		660	590	
Nitrite	20	<20		20	<20		<20	<20	
TKN	3952	<2000		4883	<2000		3151	<2000	
Ammonia	<100	<100		<100	<100		<100	<100	
Arsenic	1.6	4.2		0.4	4.5		<0.1	4.3	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**11.5**		<0.05	**7.4**		<0.05	**6.1**	
Mercury	**2.5**	1		1	**1.6**		**1.4**	0.8	
Cadmium	0.9	0.9		**1.3**	0.9		<0.003	**2.6**	
Chromium	11.3	<0.5		8.3	<0.5		1	<5	
Nickel	13	<0.1		6.5	<0.1		<1	<0.1	

Bold - above regulatory standard limits Underlined - Above E.P.A. recommended level *Italic - groundwater sample*

Table 6. (cont'd)

Parameters	1YAG6	2YAG6	3YAG6	1YAG3	2YAG3	3YAG3	1YAG9	2YAG9	3YAG9
Total Coliforms	2400	**18000**	**2400000**	**240000**	**240000**	**2400000**	140	**160000**	**2400000**
Fecal Coliforms	2400	**18000**	**2400000**	**240000**	**240000**	**2400000**	140	**160000**	**2400000**
Organic Comp.	0	0	0	0	0	**1.1**	0.2	0	0
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	680	500		730	480		790	700	
Nitrite	<20	<20		<20	<20		<20	<20	
TKN	4262	<2000		3647	<2000		2034	<2000	
Ammonia	<100	<100		414	<100		<100	<100	
Arsenic	<0.1	4.5		<0.1	4.3		<0.1	4.3	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**7.5**		<0.05	**10.7**		<0.05	**8.1**	
Mercury	<0.5	1		<0.5	**1.6**		0.7	0.5	
Cadmium	<0.003	0.9		<0.003	**1.4**		<0.003	**1.3**	
Chromium	5.1	<0.5		2.6	17		1.2	<0.5	
Nickel	6.3	<0.1		2.4	<0.1		<0.1	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italic - groundwater sample*

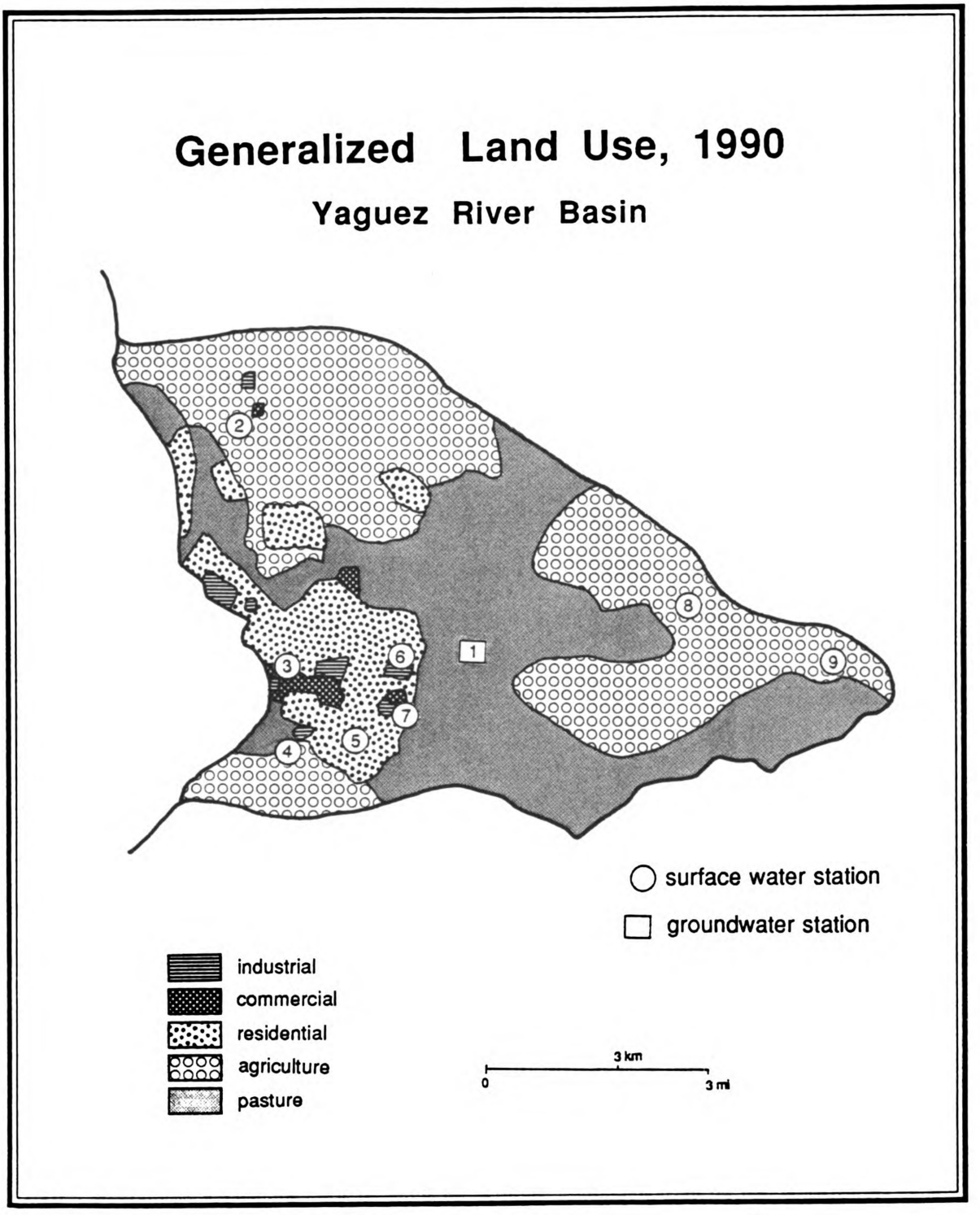

Figure 8. Generalized Land Use, 1990 - Yaguez River Basin

elevated. Overall, the Yagüez river basin was found to be the most bacteriologically contaminated of the three basins under study.

However, the BOD-5 parameter, an indirect test to indicate the gross amount of organic material in water, was above the standard limit in only two of these stations. Nevertheless, the highest BOD-5 reading in this basin (15.7 mg/l) was obtained from the same station, and sampling, at which the highest concentration of semi-volatile organic compounds (39 8 ug/l) were detected This was also the highest concentration of semi-volatile organic compounds detected in the survey.

The station in question (Yagüez basin #7) is surrounded by three main urban activities: industrial (textiles), commercial (supermarket), and residential. From the first sample taken at this station, nine semi-volatile compounds were separated through the GC/MS method. Their concentrations ranged from 0.1 ug/l to 9.1 ug/l (Appendix B).

Among the compounds detected diphenylhydrazine, a carcinogen, was identified in a concentration of 9.1 ug/l. Although there is no water quality standard for this compound, the quality criteria for water issued by U.S.P.A. in 1986 (U.S.E.P.A., 1986) recommended that for the maximum protection of human health from the potential carcinogenic effects of being exposed to this compound through the ingestion of contaminated water and contaminated organisms, the ambient water concentration should be zero based on a non-threshold assumption for this chemical. Recognizing that a zero level may not be attainable, concentrations which may result in incremental increase of cancer risk over a lifetime are estimated. A concentration of 4 nanograms per liter (0.004 ug/l) is recommended as a

minimum risk level in water that is going to be ingested. For consumption of aquatic organisms only, excluding consumption of water, the level recommended is 0.056 ug/l.

Detectable concentrations of other compounds were identified at the same station, among them, 1-Aminonaphthalene, another carcinogen regulated by OSHA, in a concentration of 6.3 ug/l. Also detected were 7.3 ug/l of dodecanamide, N-(2-hydroxyethyl) or decanamide,N-(2-hydroxyethyl), both of which have been used as pesticides. The two other samples from this station did not contain detectable concentrations of semi-volatile organic compounds, which may indicate that the sources from which they were generated are intermittent, all of which have implications for monitoring purposes.

The E.P.A. water quality criteria do not have regulatory impact. They are criteria based on scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements. Although some potential toxicants are mentioned specifically in stream or drinking water standards because their effects are known, or may be reasonably estimated, many others are not because they may have been developed only recently or their potential for causing harmful effects at the low concentrations commonly encountered in waters are uncertain.

Although this is not the only station in the basin in spatial association with urban land uses, and even though the concentration of semi-volatile compounds in the other stations were all below the concentration of one part per billion, the compounds detected and identified

can be constituents or by-products of the urban related activities surrounding it. Phthalates, for example are known ubiquitous plasticizers, although some of them have been used as pesticides. Recommended concentration levels for phthalates vary according to the particular phthalate, but they are in the order of a milligrams per liter, a concentration level that was not found in any of the samples.

None of the parameters related to nitrogenous waste were detected at above standard limits. The presence of nitrate or ammonium might be indicative of pollution through disposal of sewage or organic waste. The sources of organic nitrogen include not only natural materials, but also numerous synthetic organic ones likely to be associated with industrial processes. BOD-5 was exceeded three times at two sites in association with industrial and commercial land.

Among the heavy metals, the standard for mercury in surface waters was violated at five of the eight surface stations. Inorganic mercury is relatively insoluble and is not usually a threat to the human food chain, but organic complexes of mercury such as methyl mercury can be produced by methane-generating bacteria in contact with metallic mercury in lake or stream sediment. The surface water quality standard (1.0 ug/l) was issued to protect waterbodies or the aquatic life from the potential for bioaccumulation through the food chain. The highest measurement readings (2.5 and 2.3 ug/l) were detected at sites surrounded by urban land uses (residential, industrial, commercial). These are also the highest readings obtained for mercury, all samples considered. Various cultural uses of mercury, such as battery cells, paints, agricultural uses and pharmaceuticals, and its release to the atmosphere in smelting and fossil-

fuel combustion have probably raised the general background level of this element in the environment. However, the amount of mercury that would be present in water open to the atmosphere is low owing to its tendency to escape as a vapor.

The surface water parameter for chromium (50.0 ug/l) was not violated at any of the stations in this or the other two basins. The standards limits for lead, nickel and cadmium were not violated either according to the previous regulation. However, if the concentration of these three metals were to be evaluated against the concentration of calcium carbonate in the station selected for the Yagüez River basin (110 mg/l), their respective standard limits would have been lowered.

In the case of lead it would have dropped from 50.0 ug/l to 3.59 ug/l. This numerical limit was exceeded at all surface water stations during the second sampling. The highest lead concentration was 22.6 ug/l detected at the same site, although not the same sampling time, at which the highest concentration of semi-volatile organic compounds was detected. The first sample collected at each of these stations did not give lead readings above standard limits, in fact, all except the sample from groundwater, were reported as being below the detectable concentration of 0.05 ug/l. The concentration of lead at the well was 1.1 and 8.1 ug/l during the first and second samplings respectively, which are not above the limits for this metal in either drinking water or groundwater regulations (50.0 ug/l).

The standard limit for cadmium would have also been lowered from 5.0 ug/l to 1.22 ug/l if the concentration of calcium carbonate were to be considered. A limit that was surpassed at five surface water stations with

a highest reading of 2.6 ug/l from a stream surrounded by a coffee cultivation area. The other stations exceeding the numerical limit included almost all the other land uses in the basin. Cadmium is known to be present in fertilizers. However the amount of this metal added to soil in this way is very low. More important sources of cadmium are the industrial uses for electroplating, pigments and plastics. The concentrations of cadmium detected at the groundwater station were below the standard limits for drinking water (10.0 ug/l) and groundwater (5.0 ug/l) as well.

Nickel did not have a standard limit in surface water in the previous regulation. The new standard limit, based on the concentration of calcium carbonate, is of 170.91 ug/l in surface waters. This limit was not violated at any of the stations. However E.P.A. quality criteria for water in 1986 recommends a concentration of 13.4 ug/l for the protection of human health from the toxic properties of nickel ingested through water and contaminated aquatic organisms. The highest nickel concentration detected in this basin and in the whole study area was 44.6 ug/l. The nickel concentration at the groundwater sample was below the detectable concentration (0.1 ug/l).

The only parameter violated in the sample from groundwater was arsenic. This metalloid was detected at a concentration of 4.2 ug/l at one of the sampling activities. A concentration that is below the standard limit for potable water (50.0 ug/l), but above the numerical limit set as the standard for groundwater (0.022 ug/l) in the amended regulation. Small amounts of arsenic, a suspected carcinogen, occur in many natural materials, with trace amounts occurring in soil and water. Arsenic has

been used as a component of pesticides, especially before 1960, and thus may enter streams or groundwater through waste disposal or agricultural drainage. Arsenic may be present as organic compounds or in inorganic complexes. Its toxicity is therefore a variable that can be determined only for defined forms of arsenic and biological targets (Landner, 1989).

B. Cibuco River Basin

The Cibuco river basin is located in the municipios of Vega Baja, Vega Alta, Dorado, Morovis and Corozal. The Cibuco River has an estimated length of 22 miles (35 Kms.). It rises in the northern foothills of Puerto Rico at an elevation of approximately 600 meters, flows northward and enters the Atlantic Ocean approximately 30 kilometers west of the capital city, San Juan.

The tributaries of the Cibuco river are: Corozal River, Dos Bocas River, De los Negros River, Mavilla River, Indio River, Morovis River, Unibón River, Las Carreras River, El Toro Creek, Grande de Morovis Creek, Honda Creek and Cabo Caribe Creek. The total drainage area is approximately 131.7 Sq. miles (341.1 Sq. Km), although the exact drainage area is indeterminate due to the karst topography.

The lower part of the Cibuco basin is contained in the North Coast Province, one of the six main aquifer areas into which the United States Geological Survey has divided the island. The North Coast Province is composed primarily of Tertiary limestone and clastic beds. Groundwater in the area of the Cibuco basin exists under water-table conditions in the limestone rocks, alluvial valleys, and coastal plain deposits.

The North Coast Province is the principal aquifer system on the island and is also the one under greatest pumping stress. Since 1968, numerous wells have been drilled for industrial water supply near the coast and for public water supply further inland. In addition, groundwater flow in this area has been significantly changed from its pre-development conditions. The most significant change to the hydrology has been the dewatering of coastal wetlands and the construction of a drainage channel connecting Laguna Tortuguero with the Atlantic Ocean. The large scale effects of these changes have not been assessed. In addition, groundwater withdrawals have increased from 10 million gallons per day in the early 1940's to an estimated 60 in 1985 (U.S.G.S.,1987). Withdrawals by wells situated within the alluvial valleys are estimated at 8 million gallons per day.

The large scale modifications of groundwater flow within this area make it difficult to establish the regional flow regime. In general it is known that recharge occurs throughout the entire outcrop areas of the limestones and at topographic depressions throughout the blanket deposits. Also, the effects of streams and thick alluvial deposits on the flow system have not been adequately defined.

The climate of the Cibuco basin is characterized by a small range in temperature between the warmest and coldest months, with a mean annual temperature of 80 degrees F (27 C). Average annual rainfall over the Cibuco basin is between 1.5 meters and 1.8 meters (59-71 inches). The precipitation during the sampling period was below normal as the following average monthly rainfall figures indicate: November, 3.46 inches or 0.94 inches below normal; January, 4.38 inches or 0.39 inches above

normal; March-April, 3.10 or 1.68 inches below normal (National Oceanic and Atmospheric Administration, 1989 and 1990).

The total population in 1930 for the municipios in this basin was of 66,525 inhabitants or 505 persons per square mile, it increased to 102,916 in 1960 or 781 persons per square mile, and in 1990 it was reported as being of 170,298 or 1293 persons per square mile. The total population increase over the last 60 year period has been of 788 persons per square mile, but out of this figure 65 percent or 511 persons per square mile increase has occurred over the last 30 years alone, when the industrialization and urbanization processes were taking place.

Of the total population in these municipios 50 per cent is classified as urban. The population of Vega Alta is 71.5 percent urban, which is the highest percent among all the municipios in the basin. In contrast, the urban population of Morovis,in the mountain area, is only 12 percent.

These two municipios are an example of the general social and economic pattern that has taken place in Puerto Rico as a whole in the last 40 years. Urban and industrial activities predominate in coastal plains but diminish toward the mountain areas Vega Alta is located on the northern coast, one of the most industrialized regions on the island. This municipio itself has several industries, including: paper, glass and ceramic, electric and electronic equipment, metal tubes and machinery. There is also floriculture and minor fruits cultivation, as well as poultry and livestock activities. While Morovis, located in the central mountain region of the island, has some small manufacturing industries, cattle, coffee and fruits are the main economic activities. Typically, population concentrations

occur where the demand for jobs can be supplied not only by the industries located there, but also by a whole range of services offered at the urban centers.

The basin as a whole contains several land uses: industrial, particularly textile products, and electric and electronic equipment; agriculture, with the predominance of sugarcane, plantains, pineapple and minor fruit cultivation, as well as as some livestock and poultry activity. Although all municipios have urban and rural sectors, and thus, commercial and residential land uses are present throughout the basin, the concentration of these uses is particularly important toward the coastal low lands.

Of the twelve stations sampled in this basin, six violated the standard for total and fecal coliforms, particularly during the second sampling, when precipitation was greater (Table 7). The highest reading for total coliforms was of 160,000 colonies/ml at two stations in spatial association with residential and livestock activities. For fecal coliforms the highest reading was 92,000 colonies/ml at a site surrounded by residential land use. However, the BOD-5 parameter was not violated at any of the stations or sampling times.

In this basin the highest reading for semi-volatile organic compounds was obtained from a groundwater sample (4.4 ug/l). One ug/l of mercaptobenzothiazole and 3.4 ug/l of petroleum hydrocarbons were detected during the third sampling. Mercaptobenzothiazole is a toxic substance used as a vulcanization accelerator for rubber and is also a

Table 7. Cibuco Basin - Detected Concentrations of Water Quality Parameters

Parameters	1CIB3	2CIB3	3CIB3	1CIB4	2CIB4	3CIB4	1CIB5	2CIB5	3CIB5
Total Coliforms	490	**11000**	920	**35000**	**35000**	3300	4600	7900	3500
Fecal Coliforms	350	2300	240	**35000**	**24000**	3300	3300	2400	2400
Organic Comp.	0	0	0.1	0	0	0.2	0	0	0
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	<200	210		990	1290		930	780	
Nitrite	<20	<20		50	50		<20	<20	
TKN	11717	<2000		7226	<2000		<2000	<2000	
Ammonia	<100	<100		<100	<100		<100	<100	
Artsenic	23	4.9		1.1	5		1.7	4.6	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**18.7**		0.3	**12**		2.3	**12.3**	
Mercury	**1.3**	<0.5		0.4	<0.5		0.7	0.5	
Cadmium	0.9	<0.003		0.9	<0.003		1.2	<0.003	
Chromium	1.4	<0.5		4	6		1.2	<0.5	
Nickel	1.4	7.3		5.3	7.7		1.7	12.1	

Parameters	1CIB6	2CIB6	3CIB6	1CIB7	2CIB7	3CIB7	*1CIB8*	*2CIB8*	*3CIB8*
Total Coliforms	54000	**160000**	**160000**	**160000**	3500	9200	<2	**8**	<2
Fecal Coliforms	54000	**92000**	**35000**	**54000**	3500	2400	<2	**8**	<2
Organic Comp.	0	0	0.3	1.3	0.3	0.1	0	0.2	**0.1**
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	930	850		850	800		6200	5600	
Nitrite	<20	<20		70	<20		<20	<20	
TKN	<2000	<2000		<2000	<2000		1579	<2000	
Ammonia	<100	130		<100	<100		<100	<100	
Artsenic	1.5	4.5		1.8	4.3		**0.6**	**4.7**	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	2.3	**20.7**		4.3	**14.8**		0.8	22.53	
Mercury	0.7	1		**1.1**	<0.5		0.8	0.6	
Cadmium	1.2	<0.003		1.2	<0.003		1.6	0.003	
Chromium	1.7	<0.5		11.8	<0.5		2.5	<0.5	
Nickel	1.8	17.8		8.3	2.2		<1	6.7	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italic - groundwater sample*

Table 7. (cont'd)

Parameter	1CIB1	2CIB1	3CIB1	1CIB2	2CIB2	3CIB2	*1CIB9*	*2CIB9*	*3CIB9*
Total Coliforms	2400	**55400**	9200	**92000**	**35000**	9200	<2	<2	<2
Fecal Coliforms	1600	**24000**	2400	**54000**	**24000**	2400	<2	<2	<2
Organic Comp.	0	0.5	0	0	0	0.6	0.6	0	4.4
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	1030	1390		140	270		5270	5600	
Nitrite	140	510		690	1380		<20	<20	
TKN	13183	6830		16180	8390		1494	<2000	
Ammonia	767	1420		4174	3660		<100	<100	
Arsenic	1.2	4.5		1.5	4.5		**1.9**	**4.5**	
Cyanide	10	20		10	<10		<10	<10	
Lead	0.3	**17.9**		0.3	14.6		<0.05	20.7	
Mercury	0.5	<0.5		<0.5	<0.5		0.7	<0.5	
Cadmium	**1.6**	<0.003		1.4	<0.003		1.2	<0.003	
Chromium	1.3	<0.5		0.9	<0.5		1.9	<0.5	
Nickel	1.7	1.5		<1	1.4		<1	1.6	

Parameter	*1CIB10*	*2CIB10*	*3CIB10*	*1CIB11*	*2CIB11*	*3CIB11*	1CIB12	2CIB12	3CIB12
Total Coliforms	<2		<2	<2	<2	<2	1100	7000	920
Fecal Coliforms	<2		<2	<2	<2	<2	240	2400	240
Organic Comp.	0	0	0.4	0	0	0.4	0.2	0	0.2
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	1640	1820		4200	3450		1990	1910	
Nitrite	<20	<20		<20	<20		<20	<20	
TKN	<2000	<2000		<2000	<2000		<2000	<2000	
Ammonia	<100	<100		<100	<100		<100	<100	
Arsenic	**4.9**	**4.5**		**2.3**	**4.9**		1.6	4.9	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	11.6		3	8.1		1.28	6.68	
Mercury	<0.5	1.2		1.4	0.5		0.5	0.6	
Cadmium	0.2	<0.003		1.4	<0.003		1.4	<0.003	
Chromium	0.5	10		2.5	<0.5		5	2.5	
Nickel	2.2	<0.1		<1	3.4		1	9.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italic - groundwater sample*

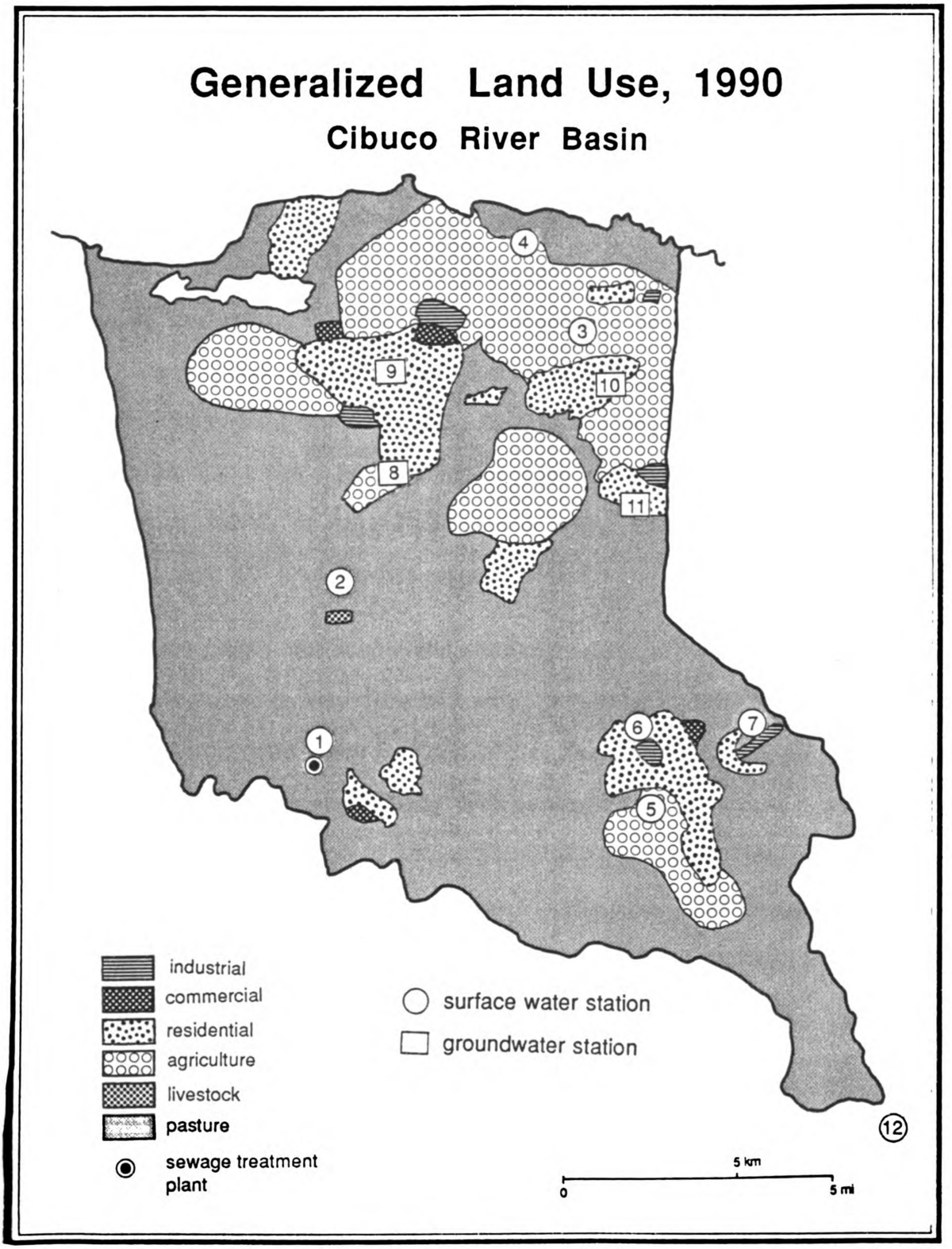

Figure 9. Generalized Land Use, 1990 - Cibuco River Basin

fungicide. Traces of phthalates were detected at the other three wells sampled in this basin.

All groundwater samples gave measurement readings of arsenic above 0.022 ug/l. The highest concentration was 4.9 ug/l obtained at two of the sites surrounded by residential, sugarcane cultivation and industrial land uses. Regarding heavy metals, mercury standard limit was violated at two of the stations with residential and industrial uses surrounding them. The highest reading was of 1.3 ug/l. The other heavy metals under study did not exceed their limits according to the previous regulation. But as indicated above the concentration of calcium carbonate as reported by the U.S.G.S was taken to roughly estimate what would have been the new standard limits for lead, cadmium and nickel.

In this basin two measured concentrations of calcium carbonate are used, each belongs to two different sampling sites in the Cibuco basin, one in the mountain area close to Corozal Pueblo, and the other in the coastal plain , close to to the river mouth. The concentration reported at the station in the mountain area was of 140 mg/l of calcium carbonate. At the other station it was of 170 mg/l, the highest for the entire sampling area. The standard limits for the metals vary according to these concentrations.

The standards obtained for cadmium were of 1.48 and 1.72 ug/l for the mountain and coastal stations respectively. Only one surface station exceeded the limit (1.6 ug/l). This is a station that receives the effluents from a sewage treatment plant. None of the groundwater samples exceeded the limit for cadmium in the groundwater or potable water regulations.

Limits for lead, as obtained by the concentration for calcium carbonate, are 4.88 and 6.25 ug/l for the mountain and coastal stations. All surface water stations violated the standard for lead during the second sampling. The highest concentration detected was 20.7 ug/l at a site surrounded by residential and industrial land uses. None of the groundwater samples violated the lead standard for groudwater or potable supplies.

The standard for nickel at the two stations would have been set at 209.59 and 246.99 ug/l at the mountain and coastal stations, but none of the samples were above these numerical limits. Nevertheless, the highest level detected in this basin was of 17.8, which is above the level concentration of 13.4 reccomended by E.P.A.

C. Guayanés River Basin

The Guayanés River is approximately 11.5 miles (28 kilometers) long with a total basin area of 53 square miles (136.19 kilometers). The Guayanés River originates in the municipio of Yabucoa, located in the southeast coast of Puerto Rico, and discharges in the Caribbean Sea. Its tributaries are Prieto River, Limones River, Ingenio River, Alejandro Creek and Guayabo Creek.

The municipio of Yabucoa has minor elevations to the north. In the south it has the Santa Elena peak at 1870 feet (570 meters) above sea level. The area comprising the municipio of Yabucoa is part of the San Lorenzo batholith, a granodiorite intrusive. Alluvium consists largely of clay, but has appreciable amounts of sand. Thickness of these deposits are as much as 300 feet in the center of the valley and average 100 feet in most areas.

Groundwater in this stream valley aquifer is under unconfined conditions within the unconsolidated deposits. In general, groundwater flows toward the coast. Recharge occurs along the alluvium-bedrock contact from numerous streams and from areal rainfall infiltration throughout the alluvium. Discharge has been significantly modified by groundwater withdrawals, which have been estimated at less than 5 million gallons per day.

The average temperature in the coastal area is around 77 degrees Farenheit and diminishes toward the interior mountain area to an average of 72 degrees. The average annual precipitation ranges from 72.2 inches at the coast to 110 inches in the mountain area. During the collection of samples the average monthly precipitation was as follows: November, 3.45 inches, no departure from normal; January 6.05 inches,no departure from normal; March 4.16 inches, no departure from normal (National Oceanic and Atmospheric Administration, 1989 and 1990).

The municipio of Yabucoa covers 55 square miles (142 sq. kilometers) sub-divided in 10 barrios. The population in 1930 was of 21,914 inhabitants or 398 persons per square mile, in 1960 it increased to 29,782 or 542 persons per square mile, and in 1990 it is reported to be of 31,898 inhabitants or 579.9 persons per square mile. This represents an increase of 182 persons per square mile for the entire 60 year period. In the last 30 years alone the population increase has only been of 38 persons per square mile, or 2,116 more inhabitants. Also, Yabucoa has 29.8 percent of its population classified as urban, all of which makes the Guayanés River basin the one, among the three under study, with the lowest population density, as well as

the one with the lowest percent of urban population, this regardless of the industrial development in the Yabucoa municipio.

The economy is based on sugarcane cultivation and industrial activity. The Roig sugarmill, located there is one of the four mills that has continued working in Puerto Rico. Other industries established in Yabucoa are as diverse as a petroleum refinery, clothes manufacture, cigarettes manufacture, graphite electrodes and electric equipment industries.

Eight of the twelve sampling stations violated the standards for total and fecal coliforms (Table 8). These violations occurred mostly during the second and third sampling activities. These were the months during which precipitation was higher in the southeastern part of the island, although not above average. Runoff from areal sources of this type of bacteriological pollution could have been increased during that period. The stations at which the standards for these parameters were violated were typically associated with livestock activity and residential land use. The highest total coliform colony count was of 240,000/ml at one of the stations surrounding the town of Yabucoa, which is an extensive area of impervious surface. However, the highest fecal coliform colony count was of 160,000/ml at a station associated with the outfall of a sewage treatment plant.

The standard for biochemical oxygen demand was violated during at least, one of the of the sampling activities at all stations, including those from groundwater samples. BOD-5 is not a standardconsidered in the

Table 8. Guayanés Basin - Detected Concentrations of Water Quality Parameters

Parameters	1GUA1	2GUA1	3GUA1	1GUA2	2GUA2	3GUA2	1GUA4	2GUA4	3GUA4
Total Coliforms	3300	**54200**	7000	2300	9200	3480	**13000**	5420	5420
Fecal Coliforms	3300	**17200**	<2.2	1300	1090	460	**13000**	790	490
Organic Comp.	0.5	0	0	0	0.2	0.1	0.2	**5**	0.1
BOD-5	**6700**	<5000		**21000**	**9800**		**24000**	**11300**	
Nitrate	290	370		210	520		240	520	
Nitrite	30	30		20	230		30	30	
TKN	4816	<2000		3764	4840		2954	11300	
Ammonia	<100	<100		<100	4690		<100	<100	
Arsenic	<0.1	4.9		<0.1	4.5		<0.1	5	
Cyanide	<10	<10		<10	18		<10	<10	
Lead	<0.05	**5.54**		<0.5	**2.7**		0.6	**5.3**	
Mercury	0.5	<0.5		<0.5	0.5		<0.5	<0.5	
Cadmium	<0.003	1.3		<0.003	1.5		<0.003	0.8	
Chromium	<0.5	<0.5		0.7	<0.5		<0.5	<0.5	
Nickel	3.3	<0.1		2.4	**10.6**		1	<0.1	

Parameters	1GUA3	2GUA3	3GUA3	1GUA9	2GUA9	3GUA9	1GUA6	2GUA6	3GUA6
Total Coliforms	230	**92000**	9200	230	**240000**	**10900**	2300	**17200**	**160000**
Fecal Coliforms	<2	**17200**	1090	79	**27800**	1300	2300	2300	**160000**
Organic Comp.	0.1	0	0.3	0.1	0	0.1	0.4	0.1	**1.7**
BOD-5	**21000**	<5000		**25500**	**6700**		**45000**	**7500**	
Nitrate	300	200		200	330		110	140	
Nitrite	30	30		120	<20		<200	230	
TKN	3986	<2000		2525	<2000		37820	5880	
Ammonia	<100	<100		1018	<100		8468	1040	
Arsenic	<0.1	4.7		<0.1	4.5		<0.1	4.7	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**6.3**		0.6	**10.17**		0.6	**41.6**	
Mercury	<0.5	<0.5		<0.5	0.6		<0.5	<0.5	
Cadmium	<0.003	0.9		<0.003	1.5		<0.003	1.6	
Chromium	<0.5	<0.5		<0.5	<0.5		0.7	<0.5	
Nickel	<0.1	<0.1		1.4	<0.1		**14.3**	0.7	

Bold - above regulatory stadard limits Underlined - above E.P.A. recommended level *Italic - groundwater sample*

Table 8. (cont'd.)

Parameters	1GUA7	2GUA7	3GUA7	1GUA8	2GUA8	3GUA8	1GUA10	2GUA10	3GUA10
Total Coliforms	3300	**17200**	5420	4900	7000	2400	**13000**	**24000**	5420
Fecal Coliforms	3300	700	80	4900	1100	110	**13000**	1090	460
Organic Comp.	0	0	0	1	0	0	**2.6**	0	0
BOD-5	**9000**	<5000		**7500**	<5000		**6000**	<5000	
Nitrate	20	<20		80	<20		20	<20	
Nitrite	<200	250		200	310		250	310	
TKN	1735	<2000		6671	<2000		4028	<2000	
Ammonia	<100	<100		<100	<100		<100	<100	
Arsenic	<0.1	4.9		<0.1	4.2		<0.1	4.3	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	**1.4**	**10.7**		<0.05	**11.7**		1	<0.5	
Mercury	<0.05	<0.5		<0.5	0.5		<0.05	**8.6**	
Cadmium	<0.003	**0.9**		<0.003	**0.9**		<0.003	**2**	
Chromium	<0.5	<0.5		<0.5	<0.5		<0.5	<0.5	
Nickel	7.6	<0.1		1	<0.1		<1	<0.1	

Parameters	1GUA5	2GUA5	3GUA5	*1GUA11*	*2GUA11*	*3GUA11*	*1GUA12*	*2GUA12*	*3GUA12*
Total Coliforms	230	**34800**	**34800**	<2	<2	<2.2	<2	**50**	<2.2
Fecal Coliforms	<2	1700	3300	<2	<2	<2.2	<2	<2	<2.2
Organic Comp.	**8**	0	**5.6**	1	0	0.2	**4.6**	0	0.3
BOD-5	**33000**	**19500**		**7500**	**5200**		<5000	<5000	
Nitrate	<200	0		<20	<20		30	<20	
Nitrite	30	750		200	220		290	200	
TKN	39310	4990		1249	<2000		4816	<2000	
Ammonia	10327	<100		<100	<100		<100	<100	
Arsenic	<0.1	4.5		<0.1	**4.3**		<0.1	**4.3**	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**6.1**		<0.05	7.6		<0.05	5	
Mercury	<0.5	<0.5		0.9	1.1		**2.7**	1.5	
Cadmium	<0.003	**0.7**		<0.003	1.5		<0.003	0.7	
Chromium	1.4	<0.5		<0.5	<0.5		<0.5	<.05	
Nickel	1.8	<0.1		1.4	<0.1		<1	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italic - groundwater sample*

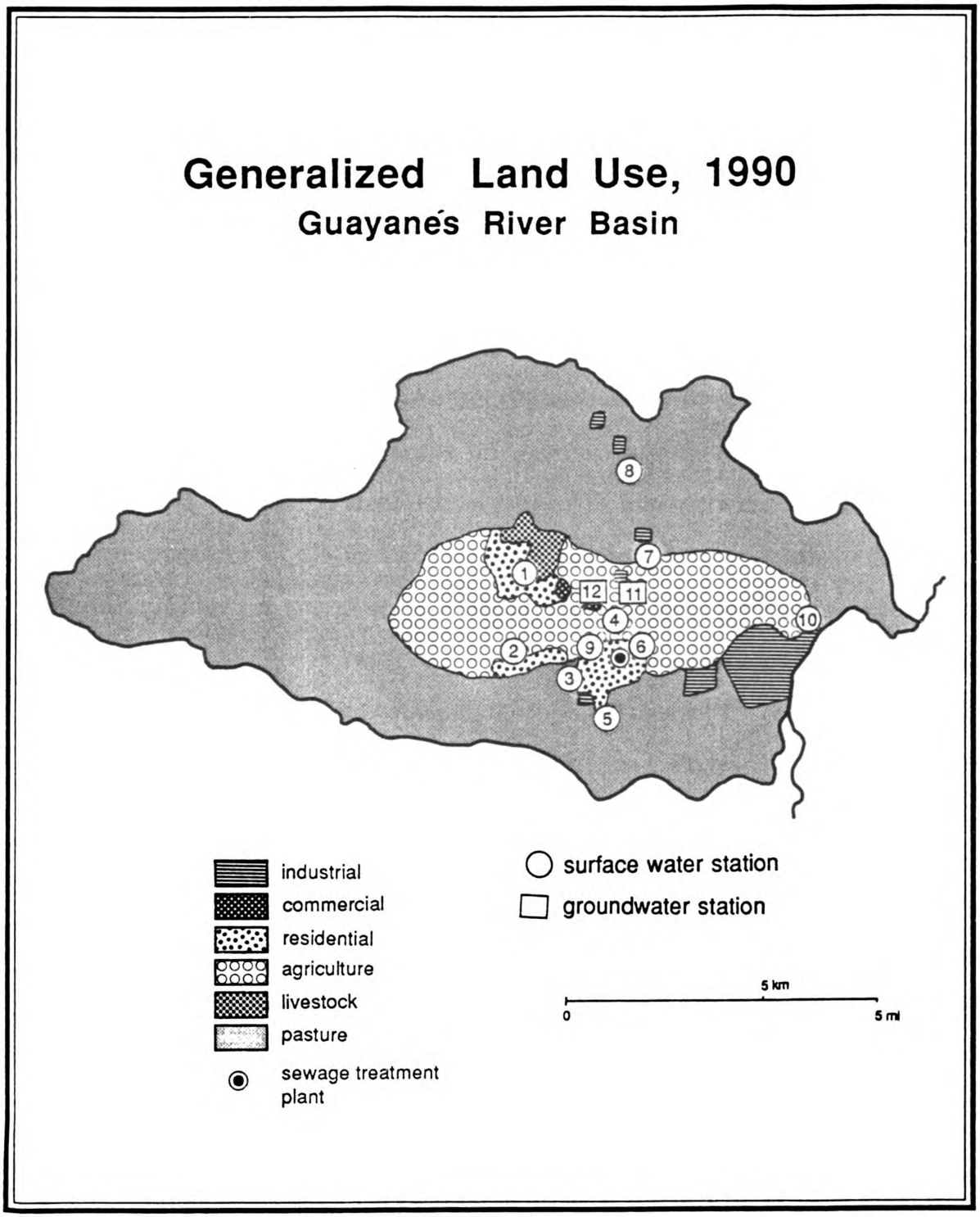

Figure 10. Generalized Land Use, 1990 - Guayanes River Basin

drinking water or groundwater regulations, but the two wells sampled in this basin gave readings above 5,000 ug/l, the standard in surface waters.

The two wells are surrounded mainly by sugarcane fields and the sugarmill industry. It is possible for fertilizers and pesticides from cultivated fields to percolate and reach the aquifer. In surface waterbodies, herbicides and insecticides in addition to being a source of toxic compounds, can also contribute to the BOD of the receiving waters. In fact, it was at one of this wells that the highest concentration of semi-volatile organic compounds (4.6 ug/l) for all groundwater sampled in the survey was detected. Through the GC/MS method a separation and identification of a concentration of 4.4 ug/l of Di-n-butyl-phthalate was obtained from this sample. This is a compound classified as a priority pollutant, which has been used as an insect repellant. At the other well trace levels of other phthalates were also detected. Although these are relatively small concentrations, their presence in groundwater indicates that contamination of the aquifer from human activities is taking place.

Detectable concentrations of semi-volatile organic compounds, above 1.0 ug/l were found at six of the twelve stations sampled in the Guayanés basin. The highest concentration was 8.0 ug/l at a station in spatial association with industrial (textile manufacture) and residential land uses. Not all of the compounds detected at this site could be identified but they included petroleum derived hydrocarbons, sulfur, and diethyl phthalate.

Diethyl phthalate is a priority pollutant that has been used in the manufacture of celluloid, varnishes and dopes. The presence of sulfur in elemental form may be as a result of the separation of compounds in the

analytical column of the GC/MS. However, many products or by-products of industrial processes contain sulfur. Traces of anthracene and fluoranthene were also detected at this station. Both compounds are priority pollutants described as policyclic aromatic hydrocarbons. They are formed during the combustion of many materials. Anthracene is used in dyestuff manufacture and is also a major constituent of coal tar neutral oils. Water quality criterium for fluoranthene suggests a concentration level of 42.0 ug/l in ambient water.

Compounds such as caprolactam and adipic acid, used in the manufacture of synthetic fibers, were detected in waterbodies in spatial association with commercial and residential land uses in this basin. This is an indication that industrial activities are not to be identified as the only sources of synthetic organic compounds.

Regarding concentrations of heavy metals, the standard for mercury in surface waters (1.0 ug/l) was violated at two stations during the second sampling. The highest reading in this basin was 10.7 ug/l at a station surrounded by sugarcane cultivation and a graphite electrode industry. The second highest reading was detected also at a site in association with a sugarcane field.

While there is no standard limit for mercury in untreated groundwater, the drinking water standard for this metal is 2.0 ug/l, which doubles the numerical limit standard for mercury in untreated surface waters (1.0 ug/l). A concentration of mercury of 2.7 ug/l was detected in one of the wells during the first sampling. The second sample provided a concentration of 1.5 ug/l. It was at this well that the highest concentration

of semi-volatile organic compounds was detected in this basin. The detection of a pesticide and mercury in this well may be indicative of contamination of the aquifer with substances used in the agricultural and commercial land uses surrounding it.

Lead, cadmium or nickel were not detected at above the standard levels establised in the previous regulation. However, when the concentration of calcium carbonate is considered (52.0 mg/l) violations for lead and cadmium standard limits occur.

A numerical limit for cadmium of 0.68 ug/l was violated at all surface water stations during the second sampling. The highest concentration was 2.0 ug/l at a site in association with a sugarcane cultivation area. None of the groundwater samples had readings above the standard for cadmium in groundwater or drinking water.

The lead standard limit of 1.38 was violated at nine of the stations. The highest reading was 41.6 ug/l and it was obtained at a site receiving the effluents from a sewage treatment plant. This was the highest reading for lead for the whole study area. Lead concentration were not in violation at any of the wells in the basin.

A nickel concentration of 14.3 was the highest detected in this basin. As mentioned before E.P.A. suggests a concentration limit of 13.4 ug/l. However, the standard limit of 90.7 ug/l for nickel in surface waters was above any of the measurements obtained in this basin in surface or groundwater samples.

As in the other two basins, the detection of arsenic was above the standard for groundwater in the two samples obtained from that source in this basin. Violations occurred during the second sampling and the concentration at both station was of 4.3 ug/l.

In summary, each of the three basins reveals frequent violations of water standards and also numerous near-violations. These include fecal coliforms, oxygen demand, nitrogen, heavy metals and semi-volatile organic compounds. Particularly regarding surface water, the main feature that the three basins have in common is widespread contamination. Possible threats to human health must be considered in both the short and long run, but cannot be evaluated here.

CHAPTER V

ANALYSIS OF RESULTS BY LAND USE

The number of samples with detectable concentrations of pollutants exhibit considerable variation among the parameters and among the land uses in the data set. With the exception of the parameters for total and fecal coliforms, the maximum concentrations also show considerable variation between land uses.

The distribution of highest concentrations detected by land use indicates that water samples taken from sites in spatial association with land uses that were predominantly urban (industrial, residential) have a larger number of parameters with maximum concentrations when compared with the other land uses included in this study (Table 9). This pattern was consistent throughout the three basins.

Municipal and industrial uses of water are directly related to, and largely based on, water carriage of wastes. For example, most industrial uses of water are for the removal of heat, impurities, or by-products from various types of processes. Also the discharge of wastes into other locations such as into air or land does not prevent wastes from ultimately reaching water bodies. Examples are the many instances of serious groundwater and surface water pollution by leachates of materials buried in landfills that enter the aquatic environment by leaching into water passing through the deposit.

Table 9. Maximum Concentrations Detected per Land Use - All Samplings

Land Use / Parameter	Agriculture (Crops)	Livestock	Industrial	Residential	Sewage Trt. Plant	Commercial
Total Coliforms	**2400000**	160000	**2400000**	**2400000**	160000	**2400000**
Fecal Coliforms	**2400000**	54000	**2400000**	**2400000**	160000	**2400000**
Org. Compounds	5	1.3	**39.8**	**39.8**	1.7	**39.8**
BOD-5	**45000**	21000	33000	33000	**45000**	24000
Ammonia	8468	4690	**10327**	**10327**	8468	414
Nitrite	520	**1380**	220	750	510	90
Nitrate	1820	370	4200	**6200**	1390	4100
Cyanide	18	18	<10	18	**20**	<10
TKN	37820	16180	**39310**	**39310**	37820	8662
Mercury	**2.7**	1.1	**2.7**	2.5	0.5	2.3
Lead	**41.6**	14.8	22.5	22.6	**41.6**	10.7
Cadmium	**2.6**	1.5	1.5	1.6	1.6	1.5
Chromium	6	11.8	**32**	17	1.3	**32**
Nickel	14.3	10.6	**44.6**	**44.6**	14.3	**44.6**
Arsenic	**23**	4.9	**23**	4.9	5	5

Bold - Maximum detected concentration

I. Maximum Concentrations per Land Uses

1. Agriculture (crops)

Water samples in spatial association with this type of land use (Table 10) exhibited highest concentrations for the heavy metals lead (41.6 ug/l) mercury (2.7 ug/l), and cadmium (2.6 ug/l), the nonmetallic element arsenic (23.0 ug/l), and the highest biochemical oxygen demand (45.0 mg/l).

Among these highest concentrations, lead, cadmium and mercury violated the standards for surface waters. The surface water quality standard for mercury has been set to 1.0 ug/l to protect waterbodies or the aquatic life from the potential for bioaccumulation through the food chain. Inorganic mercury is relatively insoluble and is not a threat to the human food chain, but organic complexes of mercury such as methyl mercury can be produced by methane-generating bacteria in contact with metallic mercury in lake or stream sediment. Consumption of aquatic organisms with excessive concentrations of methyl mercury can have severe effects on the central nervous system. Chemicals that bioaccumulate in food chains may create problems even though their concentrations in the water are well below objectionable levels. The standard for mercury was violated at a groundwater site, associated with crop cultivation activities; 2.7 ug/l at the Guayanés station #12 was the highest mercury reading from groundwater samples. The current drinking water standard for mercury is 2.0 ug/l.

While the highest concentration of arsenic was of 23.0 ug/l in a surface waterbody and thus, does not violate the standard numerical limit of 50.0 ug/l, the highest concentration of arsenic from a groundwater

Table 10. Agriculture - Detected Concentrations of Water Quality Parameters

Parameters	1GUA2	2GUA2	3GUA2	1GUA4	2GUA4	3GUA4	1GUA9	2GUA9	3GUA9	1GUA6	2GUA6	3GUA6
Total Coliforms	2300	9200	3480	**13000**	5420	5420	230	**240000**	**10900**	2300	**17200**	**160000**
Fecal Coliforms	1300	1090	460	**13000**	790	490	79	**27800**	1300	2300	2300	**160000**
Organic Comp.	0	0.2	0.1	0.2	**5**	0.1	0.1	0	0.1	0.4	0.1	**1.7**
BOD-5	**21000**	**9800**		**24000**	**11300**		**2550**	**6700**		**45000**	**7500**	
Nitrate	20	230		30	30		120	<20		110	140	
Nitrite	210	520		240	520		200	330		<200	230	
TKN	3764	4840		2954	<2000		2525	<2000		37820	5880	
Ammonia	<100	4690		<100	<100		1018	<100		8468	1040	
Arsenic	<0.1	4.5		<0.1	5		<0.1	4.5		<0.1	4.7	
Cyanide	<10	18		<10	<10		<10	<10		<10	<10	
Lead	<0.05	**2.7**		0.6	5.3		0.6	**10.2**		0.6	**41.6**	
Mercury	<0.5	0.5		<0.5	0.5		<0.5	0.6		<0.5	<0.5	
Cadmium	<0.003	**1.5**		<0.003	0.8		<0.003	**1.5**		<0.003	**1.6**	
Chromium	0.7	<.0.5		<0.5	<0.5		0.5	<0.5		0.7	<0.5	
Nickel	2.4	10.6		1	<0.1		1.4	0.1		14.3	0.7	

Parameters	1GUA7	2GUA7	3GUA7	1GUA10	2GUA10	3GUA10	*1GUA11*	*2GUA11*	*3GUA11*	*1GUA12*	*2GUA12*	*3GUA12*
Total Coliforms	3300	**17200**	5420	**13000**	**24000**	5420	<2	<2	<2.2	<2	**50**	<2.2
Fecal Coliforms	3300	700	80	**13000**	1090	460	<2	<2	<2.2	<2	<2	<2.2
Organic Comp.	0	0	0	**2.6**	0	0	1	0	0.2	4.6	0	0.3
BOD-5	**9000**	<5000		**6000**	<5000		**7500**	**5200**		<5000	<5000	
Nitrate	20	<20		20	<20		<20	<20		30	<20	
Nitrite	<200	250		250	310		200	220		290	200	
TKN	1735	<2000		4028	<2000		1249	<2000		4816	<2000	
Ammonia	<100	<100		<100	<100		<100	<100		<100	<100	
Arsenic	<0.1	4.9		<0.1	4.3		<0.1	**4.3**		<0.1	**4.3**	
Cyanide	<10	<10		<10	<10		<10	<10		<10	<10	
Lead	**1.4**	**10.7**		1	**8.6**		<0.5	7.6		<0.05	5	
Mercury	<0.5	<0.5		<0.5	<0.5		0.9	1.1		**2.7**	1.5	
Cadmium	<0.003	**0.9**		<0.003	2		<0.003	1.5		<0.003	0.7	
Chromium	<0.5	<0.5		<0.5	<0.5		<0.5	<0.5		<0.5	<0.5	
Nickel	7.6	<0.1		<1	<0.1		1.4	<0.1		<1	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

Table 10 (cont'd)

Parameters	1CIB5	2CIB5	3CIB5	1YAG2	2YAG2	3YAG2	1YAG9	2YAG9	3YAG9	1YAG8	2YAG8	3YAG8
Total Coliforms	4600	7900	3500	94	**35000**	**2400000**	140	**160000**	**2400000**	4900	**160000**	**2400000**
Fecal Coliforms	3300	2400	2400	94	**35000**	**2400000**	140	**160000**	**2400000**	4900	**160000**	**2400000**
Organic Comp.	0	0	0	0	0	0	0.2	0	0	0	0	0
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	930	780		<200	<200		790	700		660	590	
Nitrite	<20	<20		<20	<20		<20	<20		<20	<20	
TKN	<2000	<2000		6934	2040		2034	<2000		3151	<2000	
Ammonia	<100	<100		<100	<100		<100	<100		<100	<100	
Arsenic	1.7	4.6		<0.1	4.5		<0.1	4.3		<0.1	4.3	
Cyanide	<10	<10		<10	<10		<10	<10		<10	<10	
Lead	2.3	**12.3**		<0.05	**6.1**		<0.05	**8.1**		<0.5	**6.1**	
Mercury	0.7	0.5		<0.5	0.8		0.7	0.5		**1.4**	0.8	
Cadmium	1.2	<0.003		<0.003	1.1		<0.003	**1.3**		<0.003	**2.6**	
Chromium	1.2	<0.5		0.6	<0.5		1.2	<0.5		1	<5	
Nickel	1.7	12.1		<.01	<0.1		<0.1	<0.1		<1	<0.1	

Parameters	1CIB3	2CIB3	3CIB3	1CIB4	2CIB4	3CIB4	*1YAG1*	*2YAG1*	*3YAG1*	*1CIB10*	*2CIB10*	*3CIB10*
Total Coliforms	490	**11000**	920	**35000**	**35000**	3300	<2.2	<2		<2		<2
Fecal Coliforms	350	2300	240	**35000**	**24000**	3300	<2.2	<2		<2		<2
Organic Comp.	0	0	0.1	0	0	0.2	0.4	0	0	0	0	0.4
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	<200	210		990	1290		1030	1240		1640	1820	
Nitrite	<20	<20		50	50		<20	<20		<20	<20	
TKN	11717	<2000		7226	<2000		2396	<2000		<2000	<2000	
Ammonia	<100	<100		<100	<100		<100	<100		<100	<100	
Arsenic	23	4.9		1.1	5		<0.1	**4.2**		**4.9**	**4.5**	
Cyanide	<10	<10		<10	<10		<10	<10		<10	<10	
Lead	<0.05	**18.7**		0.3	**12**		1.1	8.1		<0.05	11.6	
Mercury	**1.3**	<0.5		0.4	<0.5		0.5	1.7		<0.5	1.2	
Cadmium	0.9	<0.003		0.9	<0.003		<0.003	0.7		0.2	<0.003	
Chromium	1.4	<0.5		4	6		<0.5	<0.5		<0.5	10	
Nickel	1.4	7.3		5.3	7.7		<0.1	<0.1		2.2	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

sample was 4.9 ug/l, a number that violates the standard for groundwater. One of the readings belongs to a well in close proximity to the surface waterbody with highest level of arsenic (Cibuco River Basin, stations #3 and #10). The relationships among groundwaters and surface waters are vitally important. Flows into and out of porous soils exchange water storage between a surface reservoir and an adjoining aquifer. Studies with arsenic indicate that this metal is not bioconcentrated to a high degree in fish, and thus do not represent a threat to fish predators, but that lower forms of aquatic life may accumulate higher arsenic residues than fish (E.P.A., 1986).

The highest BOD-5 and lead readings occurred at a sampling site that was also in association with a water sewage treatment plant, hence these will be discussed under that section.

2. Livestock

The only maximum concentration above those detected in association with other land uses was the concentration for nitrite (Table 11). Nitrites are generally considered to be indicators of pollution through disposal of sewage or organic waste. There are no quality standards for the concentration of nitrites in untreated surface waters.

The standard for lead was violated at all stations during the second sampling activity. The standard for the metals cadmium and mercury were also violated at two of the stations associated with livestock activities.

Table 11. Livestock - Detected Concentrations of Water Quality Parameters

Parameter	1CIB2	2CIB2	3CIB2	1CIB7	2CIB7	3CIB7	1GUA1	2GUA1	3GUA1
Total Coliforms	**92000**	**35000**	9200	**160000**	3500	9200	3300	**54200**	7000
Fecal Coliforms	**54000**	**24000**	2400	**54000**	3500	2400	3300	**17200**	<2.2
Organic Comp.	0	0	0.6	**1.3**	0.3	0.1	0.5	0	0
BOD-5	<5000	<5000		<5000	<5000		**6700**	<5000	
Nitrate	140	270		70	<20		290	370	
Nitrite	690	1380		850	800		30	30	
TKN	16180	8390		<2000	<2000		4816	<2000	
Ammonia	4174	3660		<100	<100		<100	<100	
Arsenic	1.5	4.5		1.8	4.3		<0.1	4.9	
Cyanide	10	<10		<10	<10		10	<10	
Lead	0.3	**14.6**		4.3	**14.8**		<0.05	**5.5**	
Mercury	<0.5	<0.5		**1.1**	<0.5		0.5	<0.5	
Cadmium	1.4	<0.003		1.2	<0.003		<0.003	1.3	
Chromium	0.9	<0.5		11.8	<0.5		<0.5	<0.5	
Nickel	<1	1.4		8.3	2.2		3.3	<0.1	

Parameter	1GUA2	2GUA2	3GUA2	1GUA8	2GUA8	3GUA8
Total Coliforms	2300	9200	3480	4900	7000	2400
Fecal Coliforms	1300	1090	460	4900	1100	110
Organic Comp.	0	0.2	0.1	1	0	0
BOD-5	**21000**	**9800**		**7500**	7500	
Nitrate	210	230		80	80	
Nitrite	20	520		20	20	
TKN	3764	4840		6671	6671	
Ammonia	<100	4690		<100	<100	
Arsenic	<0.1	4.5		<0.1	<0.1	
Cyanide	10	18		<10	<10	
Lead	<0.05	**2.7**		<0.05	**11.7**	
Mercury	<0.05	0.5		<0.5	<0.5	
Cadmium	<0.003	**1.5**		<0.003	0.9	
Chromium	0.7	<0.5		<0.5	<0.5	
Nickel	2.4	10.6		<0.1	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

3. Industry

The highest concentrations in water samples collected from sites surrounded by industrial land use (Table 12) were those for semivolatile organic compounds (39.8 ug/l), ammonia (10327.0 ug/l), nickel (44.6 ug/l), total kjeldahl nitrogen (39310 ug/l), chromium (32.0 ug/l), mercury (2.7 ug/l), and arsenic (23.0 ug/l).

Many of the organic compounds that have caused concern enter watercourses in discharges from chemical manufacturing plants. On the other hand, many others are released by operations that use them for various purposes, and their concentration in water might be related to their selection, handling and application, not necessarily the industrial wastewater treatment. End uses of many of these componds tend to disperse them in the environment. Daily activities of typical dense population of urban areas produce wastes (personal, commercial, or industrial) that eventually are discharged into the atmosphere, land or natural waters.

Moreover, runoff water from impervious surfaces (e.g. parking lots, buildings) becomes a vector for any component caught in its flow. It is then, not surprising that urban related land uses present the highest concentrations of these contaminants. Some organic chemicals are of concern in stream pollution control programs because they biodegrade and impose oxygen demand on watercourses. In contrast, other types of organic chemicals cause concern for the opposite reason; they are not decomposed through biological action and may persist for long periods of time, or indefinitely.

Table 12. Industry - Detected Concentrations of Water Quality Parameters

Parameter	1CIB3	2CIB3	3CIB3	1CIB6	2CIB6	3CIB6	1CIB7	2CIB7	3CIB7	*1CIB11*	*2CIB11*	*3CIB11*
Total Col.	490	**11060**	920	54000	**160000**	**160000**	**160000**	3500	9200	<2	<2	<2
Fecal Col.	350	2300	240	54000	**92000**	**35000**	**54000**	3500	2400	<2	<2	<2
Org. Comp.	0	0	0.1	0	0	0.3	**1.3**	0.3	0.1	0	0	0.4
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	<2000	210		700	850		850	800		4200	3450	
Nitrite	<20	<20		30	<20		70	220		<20	<20	
TKN	11717	<2000		<2000	<2000		<2000	<2000		<2000	<2000	
Ammonia	<100	<100		<100	130		<100	<100		<100	<100	
Arsenic	23	4.9		1.5	4.5		1.8	4.3		**2.3**	**4.9**	
Cyanide	<10	<10		<10	<10		<10	<10		<10	<10	
Lead	<0.5	**18.7**		2	**20.7**		4.25	**14.8**		3	8.1	
Mercury	**1.3**	<0.5		<0.5	1		**1.1**	<0.5		1.4	<0.5	
Cadmium	0.9	<0.003		1.2	<0.003		1.2	<0.003		1.4	<0.003	
Chromium	1.4	<5		1.7	<5		11.8	<5		2.5	<5	
Nickel	1.4	7.3		1.8	17.8		8.3	2.2		<1	3.4	

Parameter	1YAG6	2YAG6	3YAG6	1YAG3	2YAG3	3YAG3	1YAG4	2YAG4	3YAG4	1YAG7	2YAG7	3YAG7
Total Col.	2400	**18000**	**2400000**	**240000**	**240000**	**2400000**	**54000**	240000	**240000**	**240000**	**240000**	**2400000**
Fecal Col.	2400	**18000**	**2400000**	**240000**	**240000**	**2400000**	**54000**	240000	**240000**	**240000**	**240000**	**2400000**
Org. Comp.	0	0	0	0	0	**1.1**	0.1	0	0	**39.8**	1	0
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000		**15700**	**10500**	
Nitrate	680	480		730	500		390	310		2160	4100	
Nitrite	<20	<20		<20	<20		20	<20		90	50	
TKN	4262	<2000		3647	<2000		4883	<2000		8962	2070	
Ammonia	<100	<100		414	<100		<100	<100		<100	280	
Arsenic	<0.1	4.5		<0.1	4.3		0.4	4.5		<0.1	4.2	
Cyanide	<10	<10		<10	<10		<10	<10		<10	<10	
Lead	<0.05	**7.47**		<0.05	**10.7**		<0.05	**7.34**		<0.05	**22.54**	
Mercury	<0.5	1		<0.5	**1.6**		1	**1.6**		**2.3**	1	
Cadmium	<0.003	0.9		<0.003	**1.4**		**1.3**	0.9		<0.003	**1.5**	
Chromium	5.1	5		2.6	1.7		8.3	<0.5		5	32	
Nickel	6.3	<0.1		2.4	<0.1		6.5	<0.1		12.1	44.6	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

Table 12. (cont'd)

Parameter	1GUA5	2GUA5	3GUA5	1GUA7	2GUA7	3GUA7	1GUA8	2GUA8	3GUA8
Total Coliforms	230	**34800**	**34800**	3300	**17200**	5420	4900	7000	2400
Fecal Coliforms	<2	1700	3300	3300	700	80	4900	1100	110
Organic Comp.	**8**	0	**5.6**	0	1	0	1	0	0
BOD-5	**33000**	**19500**		9000	<5000		**7500**	<5000	
Nitrite	30	<20		20	<20		80	<20	
Nitrate	<20	750		<2000	250		200	310	
TKN	39310	4990		1735	<2000		6671	<2000	
Ammonia	10327	<100		<100	<100		<100	<100	
Arsenic	<0.1	4.5		<0.1	4.9		<0.1	4.2	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**6.1**		<0.05	**10.7**		<0.05	**11.7**	
Mercury	<0.5	<0.5		**1.4**	<0.5		<0.5	0.5	
Cadmium	<0.003	0.7		<0.003	**0.9**		<0.003	0.9	
Chromium	1.4	<0.5		<0.5	<0.5		<0.5	<0.5	
Nickel	1.8	<0.1		7.6	<0.1		1	<0.1	

Parameter	*1GUA11*	*2GUA11*	*3GUA11*	*1GUA12*	*2GUA12*	*3GUA12*
Total Coliforms	<2	<2	<2.2	<2	**50**	<2.2
Fecal Coliforms	<2	<2	<2.2	<2	<2	<2.2
Organic Comp.	1	0	0.2	**4.6**	0	0.3
BOD-5	**7500**	**5200**		<5000	<5000	
Nitrite	<20	<20		<20	<20	
Nitrate	<200	220		<200	<200	
TKN	1892	<2000		1249	<2000	
Ammonia	<100	<100		<100	<100	
Arsenic	<0.1	**4.3**		<0.1	**4.3**	
Cyanide	<10	<10		<10	<10	
Lead	<0.05	7.6		<0.05	5	
Mercury	0.9	1.1		**2.7**	1.5	
Cadmium	<0.003	1.5		<0.003	0.7	
Chromium	<0.5	<5		<0.5	<5	
Nickel	1.4	<0.1		1	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

As mentioned above, the single highest concentration for semi-volatile organic compounds was detected in the Yagüez River basin at a site surrounded by industrial (textile), commercial (grocery store) and residential land uses. In a study conducted by U.S.E.P.A. in the 1970's (Cornaby, 1981) to evaluate the technology available for the reduction of pollutants from textile wastewaters selected pollutants and associated measurements for the textile industry were examined. In analyses performed on effluents from textile plants, observed concentrations of priority organic pollutants ranged from 0.1 ug/l to 3000.0 ug/l. Among these compounds were benzyl butyl phthalates, nitrophenols, anthracene, diethyl phthalate, bis(2-Ethylhexyl) phthalate, di-n-butyl phthalate, naphthalene as well as detectable concentrations of the heavy metals cadmium, chromium, lead , nickel, mercury, arsenic and the compound cyanide. All of these compounds were also detected in some of the samples from industrial land uses in this study.

One of the most common types of industry in the study area was that of textile products. In the Yagüez basin, the station at which the highest concentration of semi-volatile organic compounds were detected was one associated with a garment industry for the manufacture of men's work pants. In the Cibuco basin a compound that could not be identified was detected in association with an industry fo the manufacture of mop linen, and trace levels of another of these compound at a men's knitted shirt industry. In the Guäyanés basin, the highest concentrations of organic compounds were detected at a surface water station in association with industries for the manufacture of men's jackets, fabric stamping, and leather products Although there were other types of industries at the other

sampling sites, the detection of semivolatile organic compounds was not as high.

Concentrations of lead, mercury and cadmium violated the standard limits in at least one of the samples at almost all the stations in industrial land uses. However, the highest concentrations of lead and cadmium were not detected at sampling sites from industrial land uses. The reading for mercury was detected at the well sampling site discussed above.

Nickel, another heavy metal, is an important industrial metal that is used extensively in stainless steel and other corrosion resistant alloys, and to a lesser extent for other purposes. Because of its extensive use, nickel can be added to the environment in significant amounts by waste disposal. Some nickel compounds may be carcinogenic. The highest concentration of nickel was detected at a sampling station in association with industrial (textile) land use, but the standard limit was not exceeded. However, the detected concentration of 44.6 ug/l more than triples the limit suggested by the U.S.E.P.A. for the protection of human health from the toxic properties of nickel. The examination of the concentrations of nickel in all samples indicate that these are higher in samples from industrial land uses, although there are no violations to the current water quality standards. In some instances chemicals discharged into the environment may undergo reactions that transform them into substances with different toxicological characteristics, as in the case of mercury. These possibilities may have great significance in setting standards for allowable discharges of some types of materials. The heavy metal chromium is known to be added to fertilizers and industrial applications of chromium may produce waste solutions containing chromate anions. The maximum concentration of

chromium of 32.0 ug/l was also detected at the sampling site in the Yagüez river basin with highest concentrations for semi-volatile organics and nickel. Although 32.0 ug/l is not above the current standard of 50.0 ug/l in surface waters, concentrations of chromium in natural waters that have not been affected by waste disposal are commonly less than 10 ug/l (Hem, 1985).

Ammonia can form soluble complexes with some metal ions, and certain types of industrial waste effluents may contain such species. There is no water quality standard for ammonia in surface waters. The highest detected level was 10,327 ppb at Guayanés station #5. The term total kjeldahl nitrogen (TKN) reflects the technique used in the determination of organic nitrogen and ammonia. The difference between TKN and ammonia has been determined as organic nitrogen. Nitrogenous compounds released in discharges may include nitrogen in organic chemicals (organic nitrogen) and nitrogen present as ammonia, nitrites and nitrates. Under appropriate environmental conditions, many nitrogenous compounds undergo a series of biochemical reactions that convert organic nitrogen to ammonia and oxidize ammonia to nitrites and nitrates, a process called nitrification. The oxygen required in nitrification can be a very substantial portion of the total oxygen demand in a waterbody. At the industrial site where ammonia and TKN readings where the highest, the BOD-5 was also the most elevated. The sources of organic nitrogen include not only natural materials, but also numerous synthetic organic ones likely to be associated with industrial processes.

Arsenic, as discussed above, occurs in many natural materials. Apart from its use as a component of pesticides the volatility of the element

contributes to the natural circulation of arsenic and some of its compounds. Arsenic also may be released in the burning of coal and the smelting of ores. The maximum concentrations of arsenic from industrial sites did not exceeded the standard limit for surface waters. Nevertheless the surface water station at which the highest concentration for arsenic was detected has a chemical industry, residential and sugarcane cultivation as associated land uses. Since the sources of arsenic are more related to agricultural activities this can be expected to be the most likely source and not the other two land uses mentioned. The highest concentration of arsenic from a well sample within this type of land use was the same as the highest concentration detected at a well surrounded by a sugarcane cultivation (4.9 ug/l). Without knowledge of the groundwater flow system and boundary conditions in this aquifer it is not possible to identify pollutant sources other than those in close proximity to a well. But an interconnection of the aquifer system could be expected and revealed by the presence of pollutants in common.

4. Commerce

Maximum concentrations for nickel (44.6 ug/l), semivolatile organic compounds (39.8 ug/l), and chromium (32.0 ug/l) were detected in waterbodies surrounded by commercial land use (Table 13).

The detected nickel concentration of 44.6 ug/l was the only one with such a high nickel concentration when compared with the other samples from commercial land uses. Since it is also surrounded by industrial activity (textiles), it is feasible that this and not the commercial activity could be the main source of the metal. The examination of nickel

Table 13. Commerce - Detected Concentrations of Water Quality Parameters

Parameter	1GUA4	2GUA4	3GUA4	*1GUA12*	*2GUA12*	*3GUA12*	1YAG2	2YAG2	3YAG2
Total Coliforms	**13000**	5420	5420	<2	**50**	<2.2	94	**35000**	**2400000**
Fecal Coliforms	**13000**	790	490	<2	<2	<2.2	94	**35000**	**2400000**
Organic Comp.	0.2	**5**	0.1	**4.6**	0	0.3	0	0	0
BOD-5	**24000**	**11300**		<5000	<5000		<5000	<5000	
Nitrate	240	520		<200	<200		<2000	<2000	
Nitrite	30	30		<20	<20		20	<20	
TKN	2954	<2000		1249	<2000		6934	2040	
Ammonia	<100	<100		<100	<100		<100	<100	
Arsenic	<0.1	5		<0.1	4.3		<0.1	4.5	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	0.57	**5.28**		<0.05	5.02		<0.5	**6.1**	
Mercury	<0.5	0.5		**2.7**	1.5		<0.5	0.8	
Cadmium	<0.003	**0.8**		<0.003	0.7		<0.003	1.133	
Chromium	<0.5	<0.5		<0.5	<0.5		0.6	<0.5	
Nickel	<1.0	<0.1		<1	<0.1		<1.0	<0.1	

Parameter	1YAG3	2YAG3	3YAG3	1YAG7	2YAG7	3YAG7
Total Coliforms	**240000**	**240000**	**2400000**	**240000**	**240000**	**2400000**
Fecal Coliforms	**240000**	**240000**	**2400000**	**240000**	**240000**	**2400000**
Organic Comp.	0	0	**1.1**	**39.8**	**1**	0
BOD-5	<5000	<5000		**15700**	**10500**	
Nitrate	730	500		2160	4100	
Nitrite	<20	<20		90	50	
TKN	3647	<2000		8962	2070	
Ammonia	414	<100		<100	280	
Arsenic	<0.1	4.3		<0.1	4.2	
Cyanide	<10	<10		<10	<10	
Lead	<0.05	**10.7**		<0.05	**22.6**	
Mercury	<0.5	**1.6**		**2.3**	1	
Cadmium	<0.003	**1.4**		<0.003	**1.5**	
Chromium	2.6	17		5	32	
Nickel	2.4	<0.1		12.1	44.6	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

concentrations in all samples indicates that it is higher in areas of industrial land uses. The concentration of chromium was also detected at sampling sites in association with industrial activity. The chromium concentrations at other commercial land use sites were not as high.

It was also in the Yaguez basin, station #7 that the highest concentration for semi-volatile organic compounds was detected. But runoff from commercial areas can transport different types of organic and inorganic chemicals to receiving waterbodies.

Lead, mercury or cadmium concentration levels were above standards in all stations during at least one of the sampling activities, although their highest concentrations were not detected in association with this type of land use. Washing of these metals into streams during runoff events is a potential source of river water contamination.

5. Residential

Highest concentrations of ammonia (10327.0 ug/l), nitrate (6200 ug/l), TKN (39310 ug/l), and nickel (44.6 ug/l) occurred in water samples taken from sites surrounded by residential land uses (Table 14).

The presence of nitrate or ammonium might be indicative of pollution through disposal of sewage or organic waste, but generally the pollution would have occurred at a site or time substantially removed from the sampling point (Hem, 1985). Nutrients in sewage arise from human wastes, detergents, street runoff, and industrial wastes. The detection of nitrate and nitrite in surface waters should not be above 10,000 ug/l, in order to protect a waterbody that may be use as a raw water source for

Table 14. Residential - Detected Concentration of Water Quality Parameters

Parameters	1GUA1	2GUA1	3GUA1	1GUA2	2GUA2	3GUA2	1GUA4	2GUA4	3GUA4
Total Coliforms	3300	**54200**	7000	2300	9200	3480	**13000**	5420	5420
Fecal Coliforms	3300	**17200**	<2.2	1300	1090	460	**13000**	790	490
Organic Comp.	0.5	0	0	0	0.2	0.1	0.2	**5**	0.1
BOD-5	**6700**	<5000		**21000**	**9800**		**24000**	**11300**	
Nitrate	290	370		210	520		240	520	
Nitrite	30	30		20	230		30	30	
TKN	4816	<2000		3764	4840		2954	11300	
Ammonia	<100	<100		<100	4690		<100	<100	
Arsenic	<0.1	4.9		<0.1	4.5		<0.1	5	
Cyanide	<10	<10		<10	18		<10	<10	
Lead	<0.05	**5.54**		<0.5	**2.7**		0.6	**5.3**	
Mercury	0.5	<0.5		<0.5	0.5		<0.5	<0.5	
Cadmium	<0.003	1.3		<0.003	**1.5**		<0.003	**0.8**	
Chromium	<0.5	<0.5		0.7	<0.5		<0.5	<0.5	
Nickel	3.3	<0.1		2.4	10.6		1	<0.1	

Parameters	1GUA3	2GUA3	3GUA3	1GUA9	2GUA9	3GUA9	1YAG6	2YAG6	3YAG6
Total Coliforms	230	**92000**	9200	230	**240000**	**10900**	2400	**18000**	**2400000**
Fecal Coliforms	<2	**17200**	1090	79	**27800**	1300	2400	**18000**	**2400000**
Organic Comp.	0.1	0	0.3	0.1	0	0.1	0	0	0
BOD-5	**21000**	<5000		**25500**	**6700**		<5000	<5000	
Nitrate	300	200		200	330		680	500	
Nitrite	30	30		120	<20		<20	<20	
TKN	3986	<2000		2525	<2000		4262	<2000	
Ammonia	<100	<100		1018	<100		<100	<100	
Arsenic	<0.1	4.7		<0.1	4.5		<0.1	4.5	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**6.3**		0.6	**10.17**		<0.05	**7.5**	
Mercury	<0.5	<0.5		<0.5	0.6		<0.5	1	
Cadmium	<0.003	**0.9**		<0.003	1.5		<0.003	0.9	
Chromium	<0.5	<0.5		<0.5	<0.5		5.1	<0.5	
Nickel	<0.1	<0.1		1.4	<0.1		6.3	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics - groundwater sample*

Table 14. (cont'd)

Parameter	1YAG4	2YAG4	3YAG4	1YAG7	2YAG7	3YAG7	1GUA5	2GUA5	3GUA5
Total Col.	**54000**	**24000**	**2400000**	**240000**	**240000**	**2400000**	230	**34800**	**34800**
Fecal Col.	**54000**	**24000**	**2400000**	**240000**	**240000**	**2400000**	<2	1700	3300
Org. Comp.	0.1	0	0	**39.8**	1	0	**8**	0	**5.6**
BOD-5	<5000	<5000		**15700**	**10500**		**33000**	**19500**	
Nitrate	390	310		2160	4100		<200	0	
Nitrite	20	<20		90	50		30	750	
TKN	4883	<2000		8962	2070		39310	4990	
Ammonia	<100	<100		<100	280		10327	<100	
Arsenic	0.4	4.5		<0.1	4.2		<0.1	4.5	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	**7.4**		<0.05	**22.6**		<0.05	6.1	
Mercury	1	**1.6**		**2.3**	1		<0.5	<0.5	
Cadmium	**1.3**	0.9		<0.003	1.5		<0.003	0.7	
Chromium	8.3	<0.5		5	32		1.4	<0.5	
Nickel	6.5	<0.1		12.1	44.6		1.8	<0.1	

Parameter	1YAG3	2YAG3	3YAG3	*1CIB8*	*2CIB8*	*3CIB8*	1YAG5	2YAG5	3YAG5
Total Col.	**240000**	**240000**	**2400000**	<2	**8**	<2	**54000**	**240000**	**2400000**
Fecal Col.	**240000**	**240000**	**2400000**	<2	**8**	<2	**54000**	**240000**	**2400000**
Org. Comp.	0	0	**1.1**	0	0.2	0.1	0	0	0
BOD-5	<5000	<5000		<5000	<5000		**6000**	<5000	
Nitrate	730	480		6200	5600		590	500	
Nitrite	<20	<20		<20	<20		20	<20	
TKN	3647	<2000		1579	<2000		3952	<2000	
Ammonia	414	<100		<100	<100		<100	<100	
Arsenic	<0.1	4.3		**0.6**	**4.7**		1.6	4.2	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	10.7		0.8	22.53		<0.05	**11.5**	
Mercury	<0.5	1.6		0.8	0.6		**2.5**	1	
Cadmium	<0.003	1.4		1.6	0.003		0.9	0.9	
Chromium	2.6	17		2.5	<0.5		11.3	<0.5	
Nickel	2.4	<0.1		<1	6.7		13	<0.1	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended l *Italic - groundwater sample*

Table 14. (cont'd)

Parameters	1CIB3	2CIB3	3CIB3	1CIB6	2CIB6	3CIB6	1CIB7	2CIB7	3CIB7
Total Coliforms	490	11000	920	54000	160000	160000	160000	3500	9200
Fecal Coliforms	350	2300	240	54000	92000	35000	54000	3500	2400
Organic Comp.	0	0	0.1	0	0	0.3	1.3	0.3	0.1
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	<200	210		930	850		850	800	
Nitrite	<20	<20		<20	<20		70	<20	
TKN	11717	<2000		<2000	<2000		<2000	<2000	
Ammonia	<100	<100		<100	130		<100	<100	
Artsenic	23	4.9		1.5	4.5		1.8	4.3	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	18.7		2.3	20.7		4.3	14.8	
Mercury	1.3	<0.5		0.7	1		1.1	<0.5	
Cadmium	0.9	<0.003		1.2	<0.003		1.2	<0.003	
Chromium	1.4	<0.5		1.7	<0.5		11.8	<0.5	
Nickel	1.4	7.3		1.8	17.8		8.3	2.2	

Parameters	1CIB9	2CIB9	3CIB9	1CIB10	2CIB10	3CIB10	1CIB11	2CIB11	3CIB11
Total Coliforms	<2	<2	<2	<2		<2	<2	<2	<2
Fecal Coliforms	<2	<2	<2	<2		<2	<2	<2	<2
Organic Comp.	0.6	0	4.4	0	0	0.4	0	0	0.4
BOD-5	<5000	<5000		<5000	<5000		<5000	<5000	
Nitrate	5270	5600		1640	1820		4200	3450	
Nitrite	<20	<20		<20	<20		<20	<20	
TKN	1494	<2000		<2000	<2000		<2000	<2000	
Ammonia	<100	<100		<100	<100		<100	<100	
Artsenic	1.9	4.5		4.9	4.5		2.3	4.9	
Cyanide	<10	<10		<10	<10		<10	<10	
Lead	<0.05	20.7		<0.05	11.6		3	8.1	
Mercury	0.7	<0.5		<0.5	1.2		1.4	0.5	
Cadmium	1.2	<0.003		0.2	<0.003		1.4	<0.003	
Chromium	1.9	<0.5		0.5	10		2.5	<0.5	
Nickel	<1	1.6		2.2	<0.1		<1	3.4	

Bold - above regulatory standard limits Underlined - above E.P.A. recommended level *Italics* - groundwater sample

public water supply. This standard was not violated at any of the sites sampled.

The relationship between the parameters for ammonia, TKN and organic nitrogen have been discussed above.

Regarding nickel, an adjacent industry (textile) is the most likely source at the station in which this concentration was detected and not the residential land use.

6. Sewage Treatment Plants

Sewage treatment plants are major sources of pollution and for that reason are treated here as a separate type of land use. The parameters with the maximum concentrations in spatial association ssociation with this type of land use (Table 15) were biochemical oxygen demand (45000.0 ug/l or 45.0 ml/l), cyanide (20.0 ug/l), and lead (41.6 ug/l).

Regarding lead, certain uses of this metal by humans have tended to disperse the element widely through the environment. Lead is a soft, blue-gray metal that serves no purpose in the human body, and, in fact, is toxic in high enough doses. It is found in microscopic particles in the air, in paint, food, household dust and outside dirt. It has been used for products that range from car batteries to radioactive shields. Dry fallout and rainout of particulate lead is probably a factor of major importance in the circulation of the element. Water service lines may be major sources of lead in water supplies. Lead rarely originates at a water treatment plant. Instead lead from lead pipes or lead in solder and flux in copper plumbing can dissolve in water. It is then possible for domestic waste

Table 15. Sewage Treatment Plant - Detected Concentrations of water Quality Parameters

Parameter	1CIB1	2CIB1	3CIB1	1GUA6	2GUA6	3GUA6
Total coliform	2400	**55400**	9200	2300	**17200**	**160000**
Fecal Coliform	1600	**24000**	2400	2300	2300	**160000**
Organic Comp.	0	0.5	0	0.4	0.1	**1.7**
BOD-5	<5000	<5000		**45000**	**7500**	
Nitrate	1030	1390		<200	230	
Nitrite	140	510		110	140	
TKN	13183	6830		37820	5880	
Ammonia	767	1420		8468	1040	
Arsenic	1.2	4.5		<0.1	4.7	
Cyanide	10	20		<10	<10	
Lead	0.3	**17.9**		0.6	**41.6**	
Mercury	0.5	<0.5		<0.5	<0.5	
Cadmium	**1.6**	<0.003		<0.003	**1.6**	
Chromium	1.3	<0.5		0.7	<0.5	
Nickel	1.7	1.5		14.3	0.7	

Bold - above regulatory standard limits

Underlined - above E.P.A. recommended level

Italic - groundwater sample

water to contain appreciable concentrations of the metal. This domestic waste is collected by sewage treatment plants, which are not efficient in the removal of metals during the treatment process (Guthrie and Perry, 1980). Nickel, another metal, was detected at a concentration of 14.3, above the level recommended by U.S.E.P.A. as adequate.

Approximately 152 million gallons per day of sewage treatment water are released to surface waters on the island. According to the U.S.E.P.A. 47.4 percent of the population in Puerto Rico is served by municipal sewer systems designed to provide less than secondary treatment and only 2 percent is served by secondary treatment facilities. Primary treatment removes about 30-40% of the pollutants in the influent wastewater. Secondary treatment removes about 90%. Federal law mandates secondary treatment as the minimum treatment which must be given to all municipal sewage (Van der Leeden et al., 1990).

Cyanide, a chemical form of nitrogen, may occur in water affected by waste disposal. The maximum concentration detected of cyanide was of 20.0 ug/l. This concentration corresponds with the numerical limit set in the new regulation.

The biochemical oxygen demand, as mentioned above, is an indirect test to indicate the gross amount of organic material in water. Pollutants, primarily organic compounds, cause a reduction in dissolved oxygen. These pollutants come primarily from untreated sewage, industrial wastes, food processing plants, and feed lots. As more organic material becomes available for bacterial utilization their population increases, the demand for oxygen to break down the organic material increases, and a

depletion of oxygen results. Other oxidations (e.g., of nitrogenous or sulphur-containing compounds) from chemical and or biological reactions further reduce the water's oxygen content. Inmediately downriver from a sewage treatment plant the biochemical oxygen demand is high, but as the bacteria consume the oxygen, the BOD drops.

The water quality standard states that the BOD will depend on the assimilative capacity of the particular waterbody which should comply with the standard for dissolved oxygen. The standard for dissolved oxygen, set to sustain most forms of aquatic life, is 5000 ug/l or 5.0 ml/l.

II. Groundwater Samples

In general, substances detected in samples from groundwater were in less concentration than those detected in surface waters . The exceptions occurred for the parameters nitrate and mercury. The maximum concentration of nitrate detected from all samples, surface or underground, was 6,200.0 ug/l and was detected at the well Pugnado #2 in the Cibuco River basin. However, the current drinking water standard for nitrate is 10,000 ug/l.

The most common semi-volatile organic compounds detected in wells were phthalates in concentrations of less than 1 ppb. However, Di-n-butyl phthalate, used as an insect repellant, was detected at a concentration of 4.4 ug/l in well Roig within the Güayanés River basin. This well is surrounded by three land uses: sugarcane cultivation, a sugarcane mill and commercial uses.

Well Roig also violated the drinking water standard for mercury. While there is no standard limit for mercury in untreated groundwater, the drinking water standard for this metal is 2.0 ug/l, which doubles the numerical limit set for mercury in untreated surface waters (1.0 ug/l). A concentration of mercury of 2.7 ug/l was detected in well Roig during the first sampling. The second sample provide a concentration of 1.5 ug/l. The detection of a pesticide and mercury in this well may be indicative of contamination of the aquifer with substances used in the agricultural and commercial land uses above.

Two other wells, Pugnado #2 and Vega Baja #3, both in the Cibuco River basin (northern aquifer), and both in spatial association with residential land use, had lead measuraments of 22.5 ug/l and 20.7 ug/l respectively during the second sampling. Readings obtained during the first sampling activity were of 0.8 and 0.7 ug/l, respectively. Although the current standard for lead in drinking water is of 50.0 ug/l, U.S.E.P.A. admits that this standard is obsolete. The proposed standard is a reduction to a maximum concentration of 20.0 ug/l but, according to some experts, even this concentration is not safe for human consumption.

Trace levels of mercaptobenzothiazole (1.0 ug/l), and petroleum derivated hydrocarbons (3.4 ug/l) were also detected at the well Vega Baja #3 during the third sampling activity. Although in relatively small concentrations, the presence in groundwater of chemical substances such as these questions the quality of the groundwater reservoir The slow movement and long storage in groundwater systems makes them more consistent in quantity and quality that surface water. Because of restricted movement, they respond more slowly to pollution, often requiring years for

pollutants to travel through aquifers to points of use. However, once pollution has reached the point of use, that same slow movement may require a very long time to clean the aquifer after pollution emissions have stopped.

Biochemical oxygen demand is not a parameter in the regulation for potable water, but one of the wells in the Güayanés River basin, surrounded by sugarcane cultivation and a sugarmill industry, exceded the BOD standard of 5.0 ml/l (5000.0 ug/l). In the first sample a measurement of 5.2 ml/l was obtained, and in the second sample it was of 7.5 ml/l. This being a well in a sugarcane field, it is possible for fertilizers and pesticides to percolate and reach the groundwater aquifer. Fertilizers, herbicides and insecticides, in addition to being a source of toxic compounds, can also contribute to the BOD of the receiving waters. Moreover, the BOD-5 of wastes from the sugarmill industry can be very high. Wastes from the beet sugar refining and from molasses distilling have a BOD-5 of 450-2000 mg/l and of 20,000-30,000 mg/l repectively. If wastes are not disposed of adequately they might reach the aquifer. However, monitoring of BOD-5 in waterbodies is not motivated by concern about public health impacts of discharges. It has never been demonstrated that there is any relationship between the dissolved oxygen content of water and the health of persons drinking or otherwise contacting it.

All wells had detectable concentrations of arsenic. The drinking water regulation for arsenic is 50.0 ug/l, which is the same numerical limit set for untreated surface waters. However, the new standard for arsenic in groundwater is of 0.022 ug/l. Comparisons made between this standard and the concentrations detected in well samples during the first and/or

second sampling, reveal that all wells have concentrations above the new standard limit.

For three of the samples, arsenic concentrations were circa 0.1 ug/l, which is 4.5 times the numerical limit set by the new standard. A revision of the method of analysis and the sensitivity of the instrument is therefore necessary for the detection of arsenic in groundwater samples.

Literature reports that inorganic arsenic compounds can produce toxic effects in a large number of organs. Acute and subacute effects appear in adults after ingestion of a few micrograms daily. Similar doses may result in severe intoxication and even death in infants. Chronic effects in many organ systems may also result from exposure to inorganic arsenic compounds. Among the noncarcinogenic effects are hyperkeratosis, portal hypertension, and disturbances of the peripheral vascular and nervous system. These effects have mostly been encountered following exposure to inorganic arsenic, either in drinking water or in drugs. Moreover, an increased frequency of skin cancer has been observed in people exposed to inorganic arsenic in drinking water and trivalent inorganic arsenic in drugs.

All forms of land use, including agriculture and livestock are associated with elevated levels of water contamination. Discharge from sewage plants is particularly onerous. Industry, as expected, is a major hazard, but residential land use, that is, urbanization with non-point sources of pollution, is also a major contributor. Given the crowding and multiplicity of land uses, the threats to water purity seem to be ubiquitous.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Waterbodies in spatial association with all six types of land use considered in this study presented detectable concentrations for the water quality parameters tested. Regardless of the intermittency at which the samples were collected, these substances were found at high enough concentrations to be detected during laboratory analysis. Hence, our broad postulated relationship that different land uses contribute to the pollutant loads of waterbodies from point and nonpoint sources can be accepted.

As a general caveat it should be pointed out that the interpretation of the laboratory results were like "snapshots" of the quality of the water sampled. It has been stated before that the method of sampling employed in this study serves to provide an indication of the quality of the waterbody sampled only at the time the sample is collected and thus a detectable concentration of a particular substance that is released intermittently may or may not be present at the time the sample is collected. This is particularly relevant for water samples taken from surface waterbodies where the movement of the flow of water is quicker than in groundwater.

Variation was observed among all maximum concentrations of parameters per land use, the only exceptions being those for total and fecal coliform. Regarding this parameter, we agree with the recommendations made by others on the need to develop a better method for the identification of the pollution of tropical waters with disease-causing microorganisms.

The coliform standard is not absolute and it does not entirely exclude the possibility of acquiring an intestinal bacterial infection and does not provide protection against viral diseases. It should be noted that while the World Health Organization has established international guidelines for coliform colony counts, these guidelines were stated only as general rules. Individual countries can develop their own national standards using their own risk/benefit criteria and taking into account their own particular circumstances.

Regarding the other water quality parameters, the maximum concentrations may be indicative of the type of substances to expect in association with the particular land uses. As noted, a maximum concentration detected does not necessarily imply that the water quality standard for that particular parameter was violated. However, it does indicate a potential to exceed the standard limit in the waterbody sampled.

Some of the persistent organics in existence today are objectionable because of known harmful effects on humans, fish, or wildlife. Others are considered objectionable because of adverse effects that are suspected but whose nature and extent are unclear now. This problem is different in character and dimensions from the concerns about oxygen demand and dissolved oxygen levels in waterbodies, which have represented the principal pollution control objective until now.

The relevance of the detection of semi-volatile organic compounds in the water samples, surface and underground, can be interpreted from differents points of view. With few exceptions, most of the concentrations of the detected compounds were below 1 part per billion, which can be

considered as a minor insult to the quality of the waters. On the other hand, a substantial portion of these substances are either classified as toxic substance and/or priority pollutants, and thus are subject to regulation. But no water quality standard regulation exists for them. If these waters were to be treated for potable supply, it is not certain that the contaminant substances could be removed. Furthermore, the potential health hazards are unknown, particularly when they occur in combination. In those circumstances not only additive, but the possible synergistic effects must be considered.

A concern for the presence of toxic compounds relies on the fact that various toxicants can invade the water cycle from sources such as manufacturing, agricultural, commercial and household activities. Neither water nor waste water treatment systems have traditionally been designed for the removal of toxic materials and monitoring of such materials has not been generally performed.

Toxic compounds that are not removed by the standard methods of treatment should be prevented from reaching water resources. Where such compounds do appear in waste waters, additional treatment (tertiary or advanced) must be designed for removal of the specific compounds in a particular effluent before its discharge to the water resource is permitted.

The nonmetallic element arsenic, was present in almost all samples from groundwater from sites surrounded by residential, agricultural and industrial land uses. The concentration of arsenic in these samples were above the new arsenic standard for groundwater (0.022 ug/l), but below the limit set by the drinking water regulation (50.0 ug/l). This standard was

set on recommendations by U.S.E.P.A. based on state-of-the-art information on the environmental effects of pollutants on ambient waters and the human health risk from the potential toxic effects through ingestion of contaminated waters or organisms. Health authorities must consider an evaluation of the health impacts that may have occurred or that have the potential to occur in those communities where the drinking water supplies are mainly from groundwater, and where concentrations of arsenic have been detected at above standard limits. As chlorination is the only purification treatment that groundwater receives prior to distribution for public consumption, a revision of the water quality standards for potable supplies must be in order as well as a survey of those wells used for potable water supply that do not comply with the new arsenic standard.

For an effective implementation of a water quality control program it is necessary to define clearly the goals or the requirements of a regulation. Without common standards and terminology among the regulatory agencies, water quality conditions cannot not be described in meaningful ways. Moreover, enforcement is hampered because it is difficult to prove violations of the laws and regulations. It is also difficult to identify water quality trends and evaluate progress in pollution control programs.

Most of the monitoring done to assess the effectiveness of water quality programs is usually directed to gross pollution parameters, such as turbidity, color, BOD, and suspended solids. Only in some circumstances are monitoring activities conducted for specific constituents, such as metals and organics. Generally these are done in connection with specific industrial discharges, or in water supplies where there are special grounds for concern. As more specific chemicals are defined in water

quality standards, there will be an increased need for developing monitoring methods for those substances.

It is worth noting that while no pesticide was detected in surface water samples, particularly from crop production activities, two of the wells sampled did have traces of such substances. The capacity of a surface waterbody to cleanse itself of contaminants contrasts here with the accumulation potential of toxic substances in groundwater. This is particularly important since mercury, and notably arsenic, were detected at concentrations above standard limits according to either the groundwater or drinking water regulations.

Drainage projects, groundwater pollution, and pumpage from wells may reduce the potential long-term availability of groundwater. Although none of the aquifers in the island are areally extensive, their operation and patterns of flow are generally not simple. For most of the aquifer systems, the physical properties and recharge rates, withdrawal rates, and boundary conditions are insufficiently known. Water movement through limestone may be extremely fast, so that groundwater can be similar to surface water in relation to contaminants. Rates of contaminant movement are based on groundwater flow rates, chemical interactions with aquifer materials, and changes in water chemistry. Thus, it is necessary to know the local hydrogeology in order to define paths of probable contaminant movement. Under the right conditions and given enough time, contaminating fluids that have reached an aquifer can move great distances, hidden from view and little changed in toxicity.

Since we live in an environment with multiple exposure to pollutant sources there is a vast number of pollutants and several routes of exposure. Water is only one route by which persons may be exposed to toxic chemicals. Personal habits, such as dietary preferences, alcohol consumption, tobacco smoking, and drug use further complicate efforts to predict pollution hazards and quantify human risk.

There have been few valid epidemiological surveys of populations relative to multiple chemical exposure. One of the most critical problems is defining exposure of the individual. Clinical nonspecificity makes it difficult to distinguish an effect or disease of one etiology from the same effect or disease caused by another. The problem of latency further complicates the situation because most of the health effects of concern appear only after chronic exposure, and clinical signs and symptoms may appear years after the exposure has ceased to exist.

When these compounds appear in the environment in diverse combinations, in a variety of media, and often in quantities so small that are difficult to analyze, it can be overwhelming to try to establish their toxic potential. The effect of a pollutant mixture cannot be reliably predicted by summing the toxicity of its individual components, even when these are known. For example, there is evidence that the apparent reductions in the toxicity of a metal in increasingly hard water may not be so great when other metals are concurrently present (Cornaby, 1981). Thus, any leniency that would be granted in water quality objectives for single heavy metals in hard waters may not be applicable if other heavy metals are present at the same time.

It is difficult to design a study which could establish a cause and effect relationship between a pollutant and clinical manifestations because of the various possible causes that can be implicated and the variations in the degree of exposure or dose. But the presence or lack of association between contaminants and clinical conditions can be explored. The lack of evidence to support or negate a causal relationship should not be taken as a reason to ignore the presence of a contaminant in the environment until further evidence is documented.

By epidemiologic standards, the exposure levels of most populations cannot be estimated and probably are relatively small. In addition, exposure scenarios vary from site to site. A complete understanding of disease causation should consider not only the question of what causes the disease in an individual, but also what causes differences between units at different geographical scales.

The growing recognition of the role of multiple exposures on overall human health calls for study of the interactive (additive, synergistic, and antagonistic) effects caused by multiple exposures to pollutant agents and physical factors in the environment. It has been said that in evaluating health hazards, contributions must be considered in the context of the total exposure received by an individual from all sources. In setting maximum allowable concentrations of chemicals in drinking water, for example, dosages normally received through other routes must be considered, and the amounts that might otherwise be permitted in the water must be reduced (Draggan et al, 1987).

The dynamics of pollutants in the environment are not well understood. For instance, effluent limits are a mechanism for placing specific numerical limits on multiple sources of wastes entering a water body. In the case of surface water contamination control, effluent limits are placed on point-source discharges, but for ground water contamination control, effluent limits should apply to a much broader range of activities, such as limits on types of materials disposed of in sanitary landfills, limits on specific contaminants injected into an aquifer by mean of a disposal well and pollutant discharge limitations for surface impoundments.

Environmental regulators cannot delay regulating a suspected harmful exposure until scientific consensus exists. In instances like this, decision-making under conditions of uncertainty is necessary. Research on the effectiveness of various preventive strategies is necessary. Detection of new causes of environmental disease is not an end in itself; prevention is the ultimate goal of environmental health research.

APPENDIX A

Description of Water Quality Analyses

DESCRIPTION OF WATER QUALITY ANALYSES

Total and Fecal Coliforms (MPN)

The standard procedure for this method is that culture from positive tubes of the lauryl tryptose broth is inoculated into Escherichia coli (EC) broth and incubated at 44.5 C for 24 hours. Formation of gas in any quantity in the inverted vial is a positive reaction confirming fecal coliforms. Coliform densities are then calculated from the MPN table on the basis of the positive EC tubes (EPA, Microbiological Manual, 1978).

These tables can be used for a number of sample volumes and replicates of samples volumes. The numbers of coliform group bacteria in a water sample can be thus determined based upon the observed combination of positive and negative fermentation tube results. The 95 per cent confidence limit is provided for each estimate value in the MPN tables.

BOD-5

The oxygen uptake at 5 days of incubation at a test temperature of 20 Celcius degrees is the standard BOD. The test measures the quantity of oxygen utilized by chemical or biological reactions over a 5 day period. Thus, the degree of organic pollution can be determined. If the BOD reaches the point where aerobic microorganisms (those requiring molecular oxygen for metabolic processes) cannot survive, anaerobic forms (those that grow in the absence of molecular oxygen) become predominant, producing materials that decrease water quality (Guthrie and Perry, 1980).

Heavy Metals (atomic absorption)

A sample is aspirated into a flame and atomized and a light beam is directed through the flame, into a monochromator, and on to a detector that measures the amount of light absorbed by the atomized element in the flame. The amount of energy of the characteristic wavelenght absorbed in the flame is proportional to the concentration of the element in the sample. Special procedures are necessary in order to prepare the metal in a form and concentration suitable for atomization (Standard Methods, 1985).

Total Kjeldahl Nitrogen

In the presence of H_2SO_4, potassium sulfate (K_2SO_4), and mercuric sulfate ($HgSO_4$) catalyst, amino nitrogen of many organic materials is converted to ammonium sulfate [$(NH_4)_2SO_4$)]. Free ammonia and ammonium-nitrogen also are converted to $(NH_4)_2SO_4$. During sample digestion, a mercury ammonium complex is formed and then decomposed by sodium thiosulfate ($Na_2S_2O_3$). After decomposition the ammonia is distilled from an alkaline medium and absorbed in boric or sulfuric acid. The ammonia is determinedd colorimetrically or by titration with a standard mineral acid.

Semi-Volatile Organic Compounds

The analyses of the pollutant depends upon its physical removal from the sample medium. This process is called extraction and involves bringing a suitable solvent into contact with the sample, this can be accomplished by shaking the water sample and solvent in a separatory funnel and then allowing it to separate into two layers, water and solvent.

The extracted pollutant must be concentrated to a small volume (approximately 5-10mL). This was accomplished by removal of the solvent by evaporation under vacuum. This was further concentrated to 1 mL by evaporation under a stream of nitrogen.

Once the pollutant was extracted and separated from the sample water, the actual identification procedure began. Recent advances have allowed sensitive measuraments at the parts per billion and parts per trillion levels for many pollutants. Many toxic materials present in minute quantities could not be detected until technological advances reached the present state of the art. At present most environmental pollutants are identified and quantified by gas chromatography/mass spectrometry (GC/MS). After the organics in a sample have been isolated and concentrated, they are separated on a gas chromatograph, and detected and quantified with the mass spectrometer.

Chromatography. All chromatographic processes utilize an inmobile and a mobile phase to effect a separation of components. The mobile phase can be a liquid or gas, whereas the immobile phase can be a liquid or solid.

The essential components of a gas chromatograph (GC) consist of an injector port, oven, detector amplifier. Contained within the oven is a column filled or coated with the immobile phase. The mobile phase is an inert gas (called a carrier gas) such as helium, which passes through the column.

When a sample is introduced into a heated chamber through a silicone rubber septum with hypodermic syringe the temperature is enough to vaporize the sample components. The components separate and are

swept through the column by the carrier gas to the detector which sends a signal to a recorder. The gas chromatograph is an excellent separator, but it is not a good analytical tool. Identification of the compound could not be based only on retention time because it depends on many other factors in addition to the nature of the compound.

Spectroscopy. Is a method concerned with the changes in atoms and molecules when electromagnetic radiation is adsorbed or emitted. Instruments have been designed to detect these changes. In pollution analysis mass spectroscopy (MS) is used widely for the identification of compounds. MS is a highly sensitive detector for a GC since it can be interfaced to the MS.

The GC is used to separate individual components as previously described. The column effluent them to the MS, where it is bombarded by an electron beam. Electrons are removed by this process, and the ions produced are accelerated. After acceleration, they pass through a magnetic field, where the ion species are separated by the different curvatures of their paths under gravity. Normally, only positive ions are detected. The resulting pattern is characteristic of the molecule under study. By interfacing the detector with a computer system, data analysis and quantitation are performed automatically.

Qualitative identification of the parameters in the sample extract is performed using the retention time and the relative abundance of three characteristic masses. The compounds were identified by consulting the Registry of Mass Spectral Data by Stenhagen, Abrahamsson and McLafferty, and the NBS-Wiley Library of Mass Spectra.

Quantitative analysis were performed by using anthracene and tetradecane as standards in calibration curves. Each of these two compounds represents a family of chemical compounds. The more accurate quantitation method is that one in which a calibration curve is developed using a standard identical to the compound being measured. This is virtually impossible in a study such as this one in which there is no previous knowledge of the compounds being detected, and where the number of compounds to be quantized would imply the creation of numerous calibration curves. Instead calibration curves are created with standards that represent families of chemical compounds and an assumption is made that the compound being measured behaved similar to the standard selected during the GC/MS analysis.

APPENDIX B

Detected Semi-Volatile Organic Compounds By Hydrological Basin

Cibuco River Basin - First Sampling

Sampling Site	Compound	Concentration (PPB)
1. Morovis River		
2. Hicatea Creek		
3. Ciénaga Prieta Channel		
4. Cibuco River		
5. Corozal River		
6. De los Negros River		
7. Mavilla River	Not identified	1.3
8. Pugnado #2 Well		
9. Vega Baja #3 Well	Sulfur (octathione) S8 CAS 10544-50-0	0.6
10. Sabana Hoyos 1 Well		
11. Vega Alta 1 Well		
12. Spring	Hydrocarbon	0.2

Cibuco River Basin - Second Sampling

Sampling Station	Compound	Concentration (PPB)
1. Morovis River	Hydrocarbons	0.5
2. Hicatea Creek		
3. Ciénaga Prieta Channel		
4. Cibuco River		
5. Corozal River		
6. De los Negros River		
7. Mavilla River	Not identified	0.2
8. Pugnado #2 Well	Hydrocarbons	0.2
9. Vega Baja #3 Well		
10. Sabana Hoyos 1 Well		
11. Vega Alta 1 Well		
12. Spring		

Cibuco River Basin - Third Sampling

Sampling Site	Compound	Concentration (PPB)
1. Morovis River		
2. Hicatea Creek	Not identified	0.2
	Phthalate	0.1
3. Ciénaga Prieta Channel	Not identified	0.1
4. Cibuco River	Hydrocarbons	0.2
5. Corozal River		
6. De los Negros River	Not identified	0.2
7. Mavilla River		
8. Pugnado #2 Well	Phthalate	0.1
9. Vega Baja #3 Well	2-Mercaptobenzothiazole C7H5NS2 CAS 149-30-4	1.0
	Hydrocarbons	3.4
10. Sabana Hoyos 1 well	Hydrocarbon	0.1
11. Vega Alta 1 Well	Benzyl butyl phthalate C19H20O4 CAS 85-68-7	0.2
	Hydrocarbon	0.2
12. Spring	Benzyl butyl phthalate C19H20O4 CAS 85-68-7	0.2

Guayanés River Basin - First Sampling

Sampling Station	Compound	Concentration (PPB)
1. Limones River	Hydrocarbon	0.5
2. Río Guayanés		
3. Aguas Largas Creek	Not identified	0.1
4. Guayanés River	Not identified	0.2
5. Caño Santiago Trib.	Sulfur (octathiocane) S8 CAS 10544-50-0	5.3
	Hydrocarbon	0.4
	Not identified	2.0
	Diethyl phthalate C12H14O4 CAS 84-66-2	0.4
6. Caño Santiago	Diethyl phthalate C12H14O4 CAS 84-66-2	0.2
	2,6-diteilbutyl-p-methyl phenol	0.1
	Terpenoid compound	0.1
7. Del Ingenio River Tributary		
8. Aguacate Creek	Hydrocarbons	1.0
9. Caño Santiago	Diethyl phthalate C12H14O4 CAS 84-66-2	0.1
	Not identified	0.1
10. Guayanés River	Hydrocarbons	2.5
	Not identified	0.1
11. La Grúa Well	Hydrocarbons	0.5
	Not identified	0.2
	Phthalate	0.2
12. Roig Nuevo Well	Di-n-butyl-phthalate C16H22O4 CAS 84-74-2	4.4
	Not identified	0.2

Guayanés River Basin - Second Sampling

Sampling Station	Compound		Concentration (PPB)
1. Limones River			
2. Guayanés River	Phthalate		0.2
3. Aguas Largas Creek	Caprolactam C6H11NO CAS 00105-60-2	Hexanoic acid,6-amino C6H13NO 2 CAS 60-32-2	0.8
4. Guayanés River	Hexanediodic acid, mono(2-ethylhexyl)ester C14H26O4 CAS 04337-65-9		2.4
	Dodecanamide, N, N-bis (2-hydroxyethyl) C16H33NO3 CAS 00120-40-1	Glycine, N-methyl-N-(1-oxododecyl) C15H29NO3 97-78-9	0.2
	Lauric acid (N-dodecanoic acid) C12H24O2		1.7
5. Caño Santiago Trib.			
6. Caño Santiago	Sulfur (octathione) S8 CAS 10544-50-0		0.1
7. Del Ingenio River tributary			
8. Aguacate Creek			
9. Caño Santiago			
10. Guayanés River			
11. La Grúa Well			
12. Roig Nuevo Well			

Guayanés River Basin - Third Sampling

Sampling Station	Compound	Concentration (PPB)
1. Limones River		
2. Guayanés River		
3. Aguas Largas Creek	Hydrocarbons	0.8
4. Guayanés River	Not identified	0.1
5. Caño Santiago Trib.	Sulfur S8 CAS 10544-50-0	3.7
	Anthracene C14H10 CAS 120-12-7	0.3
	Phthalate	0.5
	Fluoranthene C16H10 CAS 206-44-0	0.2
	9,10-Diphenylphenanthrene	0.1
	Not identified	0.3
	Hydrocarbon	0.5
6. Caño Santiago	Palmitic acid (Hexadecanoic acid)	0.3
	[4-Acetoxy-6-Methyl-2-Pyridone C8H9O3 CAS 05-749-2]	0.3
	Not identified	0.1
	Diethyl phthalate C12H14O4 CAS 84-66-2	0.1
	Sulfur (octathiocane) S8 CAS 10544-50-0	0.4
	Hydrocarbons	0.5
7. Del Ingenio River tributary		
8. Aguacate Creek		
9. Caño Santiago	Phthalate	0.1
10. Guayanés River		
11. La Grúa Well	Benzyl butyl phthalate C19H20O4 CAS 85-68-7	0.2
12. Roig Nuevo Well	Benzyl butyl phthalate C19H20O4 CAS 85-68-7	0.3

Yagüez River Basin - First Sampling

Sampling Station	Compound	Concentration (PPB)
1. Marini Well		
2. Caño Boquilla	Phthalate	0.4
3. Yagüez River		
4. Sábalos Creek		
5. Grande Creek	Hexanediodic acid, mono (2-ethylhexyl)ester C14H26O4 CAS 0437-65-9	0.1
6. Yagüez River		
7. Majagual Creek	Hydrazine,1,1-diphenyl-2-(2,4,6-trinitrophenyl) C18H13N5O6 CAS 01707-75-1	9.1
	Dodecanamide, N (2-hydroxyethyl) C14H29NO2 CAS 00120-40-1 / Decanamide, N-(2-hydroxyethyl) C12H25NO2 CAS 7726-08-1	7.3
	1-Aminonaphthalene C16 H13 N CAS 00090-30-2	6.3
	Pyridine,4-(phenylmethyl) C12H11N CAS 2116-65-6	0.1
	Hydrocarbon (octadeceno)	3.0
	Hydrocarbon (hexadeceno)	7.3
	Not identified	0.2
	Not identified	1.1
	Phthalates [Bis-(2-ethylhexyl) phthalate]	5.3
8. Cañas River		
9. Cañas River	Pyridine, 4-(phenyl methyl) C12H11N CAS 2116-65-6 / Benzenamine, N-phenyl C12H11N CAS 122-39-4	0.2

Yagüez River Basin - Second Sampling

Sampling Station	Compound	Concentration (PPB)
1. Marini Well		
2. Boquilla Creek		
3. Yagüez River		
4. Sábalos Creek		
5. Grande Creek		
6. Yagüez River		
7. Majagual Creek	Hydrocarbons	1.0
8. Cañas River		
9. Cañas River		

Yagüez River Basin - Third Sampling

Sampling Station	Compound	Concentration (PPB)
1. Marini Well		
2. Boquilla Creek		
3. Yagüez River		
4. Sábalos Creek	Hydrocarbon	1.1
5. Grande Creek		
6. Yagüez River		
7. Majagual Creek		
8. Cañas River		
9. Cañas River		

Am

An

Ca

Ca

Ch

Cl

Cl

C

C

C

C

C

D

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