ASSESSING ENVIRONMENTAL IMPACTS IN THE GULF OF PARIA, TRINIDAD :AN EXAMINATION OF TECHNOLOGICAL APPLICATIONS AND DATA AVAILABILITY

by

Danya L. Lougheide

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree of

Master of Arts

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ABSTRACT

This study focused on issues and problems of assessing the environmental impact of the Pt. Lisas Industrial Estate on the Greater Couva area in Trinidad. The study had three focal points. First, it documented the chronological changes in land-use/ land-cover and coastal vegetation patterns over a period of 25 years from 1962 to 1986; second, it analyzed the impacts of industrialization on this coastal environment; third, it evaluated the issues affecting environmental assessments in Trinidad.

These focal points were developed in a number of ways. Aerial photography and ground truthing contributed to the development of a land-use/ land-cover classification based on the Anderson Classification (Anderson, 1976). This classification accommodated all land-cover classes represented in the Greater Couva region, and made it possible to create (land-use/land-cover) audit maps. These maps were then introduced into a computer based Geographic Information System (GIS) to perform various Overlay and Time Series Analysis techniques. Changes were observed for the region in the interim years from 1962 -1980, and 1980 - 1986, with major changes in the following land-use categories: residential; industrial; agricultural; mangrove; reclaimed land; and transport networks. These changes were then analyzed to ascertain their relationship to the Pt. Lisas Industrial Estate, while also taking into account impacts resulting from physical changes, such as population increase, pollution, fisheries, and the effects of dredging and reclamation.

In establishing the potential for aerial photography, photogrammetry and GIS, in examining environmental impact assessment, this research also highlighted the problems of sparse and limited data.

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I would like to express my deepest appreciation to my advisors Dr. Mary Benbow (and her cricket bat), Dr. Salah Hathout, and Dr. W. Koolage, for their continued support and guidance throughout the preparation and completion of this work. I would also like to thank Dr. J. Kuz of the Department of Geography, University of Winnipeg for his belief in my abilities. In addition I wish to thank Marjorie Halmarson for her help with map presentation.

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LIST OF ABBREVIATIONS

CSO. . . . . Central Statistical Office, Government of Trinidad and Tobago
EPA. . . . . Environmental Protection Agency
FEDCHEM . . . . Federation Chemicals
FERTRIN . . . . Fertilizers of Trinidad and Tobago
IGL . . . . Industrial Gases Limited
IMA . . . . Institute of Marine Affairs
ISCOTT . . . . Iron and Steel Company of Trinidad and Tobago
PLIPDECO . . . . Point Lisas Industrial Port Development Corporation
T&TEC . . . . Trinidad and Tobago Electricity Commission
TRINGEN . . . . Trinidad Nitrogen
USEPA . . . . United States Environmental Protection Agency

CHAPTER 1

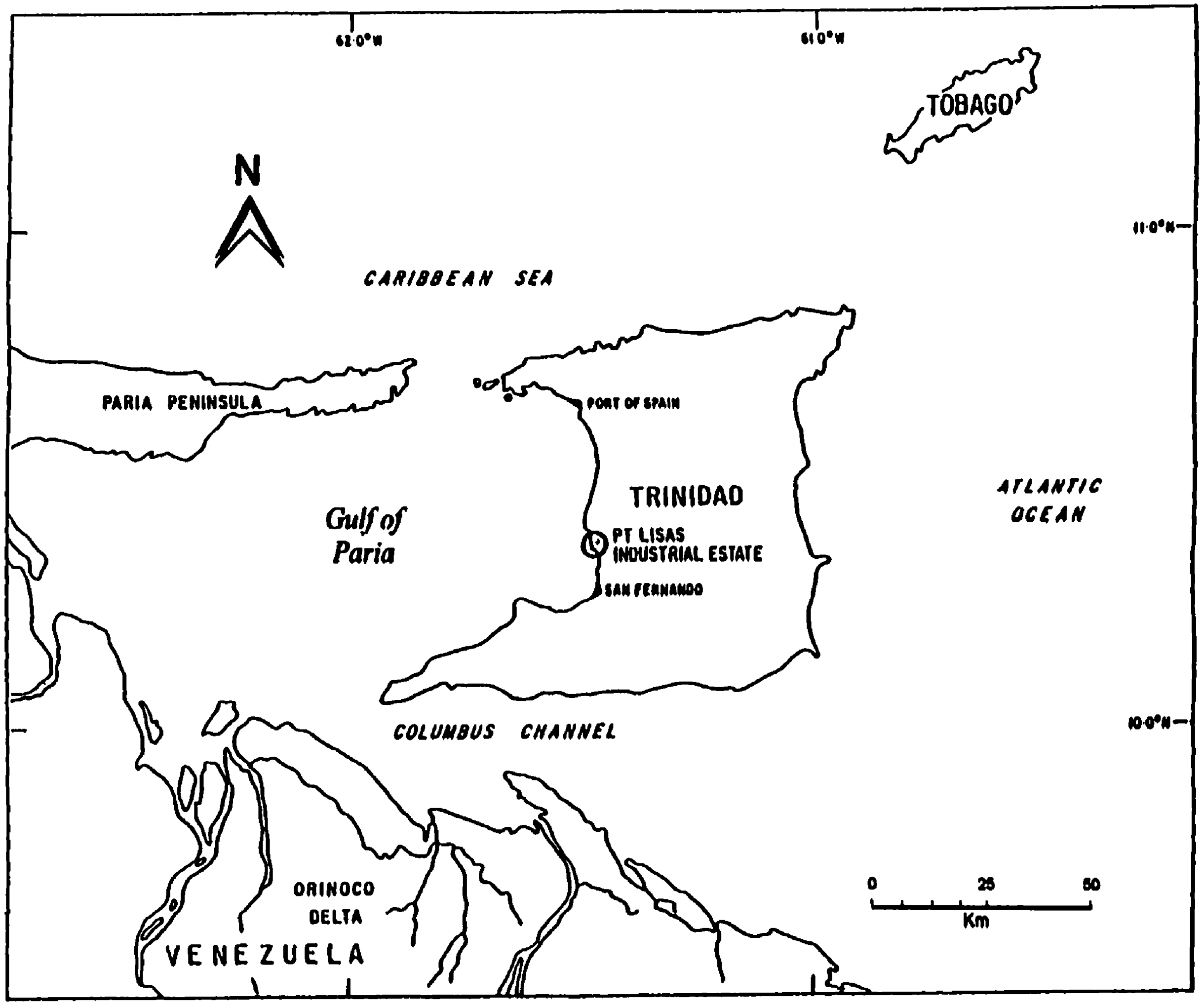
INTRODUCTION

1.0 Introduction

In the drive toward economic development, rapid urbanization and industrialization have left many developing regions with a legacy of conflict between environmental degradation and economic growth. The consequence of this legacy are growing environmental problems in many developing regions including the Caribbean. Awareness and practice of sustainable development in resource use is no longer an option, but a necessary course of action. Thus, continued economic development in developing countries must encompass evaluation and amelioration of environmental impacts.

Industrialization and urbanization generally produce adverse environmental impacts. However, in light of the perceived economic gains, these impacts do not generally receive sufficient attention from planners and administrators. For example, in the Caribbean country of Trinidad, an attempt to diversify and strengthen the economy gave rise to the development of the Point Lisas Industrial Estate in the coastal strip near the Gulf of Paria (Figure 1.1). Prior to the implementation of this project some attention was focussed on its impacts on the surrounding environment, yet little attempt was made to provide alternate siting for the project or reduce its impacts. After construction commenced and prior to the completion of the Pt. Lisas project, a few studies were performed which examined its impact on the environment; however, after the completion of the project, no comprehensive environmental studies were undertaken.

Figure 1.1: Locational Setting of Trinidad and Tobago and Pt. Lisas Industrial Estate



Source: Derived from "The Status of Coastal Management in Trinidad and Tobago", H. McShine-Muthunhu, Institute of Marine Affairs, no date, Fig. 1, p. 11.

Some specific studies examined beach pollution (Agard et al., 1988); and hazard assessment (Bertrand, 1987) in the region. However these studies did not encompass the vital issues of sustainability, fish populations, land-use or data sparsity. Therefore, this thesis is broad ranging in its approach in order to provide a comprehensive post mortem of the environmental impacts of the Pt. Lisas Industrial estate.

1.1 Statement of Problem

In the early 1970s the Government of Trinidad and Tobago committed itself to the development of an industrial estate in the vicinity of the settlement of Couva, in western Trinidad (Figure 1.1). The purpose of the proposed development was to establish a manufacturing sector which would attract metropolitan businesses. These businesses would bring not only capital, but also technology, organization, and market connections to the region. In addition it was hoped that these industries would utilize local raw materials in the manufacturing process (Carrington, 1966: 37). Construction and commissioning of the major industries at the industrial estate was completed by 1984.

The west coast of Trinidad is a highly stressed environment, since it is the home to 88% of the country's population, and economic activities generated in this region account for 93% of the country's labour force (McShine-Muthunhu, 1985: 1). In addition, situated along this coast are the country's capital, Port of Spain and its second largest city, San Fernando. Therefore in an already stressed environment, the impact of an additional large-scale human activity such as industrialization may be viewed as potentially detrimental.

The Pt. Lisas Estate lies adjacent to the Gulf of Paria, the most active fishing ground surrounding the island of Trinidad. The Greater Couva Area which encircles the industrial estate, is occupied by intensive agricultural activities. Prior to the establishment of the Estate, fishing and agriculture were the main economic activities of this rural area, with both contributing significantly to the nation's economy. Therefore to maintain these activities, it is vital that the impacts of the Pt. Lisas industrial estate on the Couva region be monitored.

Any human interaction with the environment, particularly one concerned with resource development and exploitation, will result in some impacts to the environment. In Trinidad, some concern was expressed with respect to these adverse environmental effects both prior to, and after the completion of the Pt. Lisas Industrial Estate. For example prior to the completion of the Estate, Lewsey (1981: 9) stated that "The siting of a heavy industrial complex on the west coast at Pt. Lisas is destined to have far reaching environmental impacts on an already stressed coastal zone environment. The terrestrial and marine ecosystems of this area exhibit a close geographic proximity and interrelatedness, such that an impact in one system will rapidly be transmitted to another." After the completion of the Estate, McShine-Mutunhu (1985) conducted an impact assessment of the Couva River diversion which occurred as a consequence of the industrialization in the region. This work also considered other land-use practices in the region. After an examination of the land-use practices in the region, McShine-Mutunhu concluded that industrial land-use created the most adverse environmental impacts. Similar sentiments were expressed by Archer (1992) who found that industrial, and to a lesser degree, domestic wastes were responsible for the severe reduction in fisheries and increased pollution of beaches along the west coast. More recently, Farabi, (1991) produced a comprehensive document which discussed the potential hazards posed by the Pt. Lisas industries on the surrounding environment. The research focused on the impacts of three major hazards; fire, explosion, and toxic release. Although the research reviewed 'potential' risks, he concluded that Pt. Lisas is a high risk hazard site due to the nature of the chemical industries situated there. However these studies did not address issues of sustainability, data sparsity or spatial and/or temporal variations. In order to address these issues a broad environmental approach employing a range of geographic techniques is required.

1.2 Hypothesis

The central hypothesis of this study states that: the construction and operation of the Pt. Lisas Industrial Estate have resulted in a number of negative impacts on the immediate and surrounding environment and these pose threats to the sustainability of the environment. In order to examine this broad hypothesis a number of methodologies will be employed, encompassed by the procedure Environmental Impact Assessment (EIA).

1.3 Environmental Impact Assessment

Environmental Impact Assessments (EIAs) are tools which aid in our understanding of the interaction between natural and human-made processes. They view environmental changes in the context of cause and effect and examine the magnitude and geographical extent of the change; the time scale and spatial scale of the change; and the environmental significance of the change.

Therefore, EIA may be defined as a procedure which estimates "the probable impact of the proposed action on the environment" (United States Environmental Policy Act 1969). According to Doornkamp (1985: 88-90) EIA is designed to " identify, predict, interpret and communicate information about the impact of an action on the health and well-being of both man and the ecosystem or terrain on which his well-being depends." This suggests either pre-development predictions or post-development assessment of impacts resulting from proposed or instituted activities. The main goal of these assessments is to improve decision making by increasing the awareness of the decision makers to the consequences of the decision. As a result, EIA allows for informed decisions which minimise the adverse effects of human-made activities on the environment. An EIA is thus a multi-disciplinary process which takes into consideration factors which may be considered part of an 'holistic environment' e.g. economic, social, and ecological facets.

1.3.1 EIA in Developing Countries

EIA has played an important role in environmental planning in the developed world for many years. Doornkamp (1985: 88) states, "it has found a firm place not only in the policy of the World Bank but also in other development agencies such as the US Agency for International Development (AID)." Chatzimikes (1982) describes EIA as the key to the United States National Environment Policy Act. Yet EIA though known to developing countries for many years, has been hindered by several recurring issues (Doornkamp 1985). Two of the most important issues are lack of information and lack of monitoring.

This is exemplified in a number of studies in developing countries. For example, on the basis of an environmental risk assessment study in India, Bowonder (1983) suggested that governmental decision-making procedures neglect potential risks when information was unavailable. He also stated that "administrations in Third World countries rarely have any previous experience regarding these (multidimensional) kinds of multi-sectoral risks, and this causes them to discount the outcomes even more heavily" (Bowonder, 1983: 80). Bowonder also found that continuous monitoring of the environment did not often occur, and in the few cases where it had, co-ordination between monitoring agencies and governmental ministries was minimal. This resulted in either unsound policy development or no policy development at all.

Gamman and McCreary (1988) examined EIAs in the context of Caribbean economic development. They saw the use of EIA as a means of alleviating conflicts between economic development and the region's fragile natural resources. Gamman and McCreary noted that EIA is by no means new to the Caribbean. Yet there is a need to implement policies which will make EIAs mandatory and make them an integral part of the decision-making process, since in most cases of environmental damage, there were no clear explanations as to how the formulation of past decisions contributed to environmental degradation. Moreover, most existing literature published with respect to the Caribbean provides little practical guidance on how to integrate economic development and EIA (Gamman and McCreary, 1988: 44).

The solution to these problems is two-fold. First, the procedure for EIA must be tailored to suit local needs and conditions. Second, countries in the Caribbean region as in other developing regions of the world must set up formal mechanisms to ascertain site-specific and cumulative effects of development projects. EIA should not be viewed as an obstacle to economic growth but rather as a means of mitigating costly 'remedial actions'. The problems facing many developing countries including Trinidad and Tobago are the lack of information and monitoring for ascertaining the aforementioned effects of development projects; such obstacles hinder the process of a formalized EIA.

1.3.2 EIA versus EIA Studies

The literature on EIA makes a clear distinction between *'EIA'* and *'EIA studies'* (Sankoh, 1996; Ofori-Cudjoe, 1990; and Lichfield et al., 1975). *EIAs* include the preparation of an Environmental Impact Statement which eventually becomes a legal policy making document, having been formulated for the purpose of assessing the impacts of a *proposed* action or project on the environment. It must abide by the environmental regulations of the country and/or state which prepares it, it must include public participation and feed back, and it must provide alternate suggestions and course of actions to alleviate the proposed environmental impacts.

An *EIA study* is simply a study used to assess the impacts of a project *after* its commencement. It utilizes various tools, some of which are standard to a formalized *EIA*, along with modeling of future environmental trends. A key difference between an *EIA* and an *EIA Study* is that whereas it is mandatory in *EIAs* to conduct comprehensive labour and information intensive investigations, *EIA studies* can make use of existing data on the project or ancillary information where data is lacking.

1.4 Information and Monitoring in Developing Countries

Significant disparities exist between developed countries and developing countries regarding information acquisition and dissemination. Information is to a large extent imported by developing countries from the developed countries of the world. This imported information must often be adapted to meet the specific needs of indigenous problems. However, such adaptations are not always feasible, since the economic and social conditions of developing countries require information bases different from those of the highly industrialized nations. This is where the implementation of an EIA study versus an EIA becomes significant. Apart from the inappropriateness of some types of imported information, transplantation of methodologies based on the use of this information can yield unreliable results. At present, the most important data requirements of developing countries include the need for:

1. Information regarding the identification of natural resources;
2. The specific need for informed analysis in the utilization of these resources; and
3. Utilization of these resources to ensure sustainable development (Sabourine, 1982).

In order to develop an information industry, developing countries must first embark upon an educational program where indigenous personnel receive training in information gathering, interpretation and analysis. The second step involves developing an 'overall knowledge industry 'architecture' (Sabourine, 1982: 67). This involves: "the upgrading of the internal information environment (improvement of local statistics, establishment of a national data base, improvement of telecommunications infrastructure, tapping the reservoir of accumulated knowledge embodied in indigenous technologies)" (Sabourine, 1982: 67). Choices regarding the imbalance between labour-intensive and advanced information technologies, and the extent of referral to outside advice would be incorporated into this architecture.

The move toward an information industry must be accompanied by positive social, economic and political conditions. These include a stable political climate, a decentralized power structure (i.e. no centralized power base where local elite wield undue influence), a balance in education and communication between rural and urban masses in order to facilitate the flow of and optimum utilization of information, and the maximum use of scarce resources. The phrase 'knowledge is power' embodies the significance of information to development.

1.4.1 Response to the lack of data

The Caribbean region has and continues to experience specific obstacles to the implementation of EIA. These obstacles include lack of proper legislation, inadequate funding, a shortage of individuals with planning experience, and a shortage of information. With specific reference to Trinidad and Tobago the major problem is considered to be the lack of current high quality data (Opadeyi, 1994: 380). Thus, rather than adopting formalized EIA, developing nations, have adopted EIA studies. Yet a critical part of any EIA study is environmental auditing and change analysis. The complex nature of environmental data and its interrelationships poses a challenge to this goal. Where data is limited, it becomes imperative that it be used effectively. Geographic Information Systems (GIS) has increasingly been recognised as a cost-effective tool for providing and manipulating spatial information for multi-objective decision making.

1.5 Geographic Information Systems

Tomlin, (1990: xi) defines a GIS as "a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth" In lay-persons terms, GIS is a arrangement of computer hardware and software, designed for the specific purpose of acquiring, maintaining, and manipulating cartographic data. Turk (1988) and Dangermond (1988) suggested that a GIS incorporates five basic elements: software; hardware; data (information); procedures (models); and people. A GIS can, therefore, be considered a computer based technology which stores, manages and displays data by geographic location for the specific purpose of assisting in decision making. The use of GIS in conjunction with Remote Sensing (RS) affords many options for acquiring and manipulating geo-referenced information and data which would otherwise be unattainable. Opadeyi, (1994: 383) recommended that RS be applied in Trinidad as a "cheap and fast data acquisition technology for GIS applications."

An EIA study views environmental change from three perspectives, spatial change, temporal change, and the magnitude of that change. These three attributes are also central to GIS; space and time are the two most significant concepts of any 'geo-referenced' data and change requires recognition of some trend or adjustment in the variable being monitored. In this study, GIS was used to investigate the magnitude of spatial and temporal changes in the Greater Couva region. Change must exhibit spatial and temporal 'coherence' in order to be judged as 'real' change rather than random variation (Eastman and McKendry, 1991). Since GIS provides a more than adequate means of acquiring and manipulating a wide range of environmental data from many sources, its use in this study was appropriate.

1.5.1 Analysis and Decision Making using Geographic Information Systems (GIS)

GIS may form a part of a Spatial Decision Support System (SDSS). Turk (1990: 35) defined such a system as: "....research undertaken in the general field of decision-making, especially as regards interactive computer based support for under-determined decisions." To improve the decision making process increases in the quality and quantity of information are necessary. However, management processing and presentation of this information is paramount to successful decision making. Thus, it is apparent that the decision making process can be aided through the use of GIS methodologies, since these methodologies have the capacity to aid in the construction of multi-criteria suitability maps (modeling), resource allocation, and multi-objective decision making. The transition from 'raw information' gathered by a GIS to its ultimate use in an informed decision making capacity, is the process that transforms information into knowledge. This transformation process makes GIS imperative for developing countries.

GIS also provides an excellent tool for acquiring quantitative information for interpretation in an EIA study. Used together they create a spatial decision making support system that enables planners and politicians to make informed decision about their environment. Although this research does not apply SDSS, the benefits of the technique are innumerable once a comprehensive GIS is established.

1.6 Objectives of Study

In light of the preceding discussion, the primary objective of this study is an investigation of technologies and data availability for assessing environmental impacts in the vicinity of the Pt. Lisas Industrial Estate, between the years 1962 and 1986 with the view to:

1. Producing an audit of environmental change;
2. Assessing that change in terms of environmental impacts; and
3. Evaluating Geographic Information Systems as a means of utilizing data to assess environmental impacts.

These goals are to be realized by:

1.Producing an audit of environmental change

a) acquiring aerial photography from 1962, 1980 and 1986;
b) creating mosaics from which mapping of the region is possible;
c) creating maps which show progressive change from the base year (1962) to the final year (1986) in terms of land-use/land cover; and
d) measuring change in the environment using GIS.

2. Assessing change in terms of environmental impacts

a) analysis of change
b) linking changes to indices used to measure environmental degradation
c) determining whether changes brought about by estate are directly responsible for certain short and long term environmental impacts in the Greater Couva Region.

It is hoped that the results of this investigation will be useful in producing a framework for the establishment of formalized EIA, while indicating the necessity of formalized EIA in Trinidad and Tobago, and highlighting the need for improved environmental data acquisition. The methods discussed here may also help decision-making authorities incorporate more balanced policies into land-management practices in Trinidad and Tobago, and the wider Caribbean region.

1.7 Organization of study

This study is organized into six chapters. Chapter One, the present chapter, provides an introduction. Chapter Two, provides a general description of Trinidad and Tobago, and a more detailed description of the Couva/Pt. Lisas region, while tracing the development of the Pt. Lisas Industrial Estate from inception to operation. Chapter Three reviews the literature dealing with the two most important aspects associated with coastal industrial projects, i.e., coastal mapping and monitoring, and coastal environmental concerns, and justifies the methodologies applied in the following chapter. The fourth chapter focuses on methodological factors involved in data acquisition and analysis, and describes techniques for determining change and methods of impact assessment. It also lists data sources. The results of this research are presented in Chapter Five and a discussion, conclusion and recommendations are offered in Chapter Six.

CHAPTER 2

TRINIDAD: A REGIONAL REVIEW

2.0 Introduction

A description of the physical and human geography of the region is necessary in order gain an understanding of the motivation behind the creation of the Pt. Lisas Industrial Estate. The Pt. Lisas Industrial Estate is Trinidad and Tobago's most ambitious industrial undertaking to date. Situated on the sheltered west coast of Trinidad and adjacent to the Gulf of Paria, the estate represents the country's break from a sugar-cane based economy that still dominates its landscape. The move to industrialize was intended to forge a new era in the use of modern technology, to strengthen the economy, and remedy to the problems of unemployment faced by Trinidad (Carrington, 1966).

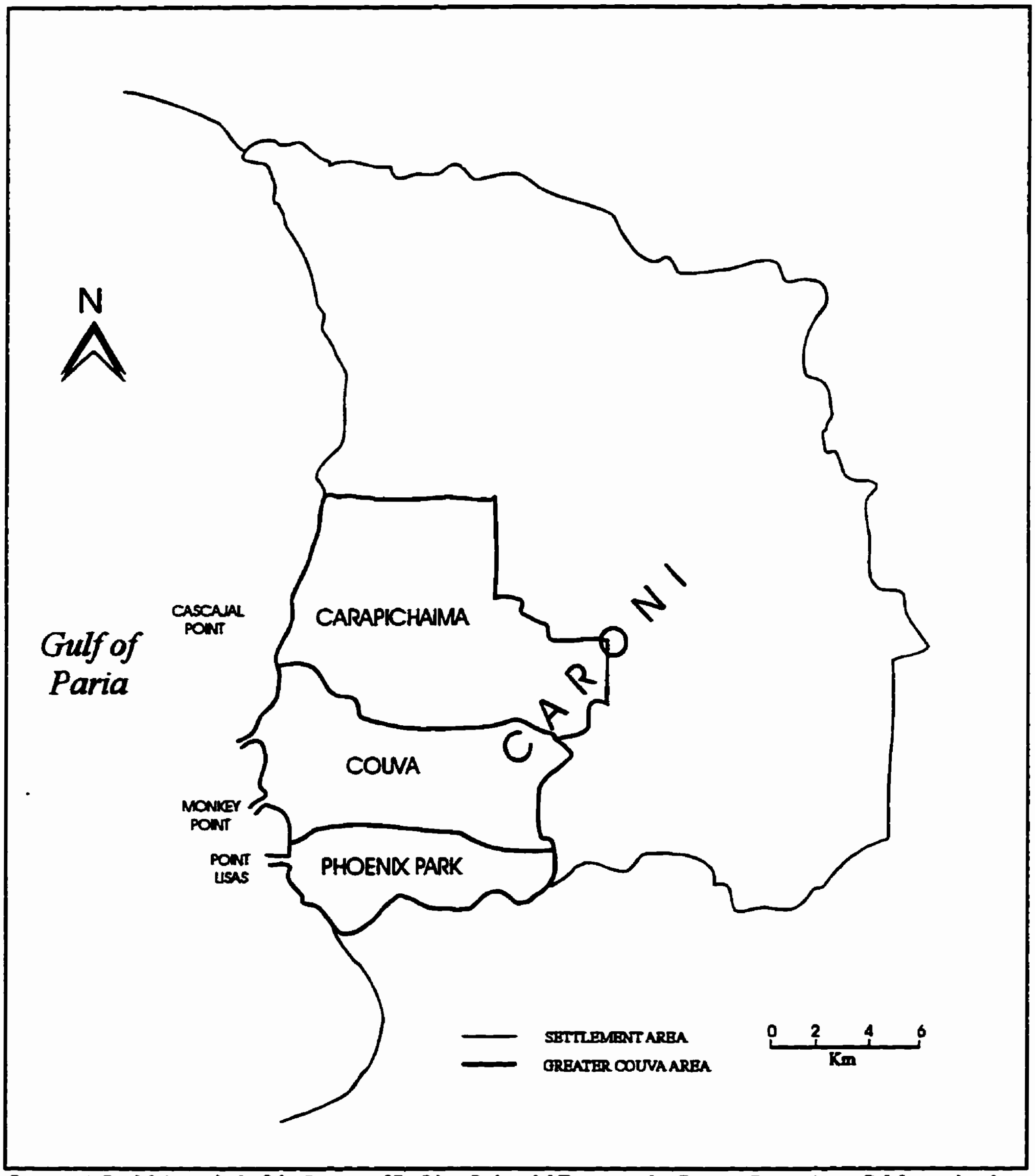
2.1 General Description of Trinidad and Tobago

The islands of Trinidad and Tobago are located in the southern Caribbean Sea on the continental shelf, off the coast of Venezuela between 10° 2' and 11° 2' North latitude and 60° 30' and 61° 50' West longitude. The two islands are the most southerly in the Caribbean chain and jointly comprise 5128 sq km (Figure 1.1). Trinidad, the larger of the two islands (constitutes 95% of the total land area) is relatively flat with three mountain ridges of east-west orientation, the 'Northern', 'Central and 'Southern' ranges. The highest and largest mountain range is the Northern range with its highest peak, El Cerro del Aripo at 940 m above sea level. Tobago is situated approximately 29 km to the north-east of Trinidad and exhibits a more rugged terrain. A single mountain range transverses two-thirds of the island and rises to a height of 576 m a.s.l..

2.1.1 Description of Couva/Pt. Lisas Region

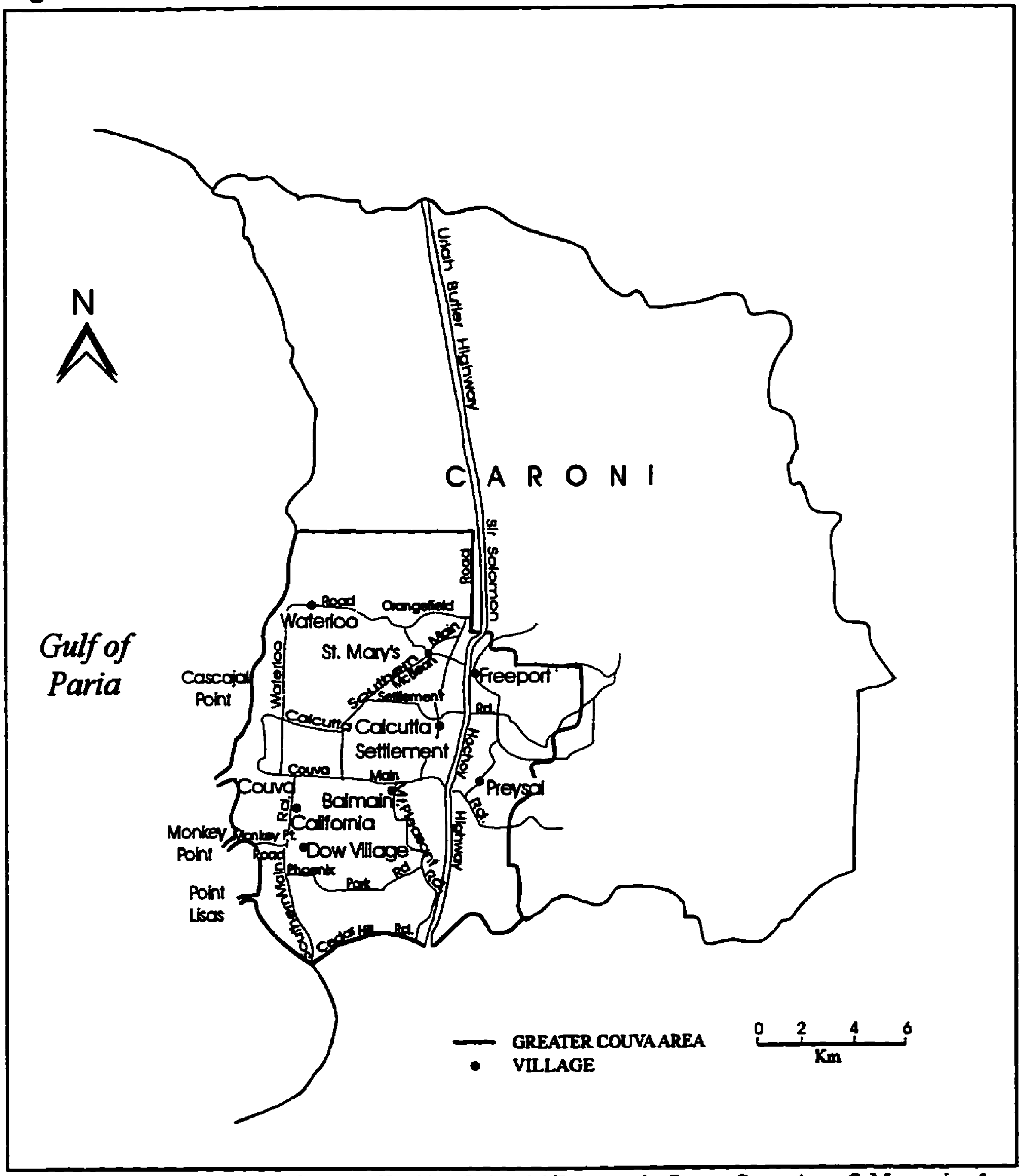
The west coast of Trinidad has been described as a highly stressed environment as it is the home of 88% of the country's population. Economic activities in this region account for 93% of the country's labour force (Town and Country Planning Division, 1974). This study focuses on County Caroni and the adjoining coastline. The Central Statistical Office of Trinidad and Tobago refers to the area either as the Couva/Pt. Lisas area or the Greater Couva Area. Henceforth, these names will be used interchangeably throughout this study to refer to the region. The Couva/Pt. Lisas area shares part of a sheltered body of water between Venezuela and Trinidad called the Gulf of Paria. This interface between land and water displays "production, consumption and exchange processes at high rates of intensity" (Ketchum, 1972:4), even though its capacity to sustain human activity is limited. For purposes of convenience, the seaward boundary of the study area is defined by the limit of the aerial photographic image coverage used in this work. The entire study area comprises the main settlement districts of Carapichaima, Couva, and Phoenix Park including the Point Lisas Industrial Estate (Figure 2.1). These districts account for approximately 29% of the area of County Caroni, and include the villages of Waterloo, Carapichaima, Chase, Freeport, McBean, Calcutta, Couva, California, Dow, and Phoenix Park (Figure 2.2).

Figure 2.1: The Greater Couva Area - Settlement Areas



Source: A Social Appraisal of the Impact of Pt. Lisas Industrial Estate on the Greater Couva Area. G. Manwaring & L. Gerald, Institute of Marine Affairs, 1986, Fig. 1, p. 139.

Figure 2.2: The Greater Couva Area - Towns, Villages, and Roads



Source: A Social Appraisal of the Impact of Pt. Lisas Industrial Estate on the Greater Couva Area. G. Manwaring & L. Gerald, Institute of Marine Affairs, 1986, Fig. 2, p. 141.

2.2 The Physical Geography of the Region

2.2.1 Physical Description of the region

The Couva/Pt. Lisas area lies to the west of the Central Range, bordered by a 15 m contour to the east and the Gulf of Paria to the west (PLIPDECO & IMA, 1982; 1). The drainage basin is comprised of flat to gently sloping land (approx 0.5 degrees) which rises to the Montserrat Hills in the east.

Two main soil types exist in the region. These are deep hydromorphic soils with free internal drainage and deep alluvial soils with restricted drainage. The latter constitutes most of the soil type coverage of the study area (Figure 2.3). Due to the gentle gradient of the land and the soil types, surface drainage is retarded and often results in flooding (PLIPDECO & IMA, 1982; 1).

2.2.2 Hydrological and Coastal Vegetation Description

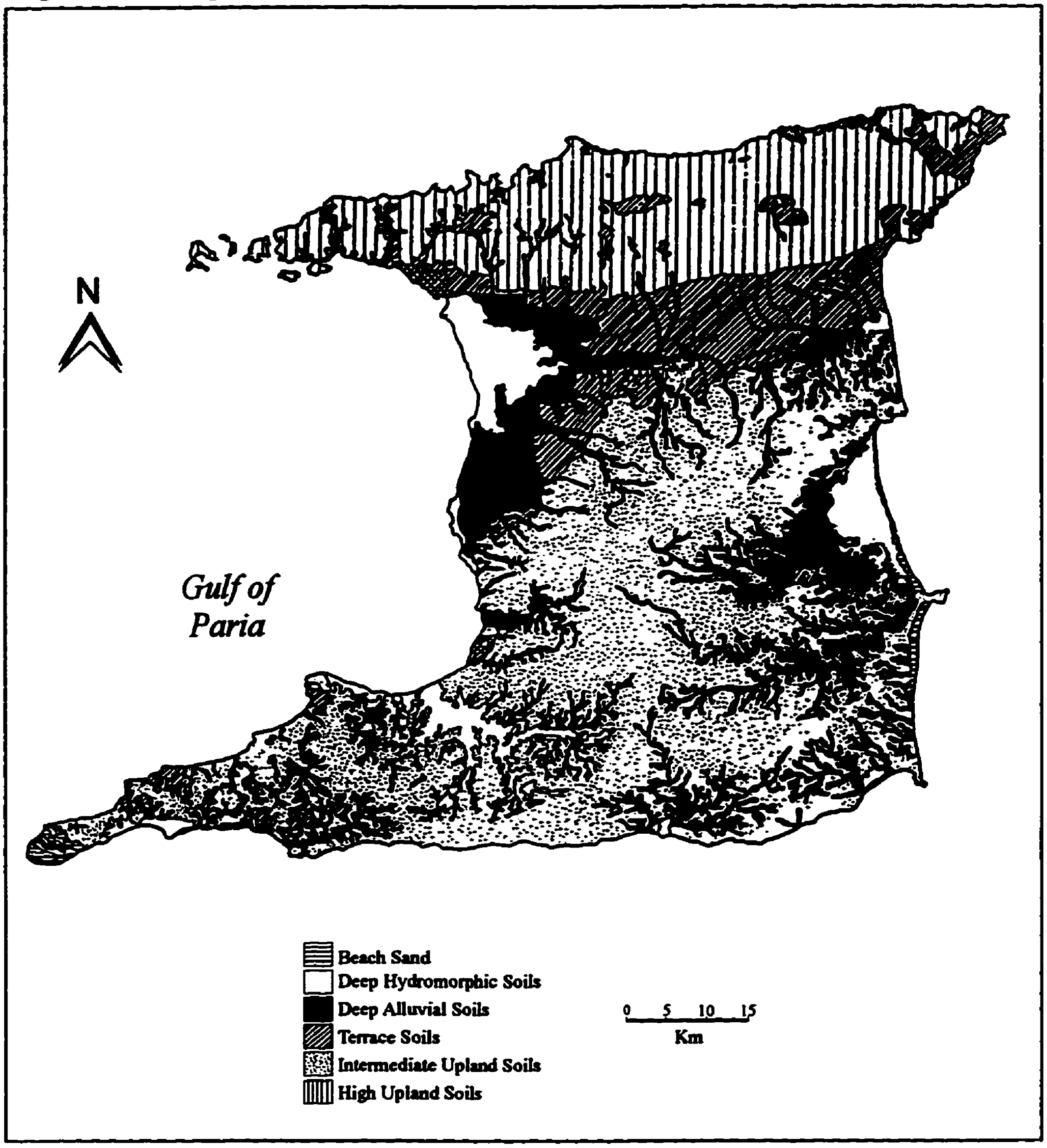
Four of Trinidad's main rivers drain into the Gulf of Paria through the Couva Drainage Basin. These are the Couva River, the Savanetta River, the B.C. River, and the L.N.G. River. The largest of these, the Caroni, traverses the study area toward the west coast and exits in the Gulf of Paria. It's drainage basin creates coastal estuarine conditions with mudflats and sandbars that give rise to prolific mangrove swamps and waters high in organic nutrients, thus creating ideal fishing grounds (Figure 2.4).

Four types of plant communities are native to the area:

1. mangroves;
2. herbaceous swamp communities;
3. coastal thickets;
4. forest communities (PLIPDECO & IMA Report Vol.111, 1981: 2).

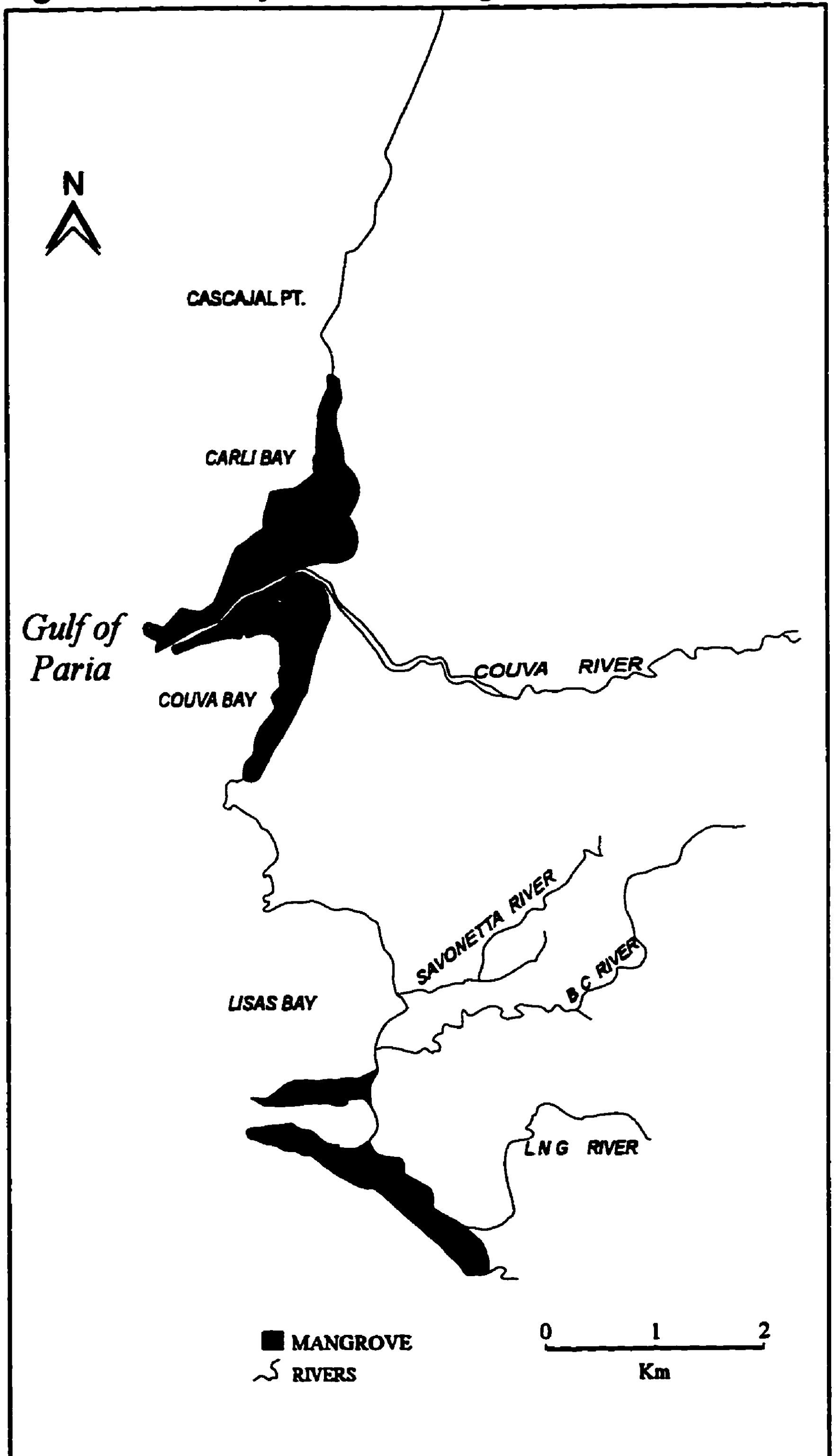
These communities occupy specific areas along the coast. Mangroves exist in tidal areas, herbaceous swamp communities occupy a narrow band between mangrove and woodland and forests, coastal thickets occupy some river banks and beaches, and forest communities occupy higher ground (PLIPDECO & IMA Report Vol.111, 1981: 2).

Figure 2.3: Simplified Soil Map of Trinidad



Source: The Natural Resources of Trinidad and Tobago, edts. by G. C. Cooper & P. R. Bacon, 1981. Fig. 1, Chapter 3, "Soils by F. Hardy, p.25.

Figure 2.4: River Systems and Mangrove in the Pt. Lisas Area



Source: Derived from Environmental Aspects of Coastal Area Development in a Small Island Nation - The Case of Trinidad and Tobago with emphasis on the Pt. Lisas Industrial Complex. C. D. Lewsey, Institute of Marine Affairs, 1981, Appendix IV, p. 17

2.3 Settlement and Housing Characteristics

2.3.1 Settlement patterns

Settlements represent a significant land-use in the region. Most of these settlements are located along the Couva Main Road (Figure 2.2). These settlement patterns can be attributed to the system of land ownership in the region. Since most of the land is owned by the state-owned Caroni Ltd., settlement coincides with the borders of sugar-cane fields and main roads.

The settlement patterns of the area can be divided into three groups: (1) spontaneous development; (2) ribbon development; and (3) planned housing development. Spontaneous development is an unplanned type of settlement pattern occurring on fairly large parcels of abandoned agricultural land such as in Couva, California and Dow Village. Ribbon development in the region represents another form of unplanned settlement, and occurs along major road systems. Calcutta, Carapichaima, Waterloo, Freeport and Mc Bean are examples of this settlement type. Finally, planned housing developments which were instituted by the Government of Trinidad and Tobago and by private enterprise, represent the most recent form of settlement.

2.3.2 Housing

According to 1980 estimates, housing in the area consisted predominantly of single-dwelling houses along with a few flats, condominiums or duplexes. During the period of the study the average household size was 4.9 persons per household, as compared to the national average of 4.5 persons per household. Most families owned their own houses (Couva/Pt.

Lisas Structure Plan, Town and Country Planning Division, no date: 18). There are three major and two minor housing developments in the study area. These are:

Major:

1. Couva Housing Project (Government of T&T)
2. Central Park/Balmain Gardens
3. Fairview Park

Minor:

1. The Midway Park Development
2. Camden Villas

2.4 Traditional Economic Characteristics of the Region

2.4.1 Agriculture

Sugar cane is the dominant agricultural crop with smaller areas devoted to tree crops, such as cocoa, coffee, and coconut, and rice and vegetables. Prior to the development of the industrial estate, sugar cane cultivation and processing were the main economic activities in the region. Data for 1980 (Trinidad and Tobago Central Statistical Office) revealed that both sugar-cane cultivation and work at the sugar refinery at Brechin Castle accounted for 30.4%, the largest share of employment in the region (Couva/Pt. Lisas Structure Plan, Town and Country Planning Division, no date; 11).

A steady decline in the world demand for sugar and the accompanying drop in prices have caused sugar-cane related agricultural activities in the region to diminish. As a result, farm land has systematically been converted into urban, residential or industrial land use.

2.4.2 Fisheries

The study area is also used for extensive commercial fishing. Approximately 120 species of fish have been identified in this region (PLIPDECO and IMA, 1982: 6). Most abundant is the 'Cat Fish'. Others include the 'Blinch', Salmon, Shrimp, Sardine, 'Carite', 'Seabob', and an important constituent of 'White Fish', 'Plateau' (see Appendix VII for species names). The most commercially important fish in the region and throughout Trinidad is the 'Carite'. Other commercially important fish in the region are 'Cavalli', Salmon, 'Racando', and three species of shrimp. The most abundant commercially important fish is 'Racando'.

2.4.3 Services and Amenities

Most of the commercial activities in the region, apart from the sugar and resource industries, are family-run businesses. These are usually operated on the ground floor of the family dwelling and are service oriented. They consist of business ventures, such as hardware stores, pharmacies, clothing and cloth stores, all purpose stores, supermarkets, doctor's offices, auto mechanic and auto parts stores and restaurants. These businesses are mostly confined to the main traffic routes, i.e. the Couva Main Road, St. Mary's junction, California Main Road, the Orange Field junction and the Southern Main Road (Figure 2.2). Two shopping malls have been built at Couva and St. Mary's junction. During the 1970s a decline in local business occurred with the completion and opening of the Sir Solomon Hochoy Highway which diverted traffic and customers from previously used village and town roads.

With the opening of the Pt. Lisas Estate, the village of California experienced increased business activity particularly in the form of restaurants and food services, which were opened to cater to the additional employees of the various industries at the estate. However, trends indicated that as the operations of the estate got underway and training of locals for the companies was completed, employment dropped from 9,000 to 2,000 (Manwaring and Gerald, 1986: 155). Although this represents a normal employment scenario for these types of projects as they move from the construction to the operational phase, this decline severely affected small business ventures in the region.

2.5 Non-Traditional Economic Characteristics of the Region

2.5.1 Industry in the region

Industry in the region consists of light industry and heavy industry, both of which are described in the following sections of this study. The pre-Pt. Lisas economic status of the region was dominated by the sugar industry. However, at present, the Pt. Lisas Industrial Estate dominates the economy of the region and consists of "large-scale energy-based industries which are capital rather than labour intensive" (Town and Country Planning Division, no date: 10). Sugar-cane continues to dominate the physical landscape of the region. Figure 2.5 shows present economic activities in the region, while Figure 2.6 shows the physical layout of the Pt. Lisas Industrial Estate.

2.5.2 Inception of the Point Lisas Industrial Project

The initial concept of the Pt. Lisas Industrial Estate envisaged a port which would service the southern part of Trinidad. This port was proposed in the 1950s by a group of businessmen who were members of the South Chamber of Industry and Commerce. During the 1960s technical and financial feasibility studies were carried out in southern Trinidad, during which time the idea evolved into a port designed to serve an industrial estate which would utilize Trinidad and Tobago's inexpensive energy resources, namely petroleum and natural gas. Point Lisas was chosen as the area with the best potential for this type of development project.

The factors which led to the selection of the site for the industrial estate are listed in the planning document published by the Point Lisas Port Development Corporation (PLIPDECO) in 1982. These factors are:

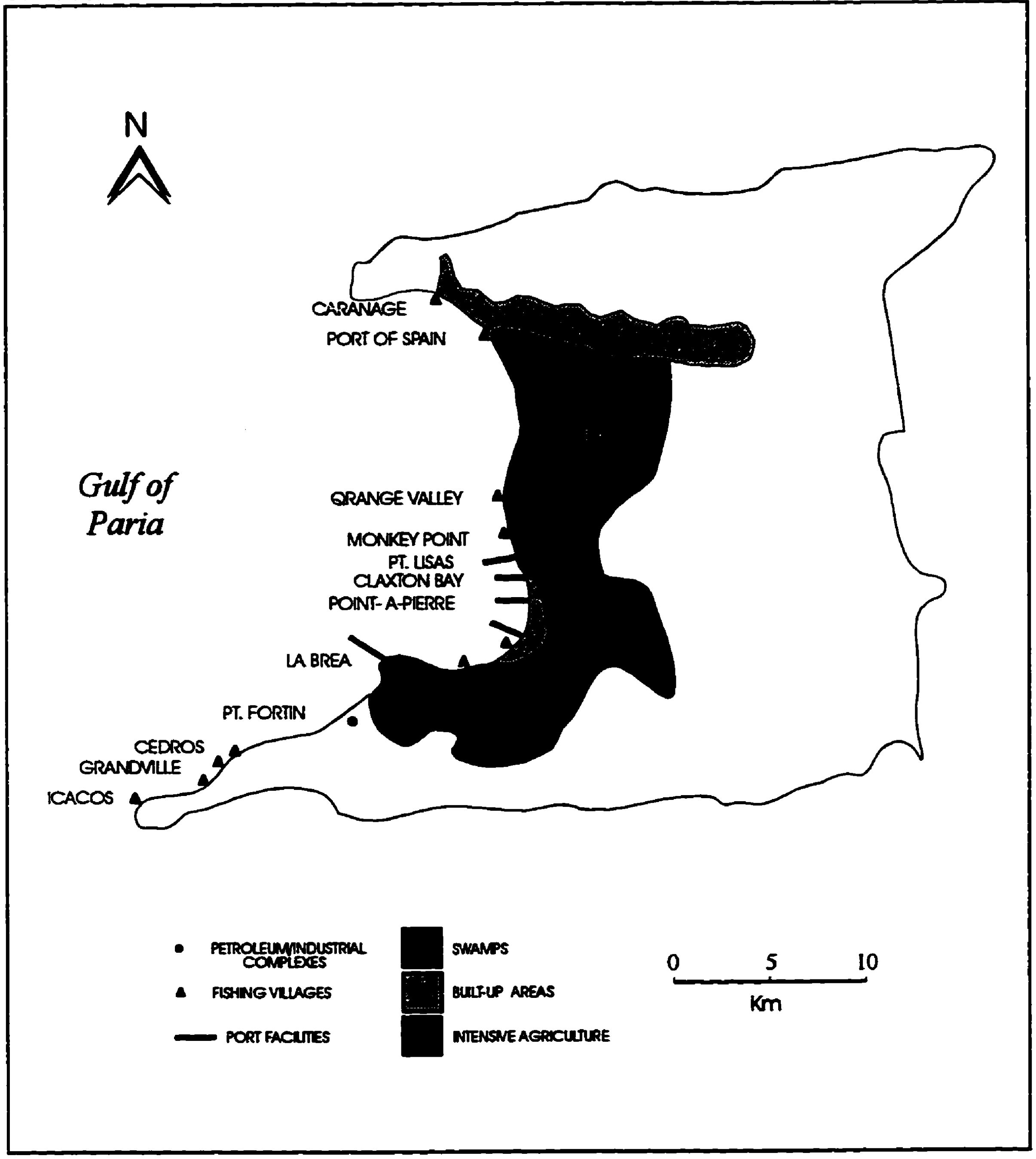
1. good accessibility of the site to develop areas both in north and south Trinidad;
2. 640 ha of sugar-cane land that could be easily developed;
3. natural gas reserves which would form fuel and feedstock for the industries on the estate;
4. physical and economic potential for port development; and
5. sub-regional proximity of several basic industries for essential inputs to subsidiary industries (PLIPDECO, 1982).

The Point Lisas Industrial Port Development Corporation was officially incorporated in 1966. Among other things, it was responsible for the promotion, growth and stimulation of industrial development within the Pt. Lisas region. These development objectives were designed to benefit Trinidad and Tobago as a whole, by generating employment and revenue for the country. With the incorporation of PLIPDECO, 1500 acres of marginal sugar cane land and mangrove swamp were purchased from Caroni Ltd.[1]. To raise funds for the project, company shares were sold to the public.

1

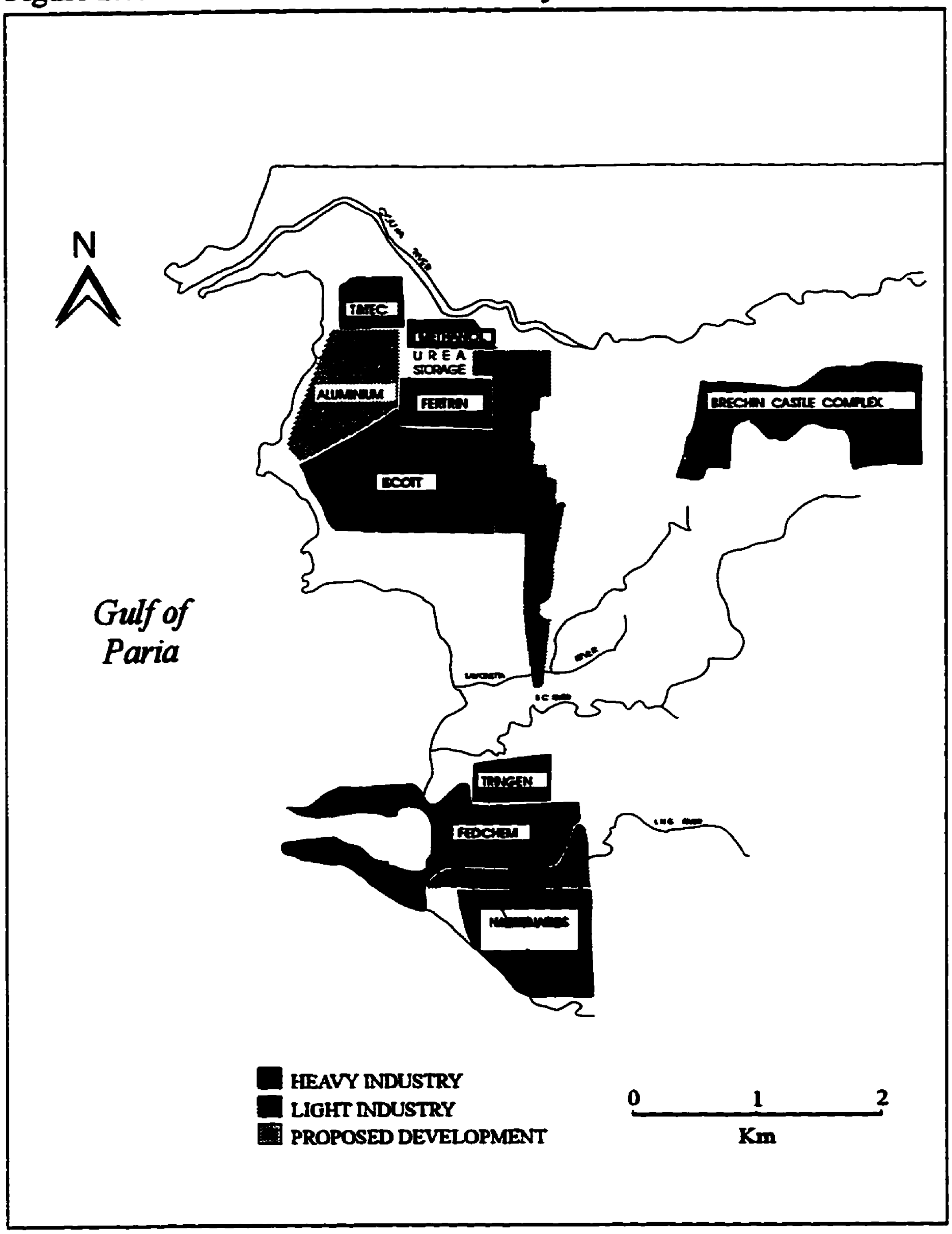
Caroni(1975)Ltd. is a Government owned industry responsible for the cultivation of cane and the refining and marketing of sugar in Trinidad. It also conducts cane related research and has recently diversified (1991) to include rice cultivation.

Figure 2.5: Economic Activities (Land Use) in The Gulf Of Paria, West Coast, Trinidad



Source: Derived from Environmental Aspects of Coastal Area Development in a Small Island Nation - The Case of Trinidad and Tobago with emphasis on the Pt. Lisas Industrial Complex. C. D. Lewsey, Institute of Marine Affairs, 1981, Appendix III, p. 16

Figure 2.6: Pt. Lisas Industrial Estate Layout



Source: Derived from Environmental Aspects of Coastal Area Development in a Small Island Nation - The Case of Trinidad and Tobago with emphasis on the Pt. Lisas Industrial Complex. C. D. Lewsey, Institute of MArine Affairs, 1981, Appendix IV, p. 17

2.5.3 Rationale for the Project

During the early 1970s the economy of Trinidad and Tobago was booming due to high oil prices on the world market. As a means of relieving its dependency on oil revenues, the government then took the decision to diversify the economy. Around the same time, vast reserves of natural gas were discovered off the southeastern coast of Trinidad, and these reserves became the focus of a government strategy to establish a heavy industry complex which would exploit this natural gas as fuel. The time had come for the idea of the Point Lisas Industrial Estate to be realized.

In 1976, the government of Trinidad and Tobago purchased 81% of the shares in PLIPDECO (PLIPDECO, 1978) and assumed majority shareholding status in the Corporation. Later that year work began on the provision of infrastructure for the estate, and in the following year, dredging and reclamation for the port and deep-water harbour commenced. By 1977, the power station on the estate began generating power. By 1981 the production of iron, steel and fertilizer had commenced. In 1983, urea production began on the estate, and methanol production began in 1984. Today, fully functional and equipped with a number of light and heavy industries, Pt. Lisas is considered by the government of Trinidad and Tobago and PLIPDECO to be a modern maritime industrial development and port.

Table 2.1: Chronology of the Pt. Lisas Industrial Project

Year	Event
1950s	Proposal for port by South Chamber of Commerce and Point Lisas Port Development Corporation (PLIPDECO) conceived
1960s	Technical and financial feasibility studies carried out at Lisas Bay for a port facility
1966	PLIPDECO incorporated and 1500 acres of land purchased for proposed port facilities
1970s	Reserves of oil and natural gas discovered in region
1972	Construction of Pt Lisas Industrial Estate begins
1976	Government of Trinidad and Tobago purchases 81% of PLIPDECO shares
1977	The first industries at the site, Trinidad and Tobago Electricity Commission (T&TEC), and Trinidad Nitrogen Company Ltd. (TRINGEN) go on-stream
1981	Opening of Federation Chemicals Ltd. (FEDCHEM); the Fertilizer Company of Trinidad and Tobago (FERTRIN) Ammonia I Plant; and the Iron and Steel Company of Trinidad and Tobago (ISCOTT)
1982	Opening of Fertilizer Company of Trinidad and Tobago (FERTRIN) Ammonia II Plant
1983	Opening of the Urea Plant
1984	Opening of the Methanol Plant

Source: Ministry of Energy, 1991.

2.5.2 Light Industry

Agro-industries such as the production of rum, bagasse, molasses, furfural (a type of colourless liquid used as a solvent in the production of pharmaceuticals and pesticides), and animal feed, form the primary light industries in the region. Other light industries include factories, for the production of clothing, confectioneries, paint and cement (Figure 2.6).

2.5.5 Heavy Industry

Heavy industries that form part of the Pt. Lisas Industrial Estate include the Iron and Steel Company of Trinidad and Tobago (ISCOTT), the Fertilizer Company of Trinidad and Tobago (FERTRIN), the Methanol Company, the Trinidad and Tobago Electricity Commission, Federation Chemicals Ltd. (FEDCHEM), the Trinidad Nitrogen Company Ltd. (TRINGEN), an aluminum smelter, a urea company, and liquid and natural gas companies. These companies are located on the Pt. Lisas Industrial Estate. Note that the Estate accommodates energy-based industries and other subsidiary and spin-off industries (Figure 2.6).

2.5.6 Ports

As the west coast of Trinidad is leeward it is sheltered, a fact which contributes to its suitability for ports for both large ocean vessels and small fishing craft. As a result the country's largest and most efficient ports are located on the west coast. The port at Point Lisas adequately meets the needs of the Point Lisas Industrial Estate, as well as those of importers and exporters all over the nation. Its harbour and docking facilities have specialized terminals built for liquid and dry bulk handling which can accommodate container and cargo vessels.

2.6 Summary

The Couva/Point Lisas area is under continuous environmental change from supporting the aforementioned human activities. This coastal area, which is part of an already stressed environment must be considered in the light of past and future impacts of these activities on the region. Comprehensive coastal area planning and management policies must be developed in order to maintain sustainable use of the regions resources. This can only be achieved through the systematic study of the temporal changes of the region and the accompanying effects, particularly in connection with the creation of the Point Lisas Industrial Estate. The following chapter will review literature relevant to this type of investigation.

CHAPTER 3

REVIEW OF LITERATURE

3.0 Introduction

"At a time when environmental studies, social studies, even development and ethnic studies are growing in schools it is important that geography should stress not only the contribution which it can make to these studies but also the uniqueness it can make to that contribution. Moreover it should reflect ...a multi-dimensional approach to explanations of man/land interactions in space, place and time" Lawton (1983: 194). This study reflects this contribution, and encompasses a multitude of factors and methods. A review of relevant literature is therefore necessary to provide contexts for the broad range of methods and environmental implications that this thesis seeks to address.

3.1 Mapping

Cartographic representation of the Earth's surface is a familiar and widely used geographic tool. A single map can present large volumes of data within a small image. Furthermore, this data can represent many different themes and facilitate many different types of analysis such as 'change analysis'.

Further, feature identification and change analysis may be undertaken using remotely sensed data derived from satellite imagery and aerial photography. This study, with the aid of computer mapping and analysis, and aerial photographs of the Pt. Lisas coastal region in Trinidad facilitates the examination and analysis of environmental change. In so doing, this study also addresses the key issues of spatial and temporal heterogeneity.

Issues specific to the use of maps and remotely sensed data are strongly influenced by the characteristics of the subject under study. Therefore literature documenting the use of aerial photography for coastal analysis in the context of this thesis can be sub-divided into two categories: coastal mapping (i.e., coastline or shoreline configuration and coastal vegetation); and land-use change analysis (involving aspects of change in such attributes as agriculture; water; transport networks; settlement areas; and vegetation).

3.1.1 Coastal mapping and the use of Aerial Photography

Coastal and shoreline mapping with the aid of sequential aerial photography involves photogrammetric as well as cartographic techniques where measurement of change is extracted directly from the photographic images. This operation requires first the acquisition of data ensuring correct scale and proper quality of selected images for unequivocal feature identification. It also requires selection of appropriate technology and methods of analysis, and a collection of supplementary information on the study area. Finally, the design of a landform classification system which accurately represents characteristics of ground features as interpreted from photographs is needed. Cartographic techniques may include base map preparation and legend selection corresponding to land feature classification and map transparencies for overlay comparison. Smirnov et al. (1987) and Weerakkody (1987 and 1988) have outlined the necessary procedures for coastal mapping of this type. Weerakkody (1987) included the use of historic documents such as historical maps and charts which assist in the documentation of coastal changes studied over a long time period in the Bay of Galle, southwestern Sri Lanka.

These studies form the basis for much of the map preparation work executed in this thesis. Smirnov et al. (1987) have provided comprehensive guide lines for coastal mapping and the documentation of coastal change, and may be considered methodological studies. While Weerakkody (1987 and 1988) have only provided analysis of coastal changes, Smirnov et al. (1987) attempted to qualitatively assess the change, a task that this thesis also undertakes. Both authors suggest that the identification, and reconstruction of phases may pose a problem with the application of this technique, while still acknowledging that the application of sequential aerial photography in coastal mapping forms "an indispensable, time saving tool" (Weerakkody, 1988).

Literature concerning coastal mapping using aerial photography encompasses many issues which justified its use in this study. The significance of sequential aerial photography in coastal mapping may be summed up in a quote by El-Ashry and Wanless (1967), who state that the method provides "an exact basis for measuring net changes in dimension or shape between photographic dates." Other early articles, such as Rea, 1941; Dietz, 1947 have also stressed the efficiency and accuracy of using aerial photographs for coastal studies, in particular to analyze and identify change in coastal features.

These early papers laid the ground work for further applications of the techniques in the field, whilst academicians in related fields also applied the techniques. Shepard (1959), in his studies in oceanography, utilized both vertical and oblique aerial photos for identifying and studying ocean and shoreline features and processes. In a later work by Shepard and Wanless (1971), the authors used aerial photographs as an illustrative tool (much like a map) in the identification of coastal types.

Snead (1982) provided a photographic atlas of coastal landforms utilizing vertical, oblique and horizontal photography as well as satellite imagery, again using the imagery as a display tool. Hwang (1981) used similar techniques to Snead (1982)for his study of beach changes as revealed by aerial photography. From these photographs he quantitatively assessed erosion, accretion, and changes in the vegetation line as indicators for assessing the long term trend of beach processes in Hawaii. The study investigated coastal conditions so that future planning policies could be better outlined based on the information.

Whereas some literature simply addressed the use of aerial photography in coastal studies, others were technical papers which provided procedures for carrying out coastal mapping studies. Stafford and Langfelder (1971) for instance conducted a reconnaissance mission to observe coastal erosion along 531 kms of the North Carolina coast. The writers provided a technique for monitoring erosion as well as a "mean composite error" application for evaluation of the procedure. Frihy (1988) conducted an 'air photographic analysis' to detect erosion and accretion of the Nile Delta Shoreline. Leatherman and Zaremba (1986) also utilized aerial photography in quantitative measurements of a barrier beach in Massachusetts.

Quantitative analysis of shoreline changes were addressed by some articles. These articles provided procedures for, and evaluations of, techniques using aerial photography in short-term and long-term shoreline change. A base map analysis for coastal change mapping from aerial photographs has been developed by the U.S. Army Corps of Engineers, Coastal Engineering Research Centre, (Everts and Wilson, 1981). The procedure involves the creation of a base map where major features are derived from the latest and earliest sets of photographic coverage of the study area. Base maps showing relevant features for the interim periods represented by photo coverage are then created by superimposing imagery onto maps and marking in features. Next, lines (one on each map) are drawn approximately parallel to the shoreline. Other lines are drawn linking a number of fixed feature reference points chosen from the study area (and included in the aerial coverage of all time periods). The distance from shoreline features to these lines can be ascertained and comparison between each base-map will provide a time series assessment of shoreline change. Smith and Zarillo, (1988) studied long- and short-term shore dynamics by employing beach profiling techniques and sequential aerial photography to a barrier beach fronting Mecox Bay off southern Long Island. The results of both studies suggest that qualitative calculations, by any method, but especially by aerial photography and beach profiling, did not adequately address the possibility of seasonal short-term shoreline changes which would produce a large error in quantitative analysis, particularly in assessing recession and/or accretion rates. These issues have been considered in this research and are discussed in Chapter Six.

Though the literature reveals some shortcomings to the use of aerial photography in coastal mapping, it also reveals the versatility of the technique, i.e., its wide range of applications. El-Ashry et al. (1977) presented a series of articles from a geological point of view outlining various applications of aerial photography in coastal problem analysis. The articles examined photo interpretation of shorelines in case studies; mapping of coastal change from sequential aerial photography; the use of satellite and radar in coastal mapping studies; and coastal zone management interests.

The dynamic nature of geomorphology, particularly coastal geomorphology, also lends itself to analysis through the use of sequential aerial photography and indeed other forms of time sequence remote sensing imagery. Verstappen (1977) described numerous applications of both aerial photography and satellite imagery in geomorphological studies, including coastal research. Gierloff-Emden (1982), Prabhakara Rao et al. (1985), Blodget et al. (1990), Rajamanickam et al. (1990), and Welby (1980), have reviewed the use of satellite imagery in monitoring shoreline change, assessing shoreline erosion prediction and the use of these results in coastal management. Landsat Thematic Mapper (TM) imagery is favoured in these studies, although Blodget et al. (1990) utilized Landsat Multi Spectral Scanner imagery (MSS). Some authors recommend however that due to resolution considerations of satellite imagery and for the purpose of identifying small-scale changes typical of coastal configuration, "difference measurements using aerial photographs are more precise." (Blodget et al., 1990).

3.1.2 Coastal vegetation Mapping

Coastal vegetation mapping and monitoring is exceedingly important for coastal studies and an integral part of coastal mapping. These vegetation surveys can be achieved through the use of aerial photographs and satellite imagery. The U.S. Federal Coastal Wetland Mapping Programs Report (1990) contains manuscripts which outline in general terms, the design and implementation of various projects which make an inventory of the nation's wetlands. It provides a comprehensive guideline for data acquisition, data processing and data analysis, as well as parameters necessary for policy planning for coastal vegetation conservation programs. Rehder and Patterson (1986) compared the use of aircraft data and Landsat MSS data for mapping and monitoring mangrove of Marco Island, Florida. Their findings suggest that although Landsat MSS data is an adequate tool for mangrove mapping purposes, aircraft data is more accurate. Rollet (1986) (Lesser Antilles, Caribbean), and Hubbard (1974) (Great Britain), have found air photo analysis for the identification and mapping of coastal vegetation to be efficient and accurate.

Satellite imagery for use in coastal analysis in the Caribbean has been recommended. Though this technique has met with success elsewhere, there are drawbacks to its use in the Caribbean. Specter and Gayle (1990: 1735-6), have listed these in a study which outlines the responses of Caribbean 'experts' to the issue. Major constraints were given as :

1. The need for experienced personnel;
2. Appropriate hardware;
3. Data-related issues;
4. Role of relevant organizations in the region;
   a) capability to co-ordinate and co-operate in the transfer of technology;
5. Economic constraints;
6. Politics and policy/decision-makers;
7. Facilities and physical infrastructure.

However, the importance of the use of aerial photography in coastal analysis is still stressed when Specter and Gayle (1990:1738) recommend that in order to alleviate some of the data related problems, it is "essential that each country have a complete coverage of large scale air photos as a base for interpretation of other types of remote sensing data."

There has been varied success in mapping techniques of coastal areas. However, the literature suggests that aerial photographs are a cost effective and accurate means of achieving this end, particularly since photographic coverage of regions exists in many countries including developing nations, where environmental and socioeconomic studies are most needed.

3.1.3 Land-Use Change

Today, changes to our environment are occurring more extensively and more rapidly than ever before. The significance of these changes becomes important as they place added pressure on our environment and its resources. As a result, it becomes increasing important to monitor our environment. Land-use/land-cover change mapping is one method of achieving this end.

Land-use change analysis using aerial photography often involves similar techniques to those involved in coastal change analysis, i.e., photogrammetric and photo interpretation techniques. Geographic Information Systems (GIS) are often implemented in this sphere of research because of their versatility in the handling of spatial and attribute data which constitute the building blocks of land-use characteristics as they exist on the Earth's surface.

Much of the literature in this area involves case studies as these best illustrate procedural activities undertaken in such research. Adeniyi (1980) explored the method of land-use change analysis using sequential aerial photography and computer techniques for monitoring urban growth in Lagos, Nigeria. Olorunfemi (1983) in a similar study focused on urban growth in Ilorin, Nigeria. Field and Collins (1986) applied the use of sequential aerial photography in assessing vegetation cover change in the Nigerian Savannah. These studies applied land-use mapping techniques as a means to collect data which would ultimately be used in an information system to address land-use conflicts, and is thus similar to this study. Further, these studies applied mapping techniques for use in land-use policy creation and management. Raghavswamy and Vaidyanadhan (1980), in the coastal city of Visakhapatnam, eastern India; and Hathout and Hildebrand (1985), for the INCO nickel mining company in Thompson, Manitoba, assessed the impact of major projects using sequential aerial photo mapping techniques to estimate land-use change. The similarity of all the studies is the attempt to apply land-use change results to assess the impacts of a given activity on an environment. However, whereas Adeniyi (1980) and Hathout and Hildebrand (1985) placed emphasis on computer aided techniques for mapping and map analysis, the other authors emphasized statistical analysis for documentation of their findings. In spite of the differing emphasis between the studies, their significance to this thesis is the strong recommendation for the use of sequential air photo interpretation in land-use mapping for environmental impact assessment and planning and management exercises. They also stress the importance of the large volume of data which this technique can provide.

Once again the versatility of the technique is revealed in its wide range of applications. Eyre et al (1970), Olorunfemi (1985), and Watkins and Morrow-Jones (1985) all successfully applied sequential aerial photography in population estimation studies. An interesting application of aerial photography to land-use changes is the study by Zube et al. (1989) where sequential aerial photos spanning a period of 13 years were used to assess change in rural Arizona. The results were compared with results of a mail-in survey to evaluate resident's responses relative to real (as measured from photos) changes. Luloff and Befort (1989) give a brief overview of the role of aerial photography, GIS, and land-use in an applied sociological study of land-use patterns in the New Hampshire seacoast (New

England). The literature suggests that sequential aerial photography mapping provides a sound method which facilitates the qualitative and quantitative analysis of land-use/land-cover changes to provide invaluable information for monitoring, managing, and planning for our environment.

3.2 Environmental concerns

In the context of this study, significant environmental concerns encompass only those aspects of the coastal environment altered due to industrialization in the study area. However, we must view these issues in a wider framework. First, what is the status of coastal management and planning and second, what are some of the coastal management problems facing the Caribbean. These and other relevant issues are listed below.

1. Coastal management and planning
2. Coastal problems of the Caribbean
3. The effects of dredging and reclamation in coastal regions
4. Reduction of mangrove communities
5. Road and transportation networks
6. Population
7. Pollution

3.2.1 Coastal Management and Planning

The literature on coastal management and planning is quite extensive. However, these studies may effectively be categorized as (i) site specific studies such as demonstrated by the works of May (1990) who attempted to assess the present and future behavior of the Hervey Bay beaches, and Lundberg (1991) who attempted to link transitions in the coastal ecosystem to new land-use and management practices; (ii) policy studies within a country as illustrated by the works of Waithe (1981) who discussed coastal management in England and Wales, and Wiggerts and Koekebakker (1982) who profiled the coastal planning and management in the Netherlands, and (iii) comprehensive studies which incorporate aspects of the two previous sections as shown by Clark (1977) who used site specific examples to illustrate how US EPA and Federal environment policies could be implemented to effectively guide the use of coastal lands and waters. From these examples it is clear that coastal issues are wide ranging. This characteristic has made it necessary to limit this portion of the literature review to literature dealing with coastal problems facing the Caribbean region, and to literature dealing with those aspects of coastal environmental concern revealed through mapping of the Pt. Lisas region.

3.2.2 Coastal Problems of the Caribbean

Literature concerning coastal problems in the Caribbean may be divided into two categories, problems of the Wider Caribbean; and problems faced by specific countries.

3.2.2.1 Problems of the Wider Caribbean

According to the 'Final Act' of the Conference of the Plenipotentiaries of the Protection and Development of Marine Environment of the Wider Caribbean (1983, Articles 5- 10, 12), the coastal problems facing the Caribbean include pollution from ships, pollution caused by dumping, pollution from land and sea based activities, airborne pollution, and threats to specially protected ecosystems.

Similar problems were mentioned in the Coastal Environmental Programme (CEP) Technical Report, no. 2 (1989). They were reiterated and expanded to include coastal erosion, mangrove wetlands, habitat loss and species reduction, fisheries, marine pollution and environmental health, sea-level changes, and tourism impacts and opportunities. The possibility of gathering and co-ordinating information, and instituting a management program were also given special attention.

Elenor Jones (1987) wrote a preliminary report on the coastal vulnerability of the Caribbean. A summary of her findings indicated (i) a loss of coastal ecosystems (reflected in the loss of coral reefs and mangrove communities); (ii) increased coastal pollution; (iii) changes in coastal zone circulation patterns; (iv) increased construction in vulnerable coastal area; (v) inadequate knowledge and implementation of hurricane resistant designs; (vi) lack of data bases and information on coastal materials and processes; and (vii) the need to include a risk analysis in project planning in the coastal zone.

Yet another study of coastal stress in the wider Caribbean region was performed by Rodriguez (1981) who discussed issues of coastal pollution due to industrial, agricultural, and domestic wastes, oil spills, mangrove community loss, and polluted river inputs. The study also identified high risk zones and zones of likely impact. He indicated that rapid development and urbanization activities were responsible for these problems and recommended that marine coastal zone management policies be implemented in the region. Rodriguez (1981) concluded that the combined effects of limited data regarding major sources and quantities of marine pollutants, poor regional co-ordination for data gathering, dissemination and exchange, and the lack of environmental standards is exacerbated by the fact that little or no policies or agencies exist within the region to enforce pollution controls and coastal and marine resource protection.

3.2.2.2 Problems faced by specific countries

Studies dealing with the coastal environmental problems of individual West Indian countries have dealt mostly with detailing the physical problems rather than the conceptual and managerial problems. Edmunds (1986), Deane (1986), Agard et al. (1988), Heileman and Ramsaroop (1990), and Archer (1992) all discuss the environmental (i.e., the physical) problems in specific countries.

Edmund (1986), and Deane (1986) reported on adverse erosional processes currently at work on beaches in St. Lucia and the Lesser Antilles respectively. In dealing with the problem of industrial pollution in Trinidad, Agard et al. (1988) looked at petroleum residues in surficial sediments in the Gulf of Paria, while Heileman and Ramsaroop (1990) (also in the Gulf of Paria) attempted to determine the seasonal variations of petroleum hydrocarbons. Archer (1992) addressed the problem of industrialization, with its accompanying land-based sources of coastal and marine pollution in the CARICOM countries of Barbados, Trinidad and Tobago, Jamaica, Guyana, Dominica, Grenada, St. Vincent, Antigua and Barbuda, St. Kitts-Nevis, Montserrat, The Bahamas and Belize. One study which dealt with the theoretical framework of coastal problems was Bertrand (1987). This paper examined the status and feasibility of coastal and marine hazard mapping and risk assessment in Trinidad.

All the reviewed literature suggests that while there are many coastal problems in the Caribbean region, much work needs to be done. First proper assessment of the types and magnitudes of the problems that exist must be undertaken. Second, the region must explore the establishment of proper environmental management standards and structures to ensure sustainable development in its coastal regions. This thesis provides a solution to the first of these issues.

Other literature reviewed dealt with individual factors of coastal problems which were expected to have been evident at the Pt. Lisas site. Many of these are covered in Clark (1977) and Nemerow (1971) although other sources such as Canter (1977 and 1996) and Rau and Wooten (1980) were found to be informative. Some of these factors which include dredging and land reclamations, reduction of mangrove communities, and increased transportation infrastructure and its side effects are reviewed in the following sequel.

Sections of this review dealing with Dredging (3.2.3) through Pollution (3.2.7), were utilized as a guide to identify potential environmental impacts and/or techniques to assess these impacts. Their contributions were largely descriptive in nature, providing a range of impacts similar to those which could exist at the Pt. Lisas Industrial Estate. They also served to compile aspects of the risk characterizations used in impact assessment, and modeling techniques. Hence, any error in these studies will be incorporated into this research.

3.2.3 The effects of dredging and reclamation in coastal regions

According to Bonvicini Pagliai et al. (1985) dredging and reclamation in coastal regions has received little attention "even though dredging is one of the most common man-made disturbances of the marine environment." This is further complicated by the fact that the data available on this topic is limited and site specific. Their study recorded benthic levels during pre- and post-dredging phases in the Thyrrenian Sea, Gulf of Cagliari, Sardinia, Italy. Analysis of the benthic data showed that dredging had limited impact on the area. The results also suggested that dredging (in the absence of other disturbances) had no long term or irreversible impacts on the coastal environment.

A similar study was performed in Behrain, the Arabian Gulf, by Al-Madany et al. (1991). This study examined the impacts of dredging and reclamation on the coastal marine ecosystems. It also considered the social and economic impacts which resulted as a consequence of the environmental impacts. Recommendations for legislation including EIAs were discussed and an environmental planning model was elaborated upon.

Raaymakers (1994), described an effective method of coastal management which was utilized during dredging operations in Townville, Queenland, Australia. This approach was described as a multi-agency, multi-disciplinary approach since it was managed and coordinated by several organizations and made use of individuals from varied disciplines. The management strategy utilized was reactive and real-time as it immediately modified dredge operations to alleviate impacts. Admittedly long-term impacts were not addressed, but the "project was completed without losing a single day of dredging or a single coral colony at the Magnetic Island reefs" (Raaymakers ,1994, 276).

Morton (1977) reviewed the physical, chemical and biological effects of dredging. The study's objective was to "identify the most critical problems relating to dredging and spoil disposal and to summerize the progress made to date in solving these problems." Dredging Coastal Ports (1985) was researched by the U. S. Water Support Center, Army

Corps of Engineers. It detailed the procedures and major environmental problems associated with dredging, and how they could be effectively managed.

3.2.4 Mangrove studies

Odum and Heald (1975), Scott (1981), Sefton (1981) and James (1985) discussed the benefit of mangrove communities to the coastal ecosystem. They spoke of the link between aquatic productivity and species diversity in mangrove communities. The authors also listed other benefits of mangrove to humans, for example its land building capabilities.

Clark (1977), Vannucci, (1988) and Knox and Miyabara (1984) provide detailed studies of mangrove systems and the impacts of mangrove community loss. Other studies such as Fortes (1988), Ramdial (1981) and Gerald (1985) looked at the changing face of specific mangrove communities in East Asia and Trinidad (second and third) respectively. They presented information on the man-induced changes and stresses which plague these habitats. De la Cruz (1990) observed cases of wetland alteration in Trinidad and Jamaica and compared the management practices in these areas with those of Indonesia and the Philippines in an attempt to demonstrate what he considered a successful management approach for tropical developing nations.

3.2.5 Roads and Transportation Networks

Clark (1977) provided information on the relationship between road network density and environmental impacts. Knox and Miyabara (1984) provided some examples of transport networks in wetland areas in South East Asia which posed a threat to the environment. Both works dealt with the effects of road and transport networks in coastal environments. Stewart (1994) assessed the environmental impact of road schemes. This work did not identify potential impacts as much as it dealt with "the management of the design process" (Stewart, 1994, 1) and policies affecting design.

The design of roadways is significant in the reduction of environmental impacts. However it is often linked in the literature to increased population and urbanization. The effects are therefore considered secondary to those posed by urbanization, and separation of the two themes is difficult. In this study it was necessary to redefine the region in terms of road density and function alteration, in order to assess the impacts of roadways and transport networks in the region. For this purpose, the Geometric Design Guide for Canadian Roads and the Urban Supplement to the Geometric Design Guide for Canadian Roads were reviewed (Appendix V).

3.2.6 Population

Clark (1977), Rau and Wooten (1980), and Canter (1977& 1996) all dealt amply with the issue of increased population and urbanization and its potential impacts on a vulnerable coastal environment. Other sources such as Arya et al. (1994), Bilsborrow and Okoth Ogendo (1992), and Kim and van den Oever (1992), dealt with rapid urbanization due to development, population-driven land use change and population-driven resource use transitions in developing countries. As with many of the variables in this study, these authors observed some overlap in the following areas (i) increased road and transport network and urbanization, and (ii) urbanization and population growth and pollution.

3.2.7 Pollution

Many studies in the coastal environment are concerned with chemical pollution (e.g., Nemerow 1985). Clark (1977), Rau and Wooten (1980), Conway and Ross, (1980) and Canter (1977& 1996) also provide information on the impacts of this form of pollution. These are accompanied by models and theories for the assessment and prediction of pollution (chemical pollutants, thermal pollutants, surface water pollution due to urbanization), as well as planning and management approaches to introduce impact assessments in various types of projects.

Yet another category of relevant literature focused on case specific studies of industrial pollution of coastal and estuarine waters. Witter and Carraso (1996) and Macauley et al. (1995) looked at the effects of industrial pollution and development on water quality in the Dominican Republic and Mexico respectively. Ibarra-Obando and Escofet (1987) also looked at industrial development by examining the effects of pollution on the ecology of a coastal lagoon in Mexico. As mentioned before, in dealing with the problem of industrial pollution in Trinidad, Agard et al. (1988) looked at petroleum residues in surficial sediments in the Gulf of Paria, while Heileman and Ramsaroop, (1990) attempted to determine the seasonal variations of petroleum hydrocarbons in this same region.

Thermal pollution effects on the environment were covered by Edinger et al. (1974), Rau and Wooten (1980), and the US Environmental Protection Agency (USEPA) (1973). These studies dealt with heat transport in the environment and its effects. They were used to identify and apply methods for modeling and controlling thermal pollution.

The threat posed by sewage disposal in coastal areas was addressed in Nemerow (1985) and Clark (1977). Studies performed in Australia by Otway (1995), and Scanes and Philip (1995) sought to document the impacts of sewage disposal into oceans. Some works provided specific environmental risks caused by specific chemicals. The Environment Canada Environmental Protection Service has written a series of manuals which deals with spills of various chemicals [Enviro-Technical Information Problem Spills (Enviro TIPS)]. The series is very extensive an covers many chemicals including chlorine, sodium hydroxide, and calcium hydroxide all of which are considered in this study.

3.3 The contribution of this work to the literature

The references discussed thus far are wide ranging and throw light on assorted aspects of the coastal environment dilemma. Diverse though they may be, three issues may be identified from these references. First, that coastal environments are fragile and unique with important resources; second, that the interactions both within the coastal ecosystems and between humans and the coastal environment are complex and not fully understood; and third, that a great deal more research and management is necessary to slow the alteration and destruction of these environments. It is the goal of this study to deal with some aspects of these issues in the context of the coastal region of Greater Couva region in Trinidad, West Indies. The following chapter outlines the methodology applied in this study.

CHAPTER 4

Methodology

4.0 Introduction

In developing countries, the establishment of cost effective and accurate methodologies for addressing environmental problems are often neglected. The establishment of such methodologies provides a framework for the implementation of standardized EIA. This thesis utilized three basic methodologies for assessing the impacts of the industrial estate on the Couva/Pt. Lisas region. The first methodology focuses on identifying general environmental changes in the region. This sequential analysis of mapped aerial photographs is called Time Series Analysis. The second methodology focuses on assessing the impacts of those changes derived from the application of the first method, and can be subdivided into two categories; statistical, and impact assessment methods. The following is a list of the methods used in this study:

1. Identification of Change;
    - a) Data Base Compilation
    - b) Mapping
    - c) Conversion to computer compatible form
    - d) Identification of change through GIS
    - e) Assessment of change (quantitative)
2. Assessing the implications of change;

2.1 Statistical Analysis;
- a) Correlation
- b) Regression analysis
- c) Modeling

2.2 Impact analysis methods;
- a) Indicator species
- b) Risk characterization
- c) Indices (Water Quality Index)

The data which aided in analysis in this study were extremely varied in both type and source. This is not unusual since the methods of analysis were also varied. The data consists of two types; (i) that generated through aerial photography and time series analysis, and (ii) government statistics, previous ecological studies of the region, and other reports.

4.1 Identification of Change

4.1.1 Data Base Compilation

The coastal environment encompasses the ecological aspects of the Couva/Pt. Lisas region. These aspects include such variables as coastal waters, the shore line, mangrove vegetation sites, and various land-use patterns of the region. As will be demonstrated later, changes in these data can be represented using a variety of mapping techniques.

4.1.2 Mapping

Mapping created the base line data for the study. The primary source for image data were panchromatic black and white aerial photographs suitable for stereoscopic viewing. These were obtained from the Department of Lands and Surveys which falls under the auspices of The Ministry of Environment, Government of Trinidad and Tobago. Uncontrolled[1] mosaics of the Couva/Point Lisas region were compiled from black and white aerial coverage for the years 1962, 1980 and 1986. All of the photographs were taken

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1 Refers to an assembly of non-rectified photos and non-controlled points (triangulation), only through matching as well as possible the details from one photo to the next.

between the months of February and March of their respective years (Table 4.1 and Appendix I).

Table 4.1: Year and Scale of Aerial Coverage used to obtain base data for study.

Year of Coverage	Scale
1962	1: 20,000
1980	1: 10,000
1986	1: 10,000

Land-use/land-cover maps for the years 1965 and 1972 were also obtained from the same source at scales of 1:10,000 and 1:25,000 respectively. Some historic maps for the region were consulted to gain knowledge of the region before 1962 and before the creation of the Port at Lisas Bay.

4.1.2.1 Ground Truthing

Ground truthing of the aerial photographs was done through tours of the Point Lisas Industrial Estate and Port. In addition, drives through the adjacent region resulted in greater familiarity with the land-use patterns, thus making map construction easier. After completing these tasks, it was possible to formulate a land-use/land-cover classification which took into account the salient features of the traditional agricultural and fishing coastal setting.

4.1.2.2 Classification scheme (Anderson Land-use Classification)

A Land Classification System based on the Anderson Classification was derived. Base maps were then created for the three years at a scale of 1:20,000. (Anderson et al.: 1986). Note that the Anderson system uses levels of categories to represent surface cover. This approach was considered appropriate for this work since:

1. It facilitated the classification of features with or without the use of supplementary information;
2. Information could easily be added to any of the levels;
3. It allowed for the classification of features based on scale selection.

The modified classification is as follows:

Level I	Level II
1 Built-up areas	11 Residential/Commercial
	12 Future Residential
	13 Industrial
2 Agriculture	21 Sugar cane
	22 Other plantation
	23 Rice
3 Vegetation	31 Forest/Trees/Scrub
	32 Mangrove
4 Water	41 Reservoirs
	42 Rivers
5 Transport network	51 First class roads
	52 Second class roads
	53 Rails (disused)
6 Reclaimed	61 Reclaimed land

4.1.2.3 Conversion to Computer Compatible Form

The base maps were reduced to a scale of 1:10,000, and scanned into the Corel Draw! computer software program at 300 dots per inch. This meant that 1 dot on the image represented 64 m^2 of the actual study area. Attempts to apply computerized supervised classification techniques to create maps directly from scanned mosaics were abandoned. This was partially due to the poor quality of some of the photos used initially to create the mosaics. Inconsistencies in the developing process affected contrast between consecutive photos, resulting in the creation of varying reflectance values for similar surface features. This made the differentiation and determination of the regional features impossible. Alternately, tracing of the scanned images allowed the land-use/land-cover maps to be created and used in change detection. These maps will be hereafter referred to as the working maps.

The accuracy of the scales of the working maps were maintained by scale adjustment. This calibration process was accomplished through manual warping and stretching of the working maps relative to a scanned base map (of identical scale). Corresponding tie points from the working maps and the base map were adjusted to provide an optimum fit between both maps. A similar manual adjustment procedure was utilized by Leatherman and Zaremba, (1986: 116) for removing distortions on photographs caused by tilt.

The final working maps displayed three primary land-use categories (see the Anderson Classification):

i) built-up areas (buildings; settlements and industrial sites);
ii) vegetation and agriculture; and
iii) rivers and transport systems.

Precision tests were performed on the final base maps to see how well land-use categories on these maps correlated to those observed on the original aerial mosaics. For this test an 85 % accuracy level was deemed acceptable (Anderson et al., 1976; and Appendix II). In all cases the computed levels of accuracy were approximately 94% thus satisfying the precision accuracy requirement. Observed discrepancies generally occurred due to difficulties involved in identifying the boundaries between sugar-cane, residential-commercial land-uses, and roads (Appendix II).

4.1.3 Identification of change through GIS

Change implies a non-random variation in the phenomena under investigation. Eastman (1991:4) defines change as implying that there exists "not only a difference in land surface characteristics between two dates, but also that the difference is uncharacteristic of the normal variation that might be found from one time period to the next." In this study, GIS will be used to investigate the land-use /land-cover patterns and the marine environment of the Couva/Pt. Lisas region. These were derived from photographic images of the region taken during 1962, 1980, and 1986. The changes were investigated using Time Series Analysis (TSA). Time Series Analysis is concerned with evaluating the temporal changes in a variable under fixed spatial conditions. However, there are two distinct types of time series analysis....qualitative and quantitative. This study focused solely on qualitative techniques. This is not to say that the results of the TSA are not quantitative. It is simply a differentiation in the overlay technique which dictates that raster or image files be utilized rather than vector or attribute data files.

Qualitative analysis in TSA requires the comparison of two images through cross-classification. The results, which are in the form of an output map and a tabulation matrix, allow evaluation of the land-cover classes on a per-category basis, and which are quantitative or measurable.

Land-use/land-cover change was assessed using Geographic Information Systems Time Series Analysis applications. GIS was chosen for this aspect of the study since the overlay and cross-tabulation theories on which the tool is based are well suited to change analysis. The software IDRISI for Windows 1 was utilized to perform the GIS TSA. This was achieved by exporting the working maps from Corel Draw! into IDRISI in a Tiff format. It was then possible through a sequence of commands to perform the TSA. These steps are discussed in the following paragraph.

Comparison of map layers was achieved using the *Crosstab* command in IDRISI. This command is used in the analysis of qualitative data to document changes between pairs of images. This step produces a cross-tabulation table (see Appendix IV) showing the frequencies of classes that have changed as well as an image which is easily reclassified into a change image. For every two map combinations, changes in land-use/land-cover were assessed according to the three primary land-use categories (see page 57). For example, the 1962 working map was 'crossed' with the 1980 working map to produce three (3) '62-80 crossed images', while the 1980 working map was 'crossed' with the 1986 working map in order to produce three (3) '80-86 crossed images'. From the cross-tabulated images, it was possible to create a total of three change maps for the differing land-use classes. Finally, the three pairs of change maps were used to form a total change map which represented all changed land-use categories from 1962 to 1986 (Figure 5.7). Other statistics derived from IDRISI included area coverage of residential/commercial and industrial land-use, agricultural land-use and various categories of vegetation cover for the region. All IDRISI commands and functions are described in Appendix III.

4.1.4 Assessment of changes

Computer-aided data generation and map overlay techniques are well established techniques for mapping impacts in the fields of urban, city, and landscape planning (Chrisman, 1987:427). These methods facilitate identification of possible impacts including their time period and spatial dimensions. However, they are ineffective in quantifying these impacts and in determining indirect and secondary interrelationships.

After change was identified by time series analysis, the extent and magnitude of the change was assessed relative to the percentage change from base line data. In this case 1962, since that year qualified for two criteria: it represented the region prior to the construction of the Pt. Lisas estate; and it was a year for which suitable aerial coverage was available. This provided an accurate reference for identifying the most drastic changes and was in general considered a good tool for documenting changes.

4.2 Assessing the implications of change

These methods entail both statistical analysis and other forms of analysis borrowed from formalized EIA. Some statistical tools were also applied to cause and effect investigations. Chapter 3, the review of literature dealt with the wide range of literature which was necessary to encompass the many and varied aspects of this study. As was discussed earlier, data sources and types utilized in this study are representative of a broad ranging topic, and are provided in Table 4.2. This data in conjunction with the quantitative results of the TSA, and applying both statistical and impact assessment methods, were used to assess the impacts of the Pt. Lisas Industrial Estate on the coastal region of the Greater Couva Area.

Table 4.2: Comprehensive list of all data on Couva Region including Pt. Lisas Industrial Estate.

Variable	Source	Method of retrieval	Time period	Units
Environmental study Volumes I - VII	Institute of Marine Affairs (IMA)	Library research at IMA	1982	various
Vol I Executive Summery	"	"	"	mostly descriptive (other)
Vol II Rivers & Mangroves	"	"	"	m, degrees, species, mg/l, ug/ml
Vol III Flora & Fauna	"	"	"	species descriptive
Vol IV Marine Water Quality	"	"	"	degrees, ppm
Vol V Zooplankton	"	"	"	species, quantities
Vol VI Benthos	"	"	"	number/m^2
Vol VII Fisheries	"	"	"	species, expected values
Vol VIII Factory Sites	"	"	"	chemical products, tonnes/day/ week/year
Population for specific study area	Town & Country Planning	Research request from agency	1960	number by enumeration district
"	Central Statistical Office Government of Trinidad & Tobago (CSO)	"	1980, 1990	"

Variable	Source	Method of retrieval	Time period	Units
Intracensal population growth rates for nation and admin. districts	CSO	Research request from agency	1946, 1960, 1970, 1980, 1990	rate
Population distribution	"	calculated from pop. data	1960, 1980, 1990	% of entire population/enumeration district
Age distribution	CSO	Research request from agency	1980, 1990	amounts by enumeration districts
Employment for Greater Couva region	CSO	Research request from agency	1960, 1980, 1990	amounts by enumeration districts
Number of registered fishermen in Caroni administration district	Agriculture, Lands and Food Production, Government of Trinidad & Tobago Fisheries Division	"	1970 - 1996	numbers
Fish catch by beach	"	"	1962 -1986	lbs, $ value, species
Fish Kills	(Two articles) Caribbean Marine Studies Vol. 1(2), 1990; IMA	library research	1976 - 1990/ 3 cases from 1979	date, location, species, quantity, remarks, possible causes
Boat Survey (boat registration)	"	personally researched	1957 -1986	number
Hydrocarbons in fish, crabs and mussels in Trinidad	IMA library	M.Sc. Thesis University of the West Indies J. G. Singh	1988	ppm/ug^{-1}

Variable	Source	Method of retrieval	Time period	Units
Distance of five fishing grounds from major industrial sites	Maps created from photomaps in IDRISI	Manual measurement	standard	m
Levels of contaminants in various bays in the vicinity of Pt. Lisas	Executive Summary Vol I IMA	research at IMA library	1982	ug^{-1}
EPA standards for industrial waste disposal	Handbook on Toxic & Hazardous Chemicals & Carcinogens (Sittig 1985)	library research Science library U of M	standard	ppm/mg
Breach of EPA standards in bays in the vicinity of Pt. Lisas	combined EPA standards and Executive summary	cross-referenced	1982	(table) bay vs. element
Metal levels as a result of dredging at Pt. Lisas	Article by L. A. Hall 1989. Environmental Pollution Vol 56, 189-207.	library research Science library U of M	1989	ppm
Acceptable levels of organic contaminants and trace elements in foods	Department of Oceans and Fisheries (U of M Campus)	Research contact	standard	ug, kgbw/day
Aerial Photos	Ministry of Lands and Surveys, Government of Trinidad & Tobago	personal search of aerial photo collection	1960, 1980, 1986	scale 1: 20,000 1: 10,000 1: 10,000

Variable	Source	Method of retrieval	Time period	Units
Computerized maps of Land-use/Land-cover (LU/LC) for study area in Corel Draw! and IDRISI	uncontrolled mosaics @ 1:10:000	scanning of traced photomaps then retracing in computer, Corel Draw! and converted via a TIFF file to IDRISI	1960, 1980, 1986	map scale 1:10,000 with computer resolution of 1 dot = $64m^2$
Change Maps 1. Built up areas 2. Vegetation and reclaimed land 3. Transport systems and rivers 4. Total LU/LC change	Corel Draw! and IDRISI	*Crosstab* in IDRISI	1960 -1980, 1980 - 1986	area km^2 map only

4.2.1 Statistical methods

The statistical techniques utilized in this thesis may be described as inferential techniques. These techniques measure the degree to which a set of data supports a hypothesis (Hammond and McCullagh, 1978). Inferential techniques are applicable where ever the issue of probability arises. The inferential techniques used in this thesis are: (1) correlation; and (2) regression.

Model making techniques are also important to statistical analysis. They seek to provide a simplified version of some aspect of reality, while still representing reality as closely as possible. This thesis applied descriptive modeling, a form of modeling which allows predictions to be made.

4.2.1.1 Correlation

Correlation in statistics is defined as the method whereby a coefficient (the correlation coefficient) is calculated to describe the degree of association between two sets of paired values (Hammond and McCullagh, 1978). The existence of a strong correlation between two or more data does not prove causality. Correlation must be viewed along with other evidence in order to determine cause and effect. In this study, correlation coefficients were most often applied to investigate the link between changes in certain environmental classes and industrial growth, (e.g. population growth in the region).

4.2.1.2 Regression analysis

The correlation coefficient does not convey information regarding the precise mathematical relationship between variables, thus it cannot be used to predict variations in one set of variables from a knowledge of the other (Hammond and McCullagh, 1973). The determination of this relationship is best done through regression analysis. Regression lines are simply 'best fit' lines drawn on a scattergrams. A 'trend' line is a special type of regression line which highlights the behavior over time in one of the variables. Trend lines were used in this study in an attempt to link changes in two variables over time (e.g., mangrove loss and shrimp catch fluctuations). In addition, trend analysis was also applied to fill in various missing data such as stormwater flows from residential land-use into the coastal waters over time. In this work, the trends were always assumed to be linear so as to simplify the analyses. It is important to note that this assumption generally satisfied the trends observed in the data.

4.2.1.3 Modeling

A model can be viewed as a simplification of reality or as a numerical means of representing a theory. Either definition is suitable for the purposes of this research since either implies some form of explanation or prediction. There are two types of explanatory models, stochastic (yielding only approximate or probable outcomes) and deterministic (yielding precise outcomes). This study makes use of the former, particulary with respect to temperature models which determine heat inputs into a body of water. In this way, thermal pollution in the Gulf was assessed.

4.2.2 Impact assessment methods

EIA studies often apply methods used in formalized EIA. Thus this EIA study focuses on the following areas:

1. Indicator species;
2. Risk characterization; and
3. Water quality index.

4.2.2.1 Indicator species

Indicator species are species which are selected for the purpose of determining the existence of and level of a pollutant in the environment. The species are 'indicative' since they are chosen on the basis of their sensitivity to or tolerance of a particular pollutant and its effects. Indicator species may be plant or animal. In this thesis, indicator species are mainly fish species. The fluctuations in these species were used to analyze the effects of various pollutants in the Gulf of Paria.

4.2.2.2 Risk characterization

Risk characterization is simply a list of the possible and probable effects which any given activity exerts on the environment. These may include anything from the removal of vegetation to the discharge of effluent into coastal waters. Both of these issues were addressed in this study.

4.2.2.3 Indices (Water Quality Index)

An environmental index is the most general descriptive tool used in environmental assessment. This tool is used to simplify data and translate it into information which can be applied in the decision making processes. In this study, a water quality index was applied to determine the extent to which the coastal waters in the Gulf of Paria were polluted.

4.3 Summary

The methodologies applied to this study are many and varied. Similar to the literature review, they reflect two fundamental themes which run throughout this research; (1) the acquisition and representation of data through mapping, and (2) the assessment of environmental issues. Despite the fact that limitations of data and information were encountered, the use of these techniques helped to reduce the impact of the limitations by providing pertinent results to environmental queries. These results are presented in the following chapter.

CHAPTER 5

Results

5.0 Introduction

The need for monitoring environmental change has been established earlier in this study. The maps which are provided in this chapter represent various elements of the physical environment which displayed change during the period 1962 to 1986. These maps are essentially land inventory maps, since they provide an inventory of the land-use /land-cover that existed at various times in the region.

More importantly, this chapter discusses the implications of these changes. An EIA study is performed in order to assess the impacts implied by the physical changes exhibited by the maps. The chapter applies a broad range of techniques, data types and data sources in order to achieve this goal. Statistical and impact assessment methods (Chapter 4) were the techniques applied to impact assessment, just as TSA and GIS were the techniques applied to derive the change maps. Therefore, this chapter presents the change maps, while focusing on assessing the impacts of the Pt. Lisas Industrial Estate by borrowing techniques from formalized EIAs.

5.1 Change Results - Maps

Chapter 4 discussed the procedure for creating working maps for TSA. These working maps for each study year are shown in Figures 5.1 to 5.3. Figure 5.1 reveals that though the region was dominated by sugar-cane cultivation, a few industrial sites existed in 1962. Residential/Commercial land-use was situated mainly in the central part of the region.

A few plantations (cultivating cocoa and coffee), existed in the east central portion of the study area. Rice is also cultivated in the north east of the region and much of the coastal region between Lisas Bay and Carli Bay exhibited continuous mangrove communities. Some small communities of natural vegetation remained in the from of trees and scrub to the central east of the region along the roadways.

Figure 5.2 reveals that the region was still dominated by sugar-cane cultivation in 1980, although the amount of land area under industrial land use has increased by just over 200%. Cocoa and coffee plantations in the central region of the area had been virtually abandoned and had reverted to the vegetation of trees and scrub. However, the central eastern region which once exhibited natural vegetation in 1962, was in 1980 dominated by transport networks, with increased Residential/Commercial land-use, both in this region and the entire study area. Rice cultivation had decreased by a minimal amount, while the continuous mangrove communities of 1962 had been interrupted by industrial sites, ports, and reclaimed land from just beneath Couva Bay to central Lisas Bay.

Figure 5.3 reveals that by 1986, although the region was still dominated by sugar-cane plantation, industrial land-use had again risen. Residential/Commercial land-use had also increased in virtually all previously built-up areas. Most of the remaining cocoa and coffee plantations had again decreased, leaving the area to revert to natural vegetation. All but a small patch of natural vegetation that existed in the central eastern region of the study area had been replace by transport networks and residential land-use. Rice production had also declined, giving way to residential land-use and its accompanying roadways, while mangrove had decreased by almost 42% from its 1962 land area coverage.

Crosstabulation and overlay procedures for documenting change were also described in Chapter 4. The resulting maps, Figures 5.4 to 5.6 display the relevant changes in the three primary land-use categories for the time periods 1962 - 1980 and 1980 -1986. Note that Figure 5.7 shows the total change in all the land-use categories between 1962 and 1986. A table quantifying these changes in terms of percentage from baseline measurements is provided in Table 5.1. It is also important to note that all changes were assessed using 1962 inventories as baseline data.

Figure 5.4 shows the changes between 1962 - 1980 and 1980 - 1986, for the category of Residential/Commercial land-use and Industrial land-use. Figure 5.5 shows the changes in vegetation and reclaimed land-use categories and Figure 5.6 shows changes in rivers and transport network systems, both for the same time periods.

The *Crosstabulation* method which yields a Kappa Index of Agreement, is a measure used to quickly gain an appreciation of the category or categories displaying the most change over a time period. This index ranges between 0 and 1, with no agreement represented by 0 and 100% agreement represented by 1. The Kappa index comparing pairs of images from Figures 5.4 through Figure 5.6 is provided in Table 5.2. An examination of the table reveals that most change occurred between 1962 and 1980 in the Built-up category and between 1962 and 1980 in the Vegetation and Agriculture category. A detailed discussion of these results is provided in the following paragraphs.

Figure 5.1: Working Map, Land-use/Land-cover 1962

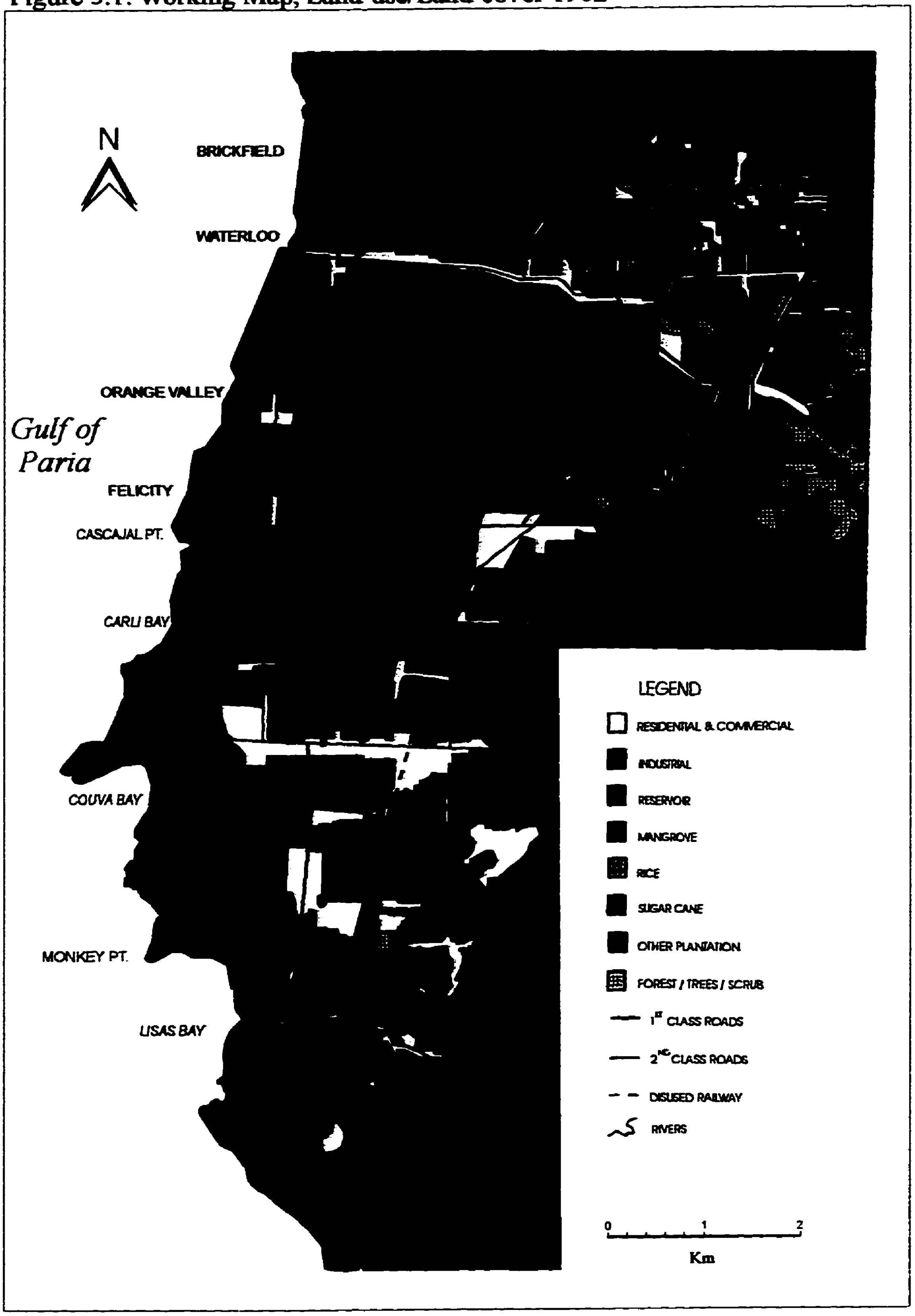


Figure 5.2: Working Map, Land-use/ Land-cover 1980

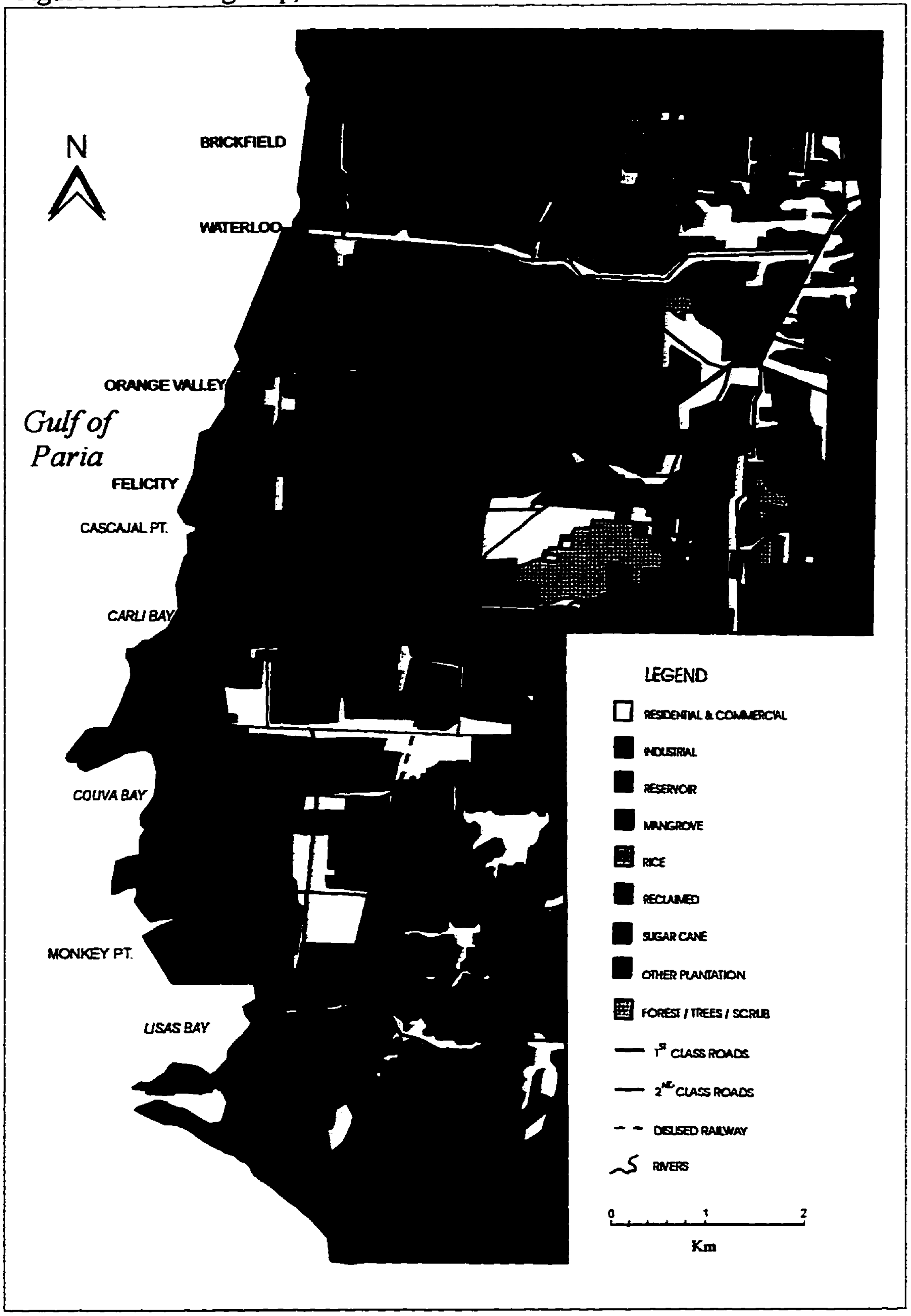


Figure 5.3: Working Map, Land-use/ Land-cover 1986

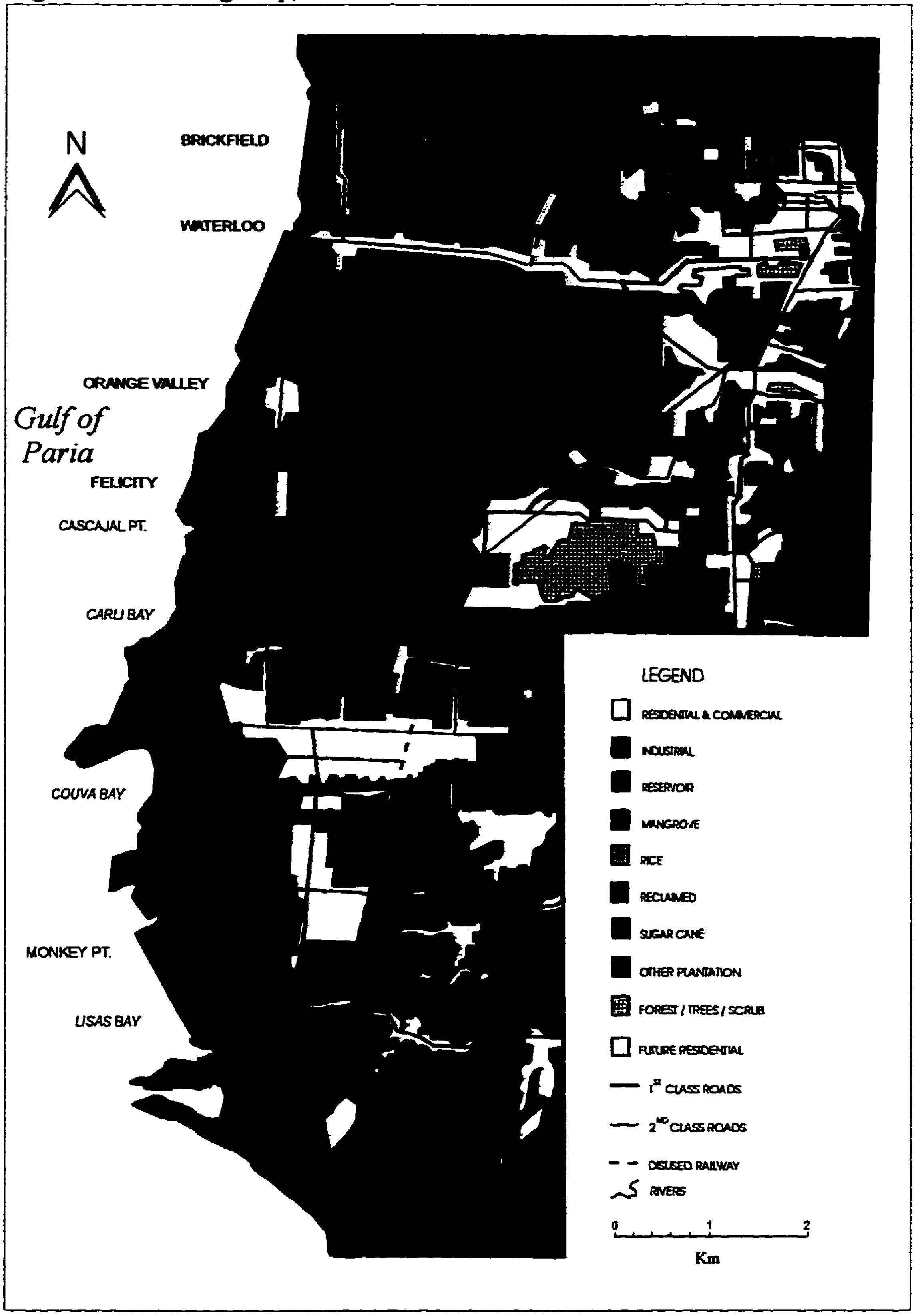


Figure 5.4: Change in Built-up Classes

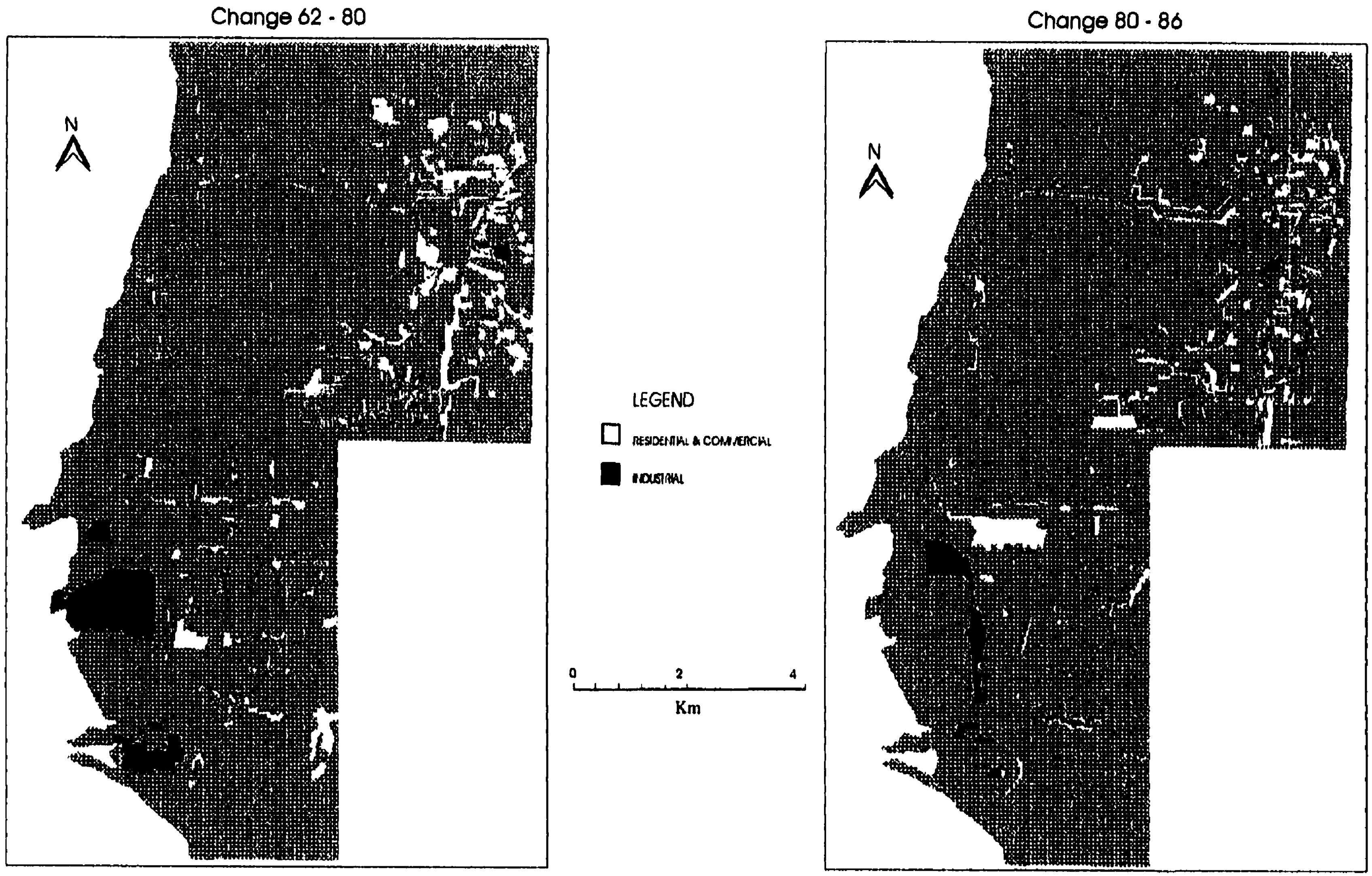


Figure 5.5: Change in Vegetation and Reclaimed Land

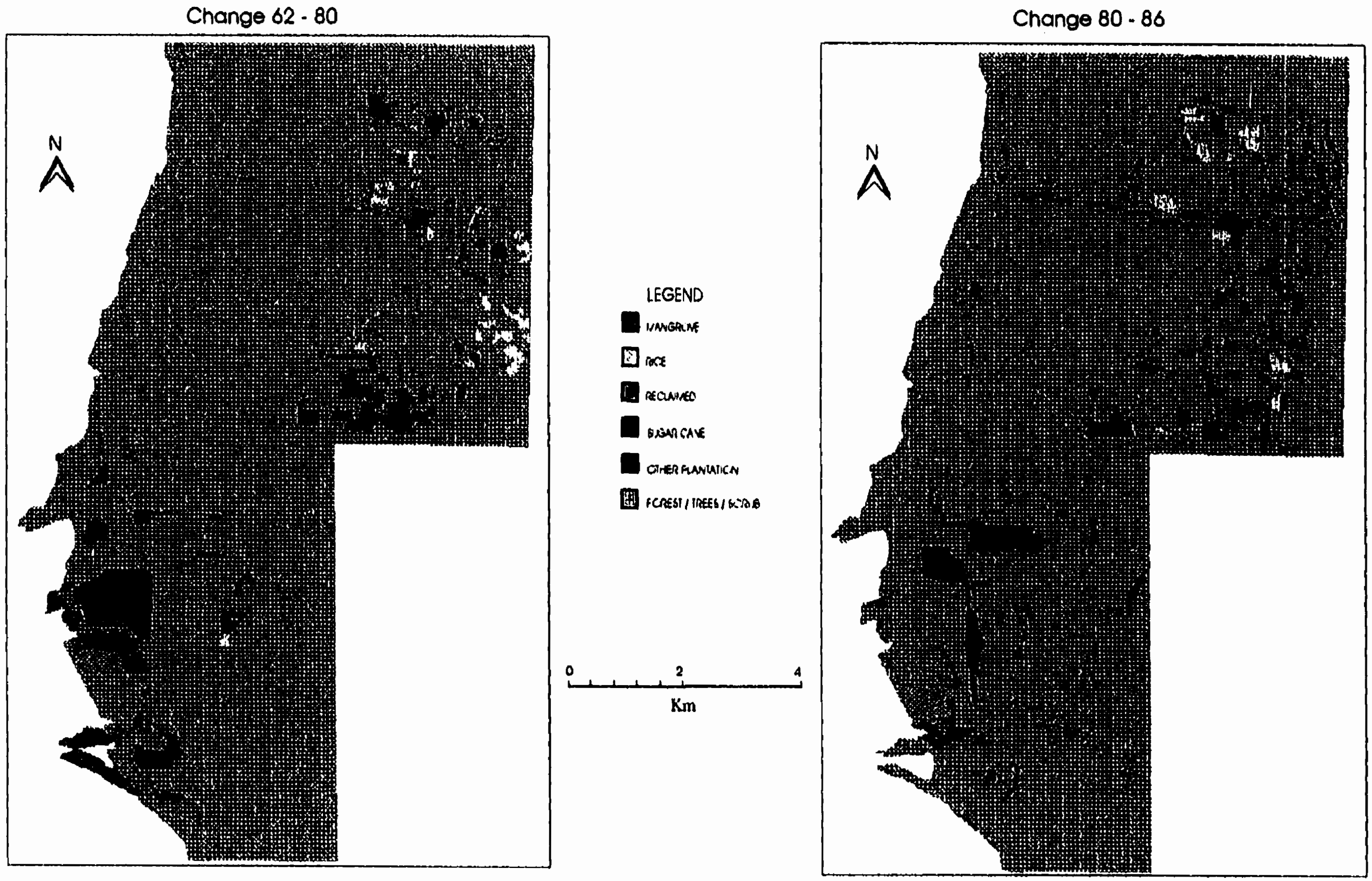


Figure 5.6: Change in Rivers and Transport Systems

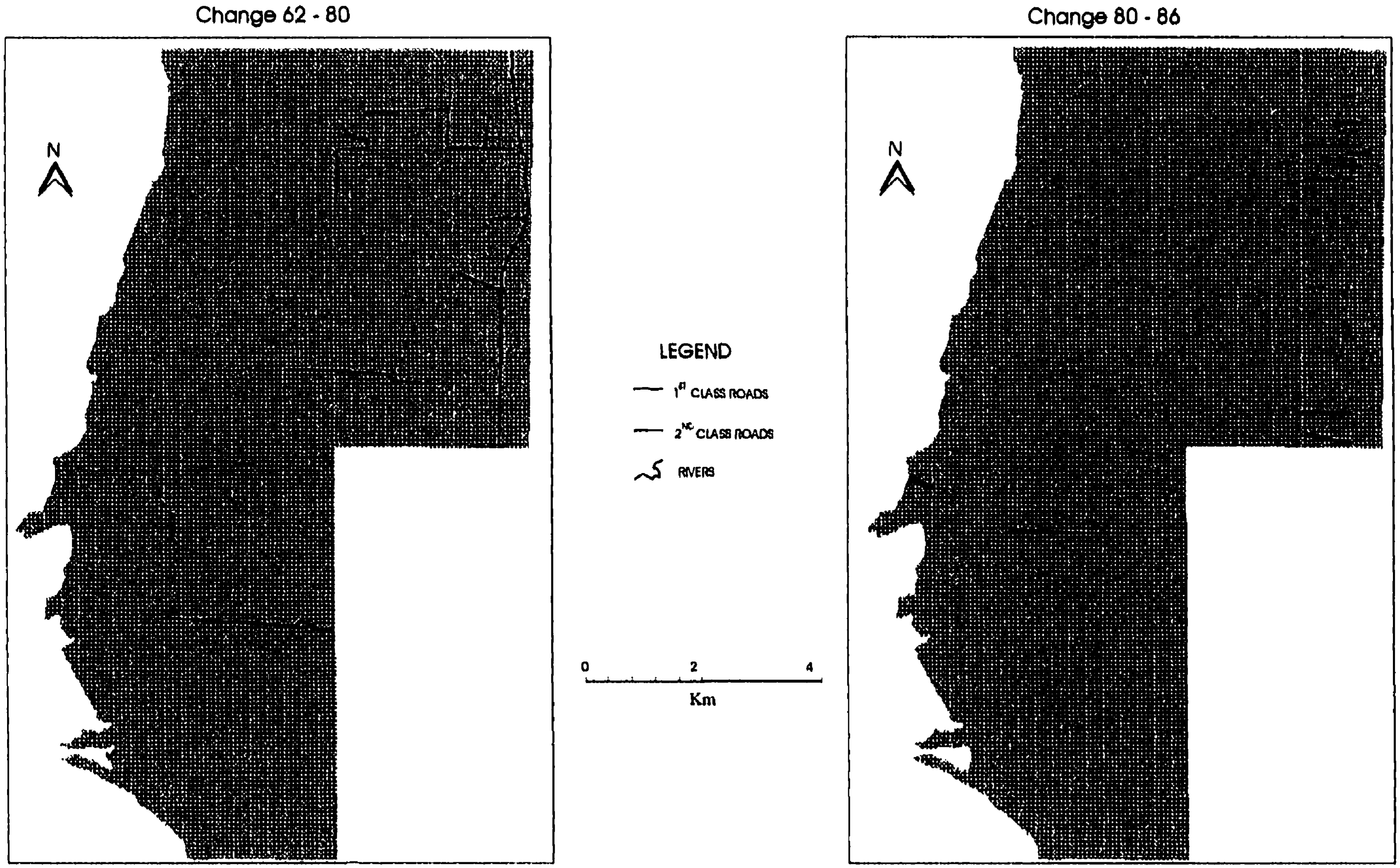


Figure 5.7: Total Land-use/ Land-cover Change 1962 - 1986

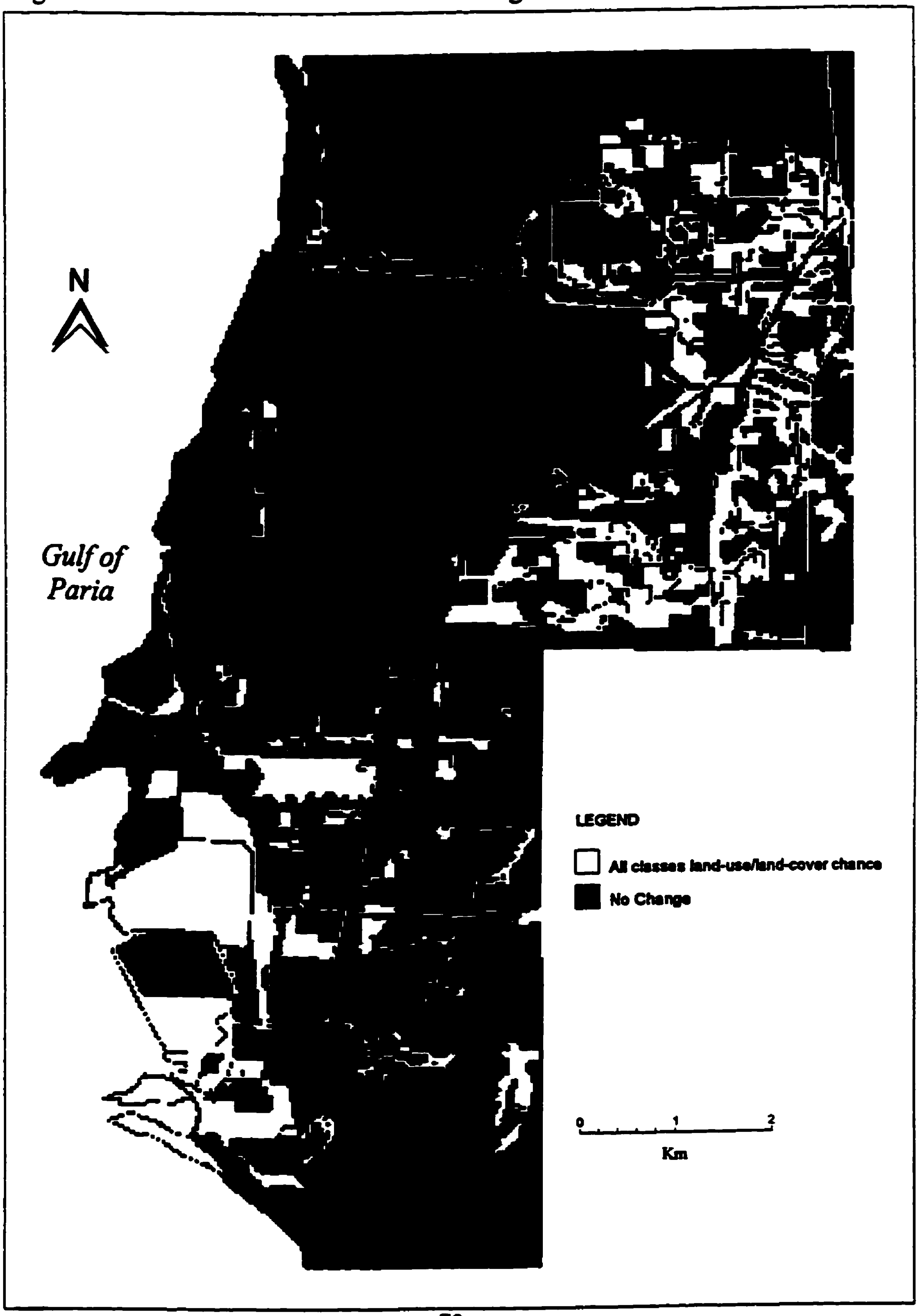


Table 5.1: Changes in Land-use/Land-cover 1962, 1980, and 1986 in km^2.

Level one Classification	Level two Classification	Change 62 - 80 km^2	Change 80 - 86 km^2	1962 (base data) km^2	% Change from 1962
Built-up	Residential/ Commercial	11.66	9.106	11.34	183.12
	Industrial	6.394	2.495	1.401	634.5
Vegetation/ Agriculture	Cane	-8.44	-10.09	181.6	-10.2
	Mangrove	-3.317	-0.602	9.374	-41.8
	Other Plantation	-1.161	-0.7616	3.931	-60.4
	Rice	-0.349	-0.977	2.198	-60.35
	Forest/Trees/Scrub	-1.455	0.552	1.795	49.6
	Reclaimed	4.287	1.667	0	100
Rivers/ Transport Systems	Rivers	0	0.079	1.043	7.6
	1st class roads	0.602	0	2.044	29.4
	2 nd class roads	0.746	0.623	0.113	1211.5

Table 5.2 : Kappa Index of Agreement for Images 1962, 1980 and 1986.

Image Pairs	Kappa Index of Agreement
1962 & 1980 Built-up	0.8058
1980 & 1986 Built-up	0.8661
1962 & 1980 Vegetation & Agriculture	0.8044
1980& 1986 Vegetation & Agriculture	0.8711
1962 & 1980 Rivers & Transport Systems	0.9204
1980 & 1986 Rivers & Transport Systems	0.9643

5.2 Discussion

5.2.1 Built-up Classes (Buildings)

Built-up classes in this study included areas from the aerial coverage that exhibited buildings. These categories included such buildings as residences, businesses, schools, hospitals, or any other 'built' infrastructure necessary to serve a community. Therefore, much of this category was included under Residential/Commercial since in many cases it was impossible to and often unnecessary to distinguish between these various types of buildings. It is also important to recall (Chapter 2), that strictly Residential and Commercial land-use categories for the region were difficult to differentiate since many entrepreneurs reside in the floor above their business venues.

Residential/Commercial

The Sir Solomon Hochoy Highway which delineates the eastern border of the study area was built between 1962-1980. This increase in roadways spawned an increase in ribbon and spontaneous housing settlements. The Couva Housing Project (Couva) and the Fairview Park Project (Freeport), two of the five planned housing developments in the region, was built to alleviate the housing problem for industry employees. It accounted for a large portion of the increase in this land-use class. Changes in the amount of commercial buildings in the region were difficult to ascertain using photogrammetric techniques, since as previously stated, many commercial activities of the region were conducted on the main floor of residential buildings.

Industry

A comparison of the area occupied by industrial sites between 1962 and 1986 showed an increase of 634.5 %. This represented the second highest increase of the primary land-use classes.

5.2.2 Vegetation and Agriculture

Although agricultural land-use in the region is a form of vegetation land-use, they were separated in this study since sugar-cane cultivation, which dominates so much of the land-use in the region, may be viewed as an economic activity. It was also necessary to distinguish between natural vegetation in the region (of which little exists), and agriculture. Reclaimed land was included in this category since loss in some mangrove communities was as a result of reclamation.

Sugar-cane

Sugar-cane represents the dominant land use in the region. However, between 1962 and 1986 it showed the largest decrease of all the Level II land-use categories. These changes represent a conversion from agricultural activity to other land-use practices. Figures 5.2 and 5.3 show that residential and industrial practices were the major land uses which replaced sugar-cane cultivation.

Mangrove and Reclaimed Land

Over a 25 year period, coastal mangrove communities decreased from approximately 9.374 km^2 in 1962 to approximately 5.445 km^2 in 1986, most of this decrease occurred in the area of Lisas Bay. Reclamation utilizing dredge spoil, and industrial land-use were the two main factors contributing to the large-scale loss of mangrove. In addition, reclaimed land accounted for an approximately 2.575 km^2 increase in the land surface of the region from 1962-1986. Reclaimed land was found to be the third largest contributor to the total change in land use change over the 25 year period. As Figure 5.5 attests, reclamation occurred in Lisas Bay between Couva and Claxton Bays.

5.2.3 Rivers and Transport Systems

Rivers and transport networks were categorized together for improved efficiency in analysis of linear features.

Rivers

The major change in the river system of the region resulted from the diversion of the Couva River into Carli Bay and produced an increase in the channel length. This change occurred mainly between 1980-1986, in order to facilitate better drainage from the Pt. Lisas Industrial Estate and from the housing complexes into the Gulf Of Paria. This diversion was responsible for an 860 m increase in the channel length of the Couva River. The associated decrease in mangrove area was 0.079 km^2 (see Figure 5.6).

Roads/Highways

The increase in second class roads represented the largest percentage increase in a single feature. The increase in road networks is a consequence of the increased access provided to new housing and industrial developments in the region. The change in the number of first class roads was due solely to the construction of the Sir Solomon Hochoy Highway between 1962 and 1980 as stated earlier (Figure 5.6). Much of the increase has therefore taken place in the northern half of the study area, especially along the north eastern strip, and particularly between 1980 and 1986. Few roadway and river changes occurred in the southern part of the study area, those which did, occurred between 1962 and 1980.

In summary, much of the change in land-use registered in the region resulted from the conversion of agricultural land to either residential/commercial or industrial land use. This change marked the decrease in traditional rural land-use to a more urbanized form of land-use. This shift represents an environmental shift from a low impact/low risk environmental system to types of land-use that may be considered high impact/high risk. This is expected to result in a set of positive and negative, short term and long term implications for the environment. The next section addresses these implications.

5.3 Implications of change

This section investigates the impacts of the Pt. Lisas estate on the environment of the Couva/Pt. Lisas region. In doing so, it considerations that while changes in land use imply environmental impacts, these impacts vary in magnitude, timescale, and spatial scale. It is in this context that the two phases of the development of the Pt. Lisas Industrial estate were investigated. The two phases of development may be described as: (1) the construction phase; and (2) the operation phase.

5.4 Impacts during the Construction Phase of Project

Three main activities took place within the construction phase of the Pt. Lisas Industrial estate. These were (1) dredging and reclamation phase; (2) the creation of transport infrastructure; and (3) the loss of mangrove [an important consequence of (1) and (2)].

5.4.1 Dredging and Reclamation

Dredging is generally undertaken for a number of reasons. For example, it may be to facilitate the construction of navigation channels, or for the laying pipes such as was the case for the Pt. Lisas Port. Other reason for dredging include the creation and maintenance of canals, harbours, and marinas associated with residential developments. Reclamation is performed in order to create new land areas on which a variety of activities may be sited. In the Pt. Lisas region, the reclaimed land was intended for future siting of industries.

5.4.1.1 Risk Characterization

Studies show that effects of dredging in a coastal region are extremely variable and case specific. Morton (1977), discussed the range of potential effects resulting from dredging and reclamation activities. He found that it could result in environmental impacts such as turbidity, alteration of currant patterns, altered chemistry of sediment, re-mobilization of contaminants, and destruction of habitat, to name a few. Bonvicini Pagliai et al., (1985), observing dredging and reclamation in the Gulf of Cagliari, Sardina, Italy, found that benthic microfauna in the area was wiped out due to increased turbidity. However within a six-month period after dredging; the benthic microfauna communities returned in comparable quantities to those of the pre-dredging period. It was therefore ascertained that no long term environmental effects accrued from the project. Al-Madany et al., (1991), while reviewing dredging and reclamation activities in Bahrain, in the Arabian Gulf, found that the loss of coral colonies, mangrove communities and sea-grass beds due to said activities, caused adverse social, economic and environmental impacts. Nonetheless, there are a number of possible effects which are associated with access channel dredging and coastal reclamation.

Changes in the immediate environment of a dredged area generally resulted in increased turbidity (Morton, 1977 and Bonvicini Pagliai et al., 1985). This causes a number of ecological changes such as decreases in the benthic fauna; chemical changes in bottom sediment as well as in the surrounding water; and changes in channel floor topography, circulation and transport patterns. These impacts may later be amplified by the action of pollutants from fuel tanker leakage and spillage, dumping of shipboard wastes, and cleaning methods for industrial pipeline flushing. Other impacts include:

1. Disturbance of vital habitat areas, (e.g., damage to and/or destruction of mangrove communities);
2. Localized increase in turbidity resulting in modification in bottom sediment and changes in light penetration, with accompanying decrease of variety in benthos communities that may be a food source for commercial fish species;
3. Change and increase in chemical components of sediment and water, specifically metals, which could result in the decrease of certain susceptible fish species as well as endanger human health due to the intake of contaminated fish;
4. Alteration of local current patterns;
5. General decrease in water quality during and for a short period subsequent to dredging.

5.4.1.2 Dredging and Reclamation in the Pt. Lisas Region

Large scale changes in the Pt. Lisas region resulted from dredging and reclamation. In 1962 no dredging or reclamation was visible. Between June 1979 and September 1981 a navigational channel designed to provide ships access to the industrial estate was dredged in the Gulf of Paria. Between 1980 and 1981 a turning basin was dredged at Monkey Pt.. The spoil from both these projects was utilized as fill material for reclamation in Lisas Bay. To accomplish this, large tracts of vegetation were removed from the reclamation site. In total the reclamation produced 5.954 km^2 of land. Dredging was also done to change the course of the Couva River. As a consequence of the diversion, the exit of the Couva River was changed from Couva Bay to Carli Bay. The length of the dredged channel required to produce this diversion was 860 m.

5.4.1.3 Impacts of Dredging and Reclamation in the Pt. Lisas/Couva Region

Few studies of the impacts of this human-made alteration have been conducted. This makes its impacts difficult to analyze. Another factor which hinders impact assessment is the possibility of long-term effects. Without consistent monitoring, the long term effects of dredging and reclamation can go unheeded. In the Pt. Lisas region, no long-term effects of these operations have been investigated. Therefore a qualitative, short term identification of the problems associated with these practices will be addressed.

Disturbance of vital habitat areas (e.g. damage/destruction of mangrove)

The loss of vital habitat in the region can be linked to the reclamation of large areas of land in Lisas Bay. For example, reclamation accounted for the loss of 3.929 km^2 in mangrove communities between 1962 and 1986. The implications of the large-scale loss of mangrove in the region are addressed later in this chapter.

Localized increase in turbidity resulting decrease of variety in benthos communities

Research performed by McShine-Mutunhu (1985) examined the environmental and sociological impacts associated with dredging the Couva River diversion. This research concluded that the dredging of the Couva River had destroyed the benthic animals in the vicinity. As a result, the populations of fish species in the region which preyed on these animals (e.g., Croker and Salmon) were expected to diminish. The author described other adverse effects of dredging. In addition to destroying large portion of the mangrove swamp, dredging increased the intrusion of salt water into coastal inland areas (McShine-Mutunhu, 1985; 13).

Change and increase in inorganic chemical (metal) components

A study carried out by Hall (1989) examined the fluctuations in concentration of various metal ions present in the water and sediment during and after the dredging phase at Pt. Lisas (Savonnetta Pt.). Of the metals studied, [Iron (Fe), Chromium (Cr), Magnesium (Mn), Nickel (Ni), Lead (Pb), and Cadmium (Cd)], Hall (1989) found that in areas adjacent to the dredging sites sediments showed significant increases in the concentrations of Fe, Ni and Cr. In particular, there were sharp increases in the concentrations of these metals in sediment samples collected during the dredging phase. These concentrations tapered off when the dredging operation was discontinued. Nevertheless, gradual increases in the concentrations of these metals were observed with time in areas distant from the dredged site. Hall (1989) attributed these increases to ocean-current action. In general, concentrations of these metals in sea-water (with the exception of Pb and Ni) appeared to be unaffected by the dredging operations. Though not proven, Hall (1989) conjectured that the gradual increase in certain metals away from the dredge site following the termination of dredging operations, may also be attributable to these currents leaching metals from the dredge spoil deposited nearby for reclamation purposes.

Alteration of local current patterns

Coastal configuration is another factor which has been altered largely through dredging and reclamation. Dredging has not greatly changed the shape of the coast line (except where the diversion of the Couva River took place), however reclamation has. Any such alteration in coastal configuration is usually accompanied by a localized transformation in coastal current patterns.

General decrease in water quality

Both Hall (1989) and McShine-Mutunhu (1985) expressed concerns about changes in water quality due to the dredging and reclamation activities in the region. Hall (1989) suggested continued monitoring, while McShine-Mutunhu (1985) suggested discontinuing further dredging in the region.

5.4.2 Roads and Transport Networks

Prior to the Pt. Lisas Industrial Estate, the Couva/ Pt. Lisas region was characterized as a series of rural, agricultural communities or villages. Following construction and the commencement of operations at the industrial site, the region's size and functions had been altered. The new functions have led to an increase in the number of roadways and transport systems. As pointed out earlier, these formed the single largest percentage change in land-use in the region over the period of study.

5.4.2.1 Road Classification

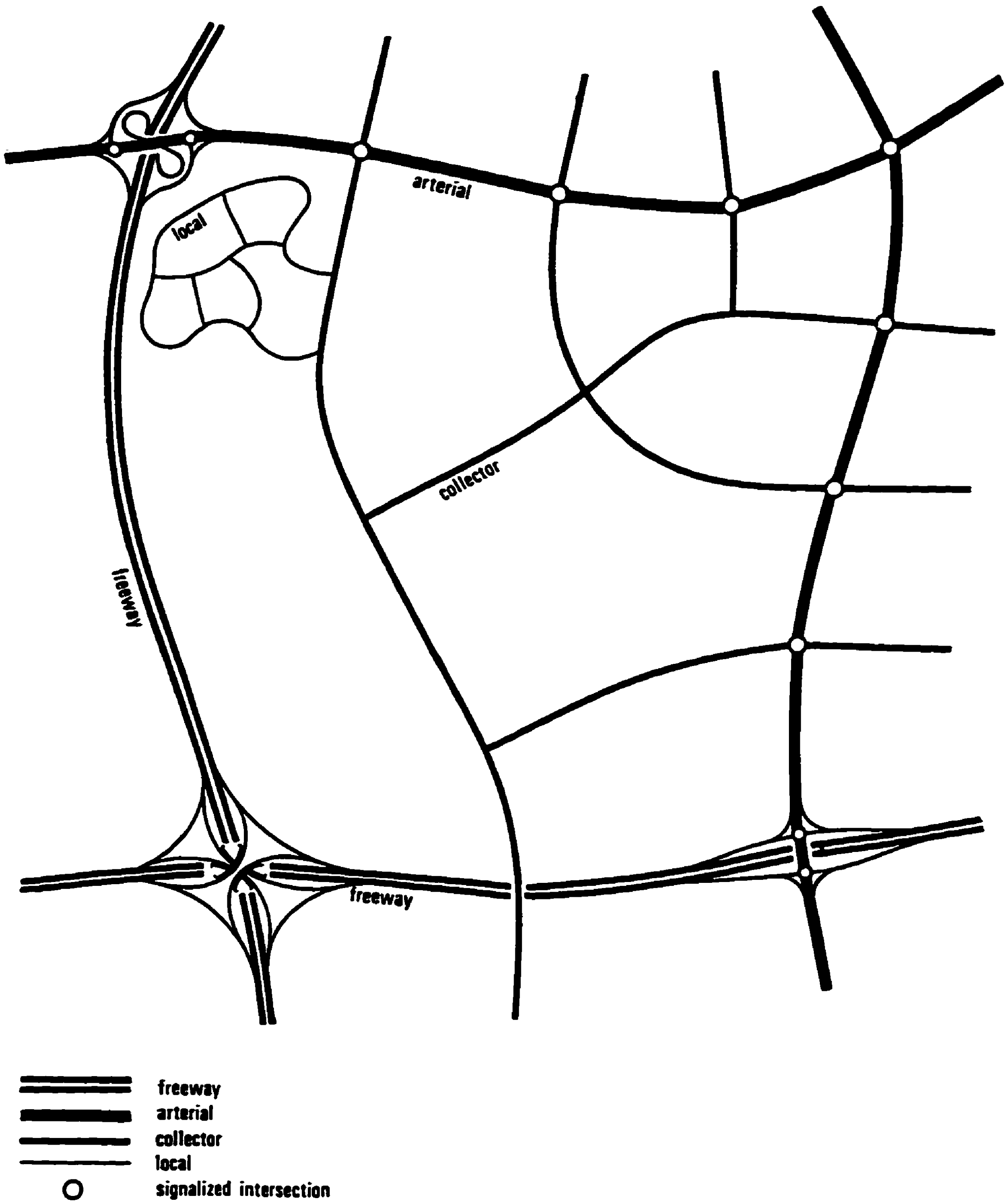
Roads are generally classified according to function. The Roads and Transportation Association of Canada (RTAC) developed a road classification scheme based on geometric design (Appendix V). This geometric design takes into account function, traffic type and traffic volume. Geometric design standards are generally applied because they are geared toward designers working closely with both highway planners and land-use planners, and thus satisfy criteria from all three disciplines. These standards also embrace other forms of classification since they differentiate between land service, traffic service and traffic use. The Canadian geometric design standards are composed of eight primary divisions shown in Table 5.3 (Figure 5.8 shows the relationship between each classification):

Table 5.3: Geometric design standards primary divisions.

Rural	Urban
Local	Local
Collector	Collector
Arterial	Arterial
Freeway	Freeway

The terms 'rural' and 'urban' also refer to the main characteristics of the adjacent land-use, not solely to jurisdictional boundaries or features of typical cross section. Important factors considered in this classification are service function, traffic volume, flow characteristics, running speed, vehicle type, and connections (RTAC, 1986, A 9-10). These are shown in Tables 5.4a and 5.4b. Although designed for Canadian needs, these standards are used in this study to assist in the categorization of the Couva/ Pt. Lisas region based on its road system characteristics.

Figure 5.8: Relationship of road classification.



(Source: Geometric Design Guide for Canadian Roads, 1986, Figure A.5, A 12.

Table 5.4a :Characteristics of rural roads

	rural locals	rural collectors	rural arterials	rural freeways
service function	traffic movement secondary consideration	traffic movement/land access equal importance	traffic movement primary consideration	optimum mobility
land service	land access primary consideration	ditto	land access secondary consideration	no access
traffic volume vehicles/day (typically)	<1000	<5000	<12000	<8000
flow characteristics	interrupted flow	interrupted flow	uninterrupted flow except at signals	free flow (grade separate)
design speed, km/h	50 - 90	60 - 100	80 -130	100 - 130
average running speed, km/h	50 - 90	50 - 90	60 -100	80 -110
vehicle type	predominantly passenger cars, light to med. trucks, occ. heavy trucks	all types up to 30% trucks in the 3 to 5 range	all types up to 20% trucks	all types up to 20% heavy trucks
normal connections	locals collectors	locals, collectors, freeways	collectors, arterials, freeways	arterials, freeways

Source: Geometric Design Guide for Canadian Roads, 1986, Table A.5a, A 13.

Table 5.4b: Characteristics of urban roads

	urban locals	urban collectors	urban arterials	urban freeways
service function	traffic movement secondary consideration	traffic movement/land access equal importance	traffic movement primary consideration	optimum mobility
land service	land access primary consideration	ditto	land access secondary consideration	no access
traffic volume vehicles/day (typically)	<3000	1000 - 12000	5000 - 30000	> 20000
flow characteristics	interrupted flow	interrupted flow	uninterrupted flow except at signals and crosswalks	free flow (grade separate)
design speed, km/h	30 -50	50 - 80	40 -100	80 - 120
average running speed, km/h	20 - 40	30 - 70	40 -90	70 -100
vehicle type	passenger and service vehicles	all types	all types up to 20% trucks	all types up to 20% trucks
normal connections	locals collectors	locals, collectors, arterials	collectors, arterials, freeways	arterials, freeways

Source: Geometric Design Guide for Canadian Roads, 1986, Table A.5b, A 14.

5.4.2.2 Function of the Couva/ Pt. Lisas region based on road classification

The Couva/ Pt. Lisas region is dominated by collector roads which provide access to land adjacent to sugar-cane fields. In addition, the region is characterized by many arterial roads which connect into a single freeway (The Solomon Hochoy Highway). In residential areas, local roads dominate. Due to the changes in density and functional variability of the road networks in the region, a reclassification of settlements in the region based on road function and traffic type was produced. It is important to note that between 1962 and 1986, the function of the collector roads has remained unchanged. Therefore this analysis only compared the characteristics of rural freeway and rural local roads, as well as those of urban freeway and urban local roads.

Rural/urban freeways

The service function of a rural freeway is to "connect larger cities, industrial concentrations and recreational areas; from the major highway routes through intensely developed areas" (Geometric Design Guide for Canadian Roads, 1986, A 13). Alternately, the service function of an urban freeway is to "connect primary areas of traffic generation and serve as urban extensions of principal rural highways. They are intended to serve traffic between large residential areas, industrial or commercial concentrations and the central business district" (Geometric Design Guide for Canadian Roads, 1986, A 15).

In 1962 no freeway existed; although not designed as a freeway, the Southern Main Rd. (Figure 5.1) acted as such. With the addition of a freeway (The Sir Solomon Hochoy Highway), the characteristics of travel within the region changed. The Sir Solomon Hochoy

Highway was built to facilitate transport "for the anticipated increased movement of people and goods between northern and southern Trinidad" (Town and Country Planning Division, 1974, 5.12). This freeway (highway in local jargon) connects the larger residential settlements along the countries north/south axis while connecting central (region under investigation) and south Trinidad to the business centre of Port-of-Spain in the north. It also connects the north and south to Pt. Lisas industries. The Sir Solomon Hochoy Highway can therefore be classed as an urban freeway.

Rural/urban local roads

The residential areas in 1962 exhibit a sparser density of local roadways than in 1980 or 1986. The areas of greatest change in descending order of importance are Couva, Dow, and Agostini (Figure 2.3).These 'local' roads differ from 1962 to 1986 in service function, traffic volumes, and flow characteristics.

The primary function of both rural and urban roads is land access. Prior to 1980, the roads in the Couva/ Pt. Lisas region served as rural local roads. However, by 1980 the roads in the region were upgraded from rural to urban in order to cater to the expanded services required by the growing population. The traffic volumes of rural local roads are generally low, whereas those for the urban local roads are much higher due to urban development (residential and commercial) along its shoulders. In addition, the traffic flow characteristics of rural local roads differ from those of urban local roads. In rural areas traffic flow is generally interrupted by stop conditions at intersecting roads and pedestrian traffic is generally unrestricted. Urban local roads have interrupted flows which are characterized by signalized controls. Moreover, pedestrian flow is in some cases restricted and regulated. The transition of settlements such as Couva and Dow from villages in 1962 to bustling towns by 1986 with their own commercial services confirms the transition from rural to urban land classification.

Other roadways in the region were built to allow organized movement "within the main urban centres" and to provide a "more reliable public transport system to give access to urban and rural settlements" (Town and Country Planning Division, 1974, 5.12). These 'urban centres' were upgraded from rural post 1962. The upgrading from rural to urban, and therefore a shift in function, resulted in both increased pollution and associated impacts on the environment.

5.4.2.3 Residential and industrial land-use and implications of road increase

Roadways and residential land-use in the region of study show a high degree of association. This association is demonstrated in Figure 5.9. Residential land-use and roads are inextricably tied. This is seen in the case of in 2nd class roads, increases of which arose from the need for access roads to connect major roads to housing developments provided for employees of the industrial estate. It follows therefore that roadway expansion in the region was directly linked to industrial growth. A comparison of industrial growth and the expansion of transport networks in the region also suggest a strong association. Figure 5.10, presents a graph of the two variables.

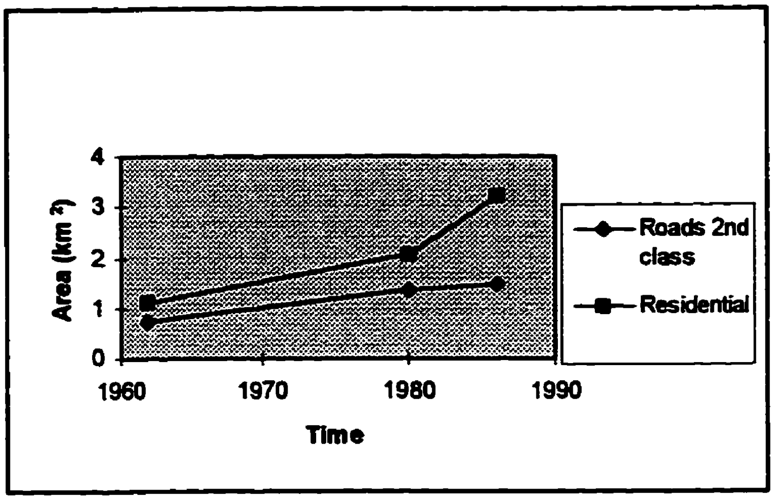
5.4.2.4 Risk Characterization of increased roads on the environment

Apart from the expected increase in traffic and air pollution, the construction of additional roadways in the study region induced new forms of land-use along the transport corridors (see Figure 5.12). When such developments occur in coastal regions they can have a great impact on the coastal ecosystems. In the case of the study region, the increase in the number of ribbon settlements which followed road construction played a role in the ultimate degradation of the environment of the Gulf of Paria. The consequences of a system of progressively denser road networks are:

1. spawning of residential/commercial activities
2. vegetation/habitat loss and/or disruption;
3. drainage pattern alteration;
4. surface water runoff flow de-stabilization.

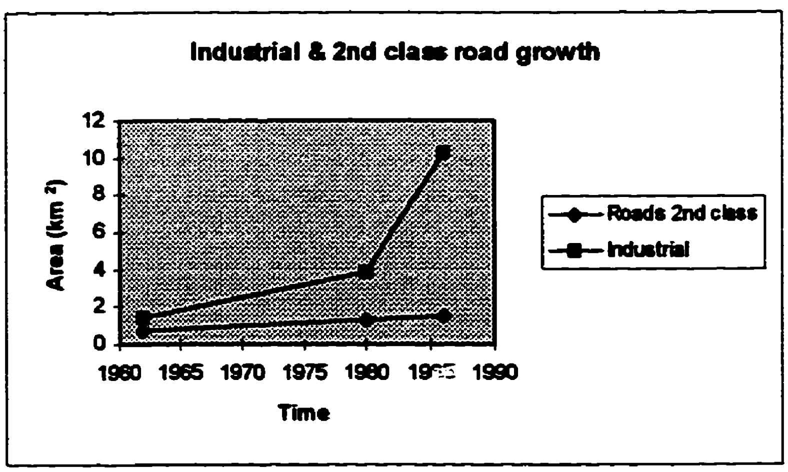
(Clark, 1977, 485-487).

Figure 5.9: Residential/Commercial land-use growth and 2nd class road growth between 1962 and 1986.



Source: Derived from Land Inventory Maps, 1962 - 1986.

Figure 5.10. Industrial and 2nd class road growth between 1962 and 1986



Source: Derived from Land Inventory Maps, 1962 - 1986.

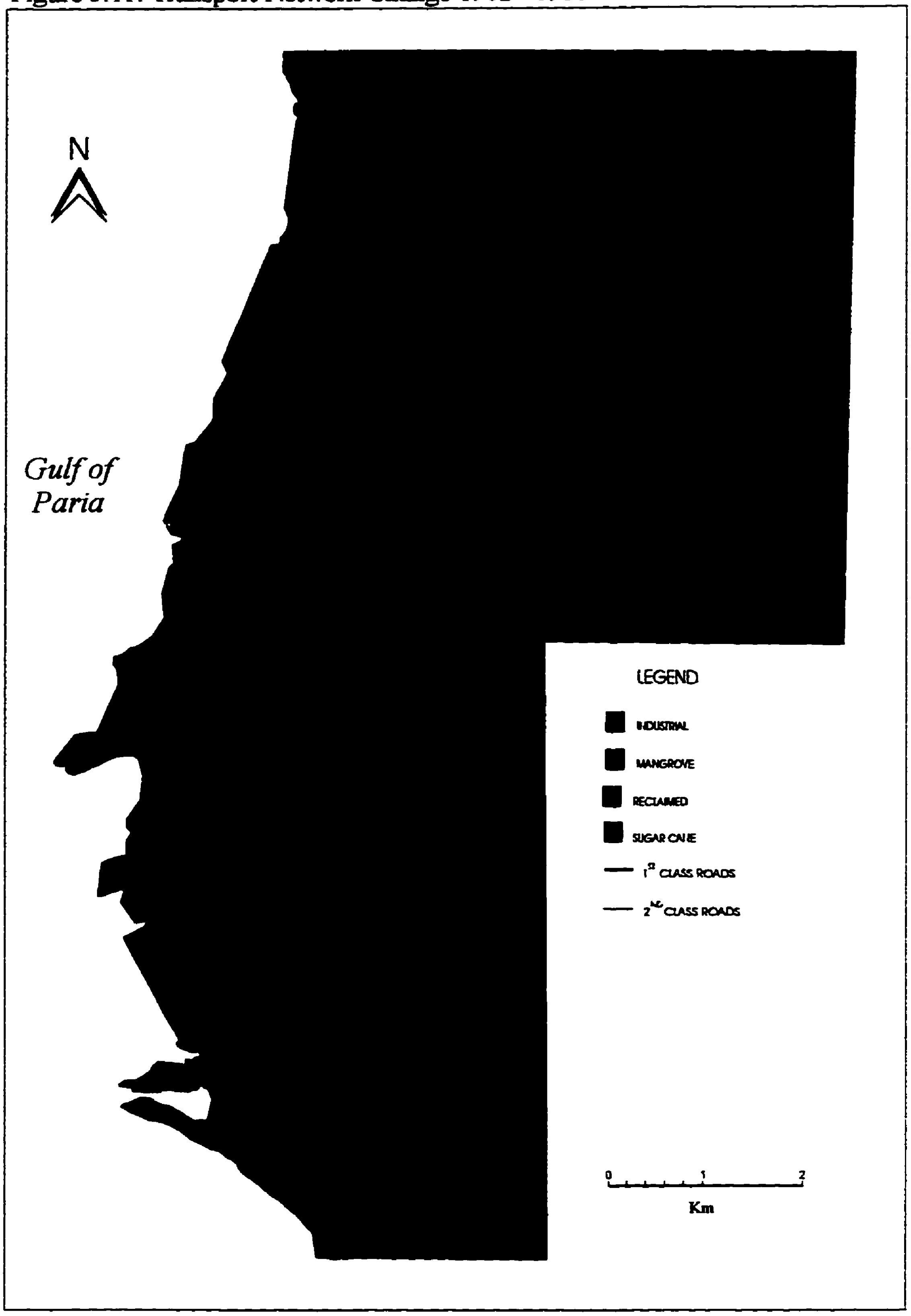
5.4.2.5 Impact assessment of increased roadways

As previously explained, the roadways in the study area have increased considerably in the 25 year period covered in this analysis. Over this period, 1st class roads grew by 29.4% or by 0.0602 km^2 while 2nd class roads increased by 1211.5% or 1.369 km^2, Figure 5.11 (See also Table 5.1).

Spawning of residential/commercial activities

Roadways have increased significantly in three localities within the study area. These are (1) near Dow (south central); (2) the Couva Housing Project (central), and finally (3) near Freeport and Agostini (north). Increases in the first two localities coincided with housing developments designed and implemented by Town and Country Planning under the Couva/ Pt. Lisas Development Plan (Manwaring and Lloyd, 1986, 145), whereas increases in the third locality spontaneously sprung up between the now arterial Southern Main Road and the Sir Solomon Hochoy Highway. This shows that in some cases settlements may spawn roads whereas in other case the reverse can be observed. It is important to note that this is in accordance with the historic patterns of settlement observed in the region. The consequences of increased population, increased road construction and increased traffic volume are increased land pressure and an associated increase in pollution.

Figure 5.11: Transport Network Change 1962 - 1986



Vegetation/habitat loss or disruption

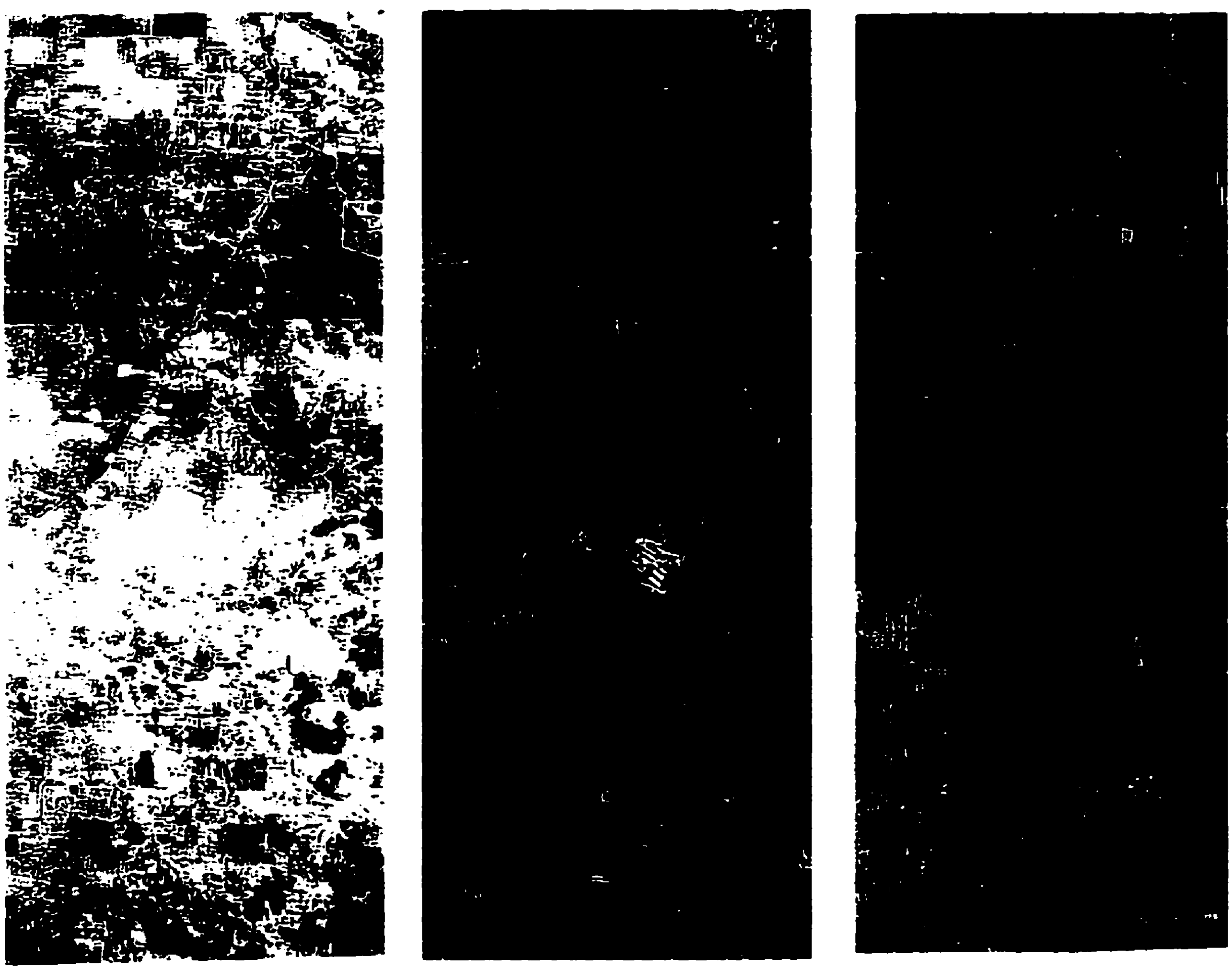
Although the region mainly displays an artificial or man made vegetation regime (sugar cane), some natural vegetation still remains, particularly in the form of coastal mangrove, and on river banks in the form of mangrove, small shrubs and bushes, grasses and wild cane (PLIPDECO and IMA, 1981: 44 ,15). The loss of vegetation between 1962 and 1986 occurred mainly along the Eastern Corridor of the region (i.e., the area dominated by the Sir Solomon Hochoy Highway). The construction of this highway necessitated the removal of some vegetation, as seen in Figure 5.12. This Figure 5.12 (a-c), represents the progressive loss of vegetation and the accompanying increases in settlements described earlier between 1962 and 1986, along the Eastern Corridor. Although 5.12 (a) is unclear, it can still be seen that a large increase in land-use other than agriculture or natural vegetation has occurred over the 25 year period.

Some loss of vegetation has also occurred along the bank of the Couva River. This corresponded with the increase in roads in the vicinity of the Couva settlement. Residential and commercial growth along with the increased road traffic in the immediate vicinity of the bank of the Couva River have degraded the natural plant life in this zone between 1962 and 1986 (Figure 5.13).

The disruption of the coastal habitat (in this case mangrove) near the mouth of the Couva River (north of Couva Bay), provides more evidence of the effect of environmental degradation caused by increased road usage. Although for sometime prior to 1962 an access road dissected the mangrove area north of Couva Bay its impact on the habitat in the region was considered minimal. However, between 1962 and 1986, with increased activities in the region and the Couva river diversion this road became more heavily utilized. The net result of this increased utilization was a massive decline in the mangrove (Figure 5.14).

Figure 5.12: Example of vegetation/habitat loss due to roadways between 1962 -1986, Eastern Corridor (a) 1962; (b) 1980; (c) 1986.

a b c



Source: Photo Mosaics 1962, 1980 and 1986.

Figure 5.13: Example of vegetation/habitat loss due to roadways between 1962 -1986, Couva River banks (a) 1962; (b) 1980; (c) 1986.

a

b

c

Source: Photo Mosaics 1962, 1980 and 1986.

Figure 5.14: Example of Habitat disruption by road construction (a) 1962; (b) 1980; (c) 1986.

a

b

c

Source: Photo Mosaics 1962, 1980 and 1986.

Drainage pattern alteration

No evidence was obtained from the imagery of drainage pattern alteration. This aspect of environmental degradation needs to be examined at a larger scale than that of the photos used in this analysis. Evidence would include running water at the sides of roadways where circulation and natural pathways have been blocked by the construction of roads. Other evidence would include frequent flooding of roadways in the rainy season that did not occur prior to road construction. This and the following impact may be difficult to determine since the gradient of the land and the soil types in the region already give rise to some flooding (see Chapter 2).

Surface Water Runoff flow de-stabilization

Surface water runoff flow de-stabilization which may result from construction of roadways exhibits phenomena similar to that of drainage pattern alteration. Evidence supporting this problem would include stagnant water at the sides of roadways where circulation and natural pathways have been blocked by road construction, a raised water table, and flooding.

5.4.3 Mangrove loss

Of the world's tropical coastlines, approximately one-fourth is covered by mangrove (Odum and Heald, 1975: 129). The Malay Archipelago, Indonesia, New Guinea and the Philippines possess the most lush and developed of these mangrove communities (Scott, 1981: 260). Mangrove forests have been attributed with up to 20 times the productivity of the open sea (Sefton, 1981: 267). It is argued that these forests facilitate biological productivity (fisheries, forests), bio-diversity (acts as reservoir and shelter) and, contribute to fisheries enhancement because they create stability in the physical environment providing refuge and contributing to the food chain. They also afford coastal protection, climate regulation, flood control, recreation, land building, coal formation and water purification. (James, 1985: 59).

The importance of mangrove forests extends into other realms. It is used as fuel; in construction; to create fodder and green manure; glue; hairdressing oils; Tannin for leather and net preservation; dyes; and matchsticks and incense, to name a few. Other benefits of mangrove specific to coastal communities arise from its utilization in making fishing poles, fish traps, fish poison, and fishing floats.

5.4.3.1 Loss of Mangrove Communities

The loss of mangrove forests around the world is increasing. Some loss is due to natural stresses such as cyclones, typhoons, tidal waves and diseases. Other stresses which are human-made include the exploitation of mangrove resources and land reclamation. For example, in the Philippines alone, of the 450,000 hectares estimated to be covered by mangroves in 1920, only 146,139 hectares remained in 1978 and about 2000 hectares are lost annually to fish ponds (Vannucci, 1988: 216). In Indonesia in 1988, there was an annual exploitation of 2000 km^2 of mangroves to produce 250,000 km^3 woodchips (a key by-product of mangroves) for export (Fortes, 1988: 210). Large areas of mangrove forest have been converted to prawn ponds in Singapore (Fortes, 1988: 210).

Christopherson (1994: 498) observed that the United Nations Environmental Programme reported a 40% loss in mangrove areas in some countries (e.g. Cameroon and Indonesia) and an 80% loss in mangrove areas in some countries (e.g. Bangladesh and Philippines) from pre-agricultural times to the present.

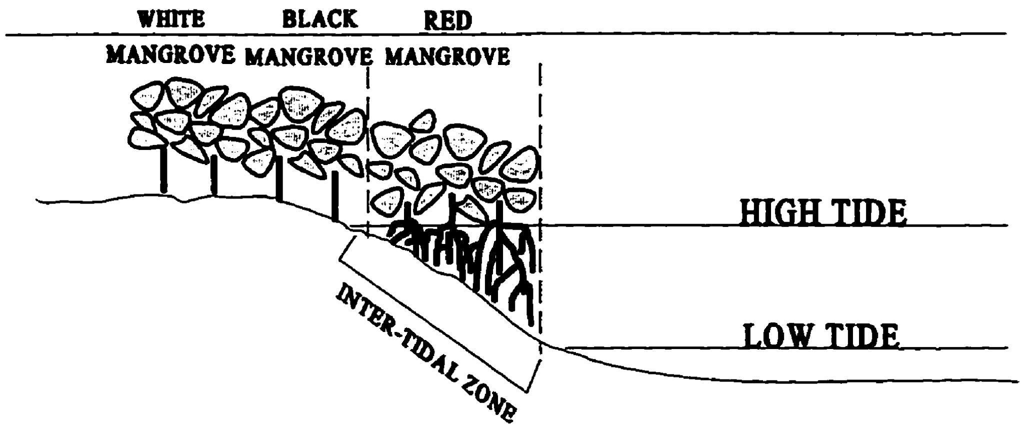
An example quoted in James, (1985: 57-58) refers to an illustration by Dr. Arsenio Rodriguez (a previous UNEP's Regional Advisor to Latin America and the Caribbean). The example sited a country in the Caribbean where the removal of sand dunes for the construction of a runway lead to the destruction of the coastal mangrove forests, a road and some community buildings by storm tides during a hurricane. The road and community buildings were rebuilt along with an engineering work to protect the area against future storm destruction, but the mangrove forests were not replaced. In the following year, another hurricane which produced storm tides destroyed the road, the community buildings and the engineering works designed to protect the coast. It is therefore evident that the removed sand dunes and mangrove forests had protected the coasts from past storms.

As the need for land grows and the coastal environments become stressed, there will be more reclamation and destruction of mangrove forests. It is imperative that the interaction between coastal resources and mangrove communities be understood.

5.4.3.2 Mangrove communities in the study area

The mangrove species in the study area are basically comprised of prop-root, Red Mangrove (Rhizophora mangle L.), Black Mangrove (Avicennia germinans/Avicennia schauerana), White Mangrove (Laguncularia racemosa) and Button Mangrove (Conocarpus erectus). Red mangrove, by far the most dominant species in the region, occupies sand banks and mud flats washed by daily high tides. Black Mangrove occurs where the soil is dryer and more compact (landward), and are mixed with White Mangrove along drainage channels. Finally, these areas are occasionally mixed with Button Mangrove although this type is rare.

Figure 5.15: Idealized scheme of mangrove zonation



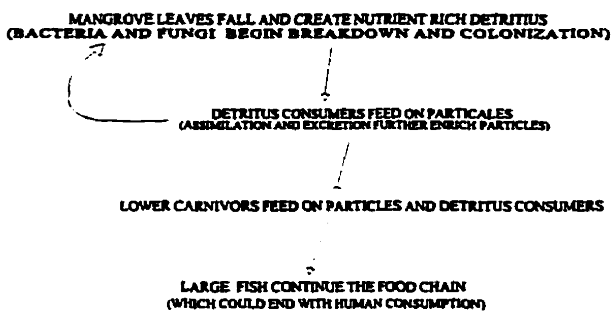
Source: Derived from Clark, John R., 1977 Coastal Ecosystem Management: A Technical manual for Conservation of Coastal Zone Resources. John Wiley and Sons.

5.4.3.3 Specific Functions of Mangrove Species in the region

Food Webs

Mangrove forests have always been an important asset to tropical coastal ecosystems. This is also the case in the Gulf of Paria. Mangrove forests are an important link in the food webs of coastal areas. It is estimated that they can produce up to " 80% of the total organic materials available to the aquatic food chain" (Clark, 1977: 662). Leaf litter from these forests are processed into finer particles by microbial decomposers. These particles are then colonized by bacteria, fungi and protozoan populations and become a source of food for several species of detritus consuming organisms (Clark, 1977; Ramdial, 1981; Knox and Miyabara, 1984). In the study area these organisms include oysters, mussels, the Hairy Land Crab (*Ucides cordatus*), the Blue Land Crab (*Cardisoma guanhumi*) and Shrimp (PLIPDECO Report Volume 1, 1982, 5-6). After ingestion the organisms assimilate the material, excrete it, and the cycle begins again. The organisms are also eaten by small fish which are in turn eaten by larger fish and finally consumed by humans.

Figure 5.16: Flow Chart of Principle Food Routes in Mangrove Systems.



Source: After Clark, 1977: 662.

Nursery Grounds and Shelter

Mangrove swamps also act as spawning and nursery zones for numerous fish species in the region. Many species utilize these forests as shelter from larger predators. The structure of the mangrove root systems provide safety for juvenile fish and also act as a protective barrier against wave action; this is of specific significance to shrimp. Studies suggest a positive correlation between the size of mangrove area and shrimp production (Martosubroto and Naamin, 1977; Ramdial, 1981). Shrimp is one of the two most commercially important marine catches in the region. Mussel populations are also known to inhabit the mangrove swamps of the region.

Land Building

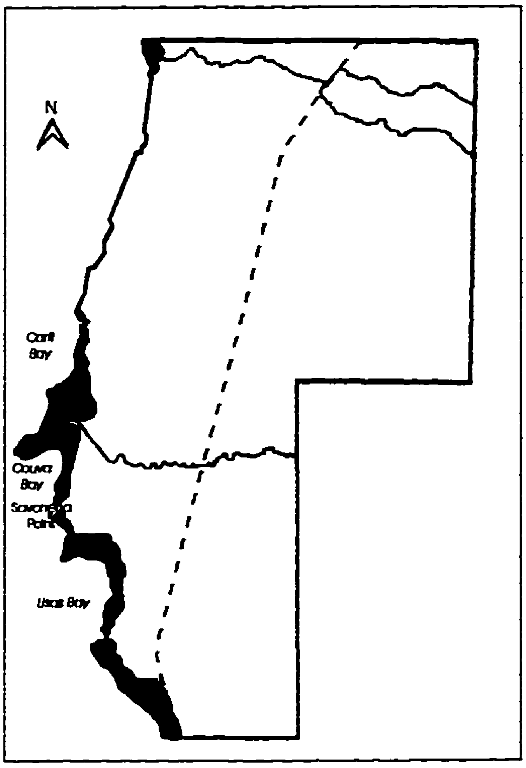
Land building by mangrove forests is achieved by the stabilizing effect of the root systems on fine coastal sediment. The roots tend to slow water movement and therefore play a role in accretion of sediment which leads to land building. The loss of mangrove communities can lead to the loss of land, since these aquatic plants act as land builders thus protecting coastal areas from erosional currents and storm waves.

5.4.3.4. Mangrove loss in the region

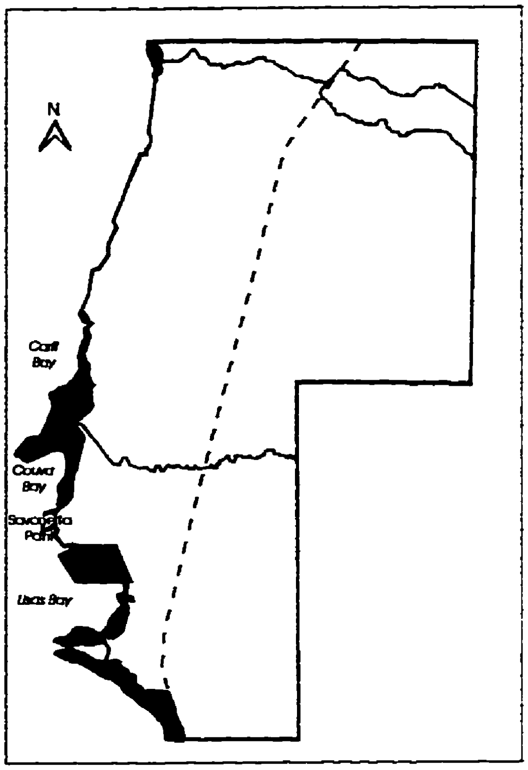
Whereas changes in vegetation in the region have been the result of different activities, most mangrove loss in the region has resulted from industrial expansion and accompanying activities. Large-scale mangrove destruction was a consequence of reclamation and dredging in the Couva/Pt. Lisas region, with most destruction occurring between Savonetta Point and Point Lisas. Over the 25 year period of this study, coastal mangrove communities have decreased from 9.374 km^2 in 1962 to 5.445 km^2 in 1986 (from GIS area analysis). Most of the decrease in area occurred in Lisas Bay (Figure 5.17). The other major factor contributing to mangrove loss in the region was the diversion of the Couva River from its natural outlet in Couva Bay to an outlet in Carli Bay (section 5.3.1.2). This change which occurred between 1980-1986 was responsible for a 0.079 km^2 decrease in mangrove to facilitate the channel.

Figure 5.17: Change in Mangrove Forests 1962 -1986

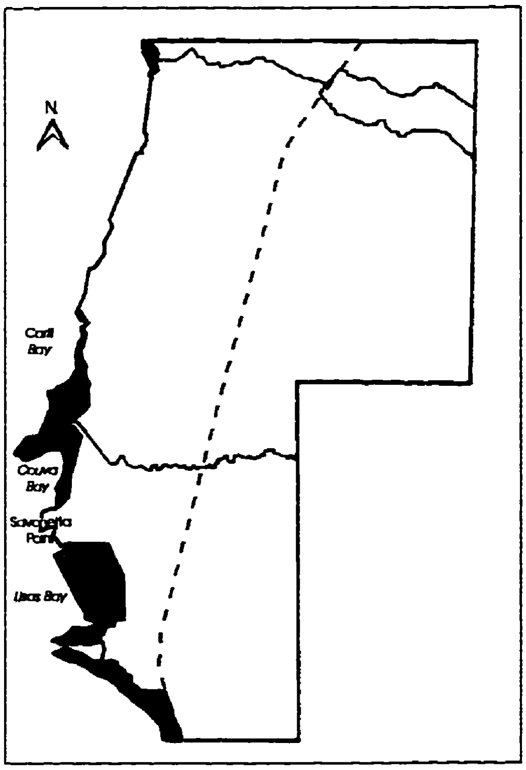
Mangrove Forests 1962

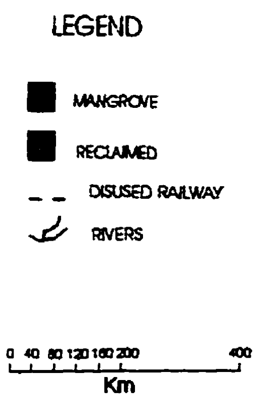


Mangrove Forests 1980



Mangrove Forests 1986





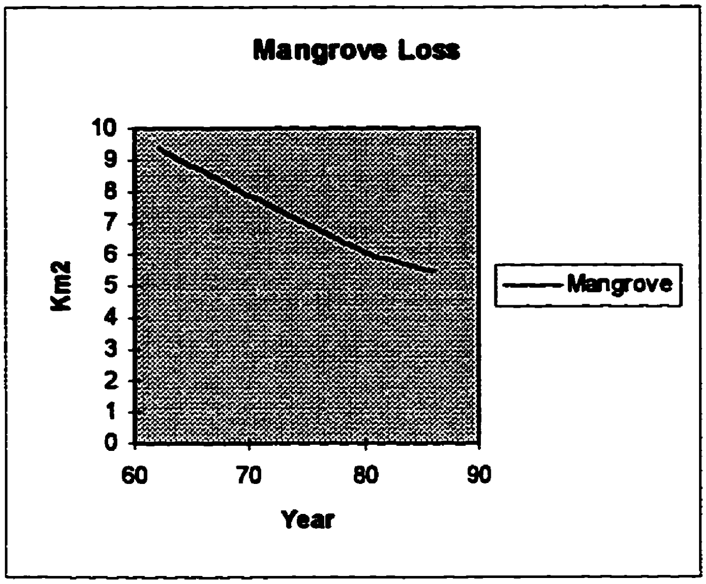
5.4.3.5 Impacts of Mangrove loss

Shrimp Production

The life cycle of the shrimp is dependent on mangrove forests for a number of reasons. Shrimp spawn in the near-shore brackish waters inhabited by the mangrove communities. The larvae remain here for protection until they reach the juvenile stage after which they migrate into the open sea. For this reason, there exists a significant positive relationship between shrimp production and mangrove area coverage. Due to the link between these two factors, many EIA studies assessing the impacts of mangrove loss use Shrimp catch as an environmental indicator. Therefore, this study also used shrimp catch as an indicator for assessing the environmental impact of mangrove loss in the region. In order to perform this assessment, the shrimp catch for the region from the period 1962 to 1986 was examined.

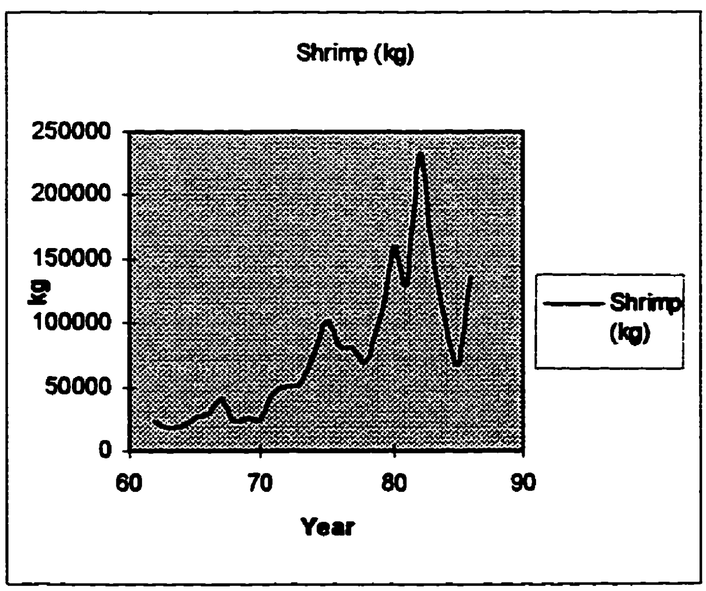
Since the mangrove coverage was calculated from imagery (Figure 5.5), it was only assessed for the years 1962, 1980 and 1986. However, assuming that mangrove decrease was linear, it was possible to interpolate the coverage for the interim years (Table 5.5). Mangrove decrease was then plotted in Figure 5.18a. Shrimp, being an indicator species for impacts on mangrove in a coastal region, was also plotted for catches between 1962 and 1986 (Figure 5.18b).

Figure 5.18a: Mangrove loss between 1962 - 1986 (km^2).



Source: Derived from Land Inventory Maps and series interpolation.

Figure 5.18b: Shrimp Catch 1962 -1986 (kg).



Source: Fish Catch by Beach, Ministry of Agriculture, Lands and Food Production, Fisheries Division, Government of Trinidad and Tobago.

Shrimp data was plotted against mangrove area for the same time period (Figure 5.19). A regression analysis was run in order to assess the relationship between shrimp catch and mangrove area. The analysis shows that a inverse relationship exists between the two variables (Figure 5.19). A correlation coefficient was also calculated for the two variables. This is shown in Table 5.6. The table shows a high negative relationship, which reiterated the results of the regression plot. This finding is contradictory to the expected results. This contradiction will be addressed in the summary.

Table 5.5: Mangrove area (km^2) and Shrimp Catch (kg) between 1962 and 1986.

	62	63	64	65	66	67	68	69	70	71	72	73	74
Mangrove	9.374	9.19	9	8.821	8.637	8.453	8.268	8.084	7.899	7.716	7.531	7.347	7.163
Shrimp	23485	17593	20339	27062	29364	40359	23417	26337	25465	44117	50449	55090	74849

Con't.

	75	76	77	78	79	80	81	82	83	84	85	86
Mangrove	6.978	6.794	6.609	6.426	6.241	6.057	5.957	5.856	5.756	5.656	5.555	5.445
Shrimp	101410	81597	80513	71308	106244	160123	130810	233110	158651	101523	69274	136546

Source: Fish Catch by Beach, Ministry of Agriculture, Lands and Food Production, Fisheries Division, Government of Trinidad and Tobago.

Figure 5.19: Relationship between Mangrove area (km^2) and Shrimp Catch (kg) between 1975 and 1986.

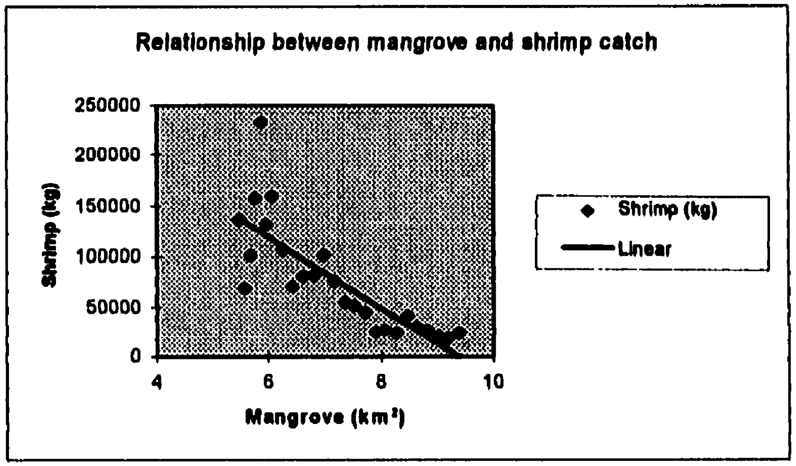


Table 5.6: Correlation Coefficient between Mangrove area and Shrimp Catch between 1962 and 1986.

	Mangrove	Shrimp
Mangrove	1	
Shrimp	-0.81313	1

Land Loss

Although the Gulf of Paria is a relatively sheltered coastline, local currents circulating in a clockwise direction can cause erosion. In an informal survey, older fishermen from the Orange Valley region recalled that the land in the region had extended further out to sea but had been receding with time. In fact, they stated that some vegetation, though not much, could be found along the Orange Valley section of the coast at one time in the recent past. One gentleman who owned a gas station said it had receded at least 1.5 m - 3 m (5 - 10 feet) and that if the trend continued his property would fall into the sea. Though no evidence of land erosion was attained from the aerial survey, it is possible that such small changes were undetectable at the scale used in the aerial survey. However, Bloch (1994:19) recorded a similar experience on Icacos, a beach south of the study area, on the south western tip of Trinidad. The Islander is reported to have said,"Every year the sea comes up a bit more. Over there was another field. And right beyond them was the village cemetery. All that's under water now.... even the lighthouse. At low tide you can just see the tip." Dr Bhawan Singh who is performing a study of sea level rise in Trinidad has estimated that the sea has encroached approximately 800 meters inland in the past six decades (Bloch, 1991:19).

5.4.4 Summary and evaluation

To date there have been few studies conducted into the effects of dredging and reclamation in the Pt. Lisas region. No studies have been conducted which shed light on any potential long-term environmental effects of said activities. The region exhibits all the expected adverse environmental impacts of dredging and reclamation. Disturbance of vital habitat has arisen due to the destruction of mangrove communities; as argued in McShine-Mutunhu (1985), localized increases in turbidity have resulted in decreased varieties of benthos communities. This in turn may result in the decline in benthos feeding fish species in the region; Hall (1989) documented the increase in concentration of various chemical components in the sediment and water in the Gulf of Paria; alteration of local current patterns has been expected to occur due to changes in coastal configuration; and a general decrease in water quality has occurred.

Not all environmental effects resulting from dredging and reclamation in the region can be demonstrated. Some will have to be determined by further detailed study. However there is sufficient evidence to warrant a judgment of diminished environmental quality due to dredging and reclamation.

On the basis of the geometric design standards of road classification it is clear that the function of the region has been altered in the 25 years under investigation. The growth from rural to urban land-use patterns suggests greater pressure on this coastal environment and the greater potential for impacts.

Increased transportation networks provide access to rural lands and can therefore increase property values. These increased transportation networks have led to increased land-use and often urban sprawl. Some evidence of the adverse impacts exists due to the progressive expansion of transport networks in the region. Of greatest concern are the loss of vegetation, and habitat disruption. Other aspects of impact might have occurred but have not been detected in this analysis. The historical model for settlement in the region plays an important part in these impacts. Both vegetation loss and habitat disruption though in-part attributable to the growth in roadways, are also influenced by the growth in residential and commercial land-uses. Although not quantifiable, the impact of increased population pressure arising from spontaneous ribbon settlement in the region may be assumed. As in most cases, more pressure on the land leads to environmental degradation.

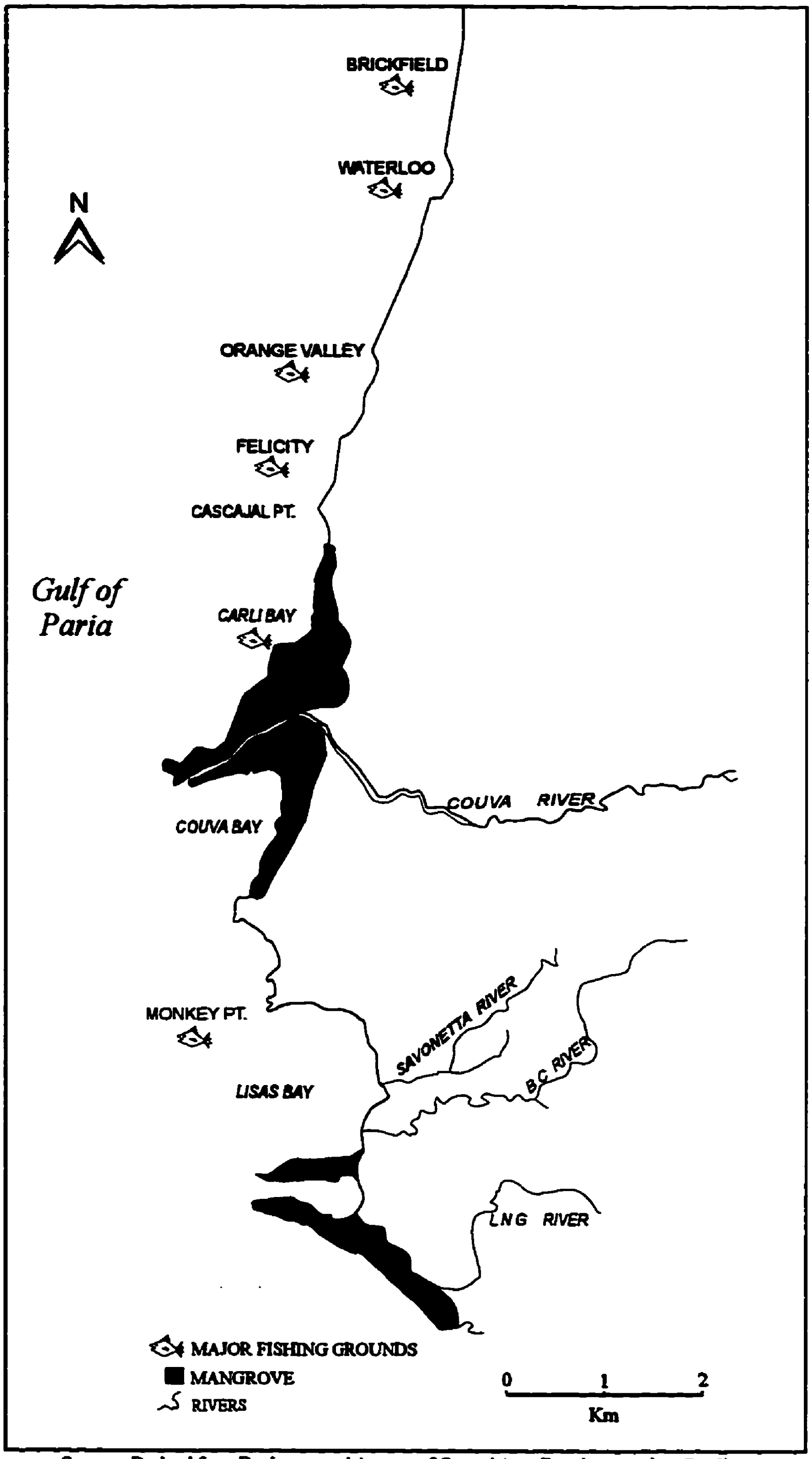
Tropical coastal ecosystems are highly vulnerable to human-induced stresses. Mangrove communities as part and parcel of these ecosystems must be protected. The Caroni Swamp immediately to the north of the study area is a protected mangrove environment. As the importance of mangrove to the coastal environment is better understood, countries with this resource will have to become more careful in their exploitation and/or destruction of these communities.

The Executive Summary of the Pt. Lisas Environmental Project (June 1982), stated that after an investigation, it was found that the mangrove communities of the region were an important nursery ground for a number of commercial and non-commercial species of fin and shell fish. It recommended that no further alteration to the mangrove communities be encouraged, as of 1982 (PLIPDECO & IMA, 30). However, between 1982 and 1986 the mangrove swamps had been reduced by 3.919 km^2, 41.8% of its area in 1962.

Although it is evident from the statistical analysis that mangrove destruction in the region has not had an adverse effect on shrimp fisheries as was expected, continued loss of this vital resource could spell disaster for the fisheries of the region. It is unclear as to the reason for the unusual trend of shrimp catch increase with mangrove destruction. It is possible that the number of fishermen in the region had increased during the period under study and /or that fishing techniques in the area had become more efficient. An attempt was made to secure information specific to fishing as an occupation in the region. The data acquired ranged from 1970 -1990. The fishing areas in the region are represented in Figure 5.20 while the number of registered fishermen for the region was graphed in Figure 5.21. Note that the plotted data represented the five major fishing villages of the region; Brickfield, Waterloo, Orange Valley, Carli Bay, and Felicity. Monkey Pt. has been neglected since insufficient data was available for this fishing ground. Using a stacked vertical bar graph (see Figure 5.21) newly registered fishermen in each village and hence the region were displayed. It is important to note that the data source supplied no distinction between the categories of full-time, part-time, or occasional fishermen.

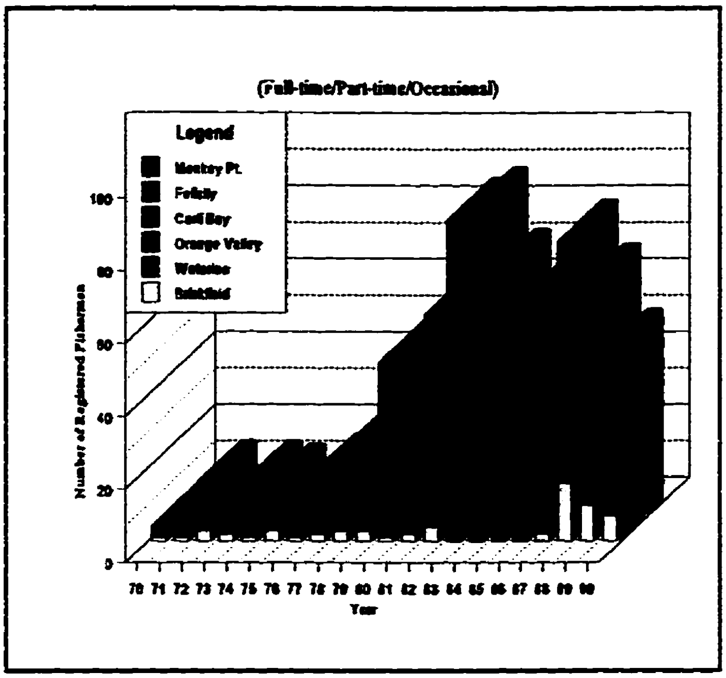
It is important to remember when viewing these statistics that some fishermen from the region may not have registered at all and that the Fisheries Division was unable to provide an estimate of these. Also, the statistics do not take into account those fishermen registered prior to 1970, but only those who registered for the first time in one of the given years during the study period. The number of new fishermen in the region increased in the 25 year period. Therefore, it can be concluded the increase in shrimp catch may be related to the increase in the number of fishermen in the region.

Figure 5.20: Major Fishing Grounds near the Pt. Lisas Area, Gulf Of Paria



Source: Derived from Environmental Aspects of Coastal Area Development in a Small Island Nation - The Case of Trinidad and Tobago with emphasis on the Pt. Lisas Industrial Complex. C.D. Lewsey, Institute of Marine Affairs, 1981, Appendix IV, p. 17

Figure 5.21: Number of Fishermen in the Couva/Pt. Lisas region from 1970 to 1990.



Source: Number of registered fishermen in the Caroni administration district, 1970 - 1990, Ministry of Agriculture, Lands and Food Production, Fisheries Division, Government of Trinidad and Tobago

Shrimp catch per Fisherman/Boat

It has been established that the number of fishermen in the region has increased over the 25 year period of this study. It is now incumbent to assess the Shrimp catch per fisher/Boat for the region. This investigation may shed some light on the unexpected results of the inverse relationship between mangrove loss and shrimp catch.

The data used in this investigation is the same data for the number of registered fishermen in the Caroni administration district, 1970 - 1990. Since this data does not include the fishermen who registered prior to 1970, it was necessary to also perform a Shrimp catch/boat investigation, and compare the results of the two. Fish catch data for the region ranges from 1962 - 1990 but fisherman registration ranges only from 1970 - 1986, and Boat data ranges only from 1975 - 1986, therefore, it was necessary to use the shrimp catch data for the years corresponding to either the fisherman data or the boat data. The numbers of boats registered prior to 1975 was approximated by the staff of the Ministry of Agriculture Lands and Food Production, Fisheries Division. The average shrimp catch/fisherman and average shrimp catch/boat is presented in Table 5.7 (a).

Note that although the data for the number of fishermen registered in a given year is reliable data, no record was kept of the number of fishermen who have left the occupation. In order to get a close estimate of the number of fishermen in the region Table 5.7 (b) estimates the number of fishermen in the region according to the number of boats registered. This is achieved by applying the estimate provided by the staff of the Ministry of Agriculture Lands and Food Production, Fisheries Division, of 3 - 4 fishermen per boat. The lesser value will be used to supply a conservative estimate.

Table 5.7 (a): Average Shrimp Catch per Fisherman/Boat by year, 1970 - 1986.

Year	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Average catch/ Fisherman (x 1000)	6.3	3.1	1.6	1.4	1.3	1.4	1	0.8	0.6	0.7	0.8	0.5	0.7	0.4	0.2	0.1	0.2
Fishermen compounded	4	14	30	38	54	69	76	94	116	145	194	240	302	390	481	555	617
Fishermen	4	10	16	8	16	15	7	18	22	29	49	46	62	88	91	74	62
Shrimp (x 1000)	25	44	50	55	75	101	82	81	71	106	160	131	233	159	102	69	136.5
Boats	0	0	0	0	22*	6	3	7	5	8	12	18	22	16	14	14	7
Boats compounded & including estimate	0	0	0	0	22*	28	31	38	43	51	63	81	103	119	133	147	154
Average catch/Boat (x 1000)						3.6	2.6.	2.1	1.6	2	2.5	1.6	2.2	1.3	0.7	0.4	0.8

*** Estimate of Boats registered prior to 1975**

Source: Fish Catch by Beach, Boat Registration County Caroni, Number of Fishermen Registered in the Caroni Administration District Ministry of Agriculture Lands and Food Production.

Table 5.7 (b): Average Shrimp Catch per Fisherman (estimation) by year, 1970 - 1986.

Year	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Shrimp (x 1000)	25	44	50	55	75	101	82	81	71	106	160	131	233	159	102	69	137
Boats	0	0	0	0	22*	6	3	7	5	8	12	18	22	16	14	14	7
Boats compounded & including estimate	0	0	0	0	22*	28	31	38	43	51	63	81	103	119	133	147	154
Fishermen estimates from Boats registered 3 fishermen/boat	0	0	0	0	66	84	93	114	129	153	189	243	309	357	399	441	462
Average catch/ Fisherman (by estimate) (x 1000)						1.2	0.8	0.6	0.8	0.6	0.6	0.9	0.7	0.4	0.1	0.1	0.2
Average catch/ Fisherman (x 1000)	6.3	3.1	1.6	1.4	1.3	1.4	1	0.8	0.6	0.7	0.8	0.5	0.7	0.4	0.2	0.1	0.2
Difference in averages between estimates						0.2	0.2	0.2	0.2	0.1	0.2	0.4	0	0	0.1	0	0

* Estimate of Boats registered prior to 1975

Source: Fish Catch by Beach, Boat Registration County Caroni, Number of Fishermen Registered in the Caroni Administration District Ministry of Agriculture Lands and Food Production.

Estimates for Fishermen in the region derived from boat registrations shows a similar trend of decline in Shrimp catch per Fisherman/Boat for the region. Therefore it may be assumed that Shrimp production in the region is declining but increased fishing activity is distorting the results by producing the inverse relationship found in the previous analysis.

Fishing techniques in the region

Fishing techniques in the region in the 1960s, 1970s and 1980s included Italian seines, beach seines, surface gill nets, trawling lines and bottom hard lines (Caribbean Yearbook, 1960/86, Trinidad and Tobago 'Fisheries'). The boats were privately owned and consisted of pirogues, 21 to 30 feet in length, powered by 40 to 65 horse power outboard motors. Over the years better boats and seines could have contributed to increased fish catch. Also, the provision of improved landing facilities at Orange Valley in the late 1970s and early 1980s has had a beneficial effect on fisheries in the region. These facilities include refrigeration and cold storage , running water for more sanitary conditions, and gear and boat storage lockers.

Further investigation of the fisheries in the region and other factors which might contribute to the enigma of increased shrimp catch with decreased mangrove area needs to be carried out for conclusive evidence of impacts to be determined.

5.5 Impacts during Operation Phase

Three main environmental impacts were taken into consideration in the operation phase of the Pt. Lisas Industrial estate. These factors were: (1) population increase; (2) thermal pollution; and (3) liquid pollution and water quality.

5.5.1 Population increase

> "Only four decades ago, 18 percent of humanity lived in urban communities, whereas 50 percent do so today. The lion's share of urbanization is now taking place in LDCs. Population in LDC cities is projected to mushroom from under two billion people today to almost four billion by 2025. It has been well documented that large metropolitan areas, and even medium-sized cities in LDCs are barely coping with urbanization. Housing shortages, squatter settlements, lack of infrastructure such as medical facilities and schools, traffic congestion, intolerable levels of pollution, and problems disposing of industrial and municipal wastes are all part of the scenario" (Shaw, 1992, 22).

Some aspects of this scenario are also occurring in the Couva region. An analysis of the potential environmental impacts of increased population and urbanization follows.

5.5.1.1 Industrialization and Population Growth

In 1978 the Government of Trinidad and Tobago officially endorsed the industrialization of the Couva/ Pt. Lisas region. At that time the region was identified as ideal for housing the labour force expected to migrate into the region in response to the increased job opportunities. Couva was considered a small centre with enough developable land to cater to the commercial and housing needs of such a growing and diverse population (Town and Country Planning, 1978). Changes in residential and commercial land-use can therefore be considered directly attributable to population increase and therefore changes in industrial land-use. Table 5.8 represents this increase in both variables.

5.5.1.2 Other evidence of link between Industry and Population

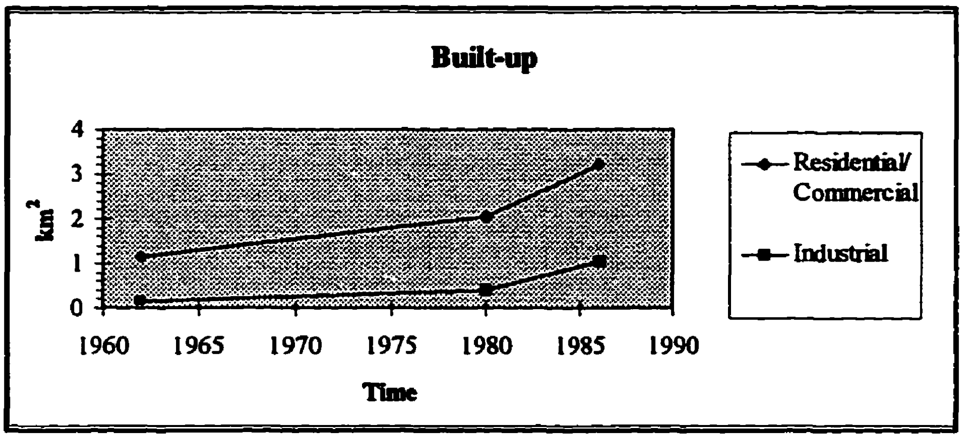
Growth in industry produced a growth in residential/ commercial activity in the region. Figure 5.22 shows residential/commercial change plotted against industrial change. Graphing the two land-use patterns reveals that the growth trends closely follow one another. Therefore, a positive correlation is identifiable.

Table 5.8: Residential/Commercial and Industrial Land-use 1962 - 1986 (km^2).

	Residential/Commercial	Industrial
Time	km^2	km^2
1962	1.134	0.1401
1980	2.045	0.3896
1986	3.211	1.029

Source: Derived from Land Inventory Maps 1962-1986.

Figure 5.22: Residential & Commercial, and Industrial land-use changes 1962, 1980 and 1986.



Source: Derived from Land Inventory Maps 1962-1986.

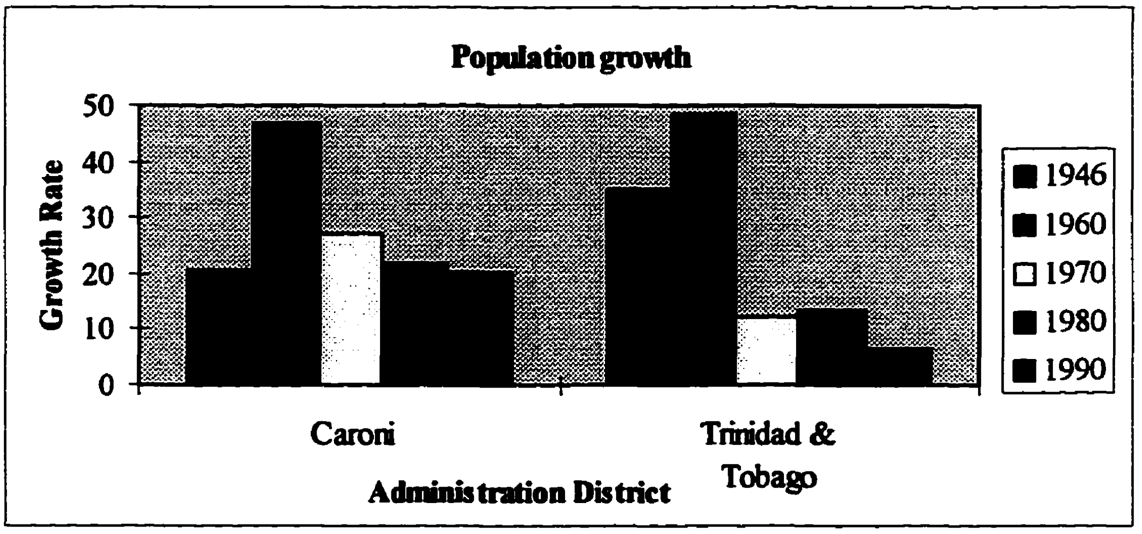
To further investigate the link between industrial growth and population growth in the region, inter-censal growth rates for the region and the nation were examined. Table 5.9 and Figure 5.23 represent this data. For the period 1946 - 1990 a comparison between County Caroni growth rates and that of the nation as a whole, showed that from 1970 onward, Caroni's growth rates are higher than that of the nation. In fact by 1990 Caroni's growth rate was three times that of the nation.

Table 5.9: Inter-censal population growth rates for Caroni and Trinidad and Tobago 1946 - 1990.

	1946	1960	1970	1980	1990
Caroni	20.6	46.61	27.33	21.8	20.26
Trinidad & Tobago	35.17	48.39	12.45	13.39	6.57

Source: Central Statistical Office, Government of Trinidad and Tobago.

Figure 5.23: Intercensal population growth rates for Caroni and Trinidad and Tobago 1946 - 1990.



Source: Central Statistical Office, Government of Trinidad and Tobago.

5.5.1.3 Risk Characterization of increased population

The major concern associated with population growth and the environment may be explained in terms of urban/suburban expansion. This expansion is the result of industrial development which spurred urban growth and population increase. The following are some of the environmental impacts associated with rapid urban growth in Point Lisas:

1. increase in wastewater flows, loads and erosion; and
2. increased pollutant runoff from the land to the sea.

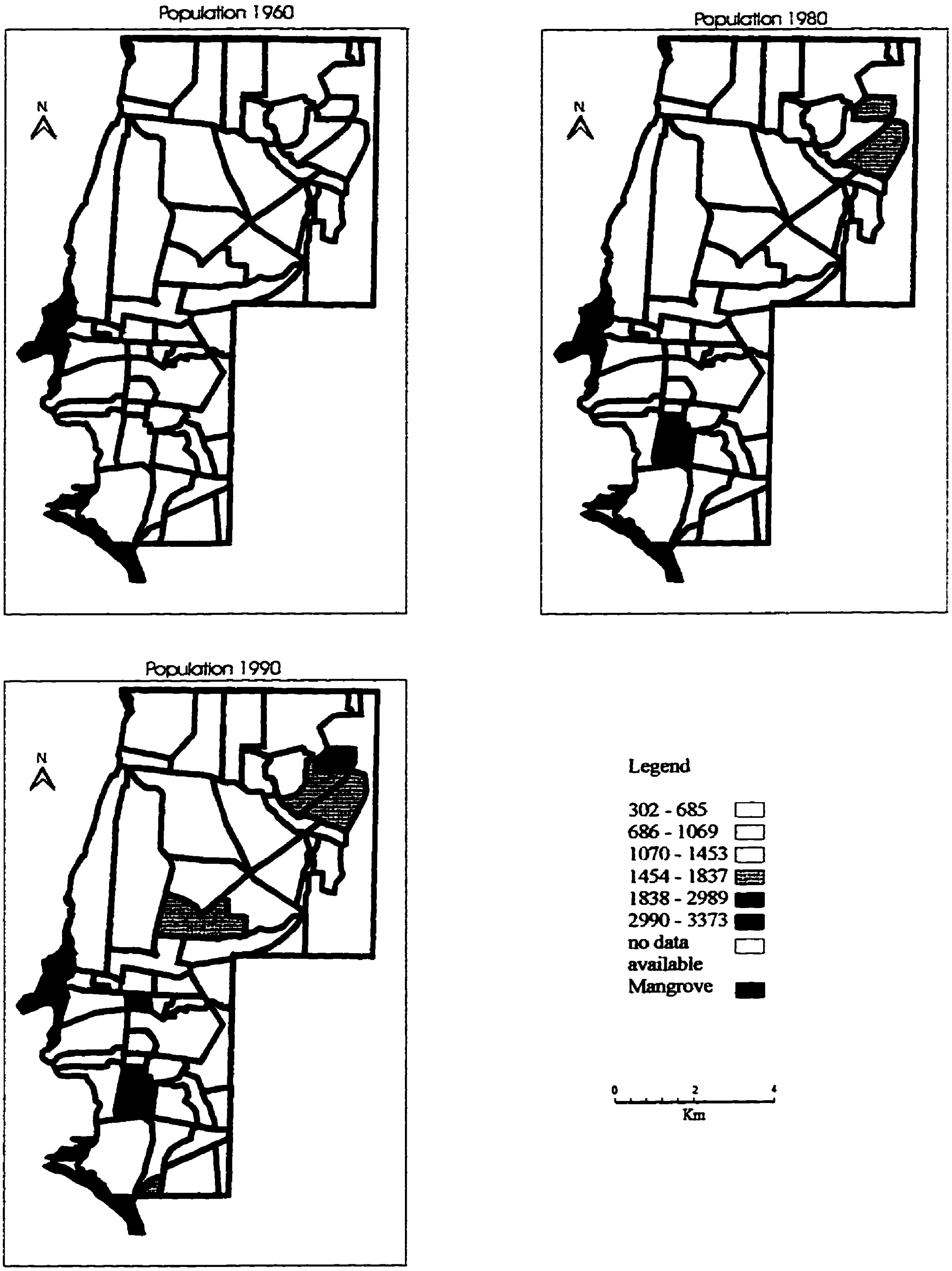
Increase in wastewater flows, loads and erosion

Increased population, along with increased commercial and construction activities contribute to increased sewage loads and also sediment discharge due to soil erosion during construction and clearing for housing. For example, simply clearing land for construction has its drawbacks. Decreased vegetation has the effect of increasing the amounts of freshwater entering the coastal waters due to lowered rates of evapo-transpiration to the atmosphere, as well as increased water runoff due to vegetation loss. This impact could not be determined from the aerial photographs, but there is some evidence of the occurrence from field observations.

Increase pollutant runoff to sea

Increased population in the region has led to a greater amount of pollution generation in the region as well as increased amounts of run off due to increased amounts of paved surfaces. Planning documents and statistical evidence show that industrial changes in the region led to residential and commercial changes. We will now examine the population distribution changes in the region. As Figure 5.24 reveals, a relatively small and evenly distributed population existed in 1960, with the highest concentrations occurring along the central region of the study area (Couva), and in northern regions adjacent to Waterloo Rd.. By 1980 a growth and shift in population had occurred such that concentrations began to arise along the coasts between Waterloo and Cascajal Point. High population concentrations also occurred in California and Dow villages (Section 5.4.2.5). By 1990 no evidence of the prior settlement patterns existed. In fact, the population concentration along the coast between Waterloo and Cascajal Point have increased in density and two extremely dense population concentration zones have developed adjacent to the major industrial sites. The only clear population distribution trend by 1990 is a sparseness of population in industrial locations, and concentrations in areas sited for increased residences due to industry.

Figure 5.24: Population by Ennumeration District Couva/Pt. Lisas 1960, 1980, and 1990.



Increased Pollution Run-off from Area to Sea

Population shifts in the region are important since they reflect the amount of pressure on the environment imposed by residential land use. This non-point source of pollution as with many others, contribute significantly to the total wastes in an aquatic environment. Using residential densities, it is possible to estimate the amount of pollution this urban land-use category adds to the coastal waters during heavy rains or stormwaters. Using a stormwater pollution index, the amount of nitrogen, phosphorous, lead, and zinc added to coastal waters from residential areas can be estimated. Table 5.10 represents the expected stormwater pollutants from residential land use while Table 5.11 provides the residential densities in the study area from 1962 -1986. The estimated amount of each pollutant derived from this index for residential land-use in the Couva/Pt. Lisas region is provided in Table 5.12.

Table 5.10: Stormwater pollution for selected urban land uses.

STORMWATER POLLUTION FOR SELECTED URBAN LAND USES					
Land use	Density[a]	Nitrogen[b]	Phosphorus[b]	Lead[b]	Zinc[b]
Residential, large lot (1 acre)	12%	3.0	0.3	0.06	0.20
Residential, small lot (0.25 acre)	25%	8.8	1.1	0.40	0.32
Townhouse apartment	40%	12.1	1.5	0.88	0.50
High-rise apartment	60%	10.3	1.2	1.42	0.71
Shopping center	90%	13.2	1.2	2.58	2.06
Central Business District	95%	24.6	2.7	5.42	2.71

[a]Based on percentage of the land covered by impervious (hard surface) material.
[b]Pounds per acre of land per year.

Source: Canter, 1996 Table 7.13 after Marsh, 1991, p 161.

Table 5.11: Residential densities from 1962 -1986.

	Residential/Commercial		Densities
Time	km^2	Acres	
1962	11.34	2800	5.5%
1980	20.45	5051	9.9%
1986	32.11	7931	15.6%

Table 5.12: Estimated stormwater pollution for residential land use (small lot) Couva/Pt. Lisas region.

Time	Density	Nitrogen	Phosphorous	Lead	Zinc
1962	5.5%	1.93	0.242	0.09	0.07
1980	9.9%	3.5	0.435	0.16	0.126
1986	15.6%	5.5	0.686	0.25	0.2

The following worst case scenario assessed the amount of pollutants which would have entered the Gulf of Paria over the 25 year study period. As no other data is available, the model was based on the assumption that past population growth rates and therefore residential growth rates would continue.

5.5.1.4 Worst Case Scenario

A linear regression analysis was performed to predict future residential land-use change densities in the region. These densities were used to assess the total amounts of nitrogen, phosphorous, lead and zinc that would be added to the Gulf of Paria through stormwater runoff. Table 5.13 presents the results of this scenario. Although the estimated added contaminants to the Gulf of Paria waters are a conservative estimate, they enable calculations of the expected amounts of the four pollutants to be performed. Planners can predict how much of these pollutants will enter a fragile ecosystem and in so doing measure how increased population densities contribute to coastal pollution.

In 1982 the coastal waters of the Gulf of Paria were evaluated at three bays (Lisas Bay, Couva Bay and Carli Bay) for levels of various chemicals and trace elements (Section 5.5.3). The amounts of the nitrogen (in the form of nitrites and nitrates), phosphorous (in the form of phosphates), lead and zinc in the region are supplied in Table 5.14. According to the United States Environmental Protection Agency (USEPA) standards, there was no excess of nitrogen compounds in the coastal waters of these three bays in the Gulf of Paria. However, the estimated minimum and maximum values of phosphates and zinc, and maximum values of lead all exceed USEPA standards. Increases in residential land-use is thus one source of pollutants. The excess levels of these three pollutants found in the coastal waters of the Gulf of Paria may therefore be linked to the increased population and residential land-use in the region.

Table 5.13: Estimated stormwater pollution for residential land-use (small lot) 1962 - 1986.

Year	Residential Density (%)	Nitrogen	Phosphorous	Lead	Zinc
1962	5.5	1.93	0.242	0.088	0.07
1963	5.74	2.02	0.252	0.091	0.073
1964	5.98	2.1	0.263	0.095	0.076
1965	6.23	2.19	0.274	0.099	0.079
1966	6.47	2.28	0.285	0.103	0.082
1967	6.72	2.36	0.295	0.107	0.086
1968	6.96	2.45	0.306	0.111	0.089
1969	7.21	2.53	0.317	0.115	0.092
1970	7.45	2.62	0.328	0.119	0.095
1971	7.7	2.71	0.338	0.123	0.098
1972	7.94	2.79	0.349	0.127	0.101
1973	8.18	2.88	0.36	0.131	0.104
1974	8.43	2.96	0.371	0.134	0.107
1975	8.67	3.05	0.381	0.138	0.111
1976	8.92	3.14	0.392	0.142	0.114
1977	9.16	3.22	0.403	0.146	0.117
1978	9.41	3.31	0.414	0.15	0.12
1979	9.65	3.39	0.424	0.154	0.123
1980	9.9	3.5	0.435	0.16	0.126
1981	10.85	3.81	0.477	0.173	0.138
1982	11.8	4.15	0.519	0.188	0.151
1983	12.75	4.48	0.561	0.204	0.163
1984	13.7	4.82	0.608	0.219	0.175
1985	14.65	5.15	0.644	0.234	0.187
1986	15.6	5.5	0.686	0.25	0.2
Total		79.42	9.92	3.61	2.88

Table 5.14: Levels of three pollutants in the Gulf of Paria by Bay.

Pollutants	EPA Standards	Lisas bay	Couva Bay	Carli Bay
Nitrite	no criteria set	0.0005 - 0.149 mg/l	0 - 0.026 mg/l	0 - 0.026 mg/l
Nitrate	no criteria set	0 - 1.5 mg/l	0 - 1.5 mg/l	0.3 - 1.1 mg/l
Phosphates	0.0001 mg/l	0.006 - 0.588 mg/l	0 - 0.12 mg/l	0 - 0.07 mg/l
Lead	0.05	<0.01 - 0.7 ppm	<0.01 - 0.7 ppm	<0.01 - 0.7 ppm
Zinc	0.01 ppm	<0.05 - 0.33 ppm	<0.05 - 0.33 ppm	<0.05 - 0.33 ppm

Source: PLIPDECO and IMA, 1982, Vol I.

5.5.2 Thermal Pollution

There are ecological effects produced by many aspects of industrial development, and thermal pollution is one of these. Of special concern is thermal pollution in areas with high productivity and diversity of species such as coastal areas. These impacts cannot be detected through the use of aerial photography and GIS. It was therefore necessary to utilize other methods to analyse thermal pollution impacts. Therefore, estimates of thermal discharges per day by the major heavy industries in the region and thermal modeling were applied.

5.5.2.1 Thermal Pollution in the Gulf of Paria

The Pt. Lisas Industrial Estate houses a number of industries which produce thermal wastes. Table 5.15 represents these industries and the bays into which the thermal wastes are discharged.

Table 5.15: Quantities and destinations of thermal discharge for heavy industries at the Pt. Lisas Industrial Estate in kj/min..

	ISCOTT	FEDCHEM & TRINGEN	Urea Plant	T&TEC	FERTRIN
Lisas Bay	85000	13	19000		
Couva Bay				67.6	1.33

Source: PLIPDECO and IMA, 1982, Vol. VIII.

The question remains, has the thermal discharge into the Gulf of Paria adversely affected the ecology of the area? In order to address this issue it is necessary to determine whether the region exhibits any of the following characteristics revealed by Conway and Ross (1980:244).

5.5.2.2 Risk Characterization of Thermal Pollution

Heat discharge affects coastal environments in a number a ways. These include:

1. Depressed dissolved oxygen levels;
2. Rare, acute lethal effects in the immediate area of discharge;
3. Rapid temperature fluctuation effects;
4. Increased sensitivity to toxic materials;
5. Shift in dominant species.

Depressed dissolved oxygen levels

The solubility of oxygen in water in related to salinity and temperature. High temperatures correspond to lowered dissolved oxygen levels. Clark (1977: 67) suggests that the level of dissolved oxygen (D.O.) in ppm found naturally in the Caribbean Sea is 6.7 ppm in summer and 6.33 ppm in winter. Between October 1979 and August 1980, D. O. readings were taken for the area spanning between the LNG River and Orange Valley, the approximate coastal span of the study area. Readings during this period ranged from 3.5 ppm - 9.4 ppm. These levels either exceed or fall below natural D. O. levels expected for the region.

Rare, acute lethal effects in the immediate area of discharge

The data and information revealed no evidence of rare, acute lethal effects in the area of immediate discharge that can be linked to temperature changes in the Gulf of Paria. However, in-depth studies in the immediate localities of heated outfall need to be investigated in order to eliminate the possibility of this effect. Temperature threshold levels for the fish species occurring in the region will also have to be investigated.

Rapid temperature fluctuation effects

Water temperatures were recorded for the cooler season from December to March (1979 -1980), and the warmer season April to November (1980) for the region. Again the measurements were taken at stations which approximately coincided with the study area. The temperatures ranged from 24°C to 27°C in the cool season and 25 °C to 31 °C in the warm season. An area of localised heat was recorded at Lisas Bay near the FEDCHEM and TRINGEN cooling water outfall. Temperatures were above 25°C in the cool months and above 30°C in the warm months. Clark (1977: 67) put natural temperature readings for the Caribbean Sea at 21.6°C in winter and 30.5°C in summer. Thus readings from the study region exceeded normal estimates. Chronically high temperatures could pose a serious threat to the commercial fisheries in the region.

Increased sensitivity to toxic materials

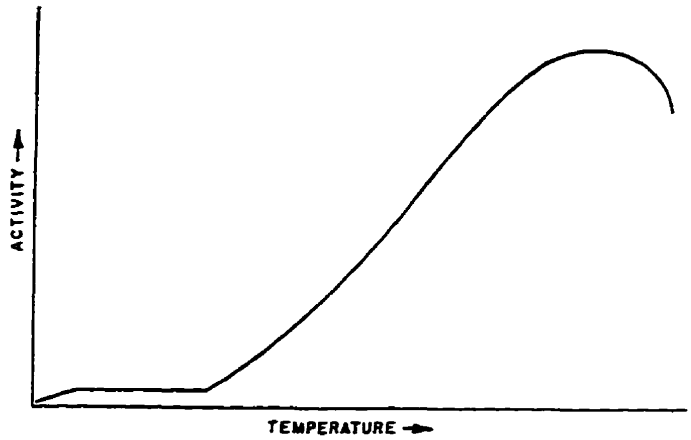
No evidence was found from the field survey or existing literature to confirm this factor. The fish kills in the region have been attributed to ammonia poisoning or unknown causes.

Shift in dominant species

General effects of thermal pollution on fish

Thermal stress has both general and specific effects on the various fish species found in the study region. Temperature preferences in fish depend on species and acclimation temperatures. Generally, within a specific temperature range, the rates of fish metabolism and activity increase without causing mortalities. However, beyond that point, mass fish mortalities may occur. Yet species can acclimatize to higher temperatures more easily than to lower temperatures.

Figure 5.25: General effects of temperature on the activity of fish



Source: Sylvester, 1972: 206.

Terminology of Thermal Responses in Fish (USEPA, 1973, 3-4)

Tolerance Range : a temperature range within which a given species can survive and carry out all physiological processes. No heat or cold death expected.

Lethal threshold : that temperature at which death will occur from either heat or cold, often defined as temperature at which 50% of individuals within a population of a given species will survive (or die) i.e. it is either a median survival or median mortality temperate.

Incipient lethal temperature : the temperature, either upper or lower at which a given species first shows heat or cold death.

Upper incipient lethal temperature : the highest temperature at which at which incipient death is noted. Is a function of past history of thermal acclimation of highest possible temperature at which the organism can survive.

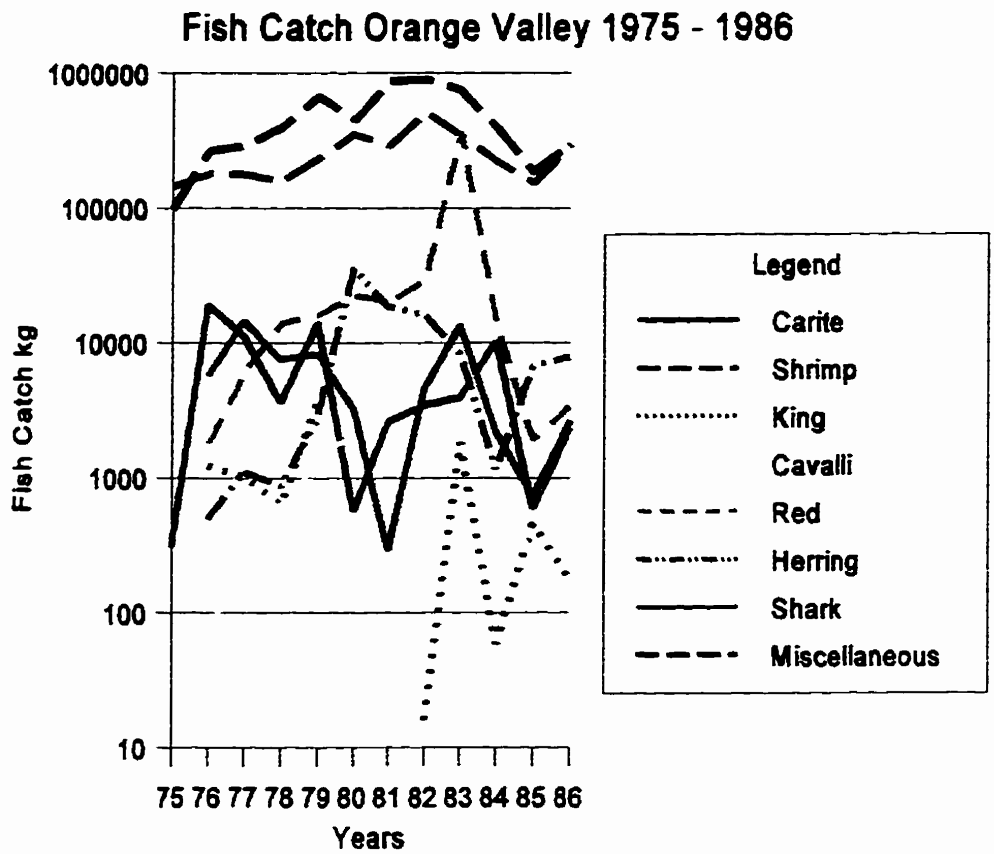
Temperature extremes: temperatures outside of the tolerance range but beyond the lethal thresholds.

Species tolerance can be adjusted either upward or downward by acclimation to warmer or colder waters.

The declining portion of the curve in Figure 5.25 represents the initial stages of decreased fish activity. Continued thermal pollution would cause the eventual incipient lethal temperature to be reached. At this point, since different species exhibit different thermal preferences and different incipient lethal temperatures, shifts in the dominant species would occur. A shift of this nature in the region would be reflected in a decline in fish catch.

The total quantities of fish landed at Orange Valley by year from 1975 - 1986 in order of commercial importance were analysed in order to establish whether there was a shift in the dominant species (Figure 5.26 and Table 5.16). Production began at the Pt. Lisas Industrial Estate in 1977 and continued to expand throughout the period examined. Graphing the species revealed changes in the data that reflect the possibility of thermal pollution.

Figure 5.26: Quantities of fish landed at Orange Valley by year from 1975 - 1986.



Source: Fish Catch at Orange Valley 1975-1986, Ministry of Agriculture, Lands and Food Production, Government of Trinidad and Tobago.

Table 5.16 : Total Quantities of Fish Landed at Orange Valley by year from 1975 - 1986.

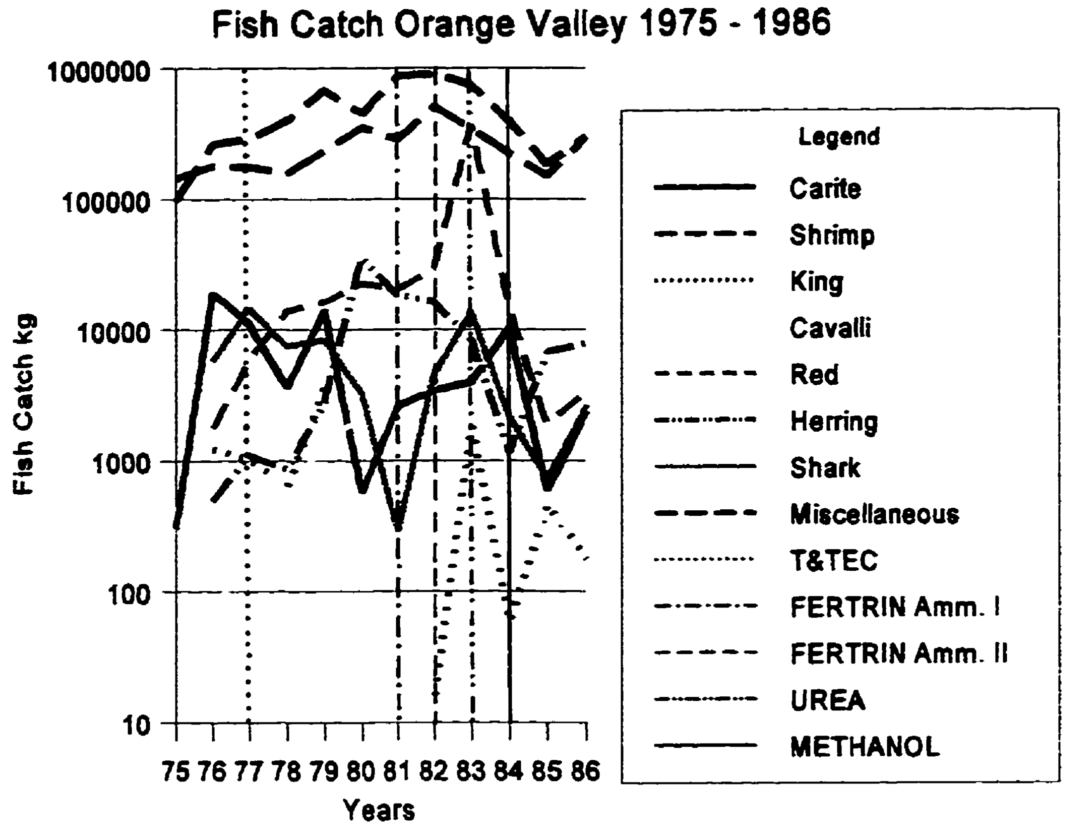
Fish species	Year											
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Carite	303	19301	11279	3657	14238	569	2611	3454	3934	10356	5890	2360
Shrimp	143152	179514	177129	156878	233736	352270	288382	513913	346760	223815	152722	301028
King	N/A	1225	1030	635	3811	N/A	N/A	16	1835	59	459	178
Cavalli	N/A	22	2606	477	1554	2019	3742	3795	13143	837	276	436
Red	N/A	1784	5958	13970	16314	22388	20242	29395	362575	14438	1922	3435
Herring	N/A	494	1106	876	2864	35807	18622	16324	8484	1158	6713	7892
Shark	N/A	5740	14658	7526	8245	3221	288	4706	13831	2213	741	2670
Miscellaneous	98032	261693	290661	398415	678263	451146	866415	903315	751302	397622	184033	300238

Source: Fish Catch at Orange Valley, Ministry of Agriculture, Lands and Food Production, Government of Trinidad and Tobago.

The dominant species prior to 1979 were 'Miscellaneous' species and shrimp. From 1979 onward there was a decline in Carite, Shark and King fish. All other species for which data were available increased, i.e. Cavalli, Red and Herring. This increase continued until 1982. However, between 1983 and 1985 all the aforementioned fish species including 'Miscellaneous' and Shrimp suddenly declined. After 1986, fish catch for the various species increased. Although between 1975 and 1977 there had not been a shift in 'Miscellaneous' and Shrimp species, an increase in Cavalli, Red, and King fish had occurred. The increase in Red fish moved it to the third most predominant fish in the region after 1978. This represents a complex pattern of catch over a short period of time. Under normal conditions, a dominant species pattern should prevail. The existing pattern suggested some environmental phenomenon had produced these oscillations, e.g. thermal or other pollution.

Figure 5.27 shows that the decline in Shrimp, King and Carite and the increase in 'Miscellaneous', Shark, Herring, Cavalli, and Red coincided with the commencement of operations at T&TEC, the national electricity commission. Declines in all except 'Miscellaneous' and Carite coincided with the commencement of operations at the FERTRIN Ammonia I plant in 1981. Increases in most of the species coincided with the commencement of operations at the FERTRIN Ammonia II plant in 1982, and the Urea plant in 1983. The opening of the Methanol plant in 1984 corresponds to a decline in all species except Carite. Thermal effluents associated with each of these operations is summarized in Table 5.15. There is evidence of a definite shift in the predominant species of commercial fish in the region, possibly resulting from thermal effluent from each of the aforementioned industries.

Figure 5.27: Quantities of fish landed at Orange Valley and start years of major heavy industry by year from 1975 - 1986.



Source: Fish Catch at Orange Valley 1975-1986, Ministry of Agriculture, Lands and Food Production, Government of Trinidad and Tobago.

As previously explained, temperature is an extremely important parameter in any environment. Every aquatic organism has a thermal tolerance or range of temperatures which are optimum to ensure growth, development, and reproduction. These temperatures are largely dependent on the stage of development, physiology, species, and environmental history of the organism, and can be termed 'preferred' temperatures. Change in historic environmental conditions will adversely affect the organism. With the commencement of operations at each heavy industry at the Estate, daily thermal effluent was discharged and the thermal balance of the waters disturbed, giving rise to a shifts in the dominant species.

5.5.2.3 Thermal effluent and Temperature Modeling for Added Heat

Increased industrialization at Pt. Lisas has given rise to the dumping of heated waste into the Gulf of Paria. The coastal region to the immediate north and south of the study area supports a large commercial fishing industry. It is therefore of special interest to this study to examine the possible effects of these thermal changes on the fish of the region. There are many methods for modeling increased temperatures of water after heated effluent has been added. Various models utilize various parameters, for example input from solar radiation, heat loss due to evaporation, and density of water. The model applied in this study was developed by Edinger (1949), and utilizes parameters such as wind speed, heat input and the surface area of the water body. This model was chosen because of its parameters are readily available and because it is recommended for use in modeling small, well-mixed bodies of water with a constant input of heat energy (Rau and Wooten, 1980: 6-27 - 6-28).

The model is as follows:

$$T_s = T_n + \frac{H_p}{AK}$$

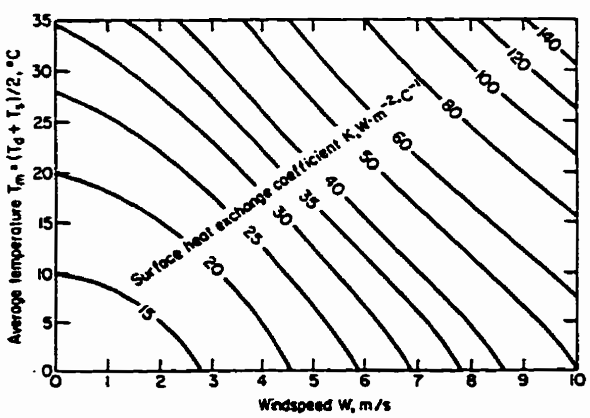
where T_s = water temperature with heated water discharge, °C
T_n = natural water temperature before heated discharge, °C
H_p = plant heat rejection rate, W
A = surface area of water body, m^2
K is the surface heat coefficient and represents a function of wind speed and average temperature T_m given by:

$$T_m = \frac{T_d + T_w}{2}$$

where T_d = dew point temperature, °C
T_w = water temperature, °C

Edinger et. al. (1970) have evaluated the surface heat coefficient for easy reference.

Figure 5.28: Evaluation of surface heat exchange coefficient.



Source: Rau and Wooten, 1980: 6-28.

By applying the Edinger model it was possible to calculate the temperature in the Gulf of Paria in the immediate vicinity of the heated outfall. An average wind speed of 5.125 knots (2.76 km/hr or 46.1 m/min or 0.768 m/s) was estimated from wind speed data in Cooper (1981: 11). T_m was estimated to be 23.3 °C in summer and 35.25 °C in winter. The surface heat coefficient determined from the Edinger K model at the aforementioned T_m values are 23 °C and 30 °C respectively (Figure 5.28). The surface area, A, of the Gulf of Paria for the specific outfall areas of Couva and Lisas Bays was calculated with a 2 km seaward limit.

For the Gulf of Paria, *summer*:

$$T_s = 21.6 + \frac{104081.9}{11000 * 23} = 22.0°C$$

for the Gulf of Paria, *winter*:

$$T_s = 30.5 + \frac{104081.9}{11000 * 30} = 30.8°C$$

The modeling of this localized thermal system is designed to assess the daily inputs of thermal pollution into the waters of the Gulf of Paria. An additional 0.41^0 C per unit mass of water per day is added in the summer (dry season) and 0.31^0 C per unit mass of water per day in winter (wet season), since operations commenced at ISCOTT, FEDCHEM, TRINGEN, The UREA Plant, T&TEC, and FERTRIN. This estimate represent only the heat added, most of which will be lost through dissipation to the atmosphere and heat diffusion effects within the water body. The potential impacts of infusion of these amounts of heat effluent on fisheries and other aquatic life in the region needs to be investigated.

5.5.3 Liquid Pollution and Water Quality

Pollution is one of the principal impacts of an industrial estate. Most developing countries view industrialization as an essential factor in development, generating employment and badly needed revenue for the country. A possible consequence of this development is environmental degradation. However pollution control is often a luxury. Even where laws and policies exist to restrict or minimise environmental deterioration, few agencies exist to enforce these laws.

In the context of the Pt. Lisas Industrial Estate, environmental pollution during the 25 year period under review was not dealt with on a governmental basis. Instead, PLIPDECO had the authority to accept or defeat a proposed industry based on environmental impact studies submitted by the client. This was clearly outlined in the PLIPDECO Information Note and Progress Report on the Development of The Point Lisas Industrial Estate and Port, (1978; 10).

> Environmental
> In the absence of legislation dealing with the discharge of effluents and other forms of pollution, potential clients must satisfy PLIPDECO that an appropriate environmental impact study had been carried out. Such a study would be made available to PLIPDECO for evaluation. Measures to deal with any expected environmental problems would have to be developed and approved by PLIPDECO. It would remain at the discretion of PLIPDECO to request such a study and preventative measures after considering the proposed operations.

This absence of pollution legislation led to inconsistent monitoring and a lack of pollution data. Consequently pollution potential analysis in this study deals only with data on point source liquid and thermal effluent being released into the Gulf of Paria. Research reveals that much of the industrial waste is disposed of via channels to the Gulf of Paria

(Figure 5.29). For each of these industries the release of certain liquid and thermal pollutants pose a specific threat to the ecological environment of the Gulf of Paria.

Industrial activity is not solely responsible for pollution in the Gulf of Paria. Agricultural activities contribute to pollution by way of :

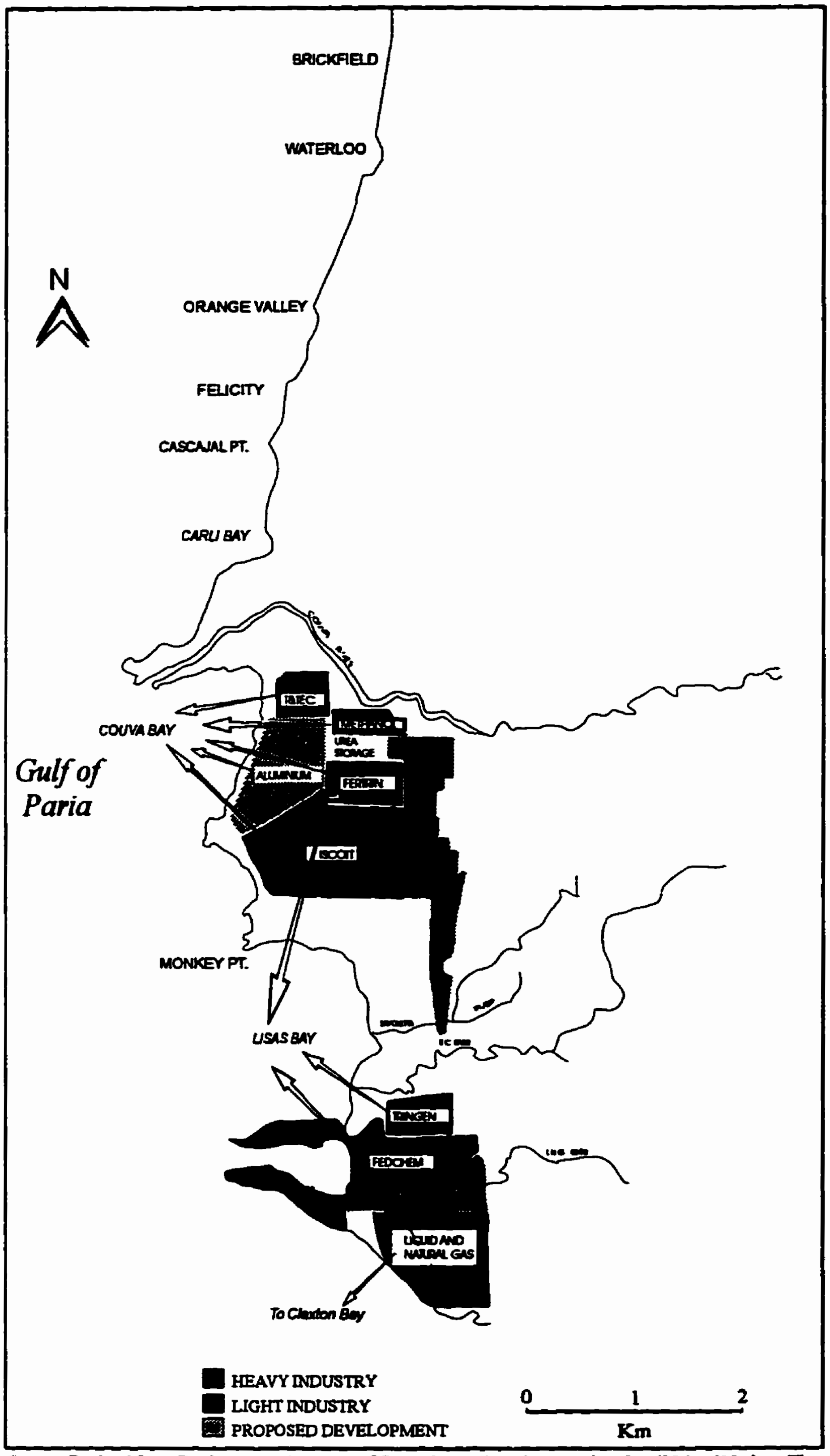
1. increased sediment discharge from rivers due to soil erosion;
2. chemical pollutants from fertilizers and pesticides.

However this study will not examine this source of pollution. The study deals with point source pollution in the region, most of which is generated by FEDCHEM, TRINGEN, ISCOTT, the Urea Plant, T&TEC, IGL, and FERTRIN. Any undertaking of pollution studies in coastal waters must take into account the circulation patterns and currents of the water body being analysed.

5.5.3.1 Currents and circulation patterns in the Gulf of Paria

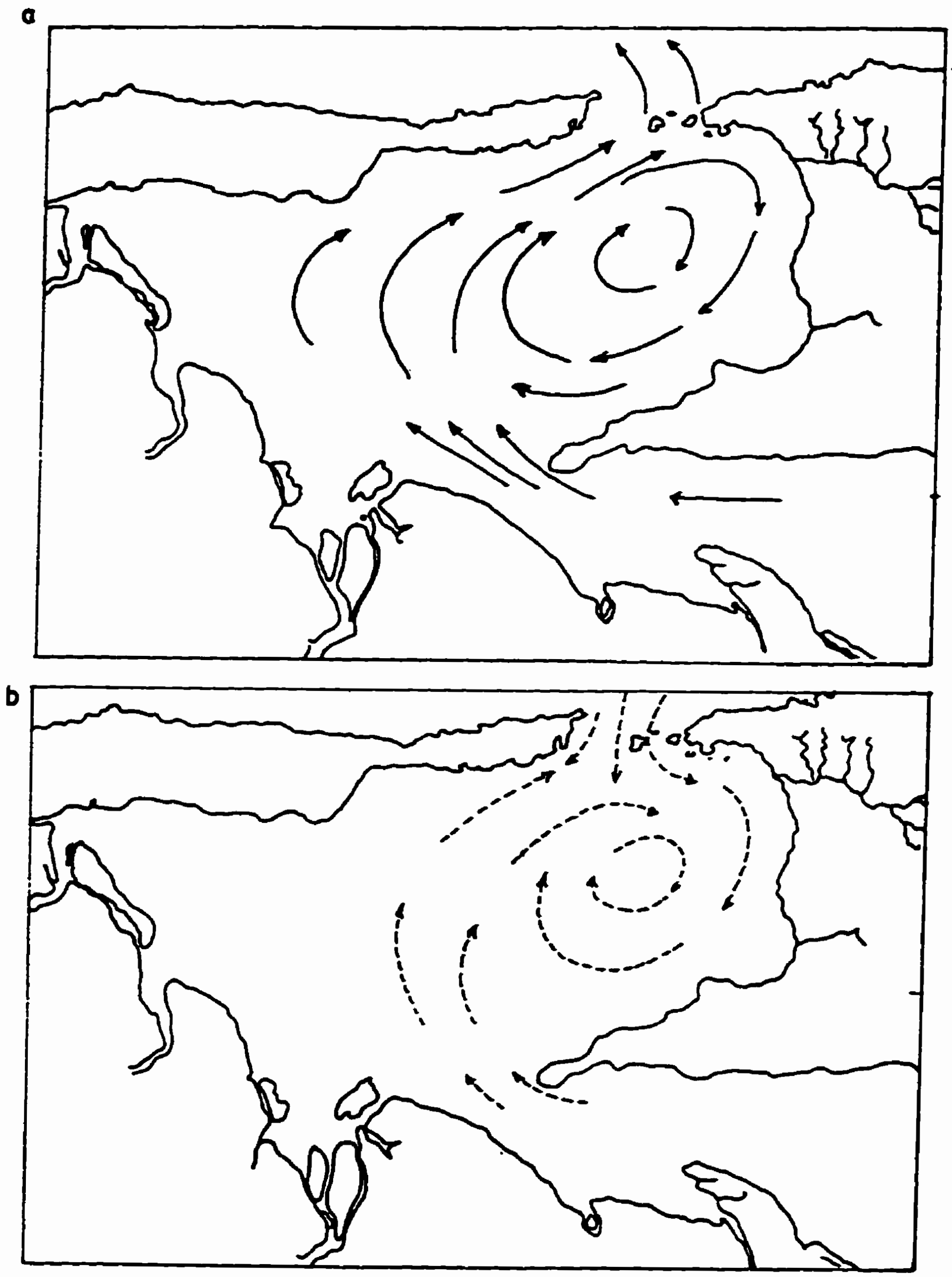
In the Gulf of Paria, currents follow a clockwise pattern (Figure 5.30), affecting mainly the upper 30-40 metre water layers. These currents operate in an enclosed bay. Current velocities are not much affected by the rivers which run along the coast. Water renewal within this eddy is therefore relatively slow. Surface directional flows are not much altered between the wet and dry seasons. However, bottom currents often flow in a direction counter to that of the dry season. Due to the slow water renewal, any form of pollutants, be they liquid or thermal, will persist in these sheltered waters. More detailed studies of thermal and liquid pollutant plumes should be carried out in the region to determine the dynamics of pollutant transport in the Gulf of Paria. In the absence of satellite imagery, the cost effective use of Thermal Infra-red photography will suit this type of investigation.

Figure 5.29: Destination of waste from Pt. Lisas Industrial estate disposed of in the Gulf of Paria



Source: Derived from Environmental Aspects of Coastal Area Development in a Small Island Nation - The Case of Trinidad and Tobago with emphasis on the Pt.Lisas Industrial Complex. C. D. Lewsey, Institute of marine Affairs, 1981, Appendix IV, p. 17

Figure 5.30: Principal water patterns and currents, Gulf of Paria (a) surface (b) bottom.



Source: Unknown after van Andel and Postma (1954)

5.5.3.2 Liquid Pollution

Liquid wastes in the region are comprised of a variety of effluents (Table 5.17 and Figure 5.31). No consistent monitoring of liquid pollution in the region had been undertaken. Thus, it was not possible to attain historical data on liquid pollutants for the region. This lack of data negated the performance of a trend analysis. Therefore, in order to establish the significance of the levels of pollutants provided in other studies (PLIPDECO and IMA, 1982), it was necessary to use risk characterizations, as well as some standard or yardstick against which these levels could be measured. This study applied USEPA standards.

5.5.3.3 Risk characterization of liquid pollutants on environment

Sewage

Low concentrations of sewage released into the ocean may not cause serious ecological damage if they are deposited at sufficient distance from the shore, and circulation and mixing patterns of the locality are high. However, high concentrations released into a single locality may cause extensive damage particularly to bottom life (Clark, 1970: 522). Sewage can be hazardous to marine life and human health, and offensive to the senses. It often contains particulate organic matter rich in microbe populations, some of which are pathogenic to man (Clark, 1970: 604). Its other common constituents are ammonia nitrogen, phosphate, phosphorus, oil and grease, cyanide, arsenic, trace metals, detergents and phenols, all harmful to aquatic life. Sewage is of particular concern when it comes to shellfish as toxins bioaccumulate in the tissue. These are passed on to humans who consume them and can result in pathological diseases such as typhoid, dysentery and the virus hepatitis.

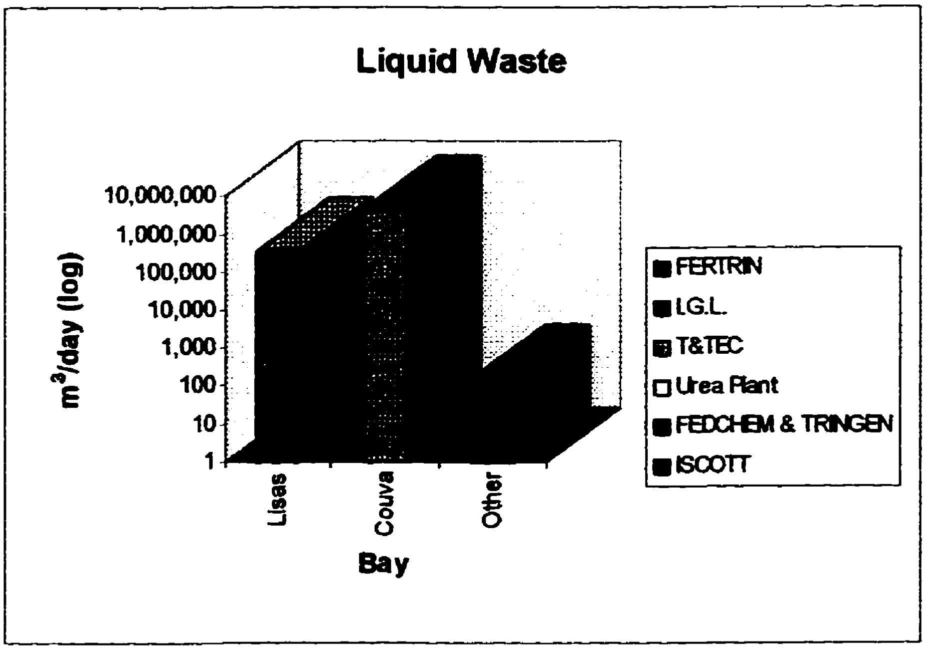
Table 5.17: Combined Liquid Wastes from Heavy Industry (m^3/day) by Disposal Destination

	ISCOTT	FEDCHEM & TRINGEN	Urea Plant	T&TEC	I.G.L.	FERTRIN
	(combined effluent & sewage discharge)	(type not specified)	(fresh cooling water @ 43°C)	(intermittent chlorination)	(NaOH & Carbide slush)	(sea water @ 40.6°C)
Lisas Bay	2325	354330	455			
Couva Bay				4255000		38160
*Other					159	

* Refers to bays outside study area.

Source: PLIPDECO and IMA, 1982, Vol. VIII.

Figure 5.31: Quantities and destinations of Liquid Waste for heavy industries, Pt. Lisas Industrial Estate, by industry



Source: PLIPDECO and IMA, 1982, Vol. VIII.

Coastal environmental effects of sewage are often difficult to determine. This is due to its components being both beneficial or debilitating, long term or biodegradable. These components have various effects upon the plankton (suspended plant and animal life), the benthos (bottom dwelling animal life), and nekton (swimming life) in a coastal ecosystem. Biodegradable constituents of sewage are of particular concern as they require oxygen to perform this process. The more sewage the more excessive the need for oxygen, so that large amounts of dissolved oxygen used in the process are removed from the water. The U. S. Environmental Protection Agency (EPA) has determined that reduction of the dissolved oxygen level in water to below 4 ppm can have an adverse effect on the species and quantities of aquatic life (Clark, 1977: 608).

Yet another concern is the particulate element in sewage. Most of this material will settle to the sea bottom, causing a reduction in light penetration (curtailing photosynthetic processes), and taking up both metals and persistent toxins. These serve as food for bacteria and filter feeding organisms such as oysters and mussels. These organisms which may eventually be consumed by humans (see food web in mangrove communities, 5.4.2), accumulate toxins through biological magnification thereby posing a serious threat to human health.

Chlorination

The treatment used for cleaning power plant cooling systems is periodic chlorine flushing. The concern is when chlorine, which does not remain in the water for a long period of time, forms 'free chlorine' (HOCI or OCI). Where ammonia is present, these are converted into monochloramine (NH2CI) or 'combined chlorine'. Although the free chlorine is more toxic, combined chlorine is more stable and therefore remains in the environment for a longer period of time. Both forms of chlorine result in anaemia and reduced oxygen to fish tissue (Heath, 1995: 3, 71). At high concentrations it can be toxic to aquatic life (Conway and Ross, 1980: 224).

Sodium Hydroxide

Sodium hydroxide or Lye is used in the process of gas production. In the Gulf of Paria, this chemical is emitted into Claxton Bay which falls outside the study area. The direction of currents in this enclosed and sheltered water body may cause the effects to be felt in bays in the immediate vicinity of Claxton Bay which fall within the study area. Lisas Bay is particularly susceptible.

Sodium hydroxide has been assigned a 10 - 100 ppm threshold limit by the USEPA. Concentrations of between 20 - 100 mg/l have been found to be lethal to a number of fish including carp, salmon, trout, and crayfish (Canadian Environmental Protection Service Sodium hydroxide Enviro TIPS, 1985: 77). Damaging effects are mostly as a result of increased pH. Fish die of suffocation due to the slow destruction of their respiratory organs and develop burns on their gills and skins accompanied by a slime coating. Acceptable pH levels are between 6.5 - 8.5 for aquatic life. NaOH does not degrade in water. It can only be chemically neutralized or lost by absorption. High levels of sodium hydroxide in water are corrosive to human skin, eyes, and mucous membranes, making swimming in NaOH contaminated waters highly unadvisable.

Carbide slush

This is a combination of calcium hydroxide solution and impurities. It is used for liberating acetylene when it is mixed with water. Although acetylene can be liquefied at ordinary temperatures with high pressure, it is violently explosive as a liquid. Acetylene gas is usually stored in metal tanks, under pressure, dissolved in liquid acetone ("Acetylene," Microsoft (R) Encarta. Copyright (c) 1994 Microsoft Corporation. Copyright (c) 1994 Funk & Wagnall's Corporation).

Trinidad and Tobago have no aquatic toxicity ratings for calcium hydroxide hence the USEPA standards are used to measure toxicity. This measure is 1000 -10 mg/l (4 day lethal median toxicity rating) (Environment Canada Environmental protection Service (EPS) Calcium hydroxide Enviro Technical Information for Problem Spills (TIPS), 1985, 31). Calcium hydroxide also has effects that are mostly related to changes in pH levels. In many cases the addition of this chemical increases the biological productivity of the water body, probably by providing more carbon dioxide. No bioaccumulation in the food chain has been detected for this chemical.

Impact assessment of liquid pollutants

The impacts of pollutants are often difficult to detect due to combining and overlap of effects in aquatic environments. This difficulty is compounded by the lack of research and inconsistency in monitoring of the levels of these aforementioned contaminants in the study area. In the absence of such data, the application of aquatic ecosystem indicators becomes necessary. The main indicator in an aquatic environment are fish and biological and chemical indices. Fluctuations in these provide managerially significant information about the state of the environment. For these reasons, the effects of pollutants will be judged on the basis of the effects on certain indicator species and water quality criteria set by the United States Environmental Protection Agency.

Water quality criteria are defined as "levels of specific concentrations of constituents which are expected, if not exceeded, to assure the suitability of water for specific uses" (Rau and Wooten, 1980, 6-2). These guidelines are developed for specific industries and effluent discharges. Impacts of sewage and other liquid pollutants will be judged using risk characterizations and various water quality criteria.

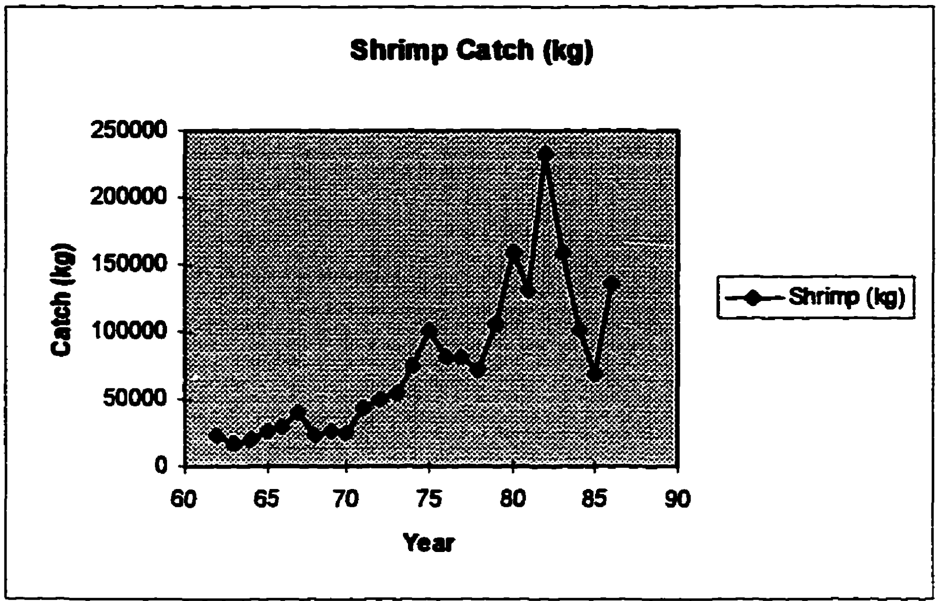
5.5.3.4 Sewage

An indicator of excessive sewage in a coastal environment is the increase in bottom feeding species. Shrimp, previously used to analyse the effect of declining mangrove along the coast, will also be used as an indicator species for sewage pollution potential. In that analysis there was no visible impact since results showed unusual fluctuations and often increase in shrimp during the period under consideration.

There has not been enough data on the quantities of the components of sewage found in the Gulf of Paria to adequately prove the excessive presence of sewage. However, since shrimp is a bottom feeder sewage pollution might be an important factor in its unusual catch increase for the region. Figure 5.32 shows the increase in shrimp for the period 1962 to 1986. In spite of the loss of spawning and shelter for this aquatic species, some factor in the environment has compensated and contributed to increased numbers of shrimp. In 1981

ISCOTT, the factory discharging most sewage into the Gulf of Paria began production. In the years immediately following the opening of ISCOTT, shrimp catch climbs at a previously unmatched rate. Arguably, there is a link between increased shrimp catch and factory discharges. However, this does not explain the sudden decline in shrimp yields around 1985. There may be other environmental processes at work. The need for consistent monitoring and further studies needs to be addressed.

Figure 5.32: Shrimp catch in Orange Valley from 1975 - 1986 in kilograms.



Source: Fish Catch by Beach, Ministry of Agriculture, Lands and Food Production, Fisheries Division, Government of Trinidad and Tobago.

5.5.3.5. Water Quality

Water quality tests in the Gulf of Paria had been performed in 1979-80 and 1982 when studies of the Pt. Lisas environment were jointly undertaken by PLIPDECO and IMA. The studies examined five bays in the region, four of which are included in the study area, Lisas; Couva; Carli; and Orange Valley, and one outside the study area; Claxton. After testing water temperatures, faecal coliform bacterial content, petroleum hydrocarbons, heavy metals, and the density and diversity of species in the bays, the results implied that only Lisas Bay was under stress at the time. However it was expected that with continued industrialization and effluent discharge into the Gulf of Paria, both Couva and Carli Bays would become stressed (Pt. Lisas Environmental Protection Project: Second Quarterly Report, 1980: 15, 49).

Another study conducted in 1981 reiterates the findings of the first study but with some changes in the status of the bays. The area was tested for:

1. Chemical Parameters/Nutrients
    a) phosphate;
    b) ammonia;
    c) nitrite;
    d) nitrate; and
    e) silicate.

1.1 Chemical Parameters/ Hydrocarbons and Trace Metals

2. Biological Parameters
    a) faecal coliform
    b) BOD_5 (Biological Oxygen Demand)
3. Sediments
4. Physical Parameters
    a) salinity
    b) temperature
    c) pH
    d) total suspended solids

Lisas Bay was again found to be the most stressed bay. Carli Bay and Orange Valley had become stressed while Couva Bay showed no signs of stress.

5.5.3.6 Risk characterization of poor water quality

Utilizing the data from the PLIPDECO and IMA study (see above) it was possible to produce a series of tables summarising the findings. However, this was not deemed enough to assess the status of water quality in the Gulf of Paria. Therefore, in addition to this data, USEPA permissible concentrations for each effluent in aquatic water were added to create a series of tables (Tables 5.18 through 5.22). Graphs were then produced which plotted EPA standards against estimated levels to assess the degree of contaminant concentrations of only those effluents that both exceeded EPA standards and are considered toxic and hazardous (Figures 5.33 through 5.37 and Table 5.23). By this means, a clear picture of the state of coastal waters in the Gulf Of Paria could be assessed. Levels of contaminants for each parameter was investigated by Bay for the three Bays of Lisas, Couva and Carli from October 1979 - August 1980. The maximum and minimum values found in the bays are documented.

Table 5.18 shows the levels of various Chemical parameters and Nutrients in the region by Bay. Minimum phosphate values were close to zero for Lisas Bay and zero for Couva and Carli Bays. Maximum phosphate values were highest for Lisas Bay, Couva Bay had the second highest readings, and Carli Bay had the lowest levels of phosphate. Ammonia minimum values are also close to zero. No minimum amounts of ammonia were recorded in Lisas Bay but constantly high values of 39 mg/l were found. By comparison small concentrations of ammonia were found in Couva and Carli Bays.

Nitrite was found in the small amounts in the regions' waters. Couva and Carli Bays sometimes exhibited no nitrite while Lisas Bay exhibited small minimum nitrite values. Couva and Carli Bays exhibited small maximum nitrite values while Lisas Bay had high nitrite values (relative to Couva and Carli Bays). Nitrate values for Lisas and Couva Bays ranged from zero to 1.5 mg/l. Carli Bay exhibited higher minimum values of nitrate, but lower maximum values at 1.1 mg/l. Silicate minimum values were zero for Lisas and Couva Bays, while Carli Bay shows high values. Silicate maximum values were 4.68 mg/l for Lisas and Couva Bays, close to, but less than the minimum value found at Carli Bay. Carli Bay shows high values for Silicate, almost twice the maximum found at the other two Bays.

Figure 5.33 shows that for Chemical concentrations in Couva, Carli and Lisas Bays, phosphate maximum and minimum levels exceeded EPA standards, while only maximum concentrations for ammonia exceeded EPA standards. Chemical concentrations of nitrate for Couva, Carli and Lisas Bays fell below EPA standards. No EPA standards were found for nitrite and silicate.

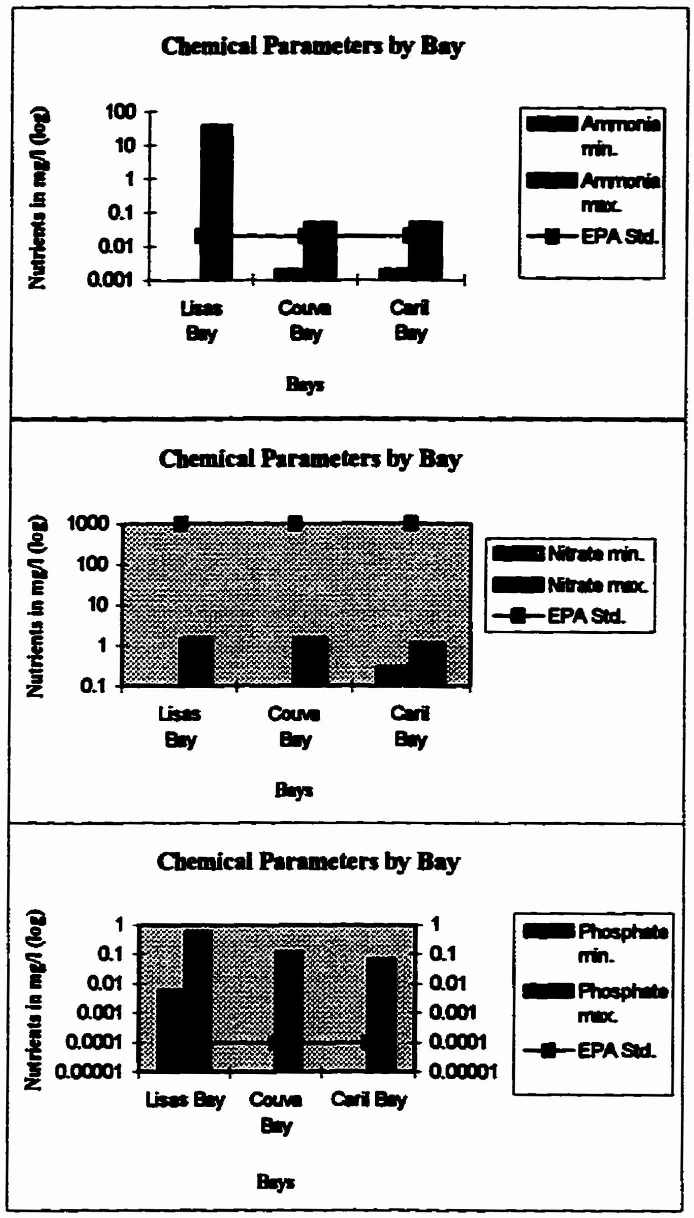
Table 5.18: Chemical Parameters/Nutrients by Bay for the Couva /Pt. Lisas region.

Nutrients	EPA Standards	Lisas Bay	Couva Bay	Carli Bay
Phosphate	*0.0001mg/ l	0.006 - 0.588 mg/l (PO_4 P)	0 - 0.12 mg/l (PO_4 P)	0 - 0.07 mg/l (PO_4 P)
Ammonia	*0.02 mg/l	39 mg/l (NH_3 - N)	< 0.002 - 0.05 mg/l (NH_3 - N)	< 0.002 - 0.05 mg/l (NH_3 - N)
Nitrite	no criteria set	0.0005 - 0.149 mg/l (NO_2 - N)	0 - 0.026 mg/l (NO_2 - N)	0 - 0.026 mg/l (NO_2 - N)
Nitrate	<1000 mg/l	0 - 1.5 mg/l (NO_3 - N)	0 - 1.5 mg/l (NO_3 - N)	0.3 - 1.1 mg/l (NO_3 - N)
Silicate	no criteria set	0 - 4.68 mg/l (SiO_2 - Si)	0 - 4.68 mg/l (SiO_2 - Si)	5.5 - 7.88 mg/l (SiO_2 - Si) (Orange Valley vicinity)

*EPA Designated Hazardous Substance

Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Handbook of Toxic and Hazardous Chemicals and Carcinogens' Second Edition 1985' and 'Coastal Ecosystem Management', Clark, 1977.

Figure 5.33: Toxic and hazardous chemical concentrations by bay against EPA standards.



Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Handbook of Toxic and Hazardous Chemicals and Carcinogens' Second Edition 1985' and 'Coastal Ecosystem Management', Clark, 1977.

Table 5.19 and Figure 5.34 denote Chemical parameters for ocean water in each bay. This data showed that lead exhibited the highest values in each of the three Bays, Lisas, Couva and Carli. All the bays exhibited similar levels of Hydrocarbon and Trace Metals. Low minimum values and high maximum values (relative to the other Hydrocarbon and Trace Metal levels) of Hydrocarbon Fuel #6 were found, although no Chlorinated Hydrocarbons were evident in any of the Bays. However, lead maximums were high compared to other chemical parameters, the maximum being 0.7 ppm. Copper and Zinc levels were similar in all three locations at approximately 0.05 ppm.

No EPA Standards were found for Chlorinated Hydrocarbons and Hydrocarbon Fuel Oil #6. Minimum mercury levels fall below the EPA standards . However maximum mercury levels exceeded these standards. Minimum lead levels also fell below the EPA standards, while maximum lead levels exceeded EPA standards. Minimum copper levels coincided with EPA standards. However maximum copper levels exceeded EPA standards. Minimum and maximum Zinc levels exceeded EPA standards.

Table 5.19 : Chemical Parameters/Hydrocarbons and Trace Metals by Bay for the Couva /Pt. Lisas region.

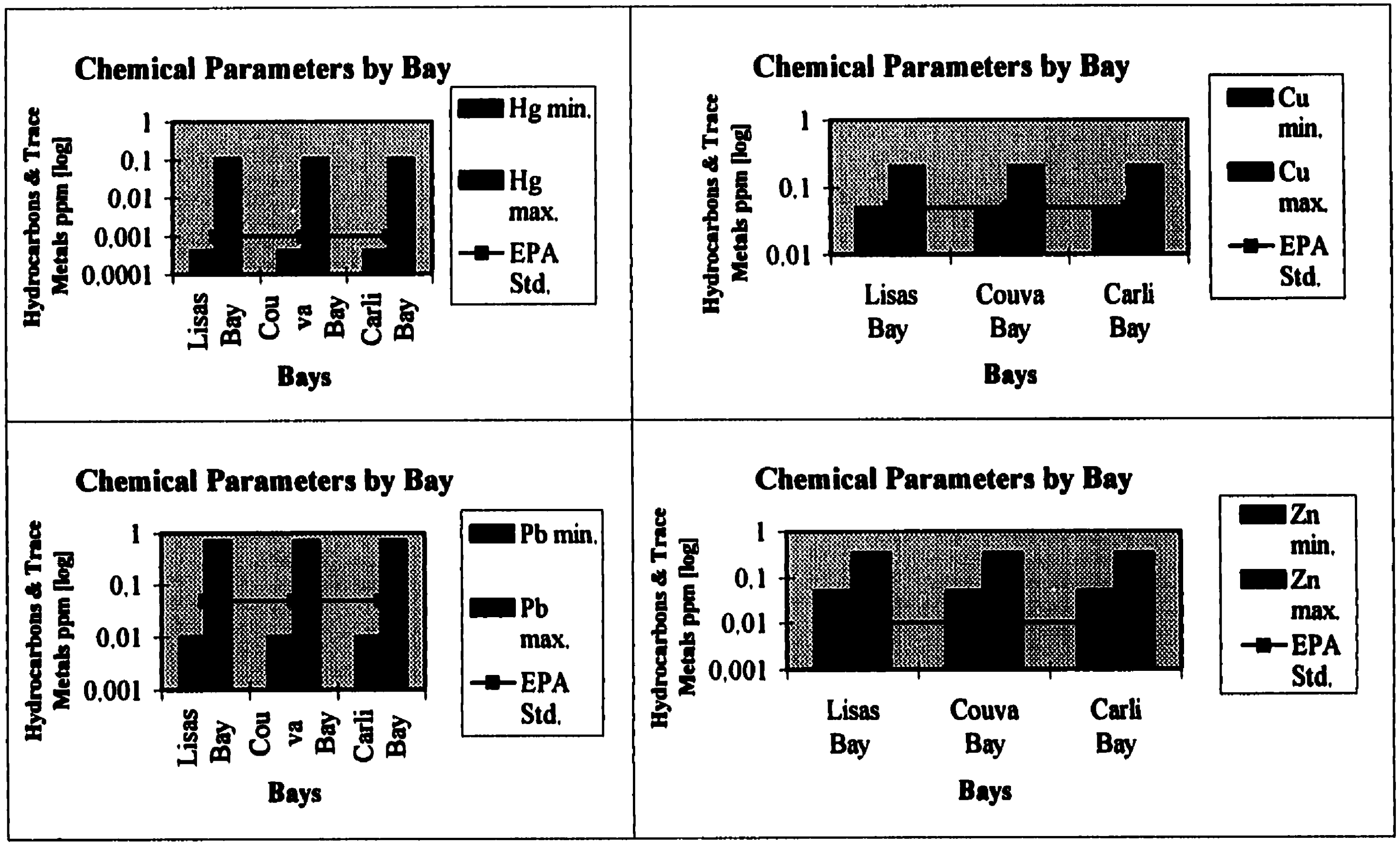
Hydrocarbons/ Trace Metals	EPA Standards	Lisas Bay	Couva Bay	Carli Bay
Hydrocarbons (measured against fuel oil #6 standard)	no standards found	< 0.01 - 0.38 ppm (highest readings)	< 0.01 - 0.38 ppm	< 0.01 - 0.38 ppm
Chlorinated Hydrocarbons (Pesticides)	0.001 - 0.1	no detectable levels (less than 1 ppm)	no detectable levels (less than 1 ppm)	no detectable levels (less than 1 ppm)
Mercury	*0.001 ppm	0.0004 - 0.104 ppm	0.0004 - 0.104 ppm (highest readings)	0.0004 - 0.104 ppm
Lead	*[a] 0.05ppm	<0.01 - 0.7 ppm	<0.01 - 0.7 ppm	<0.01 - 0.7 ppm (highest readings)
Copper	*[a] 0.05 ppm	<0.05 - 0.2 ppm (highest readings)	<0.05 - 0.2 ppm	<0.05 - 0.2 ppm
Zinc	*[a] 0.01 ppm	<0.05 - 0.33 ppm	<0.05 - 0.33 ppm	<0.05 - 0.33 ppm (highest readings)

* EPA Designated Hazardous Substance

[a] To protect saltwater aquatic life

Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Handbook of Toxic and Hazardous Chemicals and Carcinogens' Second Edition 1985' and 'Coastal Ecosystem Management', Clark, 1977.

Figure 5.34: Toxic and hazardous Trace Metal concentrations by bay against EPA standards.



Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Handbook of Toxic and Hazardous Chemicals and Carcinogens' Second Edition 1985' and 'Coastal Ecosystem Management', Clark, 1977.

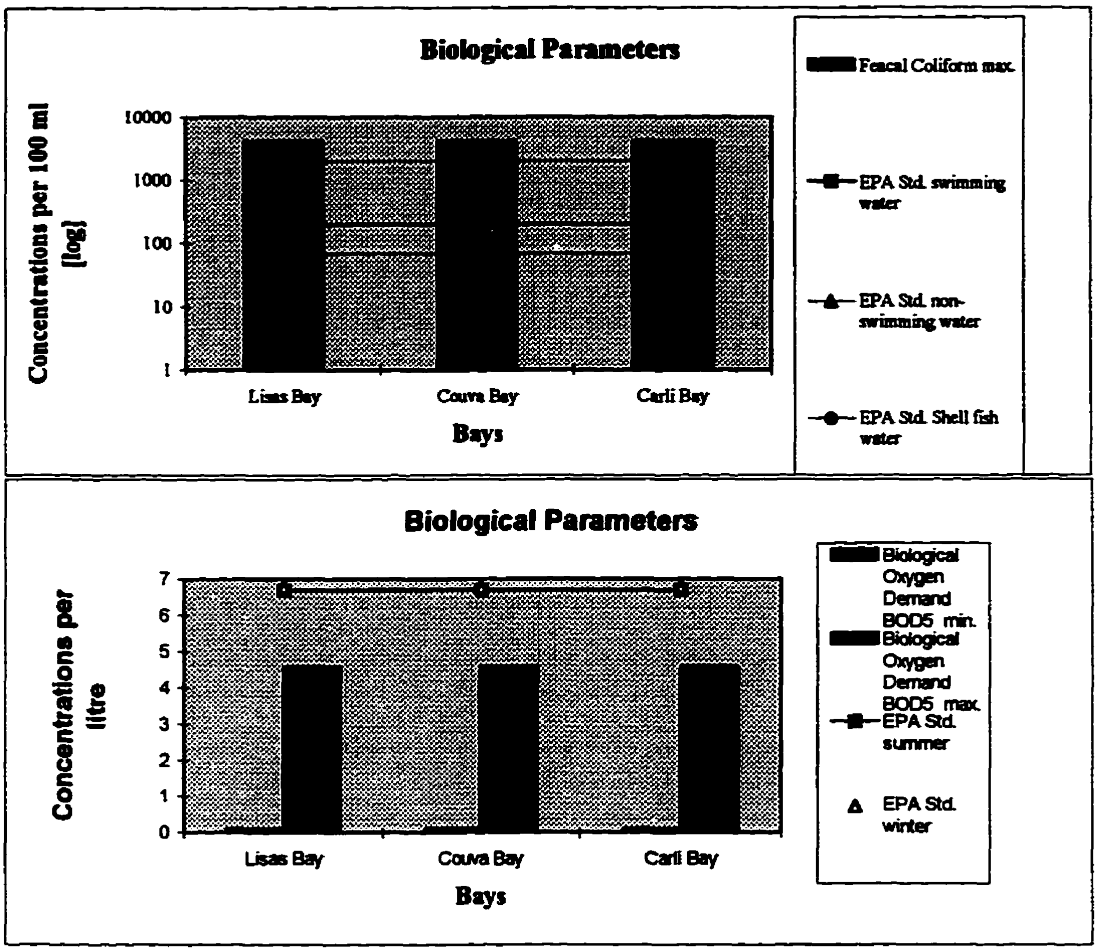
Table 5.20 lists the biological parameters Faecal Coliform and B.O.D.$_5$. Faecal Coliform levels were the same for all three bays. The minimum levels observed in the Bays were zero. Highest readings were found at the mouth of the Couva River and at Lisas Bay. Biological Oxygen Demand (B.O.D$_5$) ranged from less than 1.0 to 4.6, with the highest readings found along the shoreline (IMA Summery Vol. 1, pg 13). The readings were similar for the various bays. Figure 5.35 compares EPA standards with the levels found at the various bays. Note that faecal coliform has three standards, swimming, non-swimming and shell fish water standards. Faecal coliform maximum levels for the three bays exceed the EPA standards for all three of the aforementioned categories, the most extreme excesses being found in the shell fish category. B.O.D.$_5$ levels for the three bays fall below USEPA standards for both the summer and winter (wet) seasons.

Table 5.20: Biological Parameters by Bay for the Couva /Pt. Lisas region.

Biological Parameters	EPA Standards	Lisas Bay	Couva Bay	Carli Bay
Faecal Coliform	not > 200/100 ml swimming waters, average 2000/100 ml non swimming waters, 70 /100 ml shell fish waters	0 - 4,163/100 ml (high readings)	0 - 4,163/100 ml (highest readings)	0 - 4,163/100 ml
Biological Oxygen Demand (BOD_5)	>/= 6.0 mg/l (typical Caribbean Sea 6.70 - summer 6.77 - winter)	0.1 - 4.6 mg O_2/L	0.1 - 4.6 mg O_2/L	0.1 - 4.6 mg O_2/L

Highest levels of BOD_5 concentrated along shoreline.
Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982' and 'Handbook on Industrial Waste Disposal,' Conway and Ross, 1980, and 'Coastal Ecosystem Management', Clark, 1977.

Figure 5.35: Toxic and hazardous Biological Parameter concentrations by bay against EPA standards.



Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982' and 'Handbook on Industrial Waste Disposal,' Conway and Ross, 1980, and 'Coastal Ecosystem Management', Clark, 1977.

Table 5.21, Trace metals and Hydrocarbons levels found in sediment exhibited similar values for Lisas, Couva and Carli Bays. Figure 5.36 gives a visual representation of the extent to which these trace metals in the sediment of the Gulf of Paria surpass EPA acceptable contaminant levels.

Minimum mercury levels were zero, while maximum mercury levels were above EPA recommended levels, at 0.783 ppm. All three bay exhibited high levels of lead contaminant. Both minimum and maximum lead levels were above EPA standards ranging from 2.5. ppm to 32.2 ppm, an excess of 2.45 ppm to 32.15 ppm. Copper minimum readings were below zero, with maximum readings of 89.9 ppm for all three Bays, the second highest readings of all the trace metals. Again EPA standards were exceeded. In all three Bays, zinc levels ranged from15 ppm to 170 ppm, the highest trace metal levels in sediment for the region. Zinc levels surpassed EPA standards by 14.9 ppm to 169.9 ppm. Hydrocarbon Fuel Oil #6 exhibited a minimum level of 3.6 ppm and a maximum level of 152 ppm. No Hydrocarbon Fuel Oil #6 EPA standards were found.

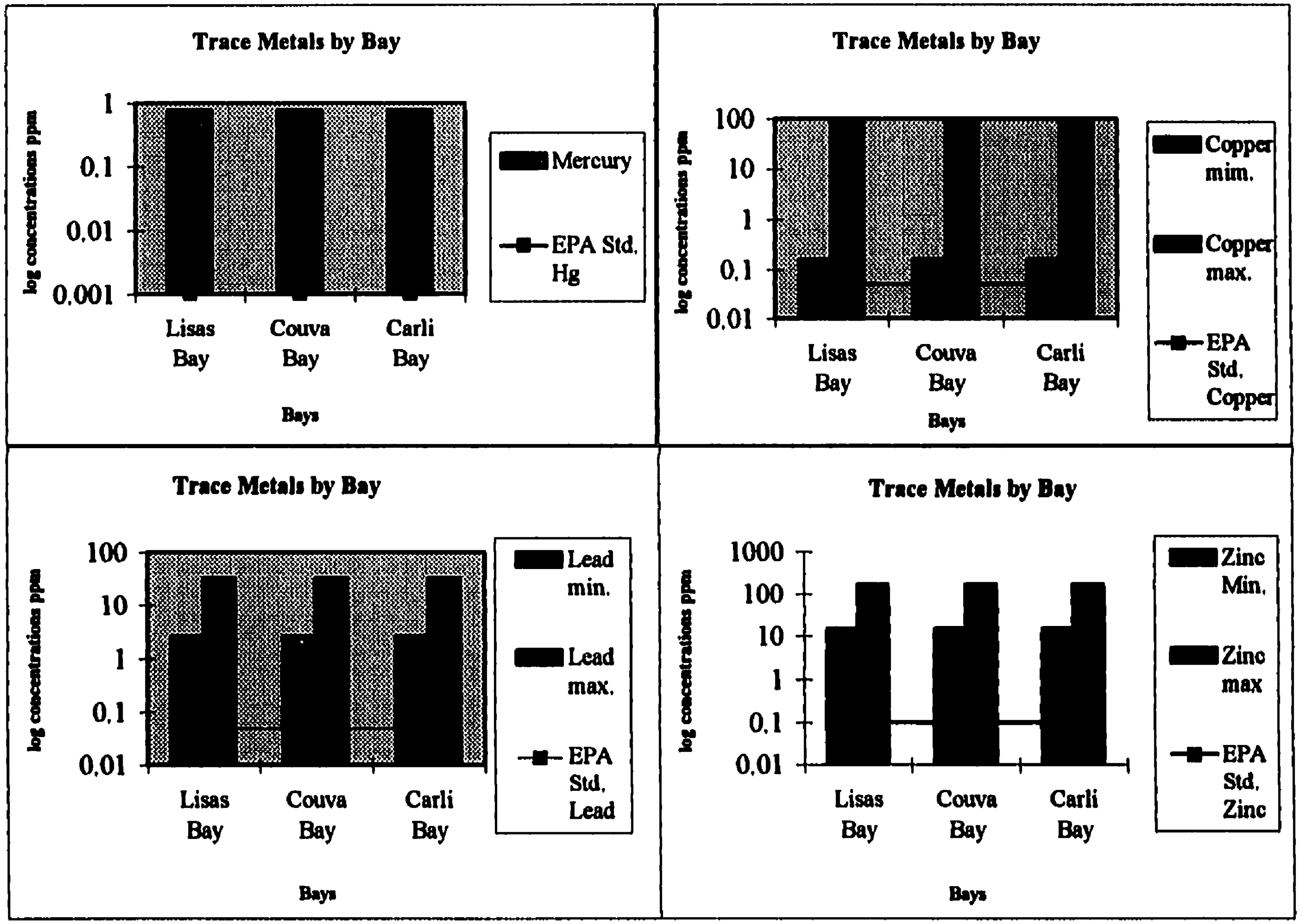
Table 5.21: Trace Metals and Hydrocarbons in Sediment by Bay for the Couva /Pt. Lisas region.

Trace Metals/ Hydrocarbons	EPA Standards	Lisas Bay	Couva Bay	Carli Bay
Mercury	*0.001 ppm	0 - 0.783 mg gm (ppm) (high readings)	0 - 0.783 mg gm (ppm)	0 - 0.783 mg gm (ppm) (highest readings Orange Valley vicinity)
Lead	*0.05 ppm	2.5 - 32.2 ppm (highest readings)	2.5 - 32.2 ppm	2.5 - 32.2 ppm
Copper	*0.05 ppm	0.16 - 89.9 ppm (highest readings)	0.16 - 89.9 ppm	0.16 - 89.9 ppm
Zinc	*0.1 ppm	15 - 170 ppm (highest readings)	15 - 170 ppm	15 - 170 ppm (high readings)
Hydrocarbons (measured against fuel oil #6 standard)	no guidelines found	3.6 - 152 ppm (highest readings)	3.6 - 152 ppm	3.6 - 152 ppm

* EPA Designated Hazardous Substance

Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982' and 'Coastal Ecosystem Management', Clark, 1977.

Figure 5.36: Toxic and hazardous Trace Metal concentrations *in sediment* by bay against EPA standards



Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982' and 'Coastal Ecosystem Management', Clark, 1977.

The physical parameters for salinity and temperature for the three bays were measured (Table 5.22). The values were taken for the wet and dry seasons. Salinity ranged from 11 ^{0}/00 - 34 ^{0}/00 in the wet season, and 27 ^{0}/00 - 36 ^{0}/00 in the dry season. Temperature readings for the three bays differed. Carli and Couva Bays showed similar temperatures for both the wet and dry seasons. The wet season temperatures ranged from 24 ^{0}C - 27^{0}C and dry season temperatures range from 25 ^{0}C - 31 ^{0}C. However, in Lisas Bay, the temperatures showed no seasonal variation and remained a constant 30 ^{0}C year round. Note that Lisas bay is the destination of most of the thermal discharge from the industries in the region (refer to Table 5.15). Salinity and temperature readings in the various Bays had not exceeded EPA Standards.

Couva and Carli Bays had similar pH levels but Lisas Bay had higher pH levels. Couva and Carli Bay levels ranged from 7.07 - 8.54, while Lisas Bay pH levels range from 8.55-8.63. Minimum and maximum suspended solids readings for the three bays differed in the wet and dry seasons. Again, Carli and Couva Bays exhibited similar values. Suspended solids ranged from 10 mg/l - 564 mg/l in the wet season and 10 mg/l - 200 mg/l in the dry season. Lisas Bay showed considerably higher measurements, both for the wet and dry seasons, with values ranging from 1060 mg/l - 1404 mg/l. Both pH and suspended solids levels have gone beyond the recommended EPA levels.

Table 5.22: Physical Parameters by Bay for the Couva /Pt. Lisas region.

Physical Parameters	EPA Guidelines	Lisas Bay	Couva Bay	Carli Bay
Salinity	[2]permanent change of </> 10% existing natural level (no data available for typical levels)	$27^0/00$ - $36^0/00$ (dry season) $11^0/00$ - $34^0/00$ (wet season)	$27^0/00$ - $36^0/00$ (dry season) $11^0/00$ - $34^0/00$ (wet season)	$27^0/00$ - $36^0/00$ (dry season) $11^0/00$ - $34^0/00$ (wet season)
Temperature	limits to artificially induced increases of not more that 17^0 C summer, 16^0 C winter (typical Caribbean Sea 31^0 C summer 22^0 C winter)	>30^0 C (year round)	24^0 C - 27^0 C (dry season) 25^0 C - 31^0 C (wet season)	24^0 C - 27^0 C (dry season) 25^0C - 31^0 C (wet season)
pH	6.0 - 8.0 (typical Caribbean Sea 8.10- summer 7.99 - winter)	8.55 - 8.63 (high levels)	7.07 - 8.54 (constant levels)	7.07 - 8.54 (constant levels)
Suspended Solids	25-80 mg/l moderate fisheries; > 80 poor fisheries	1,404 & 1060 mg/L (highest levels)	10 - 564 mg/L (fluctuations in dry season) >200 (consistently high in wet season)	10 - 564 mg/L (fluctuations in dry season) >200 (consistently high in wet season)

[2] non-quantified water quality standard

Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Coastal Ecosystem Management', Clark, 1977 and ' Liquid Wastes of Industry, Newmerow, 1971.

Figure 5.37a: Toxic and hazardous (Physical Parameter) pH levels by bay against EPA standards.

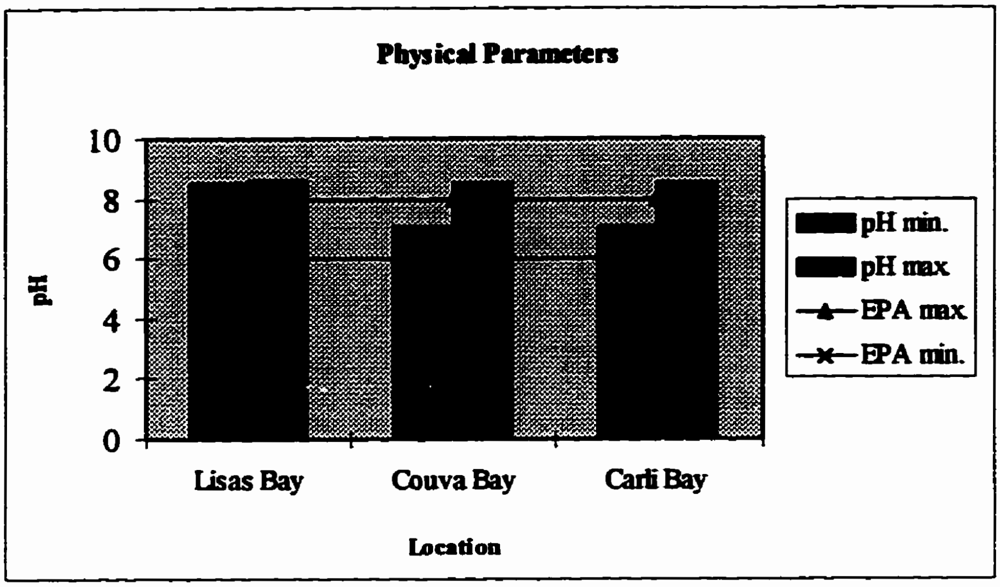
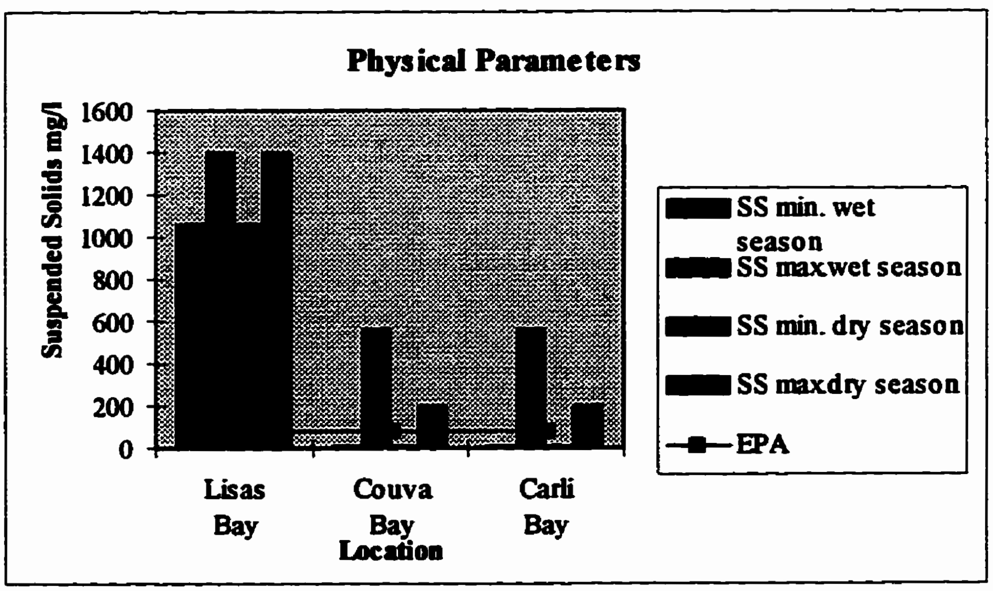


Figure 5.37b: Toxic and hazardous (Physical Parameter) Suspended Solids levels by bay against EPA standards.



Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Coastal Ecosystem Management', Clark, 1977 and ' Liquid Wastes of Industry, Newmerow, 1971.

Table 5.23: Breach of EPA Standards by Bay for the Couva/Pt. Lisas region.

Parameters	Lisas Bay	Couva Bay	Carli Bay
Chemical (Water) Nutrients	Phosphate, Ammonia (high)	Phosphate, Ammonia	Phosphate, Ammonia
Chemical (Water) Hydrocarbons/ Trace Metals	Mercury, Lead, Copper, Zinc	Mercury, Lead, Copper, Zinc	Mercury, Lead, Copper, Zinc
Biological	Faecal Coliform (high), BOD_5 (low)	Faecal Coliform (high), BOD_5 (low)	Faecal Coliform (high), BOD_5 (low)
Chemical (Sediment)	Mercury (high), Lead (high), Copper (very high), Zinc (very high)	Mercury (high), Lead (high), Copper (very high), Zinc (very high)	Mercury (high) , Lead (high), Copper (very high), Zinc (very high)
Physical	Temperature, pH, Suspended Solids	pH, Suspended Solids (wet season)	pH, Suspended Solids (wet season)

Source: Derived from information in 'Executive Summary of the Pt. Lisas Environmental Project, Vol. 1, A joint study of PLIPDECO and Institute of Marine Affairs (IMA), June 1982', 'Coastal Ecosystem Management', Clark, 1977 and ' Liquid Wastes of Industry, Newmerow, 1971.

The chronic release of pollutants into any ecosystem is the most damaging method of degradation. An examination of Table 5.23 reveals that levels of toxins and hazardous wastes found in the waters and sediments of the Gulf of Paria, exceeded acceptable US EPA Standards as early as 1982. Apart from rendering the regions' waters unsuitable for recreational and aesthetic activities, this systematic damage alters the carrying capacity of the ecosystem over time and may affect the economics of the region.

5.5.3.7 Impacts of polluted coastal waters

There are some basic results of pollution in a coastal environment. These can be expressed in terms of time, degree and in one case space. They are divided into short term or long term effects, and intense or mild effects.

Short term intense impacts

Fish Kills

In 1978, 1979 and twice in 1987 fish deaths in the Gulf of Paria in the vicinity of Pt. Lisas were a direct result of pollution. Ammonia poisoning was identified as the possible cause on all four occasions (Heileman and Siung-Chang, 130, 1990). Note that there is one urea plant and five ammonia plants on the estate. The species most affected were catfish, shrimp, grunt, mullet, butterfish, zapate, and sea trout (Trinidad Naturalist, 38-39, 1984).

Long term subdued impacts

Eutrophication

Eutrophication is the "nutrient over-enrichment of water that leads to excessive growth of aquatic plants" (Clark, 1977, 915). Large amounts of sewage discharged into coastal waters is one of the most frequent causes of eutrophication. It has already been established that large amounts of sewage were being dumped in the Gulf of Paria. Therefore algal blooms and Red tides[1] are also likely causes of fish kills in the Pt. Lisas coastal waters.

Contaminated Fish

The PLIPDECO & IMA (1982; 15) Executive Summary recorded trace metal levels in fish in the region. An analysis of fish muscle tissue was performed with the readings reported in ppm fresh weight. The analysis was for bays both inside and outside the study area. For the purpose of this study, only those amounts recorded within the study area were reviewed. The results revealed that:

1. Relatively high concentrations of hydrocarbons were found in fish and shrimp in Carli Bay and Orange Valley;
2. The highest concentrations were found in shrimp and bottom dwelling fish (catfish);
3. Abiding by the guidelines of 1.0 ppm total mercury per fresh weight in edible marine foods (PLIPDECO & IMA 1982; 14), unacceptable levels were found in 16% of the finfish and 36% of the shellfish from Pt. Lisas.
4. Mussels from Pt. Lisas exhibited concentrations of between 0.077 ppm and 1.19 ppm mercury, the highest concentrations being recorded at Couva Bay.

Overall highest concentrations within the study area occurred in Carli Bay (Figure 5.38).

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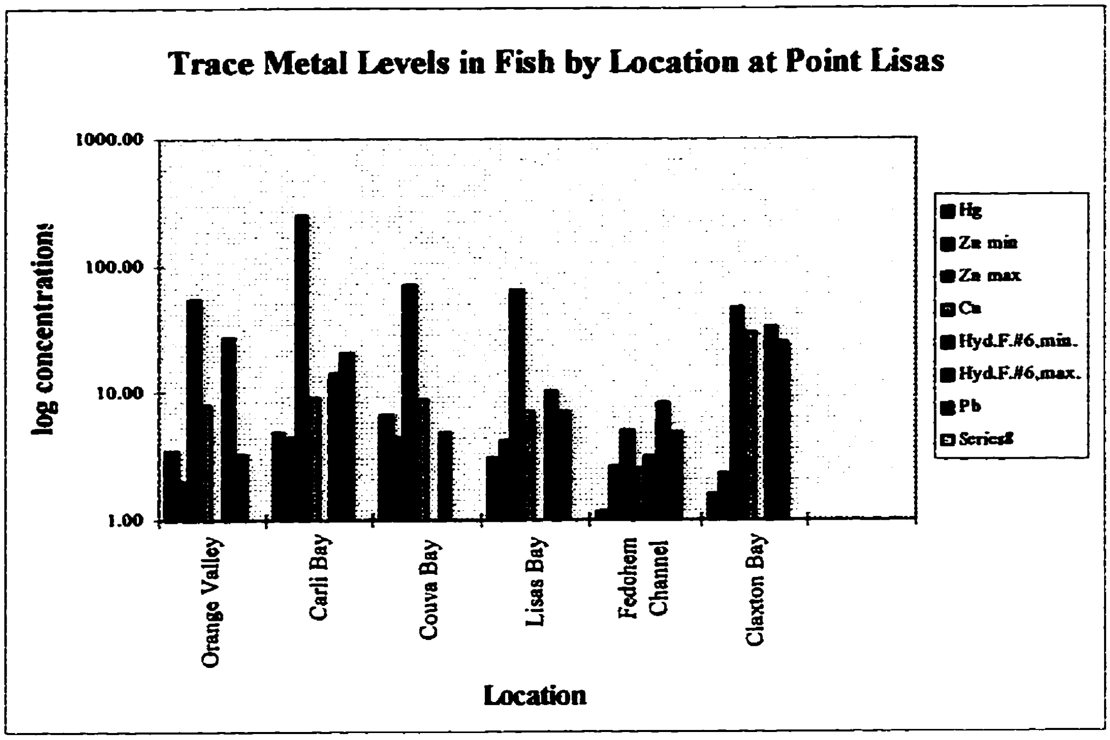
[1] Of the eutrophication phenomena where an excessive amount of nitrogen and phosphorus create ideal conditions for a type of 'red' algae capable of producing toxins and/or oxygen depletion causing fish mortalities.

Figure 5.38: Trace metal levels found in fish by location, Gulf of Paria.



Source: PLIPDECO and IMA, 1982, Vol. I

Singh (1988) undertook a study of heavy metals and hydrocarbons in the skin and muscle tissue of fish, and in the gills and muscle tissue of crabs and mussels from various fishing zones along the Trinidad coast. One sample area extended from Cacandee just north of the study area to Claxton Bay south of the study area. Note that Orange Valley and Lisas Bay fall within this sample area. Specific sampling sites occurred in shallow waters approximately 20 km north and 10 km north of Lisas Bay, about 20 m from shore.

Singh's results (Figure 5.39 a and b) showed that the levels of heavy metals in each of the marine species tested did not exceed the legal limits set by the Government of Trinidad and Tobago (1969) of copper 100 ppm (ug g^{-1}), lead 10 ppm (ug g^{-1}), and zinc 100 ppm (ug g^{-1}). This study compared these levels to U. S. and Canadian levels. When compared to legal limits set by other countries including U. S. and Canada, (50 ug g^{-1}), the mean levels in some species exceeded these limits.

Of the five commercially important fish tested, Cavalli, Carite, Salmon, Rancho, and Walliac, Singh found that Carite exhibited the highest levels of heavy metals (Carite is the most commercially important fish in the region and throughout Trinidad: see Fisheries Chapter 2). Locational effects were also noted. The most inflated levels of iron, hydrocarbons, and mercury were found in fish from Orange Valley. High mercury levels give rise to health concerns since the consumption of mercury contaminated fish has been known to have adverse health effects. Orange Valley is the major fishing location in the region, housing the fish market.

Overall results showed that fish and crab populations were not reduced by the then existing levels of heavy metals and/or hydrocarbons in the marine environment around

Trinidad. In contrast, the study revealed that mussel populations were greatly diminished due to toxic levels of iron in sediment along the west coast.

Figure 5.39a: Hydrocarbon Levels in gills and muscle of Crab (*Callinectes Sapidus*)

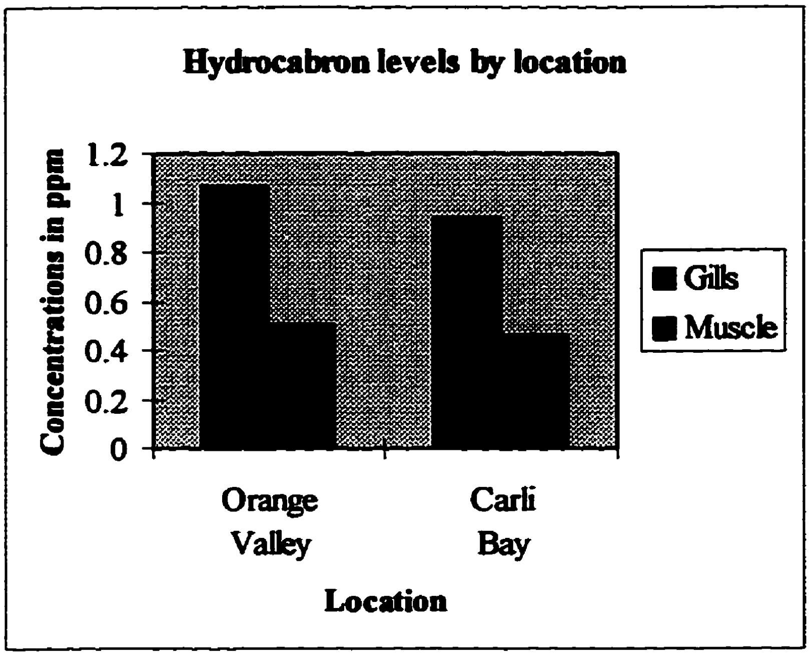
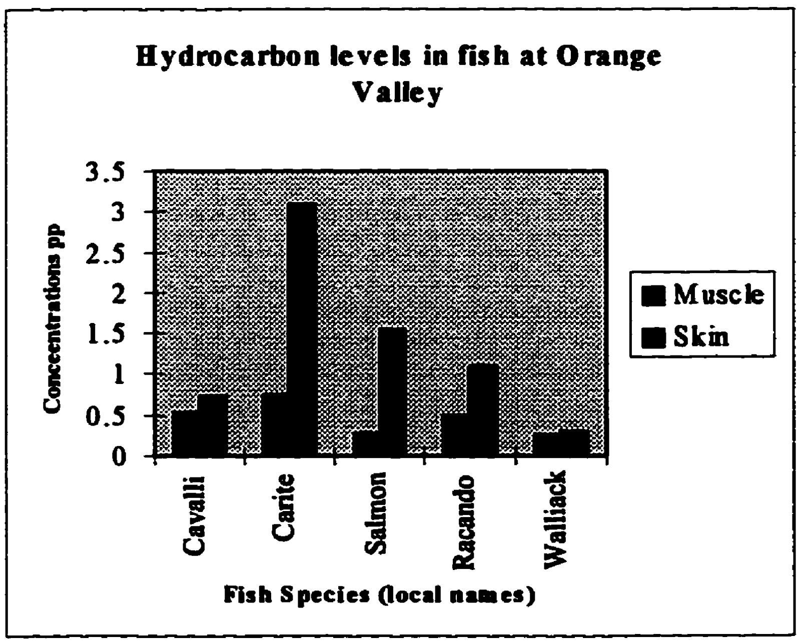


Figure 5.39b: Hydrocarbon levels in muscle and skin of various fish species at Orange Valley



Source: Singh, 1988.

Water Quality Index (WQI) for Lisas Bay

A water quality index was calculated for Lisas Bay using a WQI developed in 1970 by the U.S. National Sanitation Foundation (NSF). The steps for calculating of the WQI are provided in Appendix VI. Table 5.24 presents the aggregate WQI for a weighted linear sum (WQI_a) minimum and maximum levels of variables, and the weighted product-aggregation function (WQI_m) minimum and maximum levels of variables. It is important to note that in the absence of turbidity data for the region, the highest possible and lowest possible turbidity readings from the subindex function for turbidity were applied. This application assumed that the turbidity readings for Lisas Bay fell within these lower and upper limits. By utilizing the descriptor words provided for estimation in WQI (see Table 5.6 Appendix VI), it was assessed that the overall water quality for Lisas Bay was very bad. The (WQI_a) minimum value, and the (WQI_m) minimum and maximum values, fall within the numerical range described as 'Very Bad', while the (WQI_a) maximum value falls within the numerical range described as 'Bad".

Table 5.24: Calculations for Water Quality Index for Lisas Bay, (WQI_a) and (WQI_m)

Variable	Measurement	I_i	W_i	$I_i W_i$	$I_i^{w_i}$
DO	0/100	0/100	0.17	0	0/2.19
Faecal Coliform	4163	14	0.15	2.1	1.49
pH	8.63	60	0.12	7.2	1.63
BOD_5	4.6	60	0.1	0.6	1.51
NO_3	1.5	90	0.1	0.9	1.57
PO_4	0.588	90	0.1	0.9	1.57
Temperature Deviation	22/32	0/80	0.1	0/0.8	0/1.55
Turbidity	100/5	5/85	0.08	0.4/6.8	1.14/1.43
Suspended Solids	1404	20	0.08	1.6	1.27
				WQI_a = 13.7/37.9	WQI_m = 10.2/14.21

Source: Data from PLIPDECO and IMA 1982, Vol I; WQI formulas and descriptors from Canter, 1996.

5.5.4 Summary

In addressing the environmental impacts of industry in the Greater Couva area, it was necessary to study the impacts of increased population on the region. First, the link between population growth and industry was established. Second, three aspects of population impact on the environment were addressed. These aspects included increase in wastewater flows and loads; increased erosion; and increased pollutant runoff from the residential land-use areas into the sea.

No statistical or numerical proof exists for the first two impacts; increase in wastewater flows and loads, and increased erosion. However, these impacts are expected to occur to some degree in any environment which involves the removal of vegetation. The third impact, increased pollutant runoff, can be estimated from the amount of land in the study area which was engaged in residential land-use. This estimate calculated the increased amounts of four pollutants expected to have entered the Gulf of Paria for the 25 year period researched in this study. These pollutants are nitrogen, phosphorous, lead and zinc. This estimate, combined with evidence of the high levels of three of the pollutants found in three bays in the Gulf of Paria, suggest that population growth has had an adverse environmental effect in the region.

An example of the large quantities of heat being released into the area is provided in Table 5.15. The addition of such large amounts of heat into a fragile ecosystem generally produces adverse environmental effects. The heat energy estimates in Table 5.15 do not include heat effluent produced by the Methanol plant or the Aluminum smelter. Neither do these estimates take into account the increased amounts of heat produced by growing industrial activities since 1982 when the survey of heated effluents produced by then existing industries was performed. Although the region has not exhibited all the characteristics associated with thermal pollution, it has shown evidence of low D. O. levels, temperature ranges that exceeded normal levels for the region, and a change in species dominance. This evidence suggests thermal pollution in the Gulf of Paria.

It should be noted that the examination of added heat in the Gulf of Paria is somewhat superficial, if not simplistic. It has not accounted for heat dispersion due to local currents nor loss of heat to the atmosphere. These would require dispersion simulation modeling in liquid media and specialized coastal engineering techniques beyond the scope of this study. However, it has suggested a technique for assessing the amounts of heated effluent that would be released into surrounding waters prior to, and after the establishment of a project development in which heat effluent is expected to be discharged.

A list of the liquid effluents and their risk characterizations were provided. In addition an IMA (1982) study provided data on levels of chemical, physical and biological water quality parameters for Lisas Bay, Couva Bay and Carli Bay. These parameters in conjunction with EPA standards assessed the breaches and excesses for these parameters in the region. An overview was provided outlining the possible effects of the breaches in water standards in a marine environment, although conclusive evidence of some of these effects have not been proven to exist in the Gulf of Paria.

The threat to the ecosystem is the decline in its carrying capacity and biodiversity. Many aquatic organisms are adversely affected by high concentrations of trace metals and other toxins. High metal concentrations like those found in the bay waters of the Gulf of Paria, also pose a risk to humans, especially lead and mercury. Many marine organisms exhibit the ability to accumulate and concentrate these toxins in their tissue which in turn are consumed by humans. Shellfish are particularly vulnerable to bacterial and viral pathogens (disease causing organisms) which are filtered and concentrated in their tissue. Ingestion of these contaminated shell fish by humans has been known to cause illness in epidemic proportions.

Heat and pH are other limiting factors to biodiversity. A pH of not < 4.5 and not > 9.5 is necessary for fish to survive and reproduce (Nemerow, 4: 1971). Lisas Bay had exhibited breach temperatures, while all three bays (Lisas , Couva, and Carli), exhibited high pH levels, though not exceeding the above limits. High levels of dissolved oxygen are a sign of a healthy system, while too high temperatures act to decrease the amount of oxygen available in the system due to the increase in bacterial decomposition facilitated by increased temperature. All three bays in the region exhibit depressed levels of BOD, suggesting too high temperatures. Elevated Faecal Coliform counts similar to those found in Lisas, Couva and Carli Bays, create a similar condition (depressed BOD) as well as making the water extremely unsuitable for swimming.

Elevated levels of nutrients is another potential problem, leading to eutrophication or the excessive growth of aquatic plants. This condition further leads to a decrease in light penetration, reduction in photosynthesis and ultimately the result is a biological desert. All three bays exhibited high levels of phosphate and ammonia. Lisas Bay was especially high in ammonia. Studies performed on fish kills in the region (see Short term intense effects and Long term subdues effects) site ammonia and red tides (eutrophication) as the cause of these fish kills. Therefore evidence of the impacts of these are conclusive for the region.

The search for more recent data on pollution in the Gulf of Paria was unsuccessful. It was unclear whether the data existed or whether it simply was not available to the general public or to persons unaffiliated with those agencies responsible for collecting such data. It is possible that the Industries carry out their own effluent discharge monitoring and/or that IMA and PLIPDECO continue to monitor the coastal waters as in past studies. However research did not uncover any such evidence.

Water quality for Lisas Bay, the bay closest to the major outfall, was assessed using a WQI. The overall water quality in this bay was 'very bad'. By evaluating other parameters, Lisas Bay had already been described as stressed. By applying WQI, the consistent monitoring of physical, chemical and biological parameters of water quality can provide the necessary data to translate numerical values into simple descriptors which can aid in the decision making process.

5.5.5 Evaluation

Unlike previous studies in the region, this study has presented an holistic or comprehensive view of the impacts during the construction and operational phases of the Estate. After analysing the various factors which determine the possibility of environmental impacts, it may be concluded that adverse environmental impacts have resulted from the Pt. Lisas Industrial Estate. Due to a lack of historical data, the study combined data from previous studies along with internationally accepted environmental standards and techniques to prove that the region exhibits clear signs of environmental stress. This study has largely avoided assessing the importance of the impacts (i.e. scaled: beneficial-benign-tolerable-adverse-irreversible) since these, although based on factual information, are largely subjective. Yet this author will venture to state that during the period of this study some impacts were tolerable e.g. mangrove loss, increased road networks and residential and commercial land-use expansion. However some impacts such as thermal and liquid pollution were deemed adverse after levels exceeded accepted standards and caused intense adverse environmental episodes such as fish kills.

One objective of this study was to alleviate the problems associated with the lack of data on sources and types of marine pollutants faced by many of the Caribbean countries. It also examined methods for the manipulation and storage of historical and present day environmental data, while providing an assessment of industrial impacts. The methods proposed have been successful and can contribute to the enhancement of regional co-ordination with respect to data gathering, dissemination and exchange, while allowing for policy development in the areas of pollution control, and coastal and marine resource protection.

CHAPTER 6

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

The main objective of this study was to assesses the impact of an industrial estate on a coastal environment, while investigating technological methods of acquiring data and information to achieve this goal. This final chapter discusses the format, difficulties, and results of the thesis analysis and provides recommendation for further studies.

6.1 Discussion

It is important to note that the approach utilized in this study differs from an Environmental Impact Assessment (EIA) [see chapter 1]. Munn (1979, 1), described an EIA as an "activity designed to identify and predict the impact on the biogeophysical environment and on man's health and well being of legislative proposals, policies, programs, projects, and operational procedures, and to interpret and communicate information about the impacts."

An EIA usually requires an Environmental Impact Statement (EIS). The term EIS, which was coined by the National Environmental Policy Act (NEPA), (Leopold et al., 1971, 1) defines a statement detailing the "assessment of the effect of a proposed development on the environment and thus it is, separate from its monetary benefits and costs." In addition, an EIA requires that alternatives to the proposed action or project be suggested in order to mitigate of the projected impacts. This study does not attempt to meet these requirements. Instead it evaluates the impacts of a large-scale project which has already been executed, while providing methodologies for averting continued environmental degradation, especially if this project is slated for expansion.

EIAs are also considered legal documents whose application is inevitably political; as a consequence, it is affected by laws and policies. Governmental agencies responsible for formulating and legislating environmental guidelines are involved in the preparation and/or appraisal of EIAs and include public participation as an important factor; this study considers none of these.

"EIA" and *"EIA study"*, are two distinct terms which must be clarified (Sankoh, 1996, 187). An EIA evaluates impacts prior to the implementation of a project, whereas an EIA *study* evaluates effects which have arisen as a result of the implementation of a project and which are expected to continue. On the basis of these definitions therefore, this thesis falls within the latter category since it adopts a *"what has occurred and what is likely to occur"* approach; it is both retrospective and prospective.

Many developed countries have only recently adopted EIA policies (Sankoh, 1986: 186). The Commission of European Communities only approved a directive on EIA in 1985, while in the UK EIA only became mandatory in 1988 (Sankoh, 1996: 186). In developing countries formalized EIAs are difficult to implement.

One problem encountered in implementing EIA in developing countries is the lack of environmental laws, and inadequately equipped agencies to enforce those laws. In the absence of both laws and enforcement agencies, this tool is difficult to adopt. The very nature of EIA with its political implications negates the proper application of EIA in many developing countries. Another issue which follows along these lines is the corruption and instability that characterize some governments in developing nations. In many cases these countries are often poor and possess a weak economic base. A strong political and economic foundation is fundamental to efficient and effective EIA.

A debate which is by no means new to the discipline of geography and the social studies arena is the issue of transplantation of inappropriate technologies and methodologies from western cultures. It has already been argued that the absence of laws and money can prohibit the implementation of EIA in developing countries. But what of the political, social, and economic conditions in these country? For instance, it has often been remarked that the destruction of forests for fuel and agricultural and residential land-use in developing countries should be halted for environmental reasons. This argument has been expounded by many environmentalists. However, the dilemma faced by many developing countries remains how to provide alternate sources of fuel, food and shelter at a cost which is affordable to the every citizen. Furthermore with respect to industrial projects, it is unreasonable to expect the government of a developing country to forgo the creation of jobs and a boost to the economy in order to satisfy regulations and standards adopted from a developed country's environmental laws that could be considered harsh in the context of the developing nation's cultural, economic, and socio-political make up. Any tool applied to environmental protection must be tailored to the needs and capabilities (both economic and technological) of the country which is to implement it.

The lack of technology, expertise and money are other problems facing the developing world. Any EIA requires a significant amount of information acquired from a knowledge of, and consistent monitoring of the environment. In the absence of advanced methods of data collection, the use of existing sources of data becomes a necessity. It may not be necessary to undertake this approach in a developed country because there is greater access to accurate and cost effective data sources (e.g., satellite imagery) and means of manipulation (e.g., supercomputers). In countries lacking these facilities and where aerial photography already exists, the applications explored in this thesis can aid in the detection of past environmental impacts and help avert further adverse effects. This research attempts to bridge the gap between what would ideally be an EIA and what the realistic capabilities of assessing environmental impacts are in a developing country.

6.1.2 Space, place and time

"Where is it? Why is it there? What follows from it being there? These are old and fundamental questions in geography" (Lawton, 1983, 193). They seek to shed light on spatial relationships, interactions between people and places, the consequences of these interactions, and temporal attributes of the existence and alteration of phenomena; in other words, the concept of "space, place and time" (Lawton, 1983, 193). This study asks, where are the environmental changes, why have they occurred, and what are the consequences of those changes? In so doing it assesses the impact of the Pt. Lisas Industrial Estate on the coastal environment of the Greater Couva region. Place was easily addressed, but in addressing space and time certain questions were raised.

Space and time in this study posed unique problems. The problems arose from the fact that the study looked at long-term environmental changes and effects based on images from 1962, 1980 and 1986. It also used an array of data from past studies. However, due to the lack of consistent monitoring, attribute information was often short term (e.g. the trace metal pollutants in the Gulf of Paria were only available over a short duration of the study period). The lack of data is repeatedly referred to in literature concerning coastal issues of the wider Caribbean region. Other literature on developing countries and industrialization also refer to this problem. Hence predictability became important and as previously stated the study was both retrospective and prospective. The study thus used short term measures and processes to predict long term consequences for the environment.

"Explanations are scale dependent, both in space and time" (Clayton, 1991: 3). In this study as in many environmental studies, the data examined represented a short isolated period prior to the construction of, and after the operation of the Pt. Lisas Industrial Estate. Explanations of this data were limited to either catastrophic environmental events such as fish kills in the region, or visibly steady impacts, such as the environmental changes derived from images during the 25 year period. The regions natural coastal evolutionary processes, its past land-uses, and other factors of which we were unaware have all contributed to the status of the environment during the period under observation. Most studies are only able to provide explanations suitable to the time and space in which they were performed. The context of past occurrences is lost, and cycles, equilibrium, seasonality and sometimes causality become obscured and inestimable.

The issue of international contaminant standards also needs to be addressed. During the course of this research, it became apparent that in some cases Trinidad and Tobago did not have its own legal limits or environmental standards. It was therefore necessary to apply USEPA standards for certain contaminants. Other times, for example in the case of copper and zinc, Trinidad and Tobago's standards differed from those of other countries (United States and Canada) by as much as double the amount specified in their legal limits. The question arises then, should Trinidad and Tobago change its legal limits? The greater question arises, is there a need to establish international standards and limits?

This examination of the Greater Couva region appraised past data in order to provide assessments of environmental change and in addition, provided scenarios and methods for future predictions. Human-kind is largely land-oriented, little is known about our oceans and coastal processes. Given the complexity of environmental interactions and our lack of knowledge regarding these issues, many environmental studies apply models to make assessments. Most models consider certain variables, omitting others either based on a lack of data, understanding, or knowledge regarding these factors and their interactions. Thus modeling may be considered by some as a form of guesswork. Despite this, modeling is becoming common practice in our attempts to successfully manage environmental resources, and to estimate both our effects on the environment and its effects on us. Like many studies of this nature, this thesis is scientifically sound and well based.

6.2 Summary and Conclusions

The main objective of this thesis was to assess the impact of the Pt. Lisas industrial estate on the coastal environment of the Greater Couva region. It was hypothesized that any major human-made activities in the region would adversely affect the coastal and near-shore environments in the immediate vicinity of the Gulf of Paria. The objectives of this work were realized by conducting an audit of the land-use/land-cover changes in the region using photogrammetric techniques and Geographic Information Systems (GIS). Further, based on the premise that change implied impact, the magnitude and consequence of these changes were investigated.

Major changes in land-use/land-cover patterns over the 25 years between 1962-1986 were identified (Table 6.1). These changes were often as a direct result of the construction and operation of the Pt. Lisas Industrial estate. Research revealed a pattern of environmental impacts due to a shift from traditional land-use (agriculture) to industrial land-use practices. In order to assess these impacts, two distinct phases of the industrial site were investigated. These were the construction phase and the operation phase.

Table 6.1: % Change in Land-use Patterns for the Couva/Pt. Lisas region, 1962 - 1986.

Level Two Classification	% Change (from 1962)
Residential/Commercial	183.12
Industrial	634.5
Sugar-Cane	-10.2
Mangrove	-41.8
Reclaimed	100
Rivers	7.6
Roadways	1240.9

Source: Land-use map manipulation and analysis

6.2.1 Research Findings - Construction

6.2.1.1 Dredging and Reclamation

Dredging and reclamation in the region has had an adverse effect on the coastal environment in the Greater Couva region. The short term impacts of this activity were manifested through: elevated metal concentrations in the water and sediment in the Gulf of Paria; increased turbidity; the loss and damage to vital habitat (mangrove); alteration of local current patterns; and a general decrease in water quality. To date, no research has been conducted in the region to assess the long term effects of dredging and reclamation.

6.2.1.2 Roads and Transport Networks

Roads and transport networks in the region have increased considerably during the 25 year period covered by this study. This growth reflected the changing status of the region. With the need to provide infrastructure for the region to cater to the growing industrialization, an associated shift in settlement function occurred. This shift converted rural settlements to small urban settlements. This shift in the function of the settlements was matched by a similar shift in both the function and size of the existing transport system.

These changes in the transportation system have the potential to trigger four major impacts. Two of these impacts were identified in the region. The spawning of residential/ commercial activities in the region is one such impact. Since historic settlement patterns in the region favored spontaneous ribbon settlement along roadways, the changes in the transportation networks provided additional impetus for this phenomena to be perpetuated.

Vegetation loss and habitat disruption in the region is another identifiable impact which results from the changes in the transportation networks.

6.2.1.3 Mangrove Loss

No adverse effects attributable to mangrove loss were identified in this analysis when available shrimp catch data was utilized as an indicator. In fact, an inverse relationship characterized the dependence of these two variables. These results were reviewed in the context of the increased number of fishermen in the region and the improvement in fishing techniques during the same period. Mangrove loss also does not appear to have had any visible ill-effects on the overall fisheries of the region. Again, the increase in fishermen and improved fishing techniques may account for this, although the amount of shrimp catch per fisherman and per boat has declined over the 25 year period. This suggests that shrimp production may have declined in the region but that the increased number of fishermen biased the data to produce an inverse relationship between mangrove loss and fish catch.

More detailed studies on past and present spawning in the coastal waters of the Gulf of Paria may give a clearer idea of the extent of any damage caused by this loss. In this case, as in the other cases where impacts were assessed, the need for investigating the interaction between the physical environment and various socio-economic factors arose. No clear cut assessments of impacts can be obtained unless some understanding of the socio-economic factors involved can be brought to light.

6.2.2 Research findings - Operation

6.2.2.1 Population

Population increase was a direct result of the industrial activity in the region. Residential areas were developed to house the new industrial workers who migrated into the area. The conversion of once traditionally agricultural land to industrial land-use produced increases in residential/commercial land-use. This change in land-use was shown to have an adverse impact on the environment.

Increases in residential/ commercial land-use impacted the environment to the extent that coastal waters became polluted through: increased sewage discharges and sewage loads; increased erosion; and increased nitrogen, phosphorous, lead and zinc pollutants which entered the Gulf of Paria through river and storm-water runoff. The concentrations of phosphorous, lead and zinc measured in coastal waters of the Gulf of Paria all exceeded USEPA standards.

6.2.2.2 Thermal Pollution

Some impacts of thermal pollution were identified in the region. These were exemplified by Depressed Dissolved Oxygen (D. O.) levels, anomalous temperature ranges, and shifts in species dominance. The modeling of the water temperature increases caused by the infusion of industrial effluent into the waters of the Gulf of Paria showed that this effluent The modeling of this localized thermal system is designed to assess the daily inputs of thermal pollution into the waters of the Gulf of Paria. An additional 0.41^0 C per unit mass of water per day was added in the summer (dry season) and 0.31^0 C per unit mass of water per day in winter (wet season), most of which will be lost through dissipation to the atmosphere and heat diffusion effects within the water body. The implications for the potential impacts on fisheries and other aquatic life in the region could be considerable.

6.2.2.3 Liquid Pollutants and Water Quality

The water quality at the three bays in the Gulf of Paria; Lisas Bay, Couva Bay and Carli Bay, all exhibit environmental stress due to pollution. On the basis of USEPA standards for aquatic water quality, many of the physical, chemical and biological, parameters have been exceeded. This is exemplified by the fact that estimates of water quality in Lisas Bay using WQI indicated that the water quality was very poor.

Therefore in conclusion, it may be stated that increased industrial activity in the region produced impacts which ranged from minor disturbances such as increased localized turbidity, to major disruptions such as fish kills due to the discharge of toxic chemicals into the Gulf of Paria. Aerial photographic analysis in conjunction with GIS and time series analysis succeeded in revealing land-use/land-cover changes in the region thereby characterizing potential components of the coastal environment which may be impacted. Where these techniques cannot detect impacts, the use of techniques borrowed from formalized EIA along with internationally recognized environmental standards were successfully applied to facilitate measurement of contaminant levels through comparison. The magnitude and importance of these and other undetected impacts can only be assessed by continued long-term monitoring by specialists in coastal ecology and pollution control.

6.3 Recommendations for future studies

This study was an attempt to assess the impact of the Pt. Lisas Industrial Estate on the coastal region in which it is located. The assessment was successful in so far as it was suitable for detecting the physical changes in the environment for the 25 year period under study and in so far as these changes facilitated assessment of possible environmental impacts.

However, there are areas of the study where shortcomings are apparent. The most basic one being a lack of current information and data for many of the impact assessed. Although population and employment information for the region were available, more diverse and easily attainable information on fisheries is needed. As well, there is insufficient documented information concerning actual factory discharges per industry on the estate. Greater detail in this area will allow more precise assessments of industrial pollution. The data shortcomings of the study illustrate the urgent need for more detailed information concerning the coastal environment in Trinidad and Tobago.

Pollution in water can be detected using large-scale black-and-white aerial photography and true color transparencies. Lo (1976) utilized this method to analyze water quality change in Rambler Channel in Hong Kong from 1956 to 1975. Using black-and-white aerial photography and true color reversal transparencies at a scale of 1:10,000, Lo was able to map land-use as well as sources of pollution into the Channel. This simple yet effective method can be applied to the Pt. Lisas region to extract similar results if aerial coverage of the coastal waters of the region can be obtained. However it is uncertain whether true color coverage of this region exists.

Another method for pollution detection using remote sensing techniques involves the use of thermal-infrared imagery. This is a particularly favourable method for detecting thermal water pollution, since it is possible to detect thermal plumes in otherwise uniform (temperature) water bodies. Although these methods are clearly qualitative in nature and require ground truthing, they succeed in providing measurements of the areal extent of the phenomena and in detecting sources and dispersion patterns of pollution.

An important aspect of environmental change is that of environmental perception. This can be achieved by carefully selecting, interviewing and questioning a representative cross-section of residents of the region. This research undertook an informal investigation of opinions and perceptions of the people as regards environmental change and the impact of the industrial estate. However the information was used to get feedback on the social characteristics of the region. A formal statistically significant survey of the population will provide a wealth of information on social and economic changes in the region that would otherwise be unattainable.

6.3.1 Recommendations for future research

This final section of this thesis provides a list of recommendations for future work. These recommendations are as follows:

1. That studies of this nature be initiated as a means of moving toward the formulation of laws and policies which will eventually facilitate the implementation of formalized EIA in Trinidad and Tobago.

2. That use of existing data sources be explored more fully in an attempt to bridge the gap between information that is lacking and information necessary to perform basic

environmental studies, and consistent physical monitoring of fragile and vulnerable environments.

3. Consistent monitoring of effluents being disposed of in the Gulf of Paria, i.e. (a) recording of types and quantities; (b) sites into which effluents are dumped (fishing grounds/bays); and (c) levels of pollutants in the water (fishing grounds/bays).

4. Compilation of a comprehensive data base for fish resources in the region, i.e. (a) list of fish species in the Gulf of Paria (b) data concerning thermal preferences for each fish species; (c) sensitivity of fish species to various pollutants (indicator species); and (d)fish catch by region and by fishing ground/bay.

5. Compilation of a data base of ancillary information, e.g. population; employment; boat registration; health records for persons showing signs of diseases from the consumption of contaminated fish.

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Appendix I

Appendix I

Materials Used in Study

-Black and White Aerial Photographs of the Couva/Point Lisas region, Gulf of Paria, Trinidad suitable for stereoscopic viewing:
- 1962 at 1:20,000 scale
- 1980 at 1:10,000 scale
- 1986 at 1:10,000 scale
- 2 land use base maps of region, scale 1:25,000 (to assist with photo interpretation; scale 1:20,000 to assist in scale correction
- Pocket Stereoscope
- Bausch & Lomb 10x Stereoscope with light table
- PC Computer
- Abaton Scan 300/GS, 256 Grey Scale Flatbed Scanner

Sources of Aerial Photos

Panchromatic black and white aerial photographs suitable for stereoscopic viewing and taken between the months of February and March of their respective years and consists of:

Year of Coverage	Scale
1962	1: 20,000
1980	1: 10,000
1986	1: 10,000

The aerial photos were chosen on the basis of needs and quality requirements.

Needs requirements
- Adequate scale for identification of salient features;
- The time of day the photos were taken for all three years must be the same;
- The season in which the photos were taken must be the same for the three years;
- The photos must allow for Stereoscopic viewing.

Quality requirements
- No tilt greater than 2-3 degrees;
- Correct average scale;
- No deficient/excessive forward or side lap;
- Good tonal contrast;
- No excessively long shadows;
- Absence of 'hot spots' (reflection of sun in camera lens produces a bleached spot in photo); and
- No cloud or cloud shadows.

The 1962 coverage was not of the best quality due to inconsistencies in developing of the negatives which distort some areas on the photos. There is also some cloud cover in areas but this exists on the edges of the photos which were not used in the creation of the mosaics. The 1980 and 1986 photos were of relatively good quality in most respects. These exhibit high tonal contrast and scale accuracy. Examples of the completed mosaics follow.

Mosaic 1962

Mosaic 1980

Mosaic 1986

Base Map

Appendix II

Appendix II

Accuracy testing for the creation of working maps

Map Accuracy and the Error Matrix

Although in most accuracy tests samples are compared to existing ground cover, an obvious problem arises with time-series analysis. In this project accuracy of the traced maps is being tested, ie. how closely do the categories of the computerized maps agree with the categories of the photomaps and therefore the original ground-cover for each of the three years. Accuracy testing therefore entailed a comparison between these maps and the aerial photo mosaics from which they were created with a working knowledge of the ground-cover represented in these mosaics. This is achieved by a selection of sample points from the maps for verification of interpreted land-use/ land-cover categories. The two most important aspects of accuracy testing, sample size and point selection were assessed with the following considerations in mind:

1. sample size should be large enough to provide precision at 85% accuracy level specified by Anderson et. al., (1976) for USGA land-use\land-cover mapping and;
2. that the sample points be unbiased, ie. random.

The sample size N was determined by the equation $N = Z^2pq/E^2$,

where p is the expected percent accuracy, $q = 100 - p$, E is the allowable error, and $Z = 2$ (rounded from the standard normal deviate 1.96 for the 95% two-sided confidence level. For an expected accuracy of 85% and an allowable error E of 4% (2 sd of 2%) and with a 95% two-sided confidence probability, the sample size will be $N = 4(85 \times 15)/ 16 = 318.75$ or 319 (see Fitzpatric-Lins, 1981, p.345). Using a random sampling technique, a computer based sample selection of 319 points was achieved using Surfer software program.

An error matrix was created as a simple means of descriptive statistics. The data is presented as a square array expressing the number of sample units, in this case pixels or points. It consists the cross-tabulation of a series of equal rows and columns representing land-use/land-cover categories. The columns represent land-use/land-cover on the ground derived from the photomaps while the rows represent land-use/land-cover interpretations generated to produce the three image maps to be used as baseline data.

There are several benefits to using an error matrix. Overall accuracy of mapping can be derived by totaling the diagonal cell values and dividing these by the total number of sample points, and the level of accuracy for each individual category can also be easily assessed. It is also possible to derive errors of omission, where points are not mapped or left out of a particular category, and errors of commission, where points mapped as a particular category in fact belong to another. "It is typical to look at errors of omission as a basis for judging the adequacy of the mapping, and the errors of commission as a means of determining how to fix the map to increase accuracy" (Eastman, 1995, p. 8-26).

A sample matrix is as follows:

Table AII.1 : An Error matrix

TRUE

MAPPED		A	B	C	Total	error	
	A						
	B						errors
MAPPED	C						of
	Total						commission
	error						

errors of omission

Table AII.2 : Error Matrix 1962 mapping.

	R/C	FT	I	Cane	OP	Rice	M	F/T/S	River	Res	1st	2nd	Dis	Rec	Total	error
R/C	28	0	0	5	0	0	0	0	0	0	0	0	0	0	33	.15
FT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	0
Cane	4	0	0	236	0	1	0	0	0	0	1	0	1	0	243	.02
OP	0	0	0	1	8	0	0	0	0	0	0	0	0	0	9	.11
Rice	0	0	0	0	0	8	0	0	0	0	0	0	0	0	8	0
M	0	0	0	0	0	0	4	0	0	0	0	0	0	0	4	0
F/T/S	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4	0
River	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	0
Res	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
1st	0	0	0	0	0	0	0	0	0	0	4	0	0	0	4	0
2nd	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
Dis	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0
Rec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	32	0	4	242	8	9	4	4	4	1	5	1	5	0	319	
error	.12	0	0	.02	0	.11	0	0	0	0	.20	0	.20	0		.04

KEY

R/C : Residential/Commercial
FT : Future Residential
I : Industrial
Cane : Sugar Cane
OP : Other Plantation
Rice : Rice
M : Mangrove
F/T/S : Forest/Trees/Scrub
River : River
Res : Reservoirs
1st : 1st class rds
2nd : 2nd class rds
Dis : Disused rails
Rec : Reclaimed land

Table AII.3: Error Matrix 1980 mapping.

	R/C	FT	I	Cane	OP	Rice	M	F/T/S	River	Res	1st	2nd	Dis	Rec	Total	error
R/C	44	0	0	5	0	0	0	0	0	0	0	0	0	0	49	.10
FT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	11	0	0	0	0	0	0	0	0	0	0	0	11	0
Cane	3	0	1	205	0	0	1	0	0	0	0	0	1	0	211	.02
OP	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7	0
Rice	0	0	0	0	0	5	0	0	0	0	0	0	0	0	5	0
M	0	0	0	0	0	0	10	0	0	0	0	0	0	0	10	0
F/T/S	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5	0
River	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	0
Res	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
1st	0	0	0	2	0	0	0	0	0	0	2	0	0	0	4	.5
2nd	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	0
Dis	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0
Rec	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0
Total	47	0	12	212	7	5	11	5	3	1	2	5	4	5	319	
error	.06	0	.08	.03	0	0	.09	0	0	0	0	0	.25	0		.04

KEY

R/C : Residential/Commercial
FT : Future Residential
I : Industrial
Cane : Sugar Cane
OP : Other Plantation
Rice : Rice
M : Mangrove
F/T/S : Forest/Trees/Scrub
River : River
Res : Reservoirs
1st : 1st class rds
2nd : 2nd class rds
Dis : Disused rails
Rec : Reclaimed land

Table AII.4: Error Matrix 1986 mapping.

	R/C	FT	I	Cane	OP	Rice	M	F/T/S	River	Res	1st	2nd	Dis	Rec	Total	error
R/C	42	0	0	6	0	0	0	1	0	0	0	0	0	0	49	.02
FT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	16	2	0	0	0	0	0	0	0	0	0	0	18	.11
Cane	4	0	0	198	0	0	0	1	0	0	0	0	0	0	203	.01
OP	0	0	0	0	5	0	0	0	0	0	0	0	0	0	5	0
Rice	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	8	0	0	0	0	0	0	0	8	0
F/T/S	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4	0
River	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	0
Res	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1st	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0
2nd	0	0	0	0	0	0	0	0	0	0	0	13	0	0	13	0
Dis	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0
Rec	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	0
Total	46	0	16	206	5	0	8	6	4	0	3	13	4	8	319	
error	.08	0	0	.03	0	0	0	.33	0	0	0	0	0	0		.04

KEY

R/C : Residential/Commercial
FT : Future Residential
I : Industrial
Cane : Sugar Cane
OP : Other Plantation
Rice : Rice
M : Mangrove
F/T/S : Forest/Trees/Scrub
River : River
Res : Reservoirs
1st : 1st class rds
2nd : 2nd class rds
Dis : Disused rails
Rec : Reclaimed land

Appendix III

Appendix III

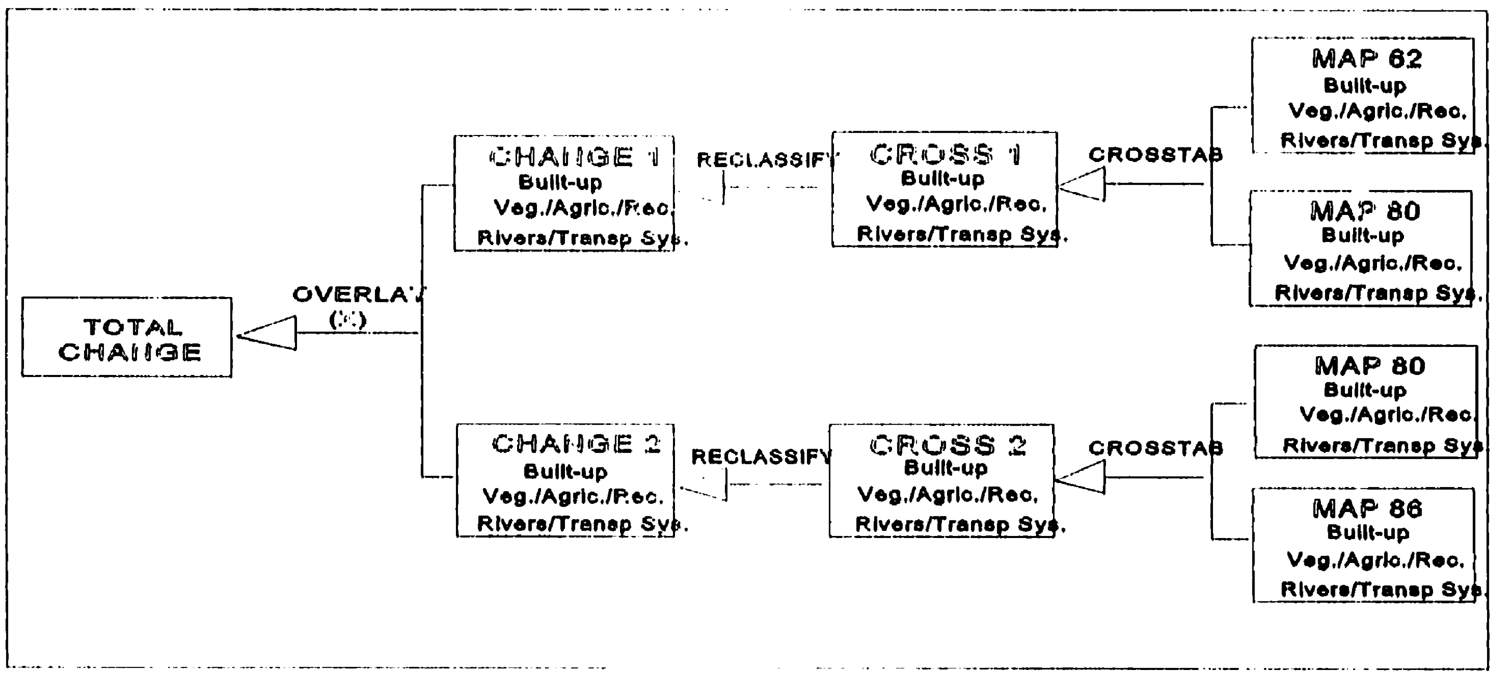
Software Packages and Commands for Mapping and Analysis

Corel Draw! version 4 (Corel Corporation 1993) a graphics package was used purely as a drawing tool for tracing in mapping the region. Though IDRISI is especially adept at raster based data analysis, it can be used for a wide range of GIS and Remote Sensing needs. The program was developed by the Graduate School of Geography at Clark University and has both geographic information and image processing capabilities. In this project IDRISI was applied in the direct manipulation and analysis of not only the imaged data but also of the attribute data such as population and fisheries data.

Commands

First a cartographic model (a graphic representation of the data and commands used in a project), was created for the project. This serves as a set of guidelines for the development of the procedures involved in data analysis for the project as well as an easy reference. There were two procedures for this study, represented in Figure AIII.1.

Figure AIII.1: Cartographic Model of Project Change Analysis 1962-1986.



The specific functions of commands found in the cartographic model are as follows:

Crossclassification

Qualitative data needs to be analyzed using different techniques from quantitative data. For this study the procedure for comparing two images was *Crossclassification*. The procedure can be summarized as a record of all possible combinations of categories from two dates. The function created a matrix and an image representing elements from one date to the next that show change as well as those that have remained the same.

Reclass

Reclass in IDRISI can be used to create a new map form existing map/maps. The user will look at the cover classes in the legend of the input map for the information she wishes to extract and recalssify or reassign values to these. From these re-coded classes, (information which is extracted), IDRISI creates the new map.

Overlay (+)

Overlay in IDRISI is used to perform operation between two maps. There are nine *overlay* operations, of which add (+) was used for this project. The add (+) function in *overlay* combines two maps adding the corresponding pixels in each to create a new output map. Maps containing differing cover classes when combined create an output map with zones representing all the cover classes represented in the input maps. e.g.

3	2	1		5	0	8		8	2	9
5	6	7	+	2	3	2	=	7	6	9
8	9	4		1	6	4		9	15	8

Area

A new map can be created with each pixel in the output map having the value of the area of the class to which the pixel belongs. It can be output in table form or attribute values file form. This was used to calculate the area of land-use classes.

Appendix IV

Crosstabulation and Reclassification Tables

Cross-tabulation of 62built (columns) against 80built (rows)

	0	30	56	79	108	125
0	16585	17884	1826	1637	475	0
30	10534	514257	2020	3075	0	0
56	654	486	18910	0	3262	0
79	437	1574	0	2209	0	0
125	0	0	0	0	0	790
143	699	2452	0	79	0	0
163	413	24	3273	0	3062	0
176	771	3176	0	4734	0	0
185	1201	15196	2357	0	1429	0
210	9317	28293	0	982	0	0
215	1517	0	1205	0	4850	0
Total	42128	583342	29591	12716	13078	790

	143	176	185	210	215	Total
0	788	246	294	3144	94	42973
30	1105	4421	499	4001	3	539915
56	0	0	28	0	0	23340
79	17	143	0	0	0	4380
125	0	0	0	0	0	790
143	4675	0	0	83	0	7988
163	0	0	0	0	0	6772
176	0	518	0	1	0	9200
185	0	74	3572	0	0	23829
210	553	265	0	31919	0	71329
215	0	0	33	0	449933	457538
Total	7138	5667	4426	39148	450030	1188054

Chi Square = 4728847.5000
df = 100
Cramer's V = 0.6309

Proportional Crosstabulation

	0	30	56	79	108	125
0	0.0140	0.0151	0.0015	0.0014	0.0004	0.0000
30	0.0089	0.4329	0.0017	0.0026	0.0000	0.0000
56	0.0006	0.0004	0.0159	0.0000	0.0027	0.0000
79	0.0004	0.0013	0.0000	0.0019	0.0000	0.0000
125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007
143	0.0006	0.0021	0.0000	0.0001	0.0000	0.0000
163	0.0003	0.0000	0.0028	0.0000	0.0026	0.0000
176	0.0006	0.0027	0.0000	0.0040	0.0000	0.0000
185	0.0010	0.0128	0.0020	0.0000	0.0012	0.0000
210	0.0078	0.0238	0.0000	0.0008	0.0000	0.0000
215	0.0013	0.0000	0.0010	0.0000	0.0041	0.0000
Total	0.0355	0.4910	0.0249	0.0107	0.0110	0.0007

143	176	185	210	215	Total

0	0.0007	0.0002	0.0002	0.0026	0.0001	0.0362
30	0.0009	0.0037	0.0004	0.0034	0.0000	0.4545
56	0.0000	0.0000	0.0000	0.0000	0.0000	0.0196
79	0.0000	0.0001	0.0000	0.0000	0.0000	0.0037
125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007
143	0.0039	0.0000	0.0000	0.0001	0.0000	0.0067
163	0.0000	0.0000	0.0000	0.0000	0.0000	0.0057
176	0.0000	0.0004	0.0000	0.0000	0.0000	0.0077
185	0.0000	0.0001	0.0030	0.0000	0.0000	0.0201
210	0.0005	0.0002	0.0000	0.0269	0.0000	0.0600
215	0.0000	0.0000	0.0000	0.0000	0.3787	0.3851
Total	0.0060	0.0048	0.0037	0.0330	0.3788	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 80built as the reference image ...

Category	KIA
0	0.3634
30	0.9066
56	0.8053
79	0.4990
125	1.0000
143	0.5827
163	0.0000
176	0.0518
185	0.1467
210	0.4287
215	0.9732

Using 62built as the reference image ...

Category	KIA
0	0.3709
30	0.7829
56	0.6318
79	0.1707
108	0.0000
125	1.0000
143	0.6526
176	0.0843
185	0.8031
210	0.8035
215	0.9996

Overall Kappa = 0.8058

Cross-tabulation of 80built (columns) against 86built (rows)

	0	30	56	79	125	143
0	19853	14645	509	579	88	857
30	7196	490431	44	2025	0	2154
56	89	0	21359	0	0	0
79	186	1014	0	903	0	217
125	60	24	0	0	641	0
143	354	543	0	0	0	3969
163	718	0	598	0	0	0
176	733	1175	0	110	0	0
185	1632	7655	605	0	0	45
210	12070	23857	0	335	61	746
214	58	571	0	428	0	0
215	24	0	225	0	0	0
Total	42973	539915	23340	4380	790	7988

	163	176	185	210	215	Total
0	186	618	642	7153	774	45904
30	245	1111	467	2854	0	506527
56	0	0	0	0	698	22146
79	0	111	0	0	0	2431
125	0	0	0	34	0	759
143	0	0	0	68	0	4934
163	6332	0	0	0	5067	12715
176	0	6721	0	552	0	9291
185	9	0	22616	221	33	32816
210	0	639	104	60447	0	98259
214	0	0	0	0	0	1057
215	0	0	0	0	450966	451215
Total	6772	9200	23829	71329	457538	1188054

Chi Square = 6439628.0000
df = 110
Cramer's V = 0.7362

Proportional Crosstabulation

	0	30	56	79	125	143
0	0.0167	0.0123	0.0004	0.0005	0.0001	0.0007
30	0.0061	0.4128	0.0000	0.0017	0.0000	0.0018
56	0.0001	0.0000	0.0180	0.0000	0.0000	0.0000
79	0.0002	0.0009	0.0000	0.0008	0.0000	0.0002
125	0.0001	0.0000	0.0000	0.0000	0.0005	0.0000
143	0.0003	0.0005	0.0000	0.0000	0.0000	0.0033
163	0.0006	0.0000	0.0005	0.0000	0.0000	0.0000
176	0.0006	0.0010	0.0000	0.0001	0.0000	0.0000
185	0.0014	0.0064	0.0005	0.0000	0.0000	0.0000
210	0.0102	0.0201	0.0000	0.0003	0.0001	0.0006
214	0.0000	0.0005	0.0000	0.0004	0.0000	0.0000
215	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
Total	0.0362	0.4545	0.0196	0.0037	0.0007	0.0067

	163	176	185	210	215	Total
0	0.0002	0.0005	0.0005	0.0060	0.0007	0.0386
30	0.0002	0.0009	0.0004	0.0024	0.0000	0.4264
56	0.0000	0.0000	0.0000	0.0000	0.0006	0.0186
79	0.0000	0.0001	0.0000	0.0000	0.0000	0.0020
125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006
143	0.0000	0.0000	0.0000	0.0001	0.0000	0.0042
163	0.0053	0.0000	0.0000	0.0000	0.0043	0.0107
176	0.0000	0.0057	0.0000	0.0005	0.0000	0.0078
185	0.0000	0.0000	0.0190	0.0002	0.0000	0.0276
210	0.0000	0.0005	0.0001	0.0509	0.0000	0.0827
214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009
215	0.0000	0.0000	0.0000	0.0000	0.3796	0.3798
Total	0.0057	0.0077	0.0201	0.0600	0.3851	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 86built as the reference image ...

Category	KIA
0	0.4112
30	0.9418
56	0.9638
79	0.3691
125	0.8444
143	0.8031
163	0.4951
176	0.7212
185	0.6828
210	0.5906
214	0.0000
215	0.9991

Using 80built as the reference image ...

Category	KIA
0	0.4404
30	0.8402
56	0.9135
79	0.2045
125	0.8113
143	0.4948
163	0.9343
176	0.7284
185	0.9476
210	0.8337
215	0.9768

Overall Kappa = 0.8661

Cross-tabulation of 62veg (columns) against 80veg (rows)

	0	5	30	56	79	108
0	20514	47	18459	1831	1599	475
5	12	2819	446	0	2	0
30	11163	358	502712	2020	3008	0
56	654	3	486	18902	0	3262
79	455	0	1520	0	2093	0
125	0	0	0	0	0	0
143	684	0	2426	0	58	0
163	413	0	24	3273	0	3062
176	801	0	3176	0	4669	0
180	142	11	1965	0	2	0
185	1175	0	15185	2357	0	1429
210	8758	42	26840	0	979	0
215	1517	0	0	1205	0	4850
Total	46288	3280	573239	29588	12410	13078

	125	143	176	180	185	210
0	0	803	236	85	303	3221
5	0	3	0	4	0	9
30	0	1102	4330	265	497	3837
56	0	0	0	0	28	0
79	0	17	143	0	0	0
125	790	0	0	0	0	0
143	0	4502	0	0	0	83
163	0	0	0	0	0	0
176	0	0	518	0	0	1
180	0	0	101	5685	1	270
185	0	0	74	0	3560	0
210	0	512	265	441	0	28422
215	0	0	0	0	33	0
Total	790	6939	5667	6480	4422	35843

	215	Total
0	94	47667
5	0	3295
30	3	529295
56	0	23335
79	0	4228
125	0	790
143	0	7753
163	0	6772
176	0	9165
180	0	8177
185	0	23780
210	0	66259
215	449933	457538
Total	450030	1188054

Chi Square = 6318750.5000
df = 144

Cramer's V = 0.6657

Proportional Crosstabulation

	0	5	30	56	79	108
0	0.0173	0.0000	0.0155	0.0015	0.0013	0.0004
5	0.0000	0.0024	0.0004	0.0000	0.0000	0.0000
30	0.0094	0.0003	0.4231	0.0017	0.0025	0.0000
56	0.0006	0.0000	0.0004	0.0159	0.0000	0.0027
79	0.0004	0.0000	0.0013	0.0000	0.0018	0.0000
125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
143	0.0006	0.0000	0.0020	0.0000	0.0000	0.0000
163	0.0003	0.0000	0.0000	0.0028	0.0000	0.0026
176	0.0007	0.0000	0.0027	0.0000	0.0039	0.0000
180	0.0001	0.0000	0.0017	0.0000	0.0000	0.0000
185	0.0010	0.0000	0.0128	0.0020	0.0000	0.0012
210	0.0074	0.0000	0.0226	0.0000	0.0008	0.0000
215	0.0013	0.0000	0.0000	0.0010	0.0000	0.0041
Total	0.0390	0.0028	0.4825	0.0249	0.0104	0.0110

	125	143	176	180	185	210
0	0.0000	0.0007	0.0002	0.0001	0.0003	0.0027
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.0000	0.0009	0.0036	0.0002	0.0004	0.0032
56	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
79	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
125	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000
143	0.0000	0.0038	0.0000	0.0000	0.0000	0.0001
163	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
176	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000
180	0.0000	0.0000	0.0001	0.0048	0.0000	0.0002
185	0.0000	0.0000	0.0001	0.0000	0.0030	0.0000
210	0.0000	0.0004	0.0002	0.0004	0.0000	0.0239
215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0007	0.0058	0.0048	0.0055	0.0037	0.0302

	215	Total
0	0.0001	0.0401
5	0.0000	0.0028
30	0.0000	0.4455
56	0.0000	0.0196
79	0.0000	0.0036
125	0.0000	0.0007
143	0.0000	0.0065
163	0.0000	0.0057
176	0.0000	0.0077
180	0.0000	0.0069
185	0.0000	0.0200
210	0.0000	0.0558
215	0.3787	0.3851
Total	0.3788	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 80veg as the reference image ...

Category	KIA
0	0.4073
5	0.8551
30	0.9029
56	0.8052
79	0.4897
125	1.0000
143	0.5782
163	0.0000
176	0.0520
180	0.6936
185	0.1465
210	0.4112
215	0.9732

Using 62veg as the reference image ...

Category	KIA
0	0.4199
5	0.8591
30	0.7781
56	0.6316
79	0.1657
108	0.0000
125	1.0000
143	0.6465
176	0.0843
180	0.8765
185	0.8011
210	0.7807
215	0.9996

Overall Kappa = 0.8044

Cross-tabulation of 80veg (columns) against 86veg (rows)

	0	5	30	56	79	125
0	25035	92	13981	483	479	88
5	21	3122	37	251	0	0
30	6897	68	481346	44	1976	0
56	89	0	0	21354	0	0
79	208	0	992	0	900	0
125	60	0	24	0	0	641
143	358	0	543	0	0	0
163	718	0	0	598	0	0
176	736	0	1175	0	110	0
180	9	4	0	0	0	0
185	1663	4	7641	605	0	0
210	11802	5	22985	0	335	61
214	58	0	571	0	428	0
215	13	0	0	0	0	0
Total	47667	3295	529295	23335	4228	790

	143	163	176	180	185	210
0	763	186	589	13	648	6753
5	0	0	0	0	0	0
30	2123	245	1105	0	454	2685
56	0	0	0	0	0	0
79	217	0	111	0	0	0
125	0	0	0	0	0	34
143	3859	0	0	0	0	64
163	0	6332	0	0	0	0
176	0	0	6721	0	0	549
180	0	0	0	8164	0	0
185	45	9	0	0	22578	221
210	746	0	639	0	100	55953
214	0	0	0	0	0	0
215	0	0	0	0	0	0
Total	7753	6772	9165	8177	23780	66259

	215	Total
0	774	49884
5	0	3431
30	0	496943
56	698	22141
79	0	2428
125	0	759
143	0	4824
163	5067	12715
176	0	9291
180	0	8177
185	33	32799
210	0	92626
214	0	1057
215	450966	450979
Total	457538	1188054

```
Chi Square =   8709189.0000
        df =       156
Cramer's V =          0.7816
```

Proportional Crosstabulation

	0	5	30	56	79	125
0	0.0211	0.0001	0.0118	0.0004	0.0004	0.0001
5	0.0000	0.0026	0.0000	0.0002	0.0000	0.0000
30	0.0058	0.0001	0.4052	0.0000	0.0017	0.0000
56	0.0001	0.0000	0.0000	0.0180	0.0000	0.0000
79	0.0002	0.0000	0.0008	0.0000	0.0008	0.0000
125	0.0001	0.0000	0.0000	0.0000	0.0000	0.0005
143	0.0003	0.0000	0.0005	0.0000	0.0000	0.0000
163	0.0006	0.0000	0.0000	0.0005	0.0000	0.0000
176	0.0006	0.0000	0.0010	0.0000	0.0001	0.0000
180	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
185	0.0014	0.0000	0.0064	0.0005	0.0000	0.0000
210	0.0099	0.0000	0.0193	0.0000	0.0003	0.0001
214	0.0000	0.0000	0.0005	0.0000	0.0004	0.0000
215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0401	0.0028	0.4455	0.0196	0.0036	0.0007

	143	163	176	180	185	210
0	0.0006	0.0002	0.0005	0.0000	0.0005	0.0057
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	0.0018	0.0002	0.0009	0.0000	0.0004	0.0023
56	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
79	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000
125	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
143	0.0032	0.0000	0.0000	0.0000	0.0000	0.0001
163	0.0000	0.0053	0.0000	0.0000	0.0000	0.0000
176	0.0000	0.0000	0.0057	0.0000	0.0000	0.0005
180	0.0000	0.0000	0.0000	0.0069	0.0000	0.0000
185	0.0000	0.0000	0.0000	0.0000	0.0190	0.0002
210	0.0006	0.0000	0.0005	0.0000	0.0001	0.0471
214	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0065	0.0057	0.0077	0.0069	0.0200	0.0558

	215	Total
0	0.0007	0.0420
5	0.0000	0.0029
30	0.0000	0.4183
56	0.0006	0.0186
79	0.0000	0.0020
125	0.0000	0.0006
143	0.0000	0.0041
163	0.0043	0.0107
176	0.0000	0.0078
180	0.0000	0.0069
185	0.0000	0.0276
210	0.0000	0.0780

214	0.0000	0.0009
215	0.3796	0.3796
Total	0.3851	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 86veg as the reference image ...

Category	KIA
0	0.4810
5	0.9097
30	0.9434
56	0.9637
79	0.3684
125	0.8444
143	0.7986
163	0.4951
176	0.7212
180	0.9984
185	0.6820
210	0.5807
214	0.0000
215	1.0000

Using 80veg as the reference image ...

Category	KIA
0	0.5044
5	0.9473
30	0.8443
56	0.9135
79	0.2113
125	0.8113
143	0.4957
163	0.9343
176	0.7312
180	0.9984
185	0.9480
210	0.8313
215	0.9768

Overall Kappa = 0.8711

Cross-tabulation of 62lin (columns) against 80lin (rows)

	0	5	30	56	108	180	185	215	Total
0	16567	10	2552	1170	83	15	55	89	20541
5	17	2717	554	0	0	3	0	0	3291
30	2347	362	639737	2020	0	246	130	3	644845
56	654	3	486	18902	3262	0	28	0	23335
162	46	0	34	422	296	0	0	0	798
163	413	0	24	3273	3062	0	0	0	6772
180	27	10	1990	0	0	6158	0	0	8185
185	1348	0	15394	2591	1525	0	1886	5	22749
215	1517	0	0	1205	4850	0	33	449933	457538
Total	22936	3102	660771	29583	13078	6422	2132	450030	1188054

Chi Square = 4537852.0000
df = 56
Cramer's V = 0.7387

Proportional Crosstabulation

	0	5	30	56	108	180	185	215	Total
0	0.0139	0.0000	0.0021	0.0010	0.0001	0.0000	0.0000	0.0001	0.0173
5	0.0000	0.0023	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0028
30	0.0020	0.0003	0.5385	0.0017	0.0000	0.0002	0.0001	0.0000	0.5428
56	0.0006	0.0000	0.0004	0.0159	0.0027	0.0000	0.0000	0.0000	0.0196
162	0.0000	0.0000	0.0000	0.0004	0.0002	0.0000	0.0000	0.0000	0.0007
163	0.0003	0.0000	0.0000	0.0028	0.0026	0.0000			
180	0.0000	0.0000	0.0017	0.0000	0.0000	0.0052			
185	0.0011	0.0000	0.0130	0.0022	0.0013	0.0000			
215	0.0013	0.0000	0.0000	0.0010	0.0041	0.0000			
Total	0.0193	0.0026	0.5562	0.0249	0.0110	0.0054			

163	0.0000	0.0000	0.0057
180	0.0000	0.0000	0.0069
185	0.0016	0.0000	0.0191
215	0.0000	0.3787	0.3851
Total	0.0018	0.3788	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 80lin as the reference image ...

Category	KIA
0	0.8027
5	0.8251
30	0.9822
56	0.8052
162	0.0000
163	0.0000
180	0.7510
185	0.0813
215	0.9732

Using 62lin as the reference image ...

Category	KIA
0	0.7174
5	0.8755
30	0.9304
56	0.6317
108	0.0000
180	0.9586
185	0.8824
215	0.9996

Overall Kappa = 0.9204

Cross-tabulation of 80lin (columns) against 86lin (rows)

	0	5	30	56	163	180
0	18826	34	1969	204	0	2
5	21	3189	37	251	0	0
30	1295	68	634661	28	143	0
56	99	0	0	21476	0	0
162	265	0	38	64	198	0
163	737	0	0	647	6407	0
180	9	0	0	0	0	8179
185	2039	0	8140	665	24	0
215	13	0	0	0	0	0
Total	23304	3291	644845	23335	6772	8181

	185	215	Total
0	0	11	21046
5	0	0	3498
30	163	0	636358
56	7	875	22457
162	88	411	1064
163	0	5067	12858
180	0	0	8188
185	20530	208	31606
215	0	450966	450979
Total	20788	457538	1188054

Chi Square = 6644236.0000
df = 56
Cramer's V = 0.8938

Proportional Crosstabulation

	0	5	30	56	163	180
0	0.0158	0.0000	0.0017	0.0002	0.0000	0.0000
5	0.0000	0.0027	0.0000	0.0002	0.0000	0.0000
30	0.0011	0.0001	0.5342	0.0000	0.0001	0.0000
56	0.0001	0.0000	0.0000	0.0181	0.0000	0.0000
162	0.0002	0.0000	0.0000	0.0001	0.0002	0.0000
163	0.0006	0.0000	0.0000	0.0005	0.0054	0.0000
180	0.0000	0.0000	0.0000	0.0000	0.0000	0.0069
185	0.0017	0.0000	0.0069	0.0006	0.0000	0.0000
215	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0196	0.0028	0.5428	0.0196	0.0057	0.0069

	185	215	Total
0	0.0000	0.0000	0.0177
5	0.0000	0.0000	0.0029
30	0.0001	0.0000	0.5356
56	0.0000	0.0007	0.0189
162	0.0001	0.0003	0.0009

163	0.0000	0.0043	0.0108
180	0.0000	0.0000	0.0069
185	0.0173	0.0002	0.0266
215	0.0000	0.3796	0.3796
Total	0.0175	0.3851	1.0000

KAPPA INDEX OF AGREEMENT (KIA)

Using 86lin as the reference image ...

Category	KIA
0	0.8924
5	0.9114
30	0.9942
56	0.9554
162	0.0000
163	0.4954
180	0.9989
185	0.6433
215	1.0000

Using 80lin as the reference image ...

Category	KIA
0	0.8044
5	0.9689
30	0.9660
56	0.9188
163	0.9455
180	0.9998
185	0.9872
215	0.9768

Overall Kappa = 0.9643

RELEASE [illegible]

0	1	23
56	23	24
79	24	25
143	25	26
176	26	28
30	28	30
0	30	33
56	33	34
0	34	35
56	35	36
0	36	38
30	38	39
79	39	40
0	40	44
30	44	45
0	45	50
56	50	51
163	51	52
0	52	53
30	53	54
0	54	66
30	66	67
0	67	68
56	68	69
0	69	83
-9999		

0	1	22
79	22	23
143	23	24
30	24	25
176	25	26
0	26	30
56	30	31
0	31	32
30	32	33
0	33	34
143	34	35
0	35	45
56	45	46
0	46	47
163	47	48
0	48	58
30	58	59
56	59	60
0	60	67
30	67	68
0	68	70
143	70	71
176	71	72
0	72	76
79	76	77
0	77	78
-9999		

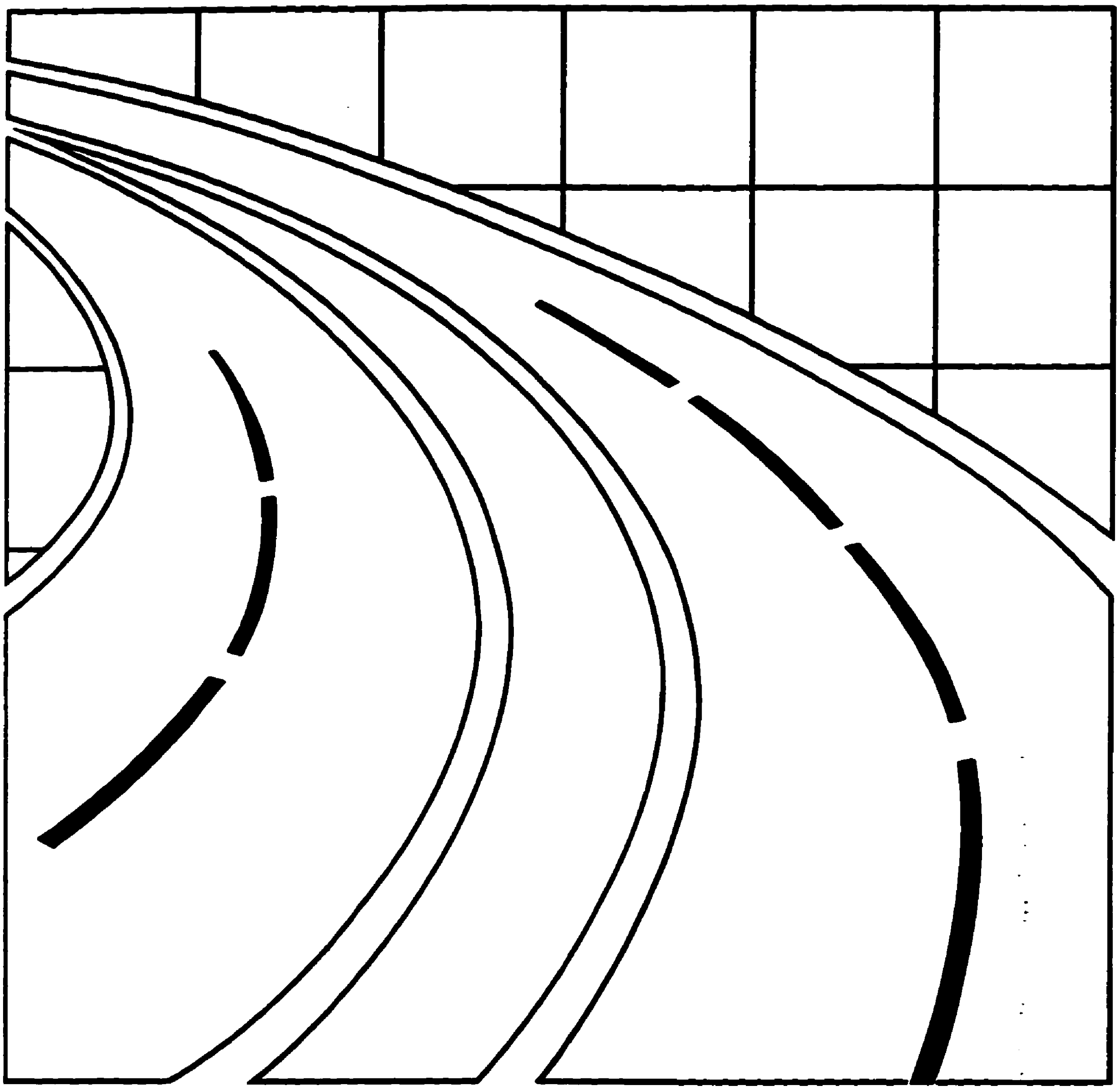
103	0	3
0	3	4
103	4	40
180	40	41
103	41	52
-9999		

103	0	3
0	3	4
103	4	10
5	10	11
103	11	40
-9999		

0	1	4
210	4	5
0	5	16
210	16	17
0	17	32
210	32	33
0	33	45
185	45	49
0	49	52
210	52	53
0	53	61
-9999		

0	1	20
210	20	21
0	21	41
210	41	42
0	42	45
210	45	46
0	46	47
185	47	48
0	48	52
185	52	53
0	53	55
210	55	56
0	56	58
210	58	59
0	59	67
-9999		

Appendix V



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CHAPTER A

CLASSIFICATION

A.1 INTRODUCTION

A road classification system groups roads into a limited number of clearly defined types. There are many different classification systems in use, each of which has been developed for a specific purpose. It would be an advantage if a single classification system were used for all purposes, however, this is not practical. Nevertheless, it is important that the classification system for any specific purpose also be adaptable to other applications. In the case of geometric design standards, the road designer finds that his work is closely connected with that of the highway planner and the land use planner. Consequently, it is necessary to have a classification system that can be satisfactorily applied by all three.

In any classification system, the division between classes is arbitrary and, consequently, there are differences of opinion as to the best definition of each class. Small variations are not significant, but it is important that, once established, the system be adhered to. It is impractical to set out specific descriptions for each group or classification, but the description provided for any classification should be clear, to convey the same message to all who use the system.

A.2 PURPOSE OF ROAD CLASSIFICATION

A road network is composed of various road types, each of which performs a particular service in facilitating vehicular travel between points of trip origin and destination, and in providing access to property.

Road classification is the orderly grouping of roads into systems according to the type and degree of service they provide to the public. When a road system is properly classified, the characteristics of each road are readily understood.

The principal purposes of road classification are to:

- establish logical, integrated systems composed of all roads which, because of their service, ideally should be administered by the same jurisdiction
- provide a basis for assigning the responsibility for each classification of road to the level of government with the primary interest
- group roads that require the same quality of design maintenance and operation.

Many different classification systems have been developed and are used for particular purposes. The bases for some of these classifications are legal control, surface type, geometric elements and traffic volume. Such listings may be useful for either engineering or administrative purposes, however, they are largely a means of describing superficial characteristics of the roads. Seldom do these classification systems differentiate between roads on the basis of the service and this characteristic is essential to the road designer and the land use planner. A road classification based on land service, traffic service and traffic use is the most useful as it embraces, to some extent, the other forms of classification.

The information required to identify the service classification of a road includes traffic volume, characteristics of traffic flow, distribution of vehicle types, speed characteristics of different vehicle types, adjacent land use, and degree of land service provided.

A.3 DESIGN CLASSIFICATION SYSTEM

The design classification system used in this Manual:

- separates roads on the basis of differences in traffic service and land services. This is the most significant factor as it makes the classification adaptable for both planning and design purposes
- separates different types of roads and streets on the basis of geometric design features
- can be related to jurisdictional road and street classifications now in use
- is suitable for all areas in Canada.

This classification system has eight primary divisions as follows:

Rural	Urban
Local	Local
Collector	Collector
Arterial	Arterial
Freeway	Freeway

The terms "rural" and "urban" refer to the predominant characteristics of the adjacent land use and not only to jurisdictional boundaries or features of typical cross section.

For geometric design purposes, it is necessary to subdivide each of these divisions because different roadways providing the same service may require markedly different geometric design standards. For a given road, geometric design elements are affected by whether the roadway is divided or undivided. This, therefore, forms the first subdivision of classification.

Traffic volumes have an effect on pavement width, shoulder width and intersection design, and are recognized as a consideration in determining classification. However, they are significant only in so far as they influence the number of lanes and whether the road should be divided or undivided.

Other variables affect geometric design and result in differences in the traffic service quality of a road. These include:

- the type of terrain the road passes through
- the general prosperity of the region, or the financial resources available for road construction
- population density, the development characteristics of the land surrounding the road, and the travel habits of the local population.

Design speed is a measure of quality, and therefore, is the final subdivision in the road classification system. The resulting design classification system contains 56 classifications of road, as shown in Table A.3.

Table A.3
Road classification

	design speed km/h	classification local	collector	arterial	freeway
rural	50	RLU50			
	60	RLU60	RCU60		
	70	RLU70	RCU70		
			RCD70		
	80	RLU80	RCU80	RAU80	
			RCD80	RAD80	
	90	RLU90	RCU90	RAU90	
			RCD90	RAD90	
	100	RLU100	RCU100	RAU100	
			RCD100	RAD100	RFD100
	110			RAU110	
				RAD110	RFD110
	120			RAU120	
				RAD120	RFD120
	130			RAU130	
				RAD130	RFD130
urban	30	ULU30			
	40	ULU40			
	50	ULU50	UCU50	UAU50	
			UCD50		
	60		UCU60	UAU60	
			UCD60	UAD60	
	70		UCU70	UAU70	
			UCD70	UAD70	
	80		UCU80	UAU80	
			UCD80	UAD80	UFD80
	90			UAD90	UFD90
	100			UAD100	UFD100
	110				UFD110
	120				UFD120

A.3.1 Low-volume roads

It is recognized that a large percentage of the rural road length in Canada carries low traffic volumes and has service functions which do not conform to the classification divisions described in Section A.3.

Chapter H, Low-volume roads, provides a suitable classification for low-volume roads together with recommended standards.

The selection of the appropriate classification system and related standards is considered to be a matter of policy, resting with the individual road agency.

A.3.2 Other road terms

Many common terms used to describe different types of roads do not appear in the classification system. The term freeway has been chosen in preference to expressway, turnpike, autoroute or thruway because it is more descriptive of the type of traffic movement.

A.3.3 Coding

A code for each design classification is given in Table A.3 to simplify reference. The method of coding may be illustrated by the example UAD 100, which refers to an urban arterial divided, 100 km/h design speed road.

A.4 FACTORS CONSIDERED IN CLASSIFICATION

The first step in any road planning, design or administration study is to designate each facility as a freeway, arterial, collector or local road. To identify the classification to which any road belongs, the service function and traffic characteristics should be considered. The important characteristics and their relation to the different classifications of roads are described in this section. Combined, these factors make it possible to identify the classification to which any road belongs, although it must be recognized that precision in this might not be achieved.

A.4.1 Service function

Most roads provide service to traffic, access to land, or both. Freeways and arterials provide for the movement of through traffic. Local roads are used almost exclusively for land access. Collectors provide a combined service. These characteristics are illustrated in Table A.4.

A.4.2 Traffic volume

High volumes of traffic are carried by freeways and arterials, while low volumes are associated with collectors and locals. However, the volume range for each classification is wide and overlaps that of other classifications.

A.4.3 Flow characteristics

In general, the desired characteristics of traffic flow determine the classification of a road. For example, roads primarily serving traffic movements, such as freeways and rural arterials, are expected to have uninterrupted traffic flow characteristics. The flow on local roads that provide full land service, is restricted by traffic crossing, entering and leaving the road by parked vehicles, and in urban areas by pedestrians.

A.4.4 Running speed

The average running speed of traffic operating under off-peak volume conditions varies on roads of the same classification depending on the type and condition of the surface, intensity of adjacent land development, access to the road, vehicle types, and traffic flow controls. Running speeds generally increase from locals to collectors, arterials and freeways.

A.4.5 Vehicle type

The proportion of passenger cars, buses and trucks using a road is generally dependent on the purposes of the road and is, therefore, related to the road classification. Local roads are used predominantly by passenger cars and small trucks, with a small percentage of large trucks; while freeways and arterials generally carry a higher proportion of commercial vehicles.

A.4.6 Connections

In an ideal road system, locals connect with collectors, collectors with arterials, and arterials with freeways. It is preferable to minimize the interconnection of locals with arterials and of collectors with freeways. Locals rarely, if ever, connect with freeways. This is illustrated in Table A.4.

Table A.4
Connections by classification

classification	normally connects with	acceptable to connect with	
local	local collector	arterial freeway	(less preferable) (rare)
collector	local collector arterial	freeway	(rare)
arterial	collector arterial freeway	local	(less preferable)
freeway	arterial freeway	local collector	(rare) (less preferable)

A.5 DESCRIPTION OF CLASSIFICATIONS

The principal characteristics of each of the eight basic road design classifications are described in the following sections, and are summarized in Tables A.5a and A.5b. The relationship of the road classifications is illustrated in Figure A.5.

A.5.1 Rural local roads

Service Function
The main function of rural local roads is provision of land access. The intended traffic service function of a local road is to allow vehicles to reach properties. Development roads that serve one or two natural resource areas may be considered as local roads unless volumes and function justify otherwise. Many rural local roads fall within the category of low volume roads and reference should be made to Chapter H.

Traffic volumes
Traffic volumes on rural local roads are generally low, but can be significant depending on the density of development adjacent to the road.

Flow characteristics
Traffic flow on rural local roads is interrupted by stop conditions at intersecting roads and is affected by traffic moving to and from adjacent properties. Pedestrian traffic is not restricted.

Design speed
Design speeds in the range of 50 km/h to 100 km/h are appropriate for rural local roads.

Running speed
Depending on the condition of the surface, the average running speed on rural local roads varies from 50 km/h to 90 km/h.

Vehicle type
In agricultural areas, trucking is generally by light and medium vehicles with occasional heavy trucks. In mining and forestry areas, heavy units predominate. The number of trucks depends upon the adjacent land use and can be in excess of 50% of the total traffic volume.

Connections
Rural local roads normally connect with collector and arterial roads.

A.5.2 Rural collector roads

Service function
Rural collector roads collect traffic from local roads and feed it to arterials, or distribute it from arterials to locals. They generally form an integrated network throughout developed areas and provide direct traffic service for developments such as tourist areas, mining areas and the smaller towns and villages. Rural collector roads have a land service function of equal importance to their traffic service function in that they directly serve the adjacent properties.

Traffic volumes
Traffic volumes on rural collector roads are typically less than 5000 vehicles per day depending on the population density.

Flow characteristics
Traffic flow on rural collector roads is interrupted by stop conditions or signalized intersections at connections with arterials or other collector roads; and is also impeded by vehicles leaving and entering the highway directly from adjacent properties. Pedestrian traffic is not restricted.

Design speed
Design speeds ranging from 60 km/h to 100 km/h are appropriate for rural collector roads.

Running speed
The average running speed on rural collector roads varies from 50 km/h to 90 km/h.

Vehicle type
Although rural collectors carry all types of vehicle, commercial traffic consists mainly of trucks in the 3 t to 5 t range. These are trucks carrying produce such as milk, feed and livestock, and amount to as much as 30% of the volume of traffic using these roads. Few heavy transport trucks use this classification of road.

Connections
Rural collector roads connect with all other classifications of road.

A.5.3 Rural arterial roads

Service function
Rural arterial roads move large volumes of traffic at high speeds. The major distinction between the rural arterial and the rural freeway is in the control of access. Roads that have full control of access fall within

Figure A.5
Relationship of road classifications

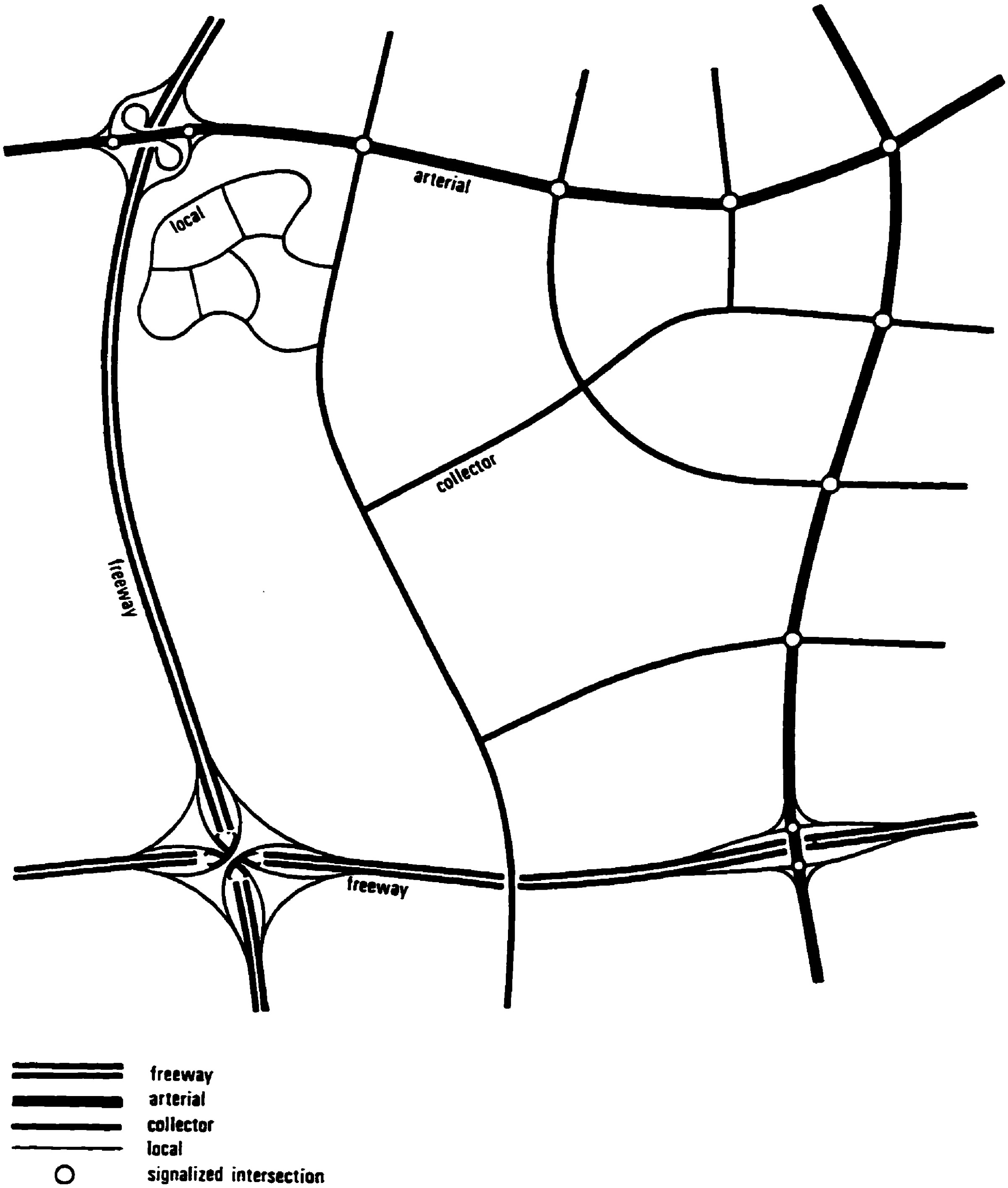

Table A.5a
Characteristics of rural roads

	rural locals	rural collectors	rural arterials	rural freeways
service function	traffic movement secondary consideration	traffic movement and land access of equal importance	traffic movement primary consideration	optimum mobility
land service	land access primary consideration		land access secondary consideration	no access
traffic volume vehicles per day (typically)	<1000	<5000	<12 000	>8000
flow characteristics	interrupted flow	interrupted flow	uninterrupted flow except at signals	free flow (grade separated)
design speed, km/h	50 - 100	60 - 100	80 - 130	100 - 130
average running speed, km/h (free-flow conditions)	50 - 90	50 - 90	60 - 100	80 - 110
vehicle type	predominantly passenger cars, light to medium trucks & occasional heavy trucks	all types, up to 30% trucks in the 3 t to 5 t range	all types, up to 20% trucks	all types, up to 20% heavy trucks
normal connections	locals collectors	locals collectors arterials	collectors arterials freeways	arterials freeways

the freeway classification. Rural arterial roads, together with freeways, serve as the major links in a network connecting major economic regions and centres such as large cities, industrial concentrations, agricultural areas and recreational facilities. Because arterials carry large traffic volumes moving at high speed, direct access to abutting lands may be restricted or even eliminated. This applies particularly in areas of intensive development and in undeveloped areas where the lack of other road service would encourage strip development.

Traffic volumes
Traffic volumes on rural arterials typically are less than 12 000 vehicles per day. This range is wide because arterials in sparsely populated regions have relatively low traffic volumes while providing an important inter-regional traffic service. Traffic volumes of 12 000 vehicles per day occur on arterial highways in more densely populated areas.

Flow characteristics
Rural arterial roads carry high traffic volumes at high speeds with uninterrupted flow characteristics except at intersections with major crossing roads.

Design speed
Design speeds in the range of 80 km/h to 130 km/h are appropriate.

Running speed
The average running speed is between 60 km/h and 100 km/h. The higher values are found on those sections of rural arterial roads having some control of access.

Vehicle type
As rural arterial roads link major regions, they serve all types of vehicles with up to 20% truck traffic.

Connections
Rural arterial roads connect with collectors, arterials and freeways.

A.5.4 Rural freeways

Service function
Rural freeways accommodate the movement of large volumes of traffic at high speeds under free flow conditions. They connect the larger cities, industrial concentrations and recreational areas; form the major highway routes through intensely developed areas, and serve international and interprovincial travel movements. The need for unrestricted traffic movement on freeways justifies the elimination of direct land access.

Traffic volumes
A freeway typically carries traffic volumes exceeding 8000 vehicles per day.

Flow characteristics
On rural freeways, traffic flow is uninterrupted.

Design speed
Design speed is in the range of 100 km/h to 130 km/h.

Running speed
The average running speed on rural freeways under most conditions varies between 80 km/h and 110 km/h.

Vehicle type
Rural freeways carry all types of vehicular traffic, with heavy trucks normally amounting to between 20% and 30% of the total volume.

Connections
Rural freeways connect with other freeways, arterials and collectors, through interchanges.

A.5.5 Urban local roads

Service function
The function of local roads is to provide land access, and direct access is allowed to all abutting properties. Local roads are not intended to carry large volumes of traffic. The local road primarily carries traffic with an origin or destination along its length. It is not intended to carry through traffic other than to immediately adjoining roads. Local roads may be residential, or commercial and residential developments might carry appreciably higher traffic volumes and therefore may be multi-lane, but are seldom divided.

Traffic volumes
Traffic volumes vary with the density of adjacent development and generally do not exceed 3000 vehicles per day.

Flow characteristics
Local roads have interrupted traffic flow, and stop, yield or signalized controls where they intersect other roads and traffic flow is interrupted.

Design speed
Design speeds are necessarily low, in the range of 30 km/h to 50 km/h.

Running speed
Running speed under free flow conditions is generally 20 km/h to 40 km/h.

Vehicle type
The type of vehicle using local roads varies. Residential roads carry predominantly passenger vehicles and some industrial roads carry a high percentage of trucks. Bus operations on residential local roads are generally avoided.

Connections
Local roads connect to other local roads and collector roads. In some cases industrial or commercial local roads connect directly to arterials.

A.5.6 Urban collector roads

Service function
Urban collector roads provide both traffic service and land service. The traffic service function of this type of road is to carry traffic between local and arterial roads. Full access to adjacent properties is generally allowed on collectors.

Traffic volumes
Traffic volumes range between 1000 and 12 000 vehicles per day. Collector roads might have more than two traffic lanes and might be divided.

Flow characteristics
The traffic flow on urban collector roads, in and near the central business district, is interrupted frequently by signalized intersections. In residential areas, simpler forms of traffic control are generally used. There are few parking restrictions except during peak hours

Table A.5b
Characteristics of urban roads

	urban locals	urban collectors	urban arterials	urban freeways
service function	traffic movement secondary consideration	traffic movement and land access of equal importance	traffic movement primary consideration	optimum mobility
land service	land access primary consideration		land access secondary consideration	no access
traffic volume vehicles per day (typically)	<3000	1000 - 12 000	5000 - 30 000	>20 000
flow characteristics	interrupted flow	interrupted flow	uninterrupted flow except at signals and crosswalks	free-flow (grade separated)
design speed, km/h	30 - 50	50 - 80	50 - 100	80 -120
average running speed, km/h (free-flow conditions)	20 - 40	30 - 70	40 - 90	70 -100
vehicle type	passenger & service vehicles	all types	all types up to 20% trucks	all types up to 20% trucks
normal connections	locals collectors	locals collectors arterials	collectors arterials freeways	arterials freeways

when traffic movement might be the most important consideration. There are generally no special pedestrian crossing restrictions, but crosswalks may be provided where traffic volumes are high. To improve traffic flow, particularly at peak hours, it is sometimes desirable to provide collector roads with bus bays or turning lanes similar to those provided on arterial streets.

Design speed
Design speeds normally range from 50 km/h to 80 km/h.

Running speed
The normal running speed under free-flow conditions varies from 30 km/h and 70 km/h, with the higher values prevailing in suburban areas.

Vehicle type
In commercial and industrial areas, all types of vehicles including truck transports moving to and from arterials use urban collector roads. In residential areas, collectors carry a low percentage of trucks composed mainly of service vehicles.

Connections
Urban collector roads are connected to arterial and local roads, but connections to freeways are rarely found except in areas of concentrated development.

A.5.7 Urban arterial roads

Service function
Urban arterial roads carry large volumes of all types of traffic moving at medium to high speeds. These roads serve the major traffic flows between the principle areas of traffic generation; and connect to rural arterials and collectors. In urban areas without freeways, arterial roads provide the best quality of traffic service.

The amount of direct access to adjacent development on urban arterial roads preferably should be limited. Desirably, such access should be confined to local and collector roads, by applying treatments such as frontage roads.

Traffic volume
Urban arterial roads normally experience traffic volumes of 5000 to 30 000 vehicles per day. Urban arterials may be divided or undivided.

Flow characteristics
The traffic flow is generally uninterrupted except at signalized intersections and crosswalks. Where signals are closely spaced synchronization minimizes the interference to through movements. Parking and unloading are often prohibited where they might seriously affect through movement of traffic, particularly at peak hour. Pedestrian crossing preferably should be limited to intersections or special crosswalks.

Design speed
Design speed is in the range of 50 km/h to 100 km/h.

Running speed
Running speed under free flow conditions normally ranges from 40 km/h to 90 km/h, with the higher values prevailing in suburban areas.

Vehicle type
Urban arterial roads are used by all types of traffic. Trucks may comprise as much as 20% of the total traffic volume. Both express and local buses are generally routed on arterial roads.

Connections
Arterial roads connect to freeways, other arterials, and collector roads. In certain cases, local industrial or commercial roads connect to arterials because of their location or the traffic volumes carried. It is undesirable to have local residential roads connect with arterials.

A.5.8 Urban freeways

Service functions
Urban freeways accommodate high volumes of traffic moving at high speeds under free-flowing conditions. Urban freeways connect primary areas of traffic generation and serve as urban extensions of principal rural highways. They are intended to serve traffic between large residential areas, industrial or commercial concentrations and the central business district. To provide optimum mobility for through traffic, service to adjacent lands is eliminated. No parking, unloading of goods, or pedestrian traffic is permitted.

Traffic volumes
Urban freeways normally carry traffic volumes in excess of 20 000 vehicles per day.

Flow characteristics
To move high volumes at high speeds, urban freeways have uninterrupted flow conditions. This is provided by grade-separated crossings and interchanges. Parking and pedestrians are prohibited. Urban freeways are generally constructed on new alignments.

Design speed
The normal range of design speed is 100 km/h to 120 km/h. In special circumstances a design speed as low as 80 km/h is acceptable.

Running speed
The normal running speed under free-flow conditions varies between 70 km/h and 100 km/h.

Vehicle type
Urban freeways carry all types of vehicles including a relatively high percentage of trucks, amounting up to 20% of the total volume. The only bus service on urban freeways is express, with stops only at interchanges.

Connections
Urban freeways connect directly to intersecting or adjacent freeways and to most intersecting or adjacent arterial streets. Some direct connections to collector streets may be provided in the central business district.

A.6 SELECTION OF ROAD DESIGN CLASSIFICATION

The design standards in this Manual are intended to be applied only after the classification of a road has been determined. The selection, is based on a knowledge of the purpose, function and general characteristics of the road and its relationship to other roads in the network.

For each road classification given, there is a range of design speeds and corresponding range of standards. This allows variation in prevailing conditions to be reflected in the geometric design by the selection of classification.

Careful application of standards for the 56 classifications shown, bring the geometric features into harmony.

A.7 DESIGN SPEED

A.7.1 Description

Design speed is a speed selected for the purposes of design and correlation of the geometric features of a road and is a measure of the quality of design offered by the road. It is sometimes considered to be the highest continuous speed at which individual vehicles can travel with safety on a road when weather conditions are so favourable and traffic density is so low that the safe speed is determined by the geometric features of the road.

Design standards are presented in this Manual for design speeds ranging from 30 km/h to 130 km/h. For particular applications such as turning roadways, standards for lower design speeds are given.

Standards for smaller increments than 10 km/h are not justified. The differences in design elements for successive values would be too small to be effective. Design speeds in excess of 130 km/h are rarely used.

A.7.2 Selection of design speed

The design speed adopted should be logical with respect to the topography, adjacent land use, and type of road. Every effort should be made to use as high a design speed as practicable to attain a desired degree of safety, mobility and efficiency while under the constraints of environmental quality, economics, aesthetics, and social impacts. Once selected, all the pertinent features of the highway should be related to the design speed to obtain a balanced design.

Certain features, such as radius, superelevation, and sight distance, are directly related to, and vary appreciably with, design speed. Others such as lane width, shoulder width and clearances to walls and barriers, are not directly related to design speed, but affect vehicle speed; and higher standards should be accorded these features for the higher design speeds. Thus, nearly all design elements of the highway are related to design speed.

A.7.2.1 Design speed for rural conditions and freeways

Driver behaviour is conditioned by the expectations of the characteristics and quality of the road ahead. Expectations are, in turn, predicated on the driver's perception of the prevailing topographic, environmental, traffic and climatic conditions. Where severe topographic conditions or surrounding development are encountered, drivers expect to travel at lower speeds and are more likely to adjust to geometric design consistant with a lower design speed than where there is no apparent reason for it. The driver recognizes or senses a logical speed for the condition based on his knowledge of the system, his appraisal of the ruggedness of the terrain, and the extent, density and size of building development; which he subconciously relates to the road and its quality. Drivers do not adjust their speeds to the classification of the highway, but to the physical limitations and the prevailing traffic conditions. Thus the driver largely accepts the speed characteristics as determined by the geometry of the road, to the extent that the selected design speed is reasonable.

The speed selected for design should fit the travel desires and habits of nearly all drivers. Where traffic, weather and roadway conditions are such that drivers can travel at their chosen speed, there is a wide range in speed. A cumulative distribution of vehicle speeds has the typical S pattern when plotted as a percentage of vehicles versus observed speeds. The design speed chosen should be represented by a high- percentile value in this speed distribution curve, (normally 95th percentile) to be inclusive of the desired speed of most drivers, or indicative of the generally highest speed that can be negotiated with safety under favourable weather and traffic conditions.

Studies have led to the conclusion that where physical features of the road are the principal speed controls, a top design speed of 120 km/h is indicative of a highway of very high quality of design. On many freeways, particularly in suburban and rural areas, a design speed in the range of 100 km/h to 120 km/h can be provided with little additional cost above that required for a design speed of 80 km/h. This could be the case where the highway corridor is relatively straight or gradually curvilinear and the form and location of interchanges permits high-speed operation. The flatter curvature and increased sight distance associated with the higher design speeds usually result in operationally more efficient and safer facilities.

Although the selected design speed establishes the minimum radius and minimum sight distance necessary for safe operation, there should be no restriction on the use of flatter horizontal curves or greater sight distances where such improvements can be provided as a part of economic design. Even in rugged terrain, an occasional tangent or flat curve may be fitting. These would not necessarily encourage drivers to increase speed but if a succession of them were introduced, drivers would naturally resort to higher speeds, and the section of highway should be designed for a higher speed. A substantial length of localized tangent between sections of curved alignment is apt to encourage operation at higher speed. Where this is the case, recognition of the higher speed should be accounted for in design of geometric features on such a tangent, particularly that of sight distance on crest curves.

A pertinent consideration in selecting design speed is the average trip length. The longer the trip, the greater the desire for expeditious movement. In design of a substantial length of highway, it is desirable where feasible, to assume a constant design speed. Changes in terrain and other physical controls may dictate a change in design speed on certain sections. If so, the introduction of a lower design speed should not be effected abruptly, but should be effected over sufficient distance to permit drivers to change speed gradually before reaching the section of highway with the lower design speed.

Where it is necessary to reduce design speed, many drivers may not perceive the lower speed condition ahead, and it is important that they be warned well in advance. The changing condition should be indicated by such controls as speed-zone signs, curve-speed signs, and where feasible by alignment adjustment leading into the curvature controlling the reduced design speed.

A.7.2.2 Design speed for urban conditions

On arterial streets, the design speed control applies to a lesser degree than on high operating speed highways. On rural highways or on high operating speed urban facilities, a certain percentage of vehicles is able to travel at or near the safe speed determined by geometric design elements, but on arterial streets, the top speeds for several hours of the day are limited or regulated to those at which the recurring peak volumes can be handled. Speeds are governed by the

Appendix VI

ENVIRONMENTAL-MEDIA INDEX—WATER QUALITY

There are numerous water quality indices which have been developed over the last 25 years. One example, called simply the "water quality index" (WQI), developed in 1970 by the U.S. National Sanitation Foundation (NSF), will be described. The WQI was based on the Delphi approach, using a panel of 142 persons from throughout the United States with expertise in various aspects of water quality management (Table 5.3). A series of three questionnaires was mailed to the members of this panel. In questionnaire no. 1, the respondents were asked to consider 35 water-pollutant variables for possible inclusion in a water quality index (Table 5.4). Respondents were permitted to add any variables to the list which they felt should be included in the WQI. They were asked to designate each variable as follows: "do not include," "undecided," or "include." Respondents also were asked to rate each "include" variable according to its significance to overall water quality. This rating was done on a scale of 1 (highest relative significance) to 5 (lowest relative significance).

When respondents returned questionnaire no. 1, the results were tabulated and returned to the respondents for their further consideration, along with questionnaire no. 2. In questionnaire no. 2, each member was asked to review their original ratings and to modify the response if desired. Each member was instructed to note his or her replies for each variable and to compare them with those of the entire group. Following the receipt of results from questionnaire no. 2, the nine individual variables of greatest importance were identified as dissolved oxygen (DO), fecal coliforms, pH, 5-day biochemical oxygen demand (BOD_5), nitrates (NO_3), phosphates (PO_4), temperature deviation, turbidity (in JTU), and total solids (TS). The resultant importance weights based on the ratings for each variable are listed in Table 5.5.

In questionnaire no. 3, the respondents were asked to develop a rating curve for each of the included variables (Ott, 1978). This was accomplished by providing blank graphs to each respondent. Levels of Water Quality from 0 to 100 were indicated on the ordinate of each graph, while various levels (or strengths) of the particular variable were arranged along the abscissa. Each respondent was asked to draw a curve on each graph which, in their judgment, represented the variation of water quality produced by the various quantities of each pollutant variable. The resultant relationships are called "functional relationships" or "functional curves."

The investigators subsequently averaged the curves from the respondents to produce a set of "average curves," one for each pollutant variable. The resulting curves are shown in Figures 5.1 through 5.9. In each figure, the solid line represents the arithmetic mean of all respondents' curves, while the dotted lines bounding the shaded area represent the 80 percent confidence limits. Approximately 80 percent of the respondents' curves lie within the shaded zone. A narrow band of shading, such as the one for DO (Figure 5.1), denotes greater agreement among respondents than does a wide band, such as the one for turbidity (Figure 5.8).

To calculate the aggregate WQI, either a weighted linear sum of the subindices (WQI_a) or a weighted product-aggregation function (WQI_m) can be used. These are expressed mathematically as follows (Ott, 1978):

$$\text{NSF WQI}_a = \sum_{i=1}^{n} w_i I_i$$

$$\text{NSF WQI}_m = \prod_{i=1}^{n} I_i^{w_i}$$

TABLE 5.5					
EXAMPLE CALCULATIONS FOR WATER QUALITY INDEX					
Variable	**Measurement**	I_i	W_i	I_iW_i	$I_i^{W_i}$
DO	60%	60	0.17	10.2	2.01
Fecal coliforms	10^3	20	0.15	3.0	1.57
pH	7	90	0.12	10.8	1.72
BOD_5	10	30	0.10	3.0	1.41
NO_3	10	50	0.10	5.0	1.48
PO_4	5	10	0.10	1.0	1.26
Temperature deviation	5'	40	0.10	4.0	1.45
Turbidity	40 JTU	44	0.08	3.5	1.35
Total solids (TS)	300	60	0.08	4.8	1.39
				$WQI_a = 45.3$	$WQI_m = 38.8$

Subindex values are from Figures 5.1 through 5.9.
Importance weights assigned to variables = W_i.

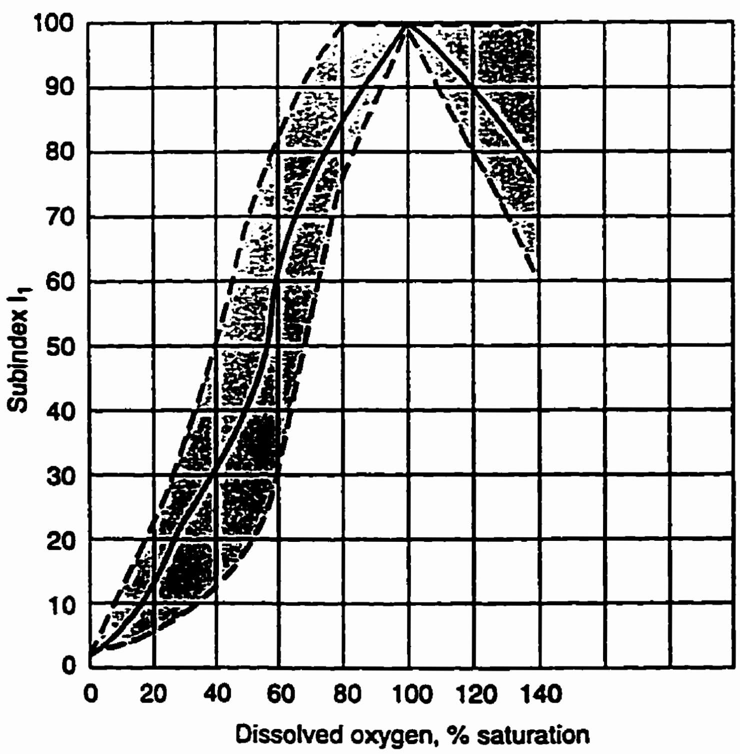

FIGURE 5.1
Subindex Function for DO in the NSF WQI (For DO > 140%, I_1 = 50) (Ott, 1978).

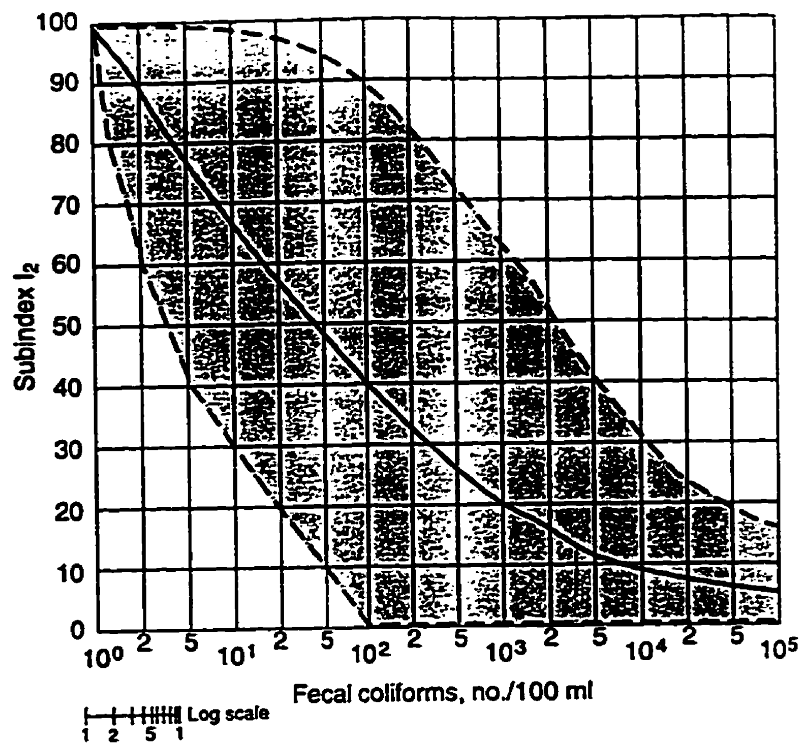

FIGURE 5.2
Subindex Function for Fecal Coliforms (average number of organisms per 100 ml) in the NSF WQI (For fecal coliforms > 10^5/100 ml, $I_2 = 2$) (Ott, 1978).

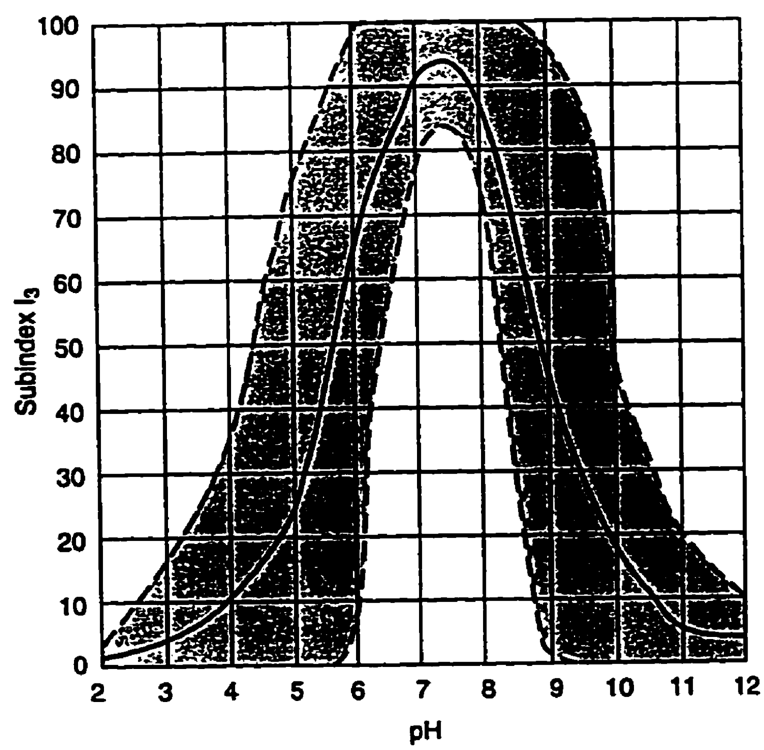

FIGURE 5.3
Subindex Function for pH in the NSF WQI (Ott, 1978).

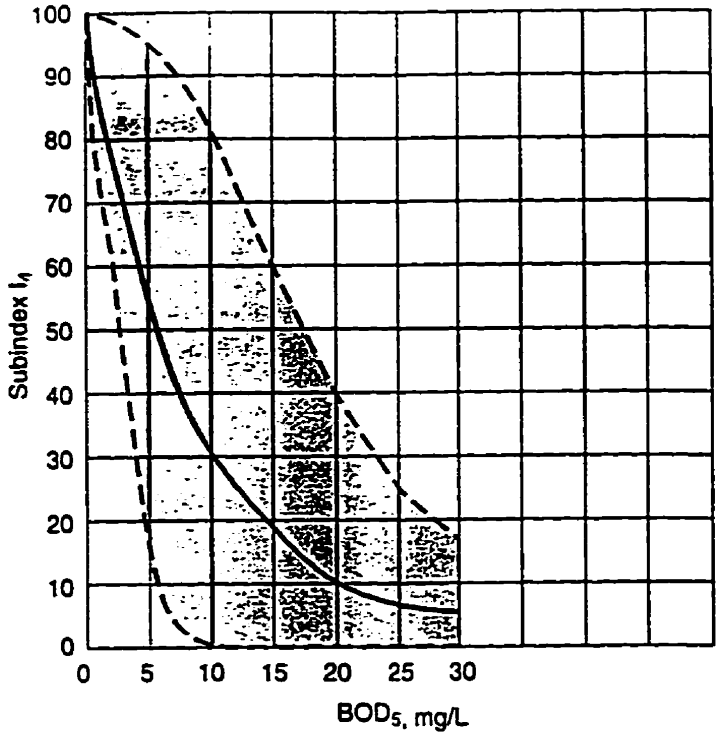

FIGURE 5.4
Subindex Function for BOD_5 in the NSF WQI (For BOD_5 > 30 mg/l, I_4 = 2) (Ott, 1978).

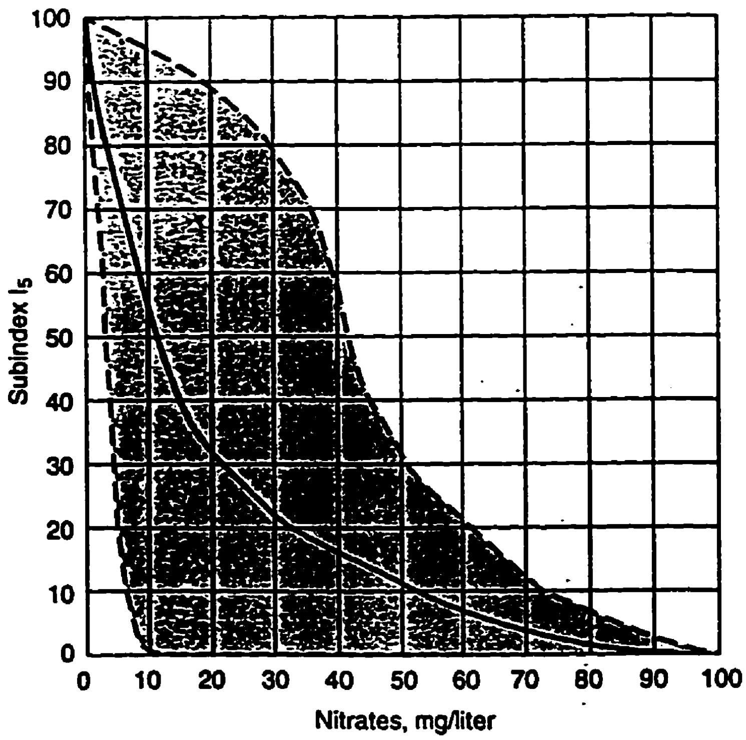

FIGURE 5.5
Subindex Function for Nitrates in the NSF WQI (For nitrates > 100 mg/l, I_5 = 1) (Ott, 1978).

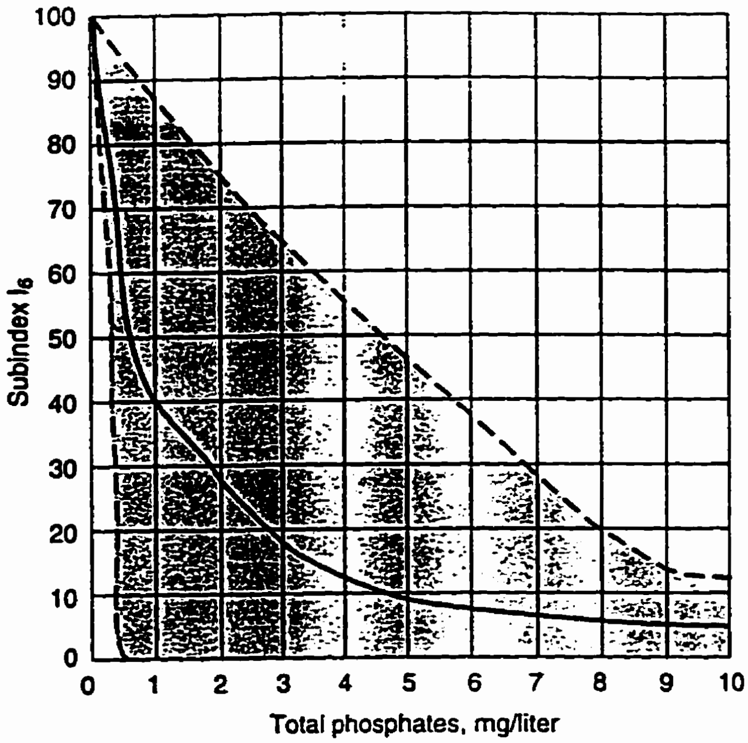

FIGURE 5.6
Subindex Function for Total Phosphates in the NSF WQI (For total phosphates > 10 mg/l, I_6 = 2) (Ott, 1978).

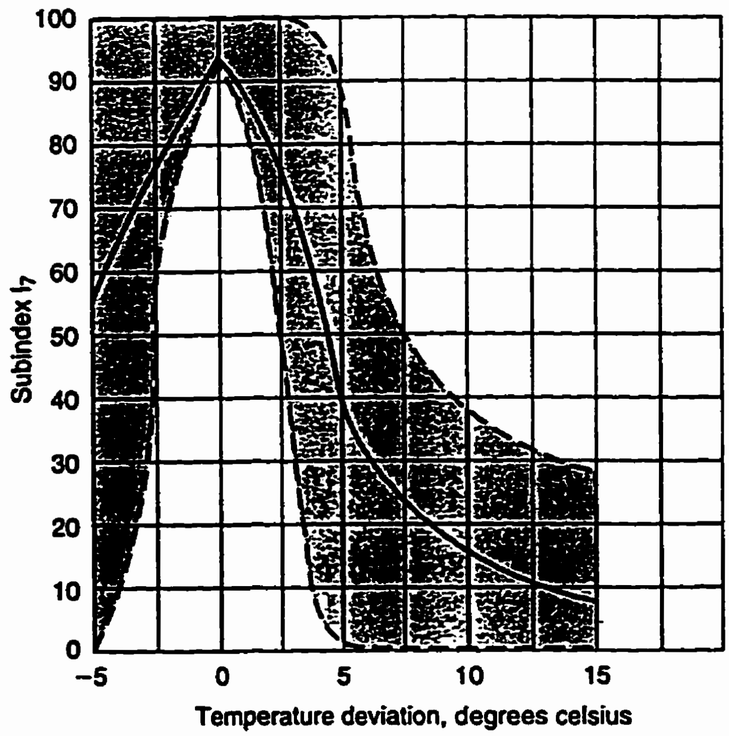

FIGURE 5.7
Subindex Function for Temperature Deviation from Equilibrium (ΔT) in the NSF WQI (For ΔT > 15°C, I_7 = 5) (Ott, 1978).

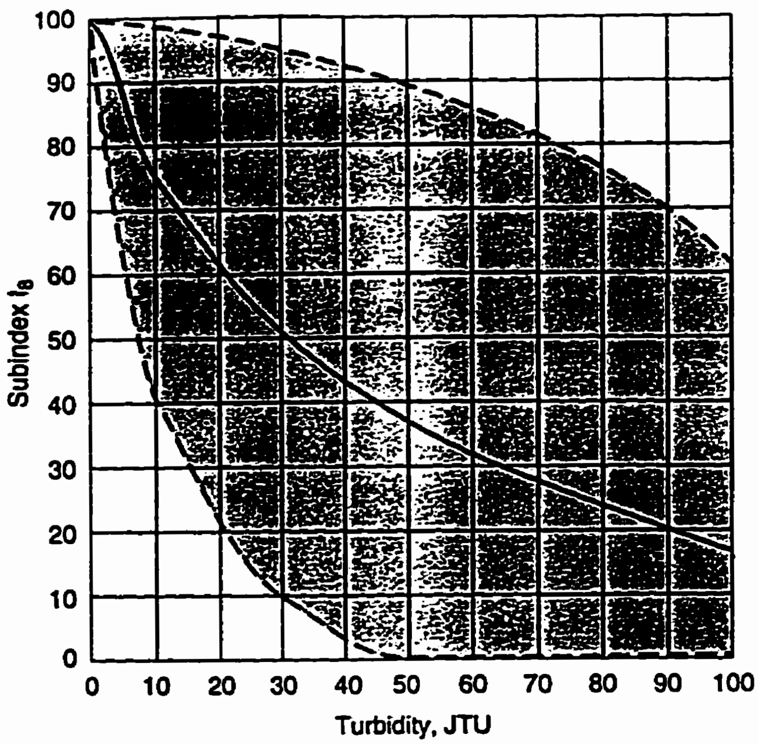

FIGURE 5.8
Subindex Function for Turbidity (Jackson Turbidity Units) in the NSF WQI (For turbidity > 100 JTU, I_8 = 5) (Ott, 1978).

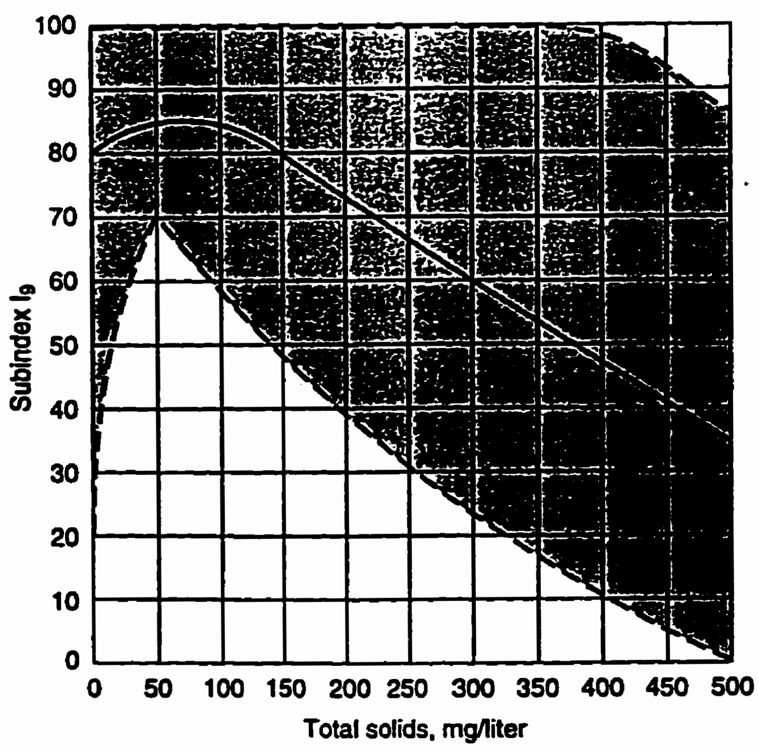

FIGURE 5.9
Subindex Function for Total Solids in the NSF WQI (For total solids > 500 mg/l, I_9 = 20) (Ott, 1978).

TABLE 5.3

PROFESSIONS OF NSF WQI PANEL PARTICIPANTS

Regulatory officials (federal, interstate, state, territorial and regional)	101
Managers of local public utilities	5
Consulting engineers	6
Academicians	26
Others (industrial waste control engineers and representatives of professional organizations)	4
Total	142

Source: Ott, 1978, p. 203.

TABLE 5.4

35 CANDIDATE VARIABLES CONSIDERED FOR THE NSF WQI IN QUESTIONNAIRE NO. 1

Dissolved oxygen	Oil and grease
Fecal coliforms	Turbidity
pH	Chlorides
Biochemical oxygen demand (5-day)	Alkalinity
Coliform organisms	Iron
Herbicides	Color
Temperature	Manganese
Pesticides	Fluorides
Phosphates	Copper
Nitrates	Sulfates
Dissolved solids	Calcium
Radioactivity	Hardness
Phenols	Sodium and potassium
Chemical oxygen demand	Acidity
Carbon chloroform extract	Bicarbonates
Ammonia	Magnesium
Total solids	Aluminum
	Silica

Source: Ott, 1978, p. 203.

An example calculation using both the WQI_a and the WQI_m is shown in Table 5.5. The interpretation of the resultant index could be based on the descriptors suggested in Table 5.6.

In summary, the steps in the application of the WQI in an impact study are as follows: (1) assemble average and extreme data for each parameter (published or monitoring); (2) use Figures 5.1 through 5.9 to determine I_i for average and extreme conditions; and (3) calculate WQI_a and/or WQI_m for average and extreme conditions, and interpret the results as appropriate.

Some general comments on the WQI are as follows: (1) it has been used in at least 17 states in the United States (Ott, 1978); (2) conceptually similar methods are used in other countries for calculating water quality indices; and (3) the focus is on "conventional" pollutant indicators, not on toxics.

Environmental indices which are indirectly related to groundwater quality have also been developed, including indices expressing the vulnerability of aquifer systems to pollution and to the transport of pesticides through the subsurface to water-bearing zones. Simple examples of these indices are presented in Chapter 8; more-detailed information is included in Canter, Knox, and Fairchild (1987) and in Knox, Sabatini, and Canter (1993).

TABLE 5.6

DESCRIPTOR WORDS AND COLORS SUGGESTED FOR REPORTING THE EXAMPLE WQI

Descriptor Words	Numerical Range	Color
Very Bad	0–25	Red
Bad	26–50	Orange
Medium	51–70	Yellow
Good	71–90	Green
Excellent	91–100	Blue

Source: Ott, 1978, p. 212.

Appendix VII

Vernacular Names	Species
Blinch	*Diapterus rhombeus*
Brown Shrimp	*Penaeus aztecus*
Carite	*Scomberomorus brasiliensis*
Cat Fish	*Cathorops spixii*
Cavalli	*Caranx hippos*
Racando	*Micropogon furnieri*
Salmon	*Cynoscion jamaicensis*
Salmon	*Cynoscion leiarchus*
Sardine	*Cetengraulis edentulus*
Seabob	*Xiphopenaeus kroyeri*
Shrimp	*Penaeus brasiliensis*
Shrimp	*Penaeus notialis*
White Fish/'Plateau	*Chloroscombrus chrysurus*